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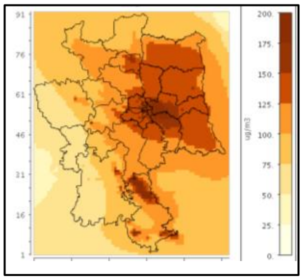
August 2018

Final Report

Source Apportionment of $PM_{2.5}$ & PM_{10} of Delhi NCR for Identification of Major Sources



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Disclaimer Notice

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The inferences, analysis and projections made in this report are based on the data gathered physically at the identified locations in National Capital Region (NCR) during April 2016 to February 2017 period. Due care has been taken to validate the authenticity and correctness of the information.

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The report has also been reviewed by the Technical Committee setup for the project.

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- Indian Institute Of Technology, Delhi

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ABBREVIATIONS

Al	:	Aluminium
As	:	Arsenic
BHG	:	Bahadurgrah
Br	:	Bromine
Br^-	:	Bromide Ion
Ca	:	Calcium
Ca^{++}	:	Calcium Ion
CHN	:	Chandani Chowk
Cl	:	Chlorine
Cl^-	:	Chloride Ion
CO	:	Carbon Monoxide
Co	:	Cobalt
Cu	:	Copper
C.V.	:	Coefficient of Variance
EC	:	Elemental Carbon
ED-XRF	:	Energy Dispersive X-ray fluorescence
F^-	:	Fluoride Ion
FBD-1	:	Faridabad 1 Sector 21 d
FBD-2	:	Faridabad 2 Near DAV College
Fe	:	Iron
GHZ-1	:	Lohia Nagar, Ghaziabad 1
GHZ-2	:	Ghaziabad 2, Industrial Sector
GRG-1	:	Huda sector 43, Gurgaon 1
GRG-2	:	Palam Vihar, Gurgaon 2
IC	:	Ion Chromatograph
ITO	:	ITO square
JNP	:	Janakpuri
K^+	:	Potassium Ion
LPM	:	Litre per Minute
Mg^{++}	:	Magnesium Ion
Mn	:	Manganese
MYR	:	Mayurvihar, Phase 1
Na^+	:	Sodium Ion
NCR	:	National Capital Region
$NH4^+$	:	Ammonium Ion
Ni	:	Nickel
$NO2^-$	:	Nitrite Ion
$NO3^-$	:	Nitrate Ion
NOI-1	:	Noida Industrial Site, sector 6
NOI-2	:	Noida sector 1, UPPCB office
NOx	:	Oxides of Nitrogen
NRN	:	Naraiana Industrial Sector
OC	:	Organic Carbon
P	:	Phosphorus
PM	:	Particulate Matter
PM_{10}	:	Particulate Matter below 10 micron size
$PM_{2.5}$	:	Particulate Matter below 2.5 micron size
PNP	:	Panipat
PPM	:	Parts Per Million
RHN	:	Rohini, Sector 6
RKP	:	R. K .Puram, Sector 2
S	:	Sulphur
S.D.	:	Standard Deviation
SHD	:	East Arjun Nagar, Shahdara
Si	:	Silicon
SNP	:	Sonipat
SO_2	:	Sulphur Dioxide
SO_4^{--}	:	Sulphate ion
TC	:	Total Carbon
Ti	:	Titanium
TOR	:	Thermal/Optical Reflectance
TOT	:	Thermal/Optical Transmission
V	:	Vanadium
WZP	:	Wazirpur Industrial Sector
Zn	:	Zinc

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Executive Summary

E1. Introduction

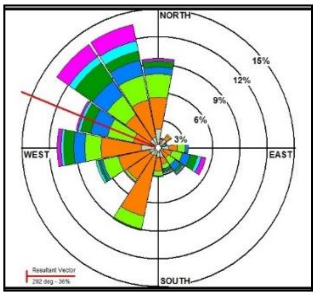
This study carried out source apportionment of $PM_{2.5}$ and PM_{10} concentrations in Delhi-National capital region (NCR) using two modelling-based approaches. The first approach relied upon monitoring and chemical characterization of $PM_{2.5}$ and PM_{10} samples. The chemically speciated samples along with source profiles were fed into the receptor model to derive source contributions. In the second approach, source-wise emission inventory, along with meteorological inputs and boundary conditions were fed into a dispersion model to simulate PM_{10} and $PM_{2.5}$ concentrations. The modelled concentrations were compared with actual observations for validation. The validated model has been used to carry out source sensitivity to derive source contributions and future projections of $PM_{2.5}$ and PM_{10} concentrations. Finally, various interventions have been tested which can reduce the pollutant concentrations in future years.

<u>Independently derived source contributions from the two approaches (receptor and dispersion) for the year 2016 are compared to judge their mutual consistency.</u> This will help the policy makers to take informed decisions and eventually the validated dispersion model can be used for future projection or intervention analysis. The results of the two approaches not only show consistency with each other but also with the previous study (IITK, 2015) in deriving source contributions. In comparison to the IITK (2015), this study has different monitoring locations and is based on different meteorological conditions prevailing in the year 2016. Moreover, this study has used newly developed emission factors, source profiles for some sources and also covered a wider study domain of NCR. Additionally, a chemical transport model has been used to account for chemical reactivity and long range transport of pollutants. This builds confidence in the estimates which may be used to formulate strategies for control of air pollution in Delhi-NCR.

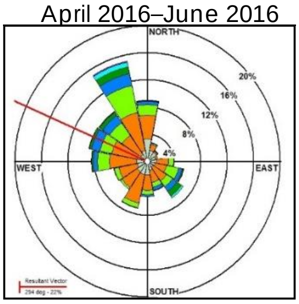
Some major findings of air quality monitoring, receptor modelling, emission inventory, dispersion modelling, and future projections are summarized in subsequent paragraphs

E2. Air Quality Monitoring

- A comprehensive exercise of air quality monitoring was carried out for a period of two seasons in one year at 20 representative locations (9 in Delhi City, 4 in Uttar Pradesh, 7 in Haryana) in the NCR including kerbside, industrial, commercial, residential, and reference sites, which has different land use pattern and sources of activity (Figure E.1).
- Twenty monitoring sites as given below were distributed in Delhi-NCR based on land use type and prominent wind direction to capture air quality levels under different activity profiles.

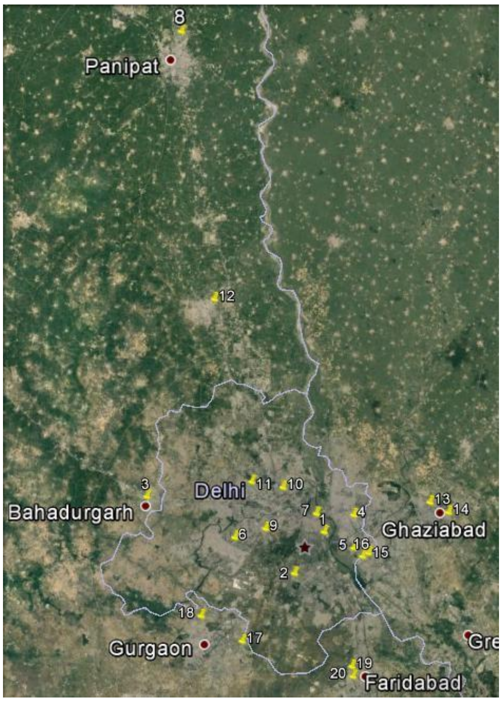


Windroses - Summer Season
April 2016–June 2016



Windroses - Winter Season
November 2016–Feb 2017

Site No.	Location	Site ID
1	ITO square	ITO
2	R. K .Puram, Sector 2	RKP
3	Bahadurgrah	BHG
4	Shahdara	SHD
5	Mayurvihar, Phase 1	MYR
6	Janakpuri	JNP
7	Chandani Chowk	CHN
8	Panipat	PNP
9	Naraiana Industrial Sector	NRN
10	Wazirpur Industrial Sector	WZP
11	Rohini, Sector 6	RHN
12	Sonipat	SNP
13	Ghaziabad 1	GHZ-1
14	Ghaziabad 2	GHZ-2
15	Noida- Sector 6	NOI-1
16	Noida- Sector 1	NOI-2
17	Huda sector, Gurgaon 1	GRG-1
18	Palam Vihar, Gurgaon 2	GRG-2
19	Faridabad 1	FBD-1
20	Faridabad 2	FBD-2



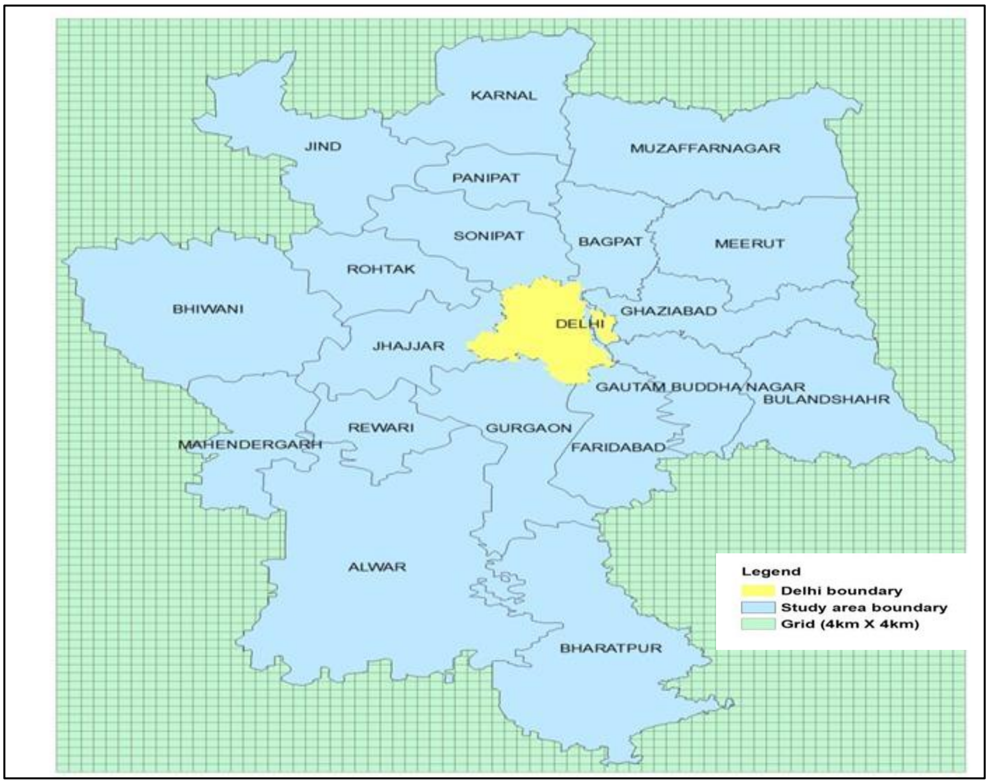
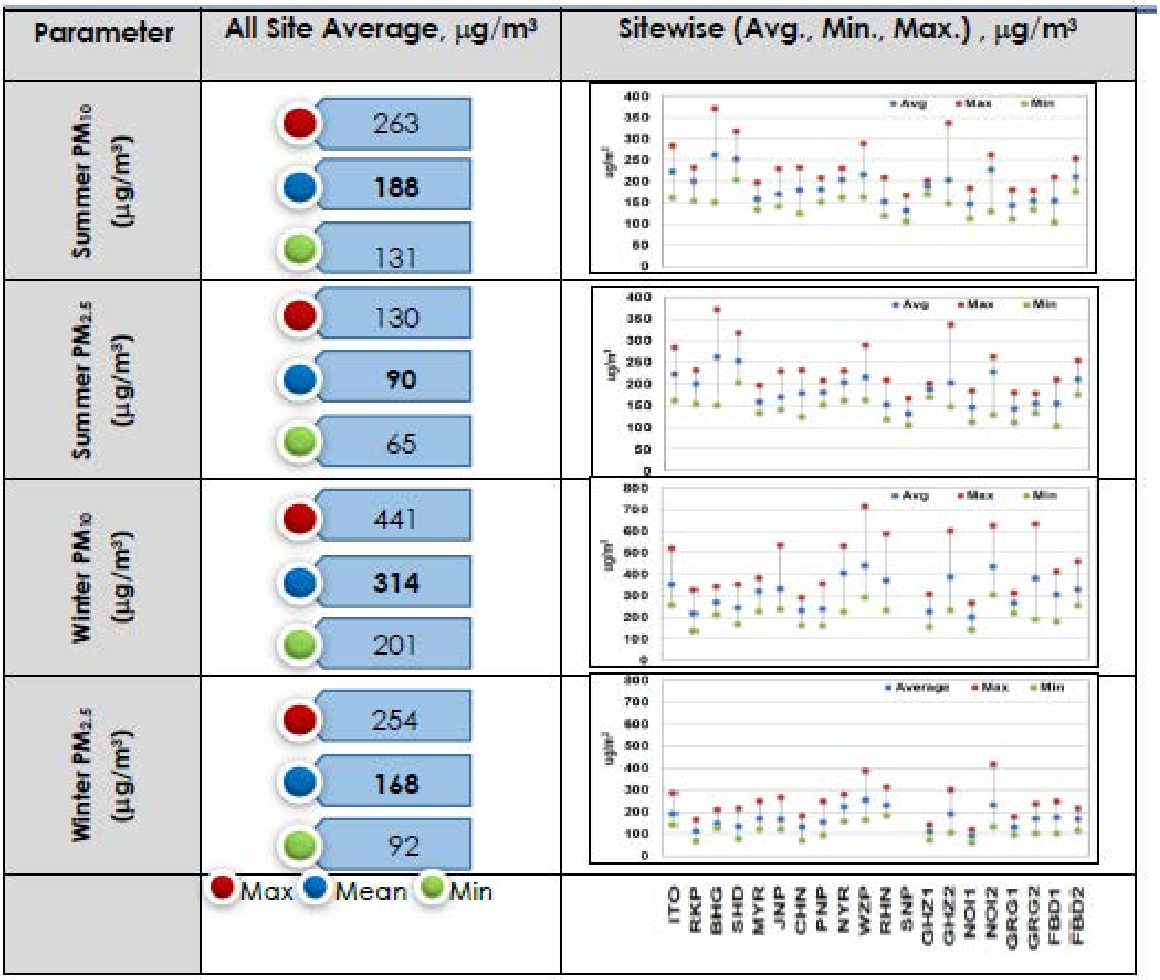


Figure E.1 : Details of locations of air quality monitoring sites and the study domain



Parameter	All Site Average, µg/m³	Sitewise (Avg., Min., Max.) , µg/m³
Summer PM_{10} (µg/m³)	263 **188** 131	
Summer $PM_{2.5}$ (µg/m³)	130 **90** 65	
Winter PM_{10} (µg/m³)	441 **314** 201	
Winter $PM_{2.5}$ (µg/m³)	254 **168** 92	
	● Max ● Mean ● Min	ITO RKP BHG SHD MYR JNP CHN PNP NYR WZP RHN SNP GHZ1 GHZ2 NOI1 NOI2 GRG1 GRG2 FBD1 FBD2

Figure E.2: Average PM_{10} and $PM_{2.5}$ mass concentration (µg/m³) at respective monitoring sites in summer and winter season

- Site-wise variation in concentrations of PM_{10} and $PM_{2.5}$ in summer and winter seasons is presented in Figure E.2. In summer season, average concentration of PM_{10} at all monitoring sites across Delhi-NCR was 188 ± 37 µg/m³. Concentration of PM_{10} varied from 131 to 263 µg/m³. Similarly, average concentration of $PM_{2.5}$ in summer season was 90±17 µg/m³ varying from 65 to 130 µg/m³.
- Both PM_{10} and $PM_{2.5}$ average concentrations were found to be more than the prescribed standard limit by the Central Pollution Control Board (CPCB).
- In winter season, average concentration of PM_{10} across all monitoring sites in Delhi-NCR was 314±77 µg/m³. Average maximum concentration was 441 µg/m³ while minimum average concentration was 201µg/m³. Similarly in $PM_{2.5}$, average concentration was 168±45 µg/m³ varying from 92 to 254 µg/m³.

E3. Chemical analysis of samples

Chemical speciation of particulate matter samples collected on filter paper can be separated into the three most common categories: elements, ions (sulphates, nitrates, ammonium, etc.) and carbon fractions. Figure E.3 depicts the overall scheme of chemical speciation of particulate samples.

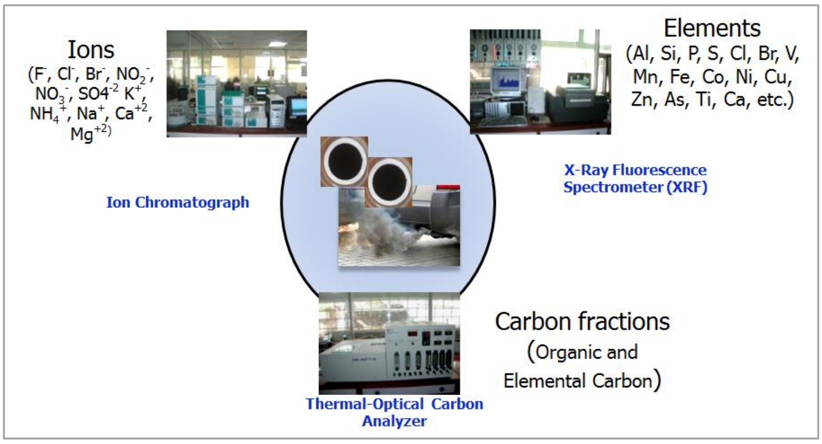


Figure E.3 : Chemical speciation of particulate matter samples

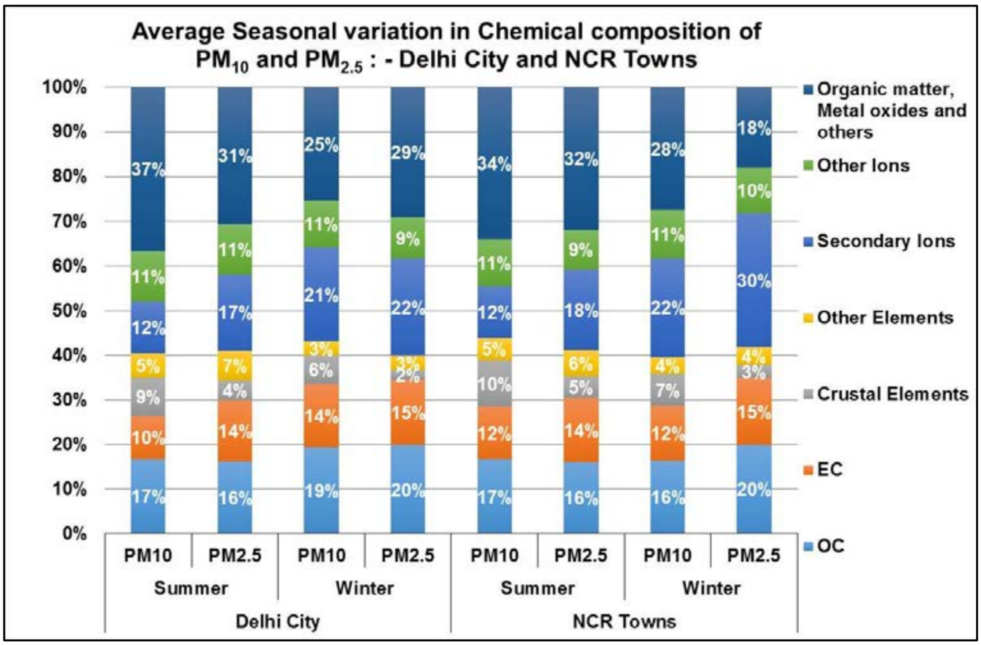


Figure E.4: Average chemical composition of PM_{10} and $PM_{2.5}$ in NCR Towns (Panipat, Sonipat, Ghaziabad, Gurgaon, Noida, Faridabad and Bahadurgarh) and Delhi-city in summer and winter seasons

Seasonal variation in average chemical composition of PM_{10} and $PM_{2.5}$ for Delhi-city and NCR Towns is presented in Figure E.4.

Average chemical composition of PM_{10} and $PM_{2.5}$ at Delhi-city and NCR Towns in summer season:

- PM_{10}: OC (organic carbon) was similar (~17%) at Delhi-city and NCR Towns. EC (elemental carbon) was found to be slightly higher at NCR Towns (~12%) compared to Delhi-city (~10%). contribution of crustal elements in Delhi City was 9% and in NCR Towns it was about 10%. Other elements contributed to about 5% in Delhi city as well as NCR Towns. Secondary ions (~12%) and other ions (~11%) were found to be similar in both Delhi city and NCR Towns. Remaining constituents of organic matter, metal oxides, and others were higher in Delhi-city (~37%) compared to NCR Towns (~34%).

- PM$_{2.5}$: Average chemical composition was found to be similar in both Delhi-city and NCR Towns. Both OC (~16%) and EC (~14%) were found to be similar. Both crustal elements (~4%–5%) and other elements (~6%–7%) were found to be similar. Secondary ions was found to be similar in NCR Towns (~17%–18%), whereas other ions were found to be higher in Delhi-city (~11%) compared to ~9% in NCR Towns. Remaining constituents of organic matter, metal oxides, and others were found to be similar (~31%–32%).

Average chemical composition of PM$_{10}$ and PM$_{2.5}$ at Delhi-city and NCR Towns in winter season:

- PM$_{10}$: OC was found to be higher in Delhi-city, that is, ~19% compared to ~16% in NCR Towns. EC was found to be higher in Delhi-city (~14%) compared to ~12% in NCR Towns. Both crustal elements (~6%–7%) and other elements (~3%–4%) were found to be similar. contribution of secondary ions was found to be significant with about 21% in Delhi city and about 22% in NCR Towns. Other ions contributed to about 11% in Delhi city and NCR Towns. Remaining constituents of organic matter, metal oxides, and others were higher in NCR Towns, that is, ~28% compared to ~25% in Delhi-city.
- PM$_{2.5}$: contribution of OC was found to be about 20% in both Delhi city and NCR Towns. Similarly contribution of EC was about 15%. Contribution of crustal elements was found to be lower i.e. about 2% in Delhi city and about 3% in NCR Towns. Other elements (~3%–4%) were also found to be similar. Secondary ions were found to be higher (~30%) in NCR Towns compared to ~22% in Delhi-city whereas other ions were found to be similar i.e. about9% in Delhi city and about 10% in NCR Towns. Remaining constituents of organic matter, metal oxides, and others were found to be higher in Delhi-city (~29%) as compared to ~18% in NCR Towns.

E4. Receptor modelling

The fundamental principle of receptor models is that mass conservation can be assumed and a mass balance analysis carried out to identify and apportion sources of airborne particulate matter in the atmosphere. The approach to obtain a data set for receptor modelling is to determine a large number of chemical constituents, such as elemental concentrations in a number of samples. Receptor models use monitored pollutant concentration and some information about the chemical composition of air pollution sources (profiles) to estimate the relative influence of these sources on pollutant concentrations at any single monitoring location.

The following approach was used for receptor modelling using USEPA's CMB model:

- Identification of probable contributing sources to the monitoring sites
- Selection of chemical species: Following species were analysed from the PM_{10} and $PM_{2.5}$ samples collected at respective sites in summer and winter seasons.
    - Carbon fractions based on temperature (organic carbon and elemental carbon) using Thermal Optical Reflectance (TOR) Carbon Analyser,
    - Ions (anions—fluoride, chloride, bromide, sulphate, nitrate; and cations—sodium, ammonium, potassium, magnesium, and calcium) using ion chromatography
    - Elements (Al, Si, K, Ca, Ti, V, Fe, Co, Ni, Cu, Zn, As, Se, Zr, Mo, Pd, Cd, Ce and Pb) using Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF)
- Selection of representative source profiles, based on the source activities around the sites and considering sources that will impact the receptor locations based on wind direction, with the fraction of each of the chemical species and uncertainty.
- Site-specific wind trajectories during monitoring period were taken from website of Air Resource Laboratory, HYSPLIT, URL: *https://www.arl.noaa.gov/ready/hysplit4.html*
- Fire data was collected for the monitoring period from NASA, Earth data, Fire Information for Resource Management Systems (FIRMS), URL: *https://firms.modaps.eosdis.nasa.gov/firemap/.* This data was collected to assess magnitude and spread of fire activity in the upwind direction.

- A few study specific profiles were developed under this project and used. Details of source profiles selected are as follows:
    - Vehicular sources:
        - a) New composite profiles of different fuel types developed for newer technology vehicles (post-2005) under this study and
        - b) Earlier profiles of pre-2005 vehicle technology. (CPCB, 2009, Vehicle Source Profiling report)
    - Non-vehicular sources: Indigenous profiles developed by IIT-Bombay (CPCB, 2009, Stationary Source Profiling report)
    - Site-specific profiles developed under this study are:
        - a) Refuse burning,
        - b) Agri-waste (sugarcane) combustion,
        - c) Agri-waste (rice) combustion,
        - d) Agri-waste (wheat) combustion,
        - e) Road and soil dust (composite of Delhi and NCR Towns).
- Estimation of both the ambient concentrations and uncertainty of selected chemical species from the particulate matter collected at respective sites; and
- Solution of the chemical mass balance equations was obtained through CMB-8.2 receptor model by using the chemical composition results of 24 hour daily samples collected in summers and winter season in 2016/17 at all sites and source profiles of applicable sources at respective sites as an input.

- Contributing sources were identified by averaging the contribution from sources observed based on daily samples across the monitoring period.
- Based on availability of source profiles and due to similar nature of source profiles leading to difficulty in resolving the CMB equation due to their collinearity, identified sources are categorized into dust and construction, biomass burning, vehicles, industry and others. Dust and construction source includes natural sources, such as soil dust and anthropogenic sources, such as paved and un-paved road dust and dust generated due to construction activity. Biomass burning includes agri-waste (sugarcane, wheat, and rice) burning and residential biomass burning. Vehicles include contribution from all categories of vehicles and all fuel-types. Distribution of contribution based on vehicle-type and fuel-type can be obtained from dispersion modelling results based on emission inventory presented in subsequent sections. Similarly detailed distribution of dust, biomass, and industrial sources is presented in dispersion modelling results.

Results of receptor modelling for summer and winter season:

- Average contribution of different sources towards PM_{10} and $PM_{2.5}$ in summer and winter seasons for sites in Delhi-city and NCR Towns is presented in Figure E.5.

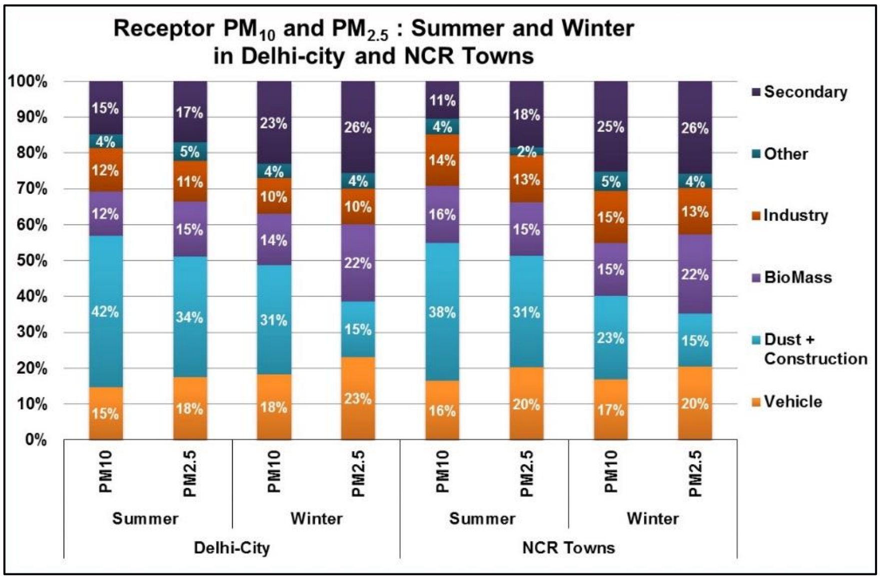


Figure E.5: Average source contribution to PM_{10} and $PM_{2.5}$ samples at representative sites in summer and winter season in Delhi-city and NCR Towns (Panipat, Sonipat, Ghaziabad, Gurgaon, Noida, Faridabad and Bahadurgarh)

*These are primary contribution from different sectors and secondary particulates are shown seperately, which are later allocated to the sectors using dispersion modeling.

Seasonal variation of different sources of $PM_{2.5}$ and PM_{10}, obtained as an out of receptor modelling, in terms of percentage contribution is shown in Figure E.5 for Delhi-city and NCR Towns.

E4.1 PM_{10}

Seasonal variation of PM_{10} shows higher contribution of dusty sources in summer (38%–42%) as compared to winter in Delhi-city as well as NCR Towns. This can be attributed to dry conditions and higher wind velocities resulting in entrainment of dust. However, contribution of dusty sources (e.g. road, construction and soil dust) was also significant in winter season (23%–31%). contribution of vehicles to PM_{10} was slightly higher in winter (17%–18%) in Delhi-city and NCR Towns than in summer (15%–16%). Biomass burning contribution was slightly higher in winter in Delhi-city (14%) than in summer (12%), whereas in NCR Towns the contribution was similar in both the seasons (15%–16%). contribution from industrial sources was similar in both summer and winter seasons in Delhi-city (10%–12%) and NCR Towns (14%–15%). Contribution in NCR

Towns was higher as compared to Delhi-city due to the presence of industries in the proximity. There are several types of industries operating in NCR Towns including bricks, sugar, paper, dyeing, rubber, chemical ceramics, iron & steel, textile, fertilizer, stone crushers, and casting & forging etc. Other sources, which include DG sets showed similar contribution of about 4%–5%. Contribution of secondary ions to PM_{10} is significantly higher in winter (23%–25%) than in summer (11%–15%) in both Delhi-city and NCR Towns.

E4.2 $PM_{2.5}$

Seasonal variation of $PM_{2.5}$ shows significantly higher contribution of dusty sources in summer (31%–34%) as compared to winter (15%) in Delhi-city as well as NCR Towns. Higher contribution of dusty sources even in $PM_{2.5}$ can be attributed to dry conditions and higher wind velocities in summers resulting in contribution from far-off sources. Primary contribution of vehicles to $PM_{2.5}$ was higher in winter (20%–23%) in Delhi city and NCR Towns than in summer (18%–20%). Biomass burning contribution was significantly higher in winter in Delhi-city and NCR Towns (22%) than in summer (15%). contribution from industrial sources was similar in both summer and winter seasons in Delhi city (10%–11%) and NCR Towns (13%). Contribution in NCR Towns was higher as compared to Delhi-city due to the presence of industries in the proximity. Other sources, which include DG sets showed contribution of less than 5%. Contribution of secondary ions to $PM_{2.5}$ was higher in winter (26%) than in summer (17%–18%) in both Delhi-city and NCR Towns.

- Significantly higher contribution of dust in PM_{10} and also in $PM_{2.5}$ particularly in summer season may be attributed to the transboundary contribution. Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at the sites particularly in summer shows wind flows from far-off regions.
- Variation in the contribution of sources, such as vehicles (15%–23%), biomass burning (12%–22%), and dust (15%–42%) may be attributed to the variation in activities at local level and meteorology.
- Secondary particulates were found to contribute significantly to both PM_{10} and $PM_{2.5}$ in winter season.
- Contribution from sources outside Delhi, such as residential cooking, agricultural waste burning, industries (tall stacks) and dust particles are likely due to winds carrying pollution with the incoming air to Delhi-city and NCR Towns.

E5. Emissions inventory

Source-wise multi-pollutants inventories of air pollutants have been prepared for the year 2016, at a high resolution of 4x4 km^2. Along with PM, inventories of sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs) have also been prepared to account for secondary particulates formation. The major sectors which have been covered in the analysis are: 1)Residential, 2)Open agricultural residue burning, 3)Transport—tailpipe emissions , 4)Construction, 5)Industries (including bricks and stone crushers), 6)Power plants- stacks, coal handling units and fly-ash ponds, 7)Road dust, 8)Diesel generators, 9)Refuse burning, 10)Crematoria, 11)Restaurants, 12)Airports, 13)Landfills, 14)Waste incinerators, 15) Solvents, 16) Ammonia emission sources, etc.

Emissions estimates were based on activity type, emissions factors, pollution abatement technology used, and the efficiency of control. Activity data was collected from both primary and secondary sources. The newly developed database of vehicular emissions factors developed by the Automotive Research Association of India (ARAI) has been used for vehicular sources. Emissions estimated from various sectors have been allocated over the study domain as per area, line, and point source categories. ARCGIS software was used for estimation of gridded emissions (4x4 km^2) for different pollutants across the NCR.

The emissions inventory for Delhi and the NCR is shown in Table E.1. The estimates presented are the annual totals for different sectors, however, there are seasonal variations in emissions from different sectors, which have been accounted for during simulations. The total emissions of PM_{10}, $PM_{2.5}$, NO_x, SO_2, CO, and NMVOC are estimated for Delhi and NCR. The percentage share of sectors in overall inventory of PM_{10}, $PM_{2.5}$, NO_x, and SO_2 emissions are shown in Figure E.6. Amongst the sources within Delhi, the share of the transport sector is significant (39%) in $PM_{2.5}$ emissions. This reduces to 19% in PM_{10} emissions in Delhi, due to the presence of other major sources, such as road dust and construction, which emit more particles in the coarser range of PM. With the closure of some of the coal based power generating units, Transport now has a dominant share (81%) in the NO_x emissions amongst the sources within Delhi. SO_2 emissions within the city of Delhi are small and are mainly contributed by Badarpur coal-based power plant. Sectoral shares are significantly different, when the entire NCR is considered. Industries (28%), road dust (13%), residential (20%), and agricultural burning (17%) are the main contributors to PM_{10} emissions in NCR. For $PM_{2.5}$, industries (24%), residential (25%), agricultural burning (19%), and transport (13%) are the major contributors in NCR. Despite dominant use of LPG within Delhi city, the residential sector contributes significantly mainly due to biomass fuel used in about 3 million households in NCR. The share of transport in NCR reduces to 60% for NO_x emissions, considering other sources, such as power plants, DG sets, and industries in NCR. SO_2 emissions in NCR are about 27 times higher than Delhi, mainly due to the presence of industrial sources and power plants. Standards for control of NO_x and SO_2 in industrial setups have not yet been implemented, and hence these emissions have remained uncontrolled. Use of petcoke and FO (which are very high sulphur fuels) was a significant source of industrial SO_2 emissions in NCR during 2016, before they were banned. Emissions of ammonia were taken from IIASA's GAINS ASIA database for India.

It is evident that the emission share of different sectors is significantly different in Delhi and NCR. The air quality in Delhi is impacted by both local and outside sources, and hence, a simulations exercise is a pre-requisite to understand the contributions of different sectors lying within or outside the city of Delhi in the NCR. Other than emissions, meteorology also plays an important role in defining pollutant concentrations and source contributions.

Table E.1 : Annual emission inventory of pollutants (kt/yr) in Delhi city and NCR (including Delhi) for 2016

SECTOR	DELHI						NCR					
	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC
TRANSPORT*	12.8	12.4	126.9	1.1	501.1	342.1	68.6	66.5	528.9	4.4	1750.9	886.5
INDUSTRIES	1.3	1.1	1.6	4.6	0.2	0.0	288.3	127.4	85.2	556.2	620.0	27.0
POWER PLANTS	6.1	3.5	11.2	23.6	3.5	0.9	73.7	41.1	132.5	297.1	13.4	9.4
RESIDENTIAL	2.9	2.0	3.7	0.2	61.1	12.7	204.3	131.5	38.0	16.8	1700.3	374.1
AGRICULTURAL BURNING	0.5	0.4	0.1	0.0	2.7	0.3	174.1	102.2	30.6	9.0	781.1	209.2
ROAD DUST	24.0	5.8	0.0	0.0	0.0	0.0	137.2	30.6	0.0	0.0	0.0	0.0
CONSTRUCTION	14.2	2.7					43.7	7.8				
DG SETS	0.1	0.0	0.7	0.0	0.2	0.1	3.7	3.2	53.0	3.5	11.4	4.3
REFUSE BURNING	1.4	1.2	0.5	0.1	4.6	2.7	17.5	14.4	5.5	0.7	56.0	33.3
CREMATORIA	0.4	0.2	0.1	0.0	2.2	1.2	1.5	0.8	0.2	0.0	7.7	4.3
RESTAURANT	1.4	0.8	0.4	1.3	2.5	0.4	1.7	1.0	0.5	1.6	2.9	0.4
AIRPORT	0.1	0.1	6.6	0.5	13.6	7.0	0.1	0.1	6.6	0.5	13.6	7.0
WASTE INCINERATORS	0.5	0.3	4.1	1.6	0.9	0.0	0.5	0.3	4.1	1.6	0.9	0.0
LANDFILL FIRES	1.8	1.5	0.6	0.1	5.8	2.2	1.9	1.6	0.6	0.1	6.1	2.3
SOLVENTS						57.3						112.8
TOTAL	68	32	156	33	598	427	1017	528	886	892	4,964	1671

Note: These are annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations. Real world emissions have also been accounted for certain sectors. Power plants include stack, flyash ponds and coal handling emissions

*Including high emitters

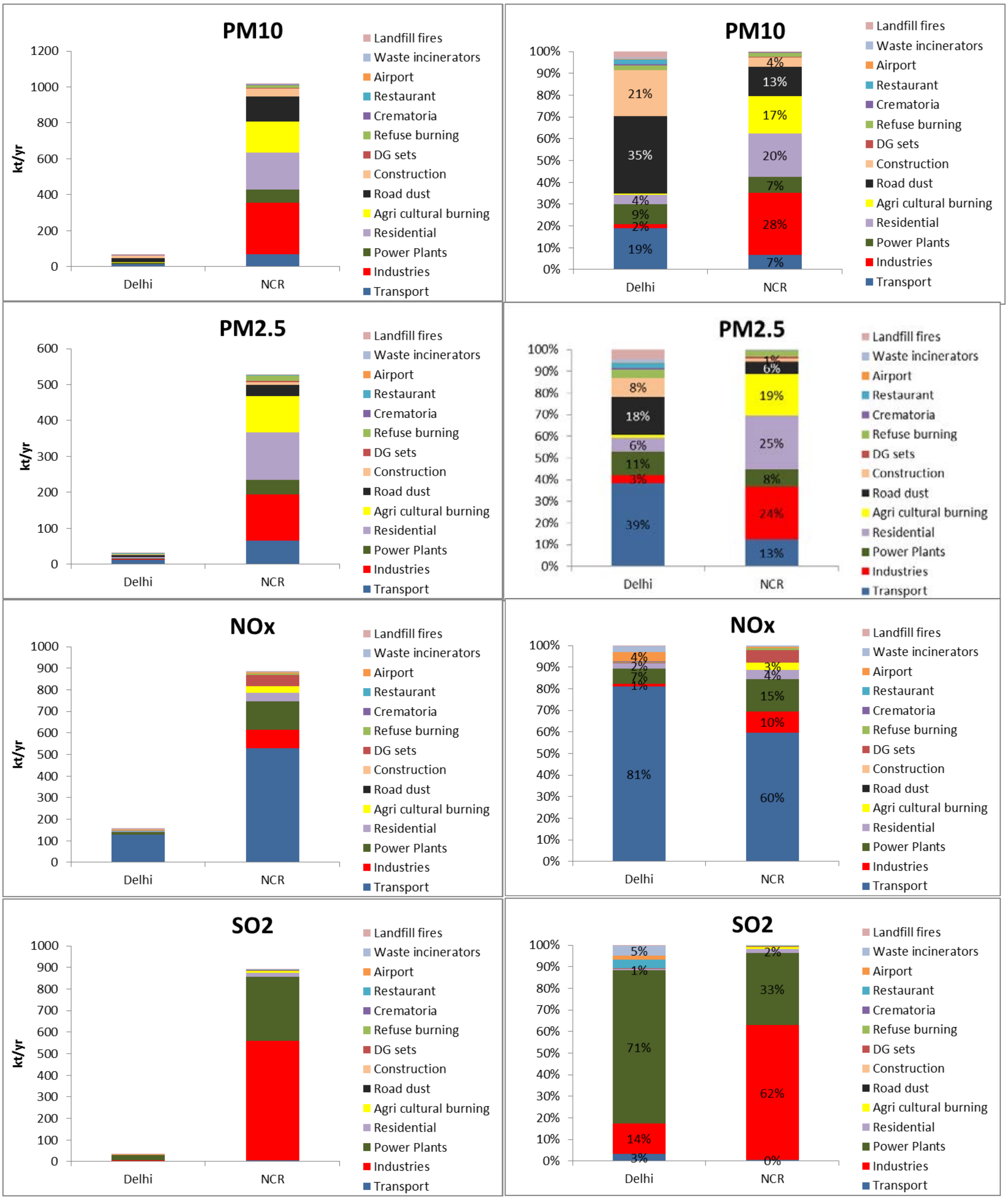


Figure E.6 : Absolute and percentage share of different sectors in overall inventory in NCR (including Delhi) and Delhi city

Note: These shares are based on annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations. The sources showing less than 1% of contributions are not labelled in the above Figure E.6.

E6. Simulation of air quality: dispersion modelling

Ambient PM_{10} and $PM_{2.5}$ concentrations were simulated in this study using the WRF-CMAQ model combination. WRF model runs have been carried out to generate 3-dimensional meteorological fields over the study domain which acts as input to the CMAQ model along with emission inventories. To account for contributions from outside NCR, India scale simulation runs have been carried out for the year 2016 using India-scale emissions inventory. In order to account for transport of pollutants from outside India, international boundary conditions have been adopted from global air quality products. Simulations have been performed for India and then for the NCR for the year 2016 to predict PM_{10} and $PM_{2.5}$ concentrations in NCR. The modelled concentrations were compared with the actual observations taken by ARAI for specific locations.

Evidently, the concentrations are significantly higher during winter than in summer, due to adverse meteorological conditions. Reduction in wind speed and boundary layer height during winter reduces the dispersive capacity of the atmosphere and leads to higher concentrations of pollutants near the ground.

Modelled $PM_{2.5}$ and PM_{10} concentrations were compared with the actual values for model validation. While the model captured seasonal variations quite well, the magnitude of PM concentrations was somewhat underestimated. The average ratio of modelled to observed $PM_{2.5}$ concentrations was 0.82–0.87. This performance of the model appears to be satisfactory, when compared with several previous studies (e.g. IITK (2015)). The small shortfall in the model estimates may be attributed to some unaccounted emissions from natural sources. Other than the overall, mass, the share of different constituent species of $PM_{2.5}$ is also satisfactorily reproduced by the CMAQ model. The validated model was used for estimating source contributions using source-sensitivity method.

6.1 Source apportionment in Delhi

Table E.2 shows the contributions of various sectors in $PM_{2.5}$ and PM_{10} concentrations, estimated using dispersion modelling for winter and summer seasons at 20 locations in Delhi-NCR. The results show source contributions in base case for the year 2016. It is to be noted that the contribution of agricultural burning is not fully accounted for in this study as the monitoring and modelling periods did not include the month of October, when the burning activities are generally at their maximum. Moreover, the sectoral contributions are averaged for the whole modelling/monitoring period, and hence, do not highlight the contribution of agricultural burning, which happens during a certain number of days and cause episodically high pollutant concentrations.

In $PM_{2.5}$ concentrations during winter, the average share of the transport sector varies from 28% in Delhi. Industries contribute to 30%, while fuel (mainly biomass) burning (in residences and agricultural fields) contributes 14%. Dust (soil, road, and construction) have a share of 17%. In $PM_{2.5}$ concentrations during summer, the share of the transport sector is about 17% in Delhi. Industries contribute 22%, while biomass burning in residences and agricultural fields contribute 15%. Dust (soil, road, and construction) have a share of 38% in summers. Significantly high contributions from outside of India have been observed during summer season. High contributions from international boundaries to India have also been reported by other studies (HEI, 2018; IITM 2017). Other sources contribute to 11% in winters and 8% in summer season.

In PM_{10} concentrations during winter, the average share of the transport sector is 24% in Delhi. Industries contribute to 27%, while fuel (mainly biomass) burning in residences and agricultural fields contributes 13%. Dust has a considerably higher share in PM_{10} concentrations (25%). During summer, the share of the transport sector is observed to be 15%. Industries contribute to 22%, while biomass burning (in residences and agricultural fields) contributes to 15%. Dust has a significantly higher share of 42% in PM_{10} fractions. Other sectors contribute to 10% PM10 concentrations in winters and 7% in summer season.

Table E.2 : Average sectoral contributions in $PM_{2.5}$ and PM_{10} concentrations in Delhi estimated using dispersion modelling during winters and summers

$PM_{2.5}$		
Sectors	**Winters**	**Summers**
Residential	10%	8%
Agri. Burning	4%	7%
Industry	30%	22%
Dust (soil, road, and const.)	17%	38%
Transport	28%	17%
Others	11%	8%
PM_{10}		
Sectors	**Winters**	**Summers**
Residential	9%	8%
Agri. Burning	4%	7%
Industry	27%	22%
Dust (soil, road, const.)	25%	42%
Transport	24%	15%
Others	10%	7%

Note: Industries include power plants (stacks, flyash ponds and coal handling units), brick manufacturing, stone crushers, and other industries. Others include DG sets, refuse burning, crematoria, airport, restaurants, incinerators, landfills, etc. Dust includes sources of natural and anthropogenic origin (soil, road dust re-suspension, and construction activities). Dust is also contributed through trans-boundary atmospheric transport from international boundaries.

E7. Comparison of receptor and dispersion modelling results

A comparison of sectoral contributions obtained from receptor modelling using CMB8.2 and dispersion modelling is presented in subsequent sections. The results of both the approaches are compared at the locations of air quality monitoring.

E7.1 $PM_{2.5}$

The results of receptor modelling are compared with the dispersion modelling outputs in Figure E.7. The receptor modelling results show primary sectoral contributions, and secondary particulates separately. It is to be noted that secondary particulates are also contributed by gaseous emissions from different sectors. The dispersion model was used to assess the contribution of different sectors to secondary particulates. The secondary particulates in the results of receptor modelling were accordingly allocated to different sectors to assess total sectoral contributions (primary and secondary).

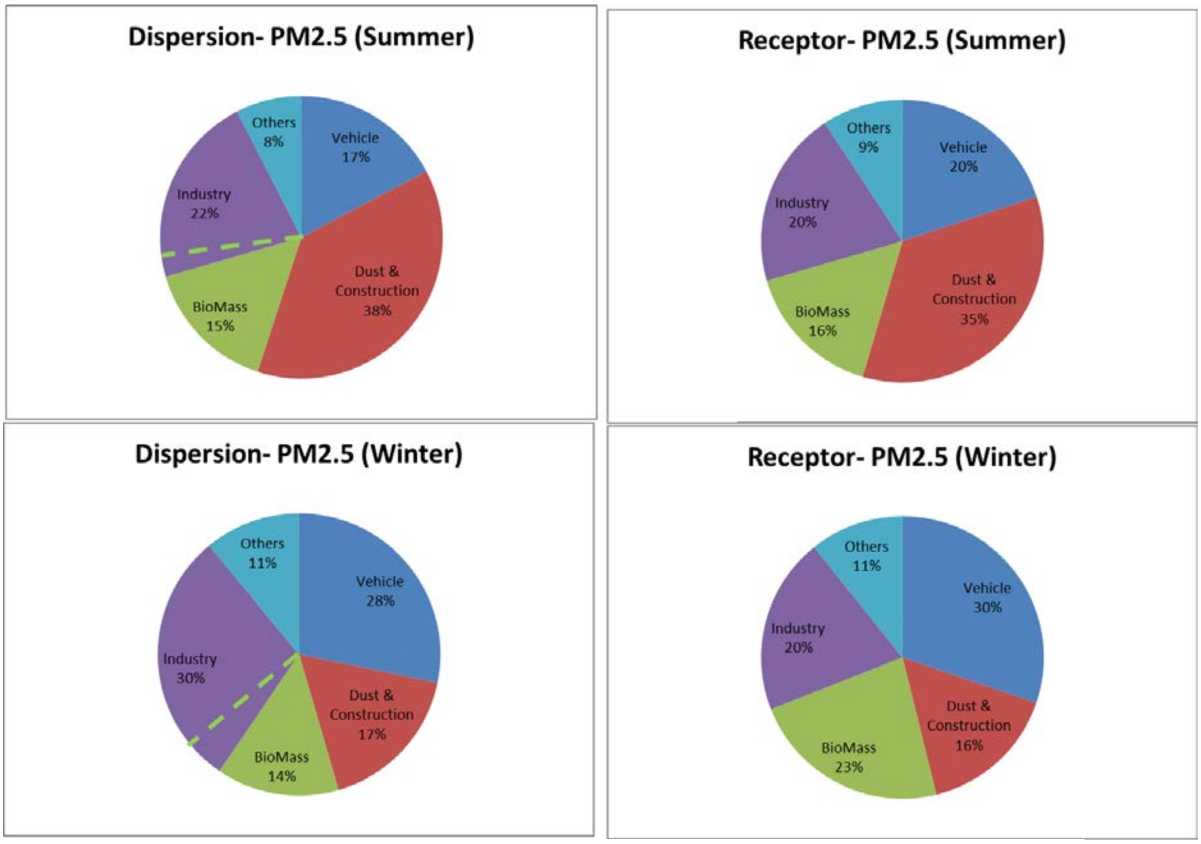


Figure E.7: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ in Delhi

* Green dotted line shows that some industries in NCR (which contribute to Delhi's air quality) also use biomass

Figure E.7 shows that the results of the two approaches are close for most sectors. It is to be noted that in the dispersion modelling approach, the industrial sector (which seems to be overestimated) includes biomass as an industrial fuel. Dust includes contributions from road dust re-suspension, construction activities, and trans-boundary international contributions. Based on the assessment of species, it may be concluded that in summers, trans-boundary contributions are mainly composed of dust. However in winters, there are also some trans-boundary contributions from sectors, such as biomass burning and industries also.

Overall, the results of source apportionment seem to be consistent for most sectors in both the approaches. In the two seasons, the dispersion model shows contributions of transport sector as 17%–28%, in comparison to the receptor model estimations of 20%–30%. These findings are higher than the contributions of transport sector reported in IITK (2015) report, because in this study we included secondary particulates along with the primary contributions.

E7.2 PM_{10}

Comparison of results of dispersion modelling with receptor modelling for PM_{10} is shown in Figure E.8. The results complement each other. Receptor modelling shows dust contributions of 31%–43%, which are shown to be in the range of 25%–41% by the dispersion modelling approach in the two seasons. The range of estimates for the transport sector is 15%–24% as per dispersion model runs in different seasons, while it is 17%–25% using the receptor model. Biomass burning consistently shows contributions in the range of 13%–15%. The two approaches show slight variation in industrial sector contributions, which ranges from 19%–27%.

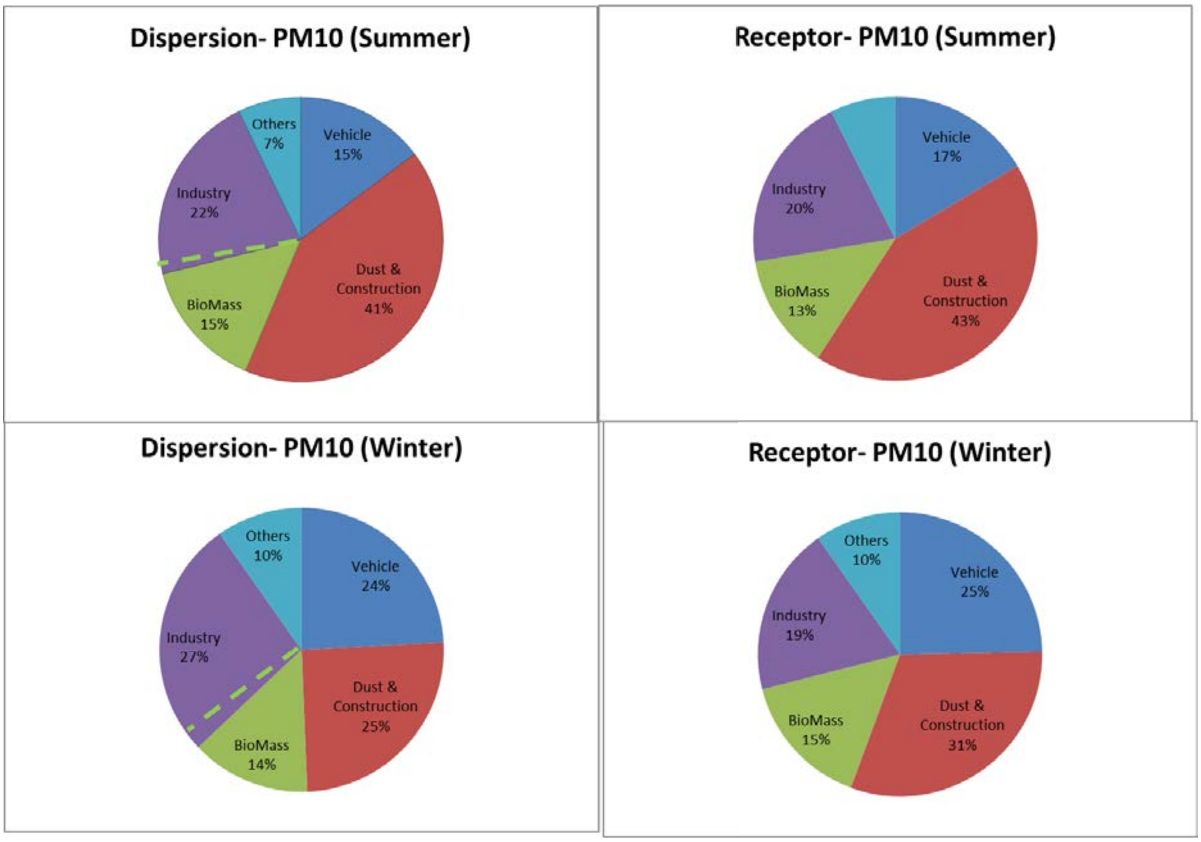


Figure E.8 : Comparison of results of dispersion and receptor modelling assessment for PM_{10} in Delhi for the two seasons

* Green dotted line shows that some industries in NCR (which contribute to Delhi's air quality) also use biomass

E7.3 Sub-sectoral contributions to PM_{10} and $PM_{2.5}$ concentrations in Delhi and NCR

While, the broad sectoral shares have been shown in the previous section, this section shows the contribution of different sub-sectors towards $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR.

In the residential sector, biomass fuel is the dominant factor contributing to $PM_{2.5}$ and PM_{10} concentrations. It contributes to 8%–10% in $PM_{2.5}$ and 8%–9% in PM_{10} concentrations in the two seasons. Within the 30% contribution of the industrial sector in $PM_{2.5}$ concentrations (winter) in Delhi, 8% is contributed by bricks sector, 6% by power stations, 2% by stone crushers, while other industries (using coal, biomass, pet-coke, and furnace oil) contributed to about 14%. Later, in 2017, petcoke and furnace oil (FO) use were banned in the region. In the others category (within the overall contribution of 11% in winters $PM_{2.5}$ concentrations), DG sets (because of high PM and NOx emissions) contribute significantly (5%), followed by refuse burning (3%), and the rest other sources contributed to less than 1% each, towards winters $PM_{2.5}$ concentrations. In the dust category, road dust and construction sectors have 4% and 1% contributions in $PM_{2.5}$ concentrations, respectively. Within the transport sector in Delhi, trucks have the highest share of 8%, followed by two-wheelers (7%), and three-wheelers (5%). This is due to their higher shares in either or both $PM_{2.5}$ and NO_x emissions. The share of two-wheelers falls to 4% at NCR level, with increase in shares of buses (diesel buses) and tractors. The share of cars in winter and summer $PM_{2.5}$ concentrations is about 3.4% and 2%, respectively. Within this, the share of older cars on road is much higher than the newer ones. Older cars (BS-II and earlier) contribute to about 31%–50%, while BS-III cars have a contribution of 19%–22% in Delhi and NCR. BS-IV cars contributed to 50% and 28% in the overall car contributions to $PM_{2.5}$ in Delhi and NCR, respectively. The fuel-wise distribution shows that diesel has a major contribution of 67%–74% in the share of cars, followed by CNG (13%–20%), and petrol (13%–14%) cars. Although, CNG cars contribute minimally to primary PM emissions, they have some secondary nitrate contributions through NO_x to nitrate conversions. Considering 2.0%–3.4% overall share of cars in $PM_{2.5}$ concentrations in two seasons, and a 19%–27% contribution of BS-IV diesel cars within this, the overall share of all BS-IV diesel cars in $PM_{2.5}$ concentrations is estimated to be about 0.5%–0.9% in Delhi and 0.3%–0.5% in NCR. Within the heavy duty segment (buses and trucks), vehicles registered after 2010 have an emission share of 30%–60% in Delhi and 30%–42% in NCR, while the older vehicles with inferior emission norms have the remaining shares. Similarly, in case of two-wheelers, post 2010 vehicles have a share of 34%–35%, while the older vehicles with inferior emission norms have higher shares. It is to be noted that these are the shares of vehicles in 2016, and with fleet turn-over, the share of BS-IV vehicles will increase and the contribution of older vehicles will gradually decline, although, the absolute quantity emissions from BS-IV vehicles will be much lower than pre BS-IV vehicles due to improved technologies. In PM_{10}, the shares for different sub-sectors almost remain same as $PM_{2.5}$. However, the share of dust increases considerably, with road dust and construction contributing to 8% and 6% in Delhi's PM_{10} concentrations. Their share increases to 10% and 7%, respectively in NCR during winters.

E8. Sectoral shares in other towns

The sectoral shares in PM_{10} and $PM_{2.5}$ concentrations have been shown in Table E.3 based on both dispersion as well as receptor modelling techniques. There are stark variations across different towns due to different monitoring schedules (and corresponding modelling results) in the NCR Towns. There are also some variations in the estimates of sectoral shares between the two approaches, which could be attributed to limitations in monitoring (only 1 or 2 stations in each city) and spatial allocations of emissions. However, directionally the results are similar. In $PM_{2.5}$ the contribution of combustion based sources, such as vehicles, industries, biomass is higher, while dust (road, construction, and ex-NCR) contributes dominantly in PM_{10} concentrations. Summers show higher dust contributions from international boundaries (mainly of natural origin) due to higher wind speeds.

Table E.3: Sectoral shares estimated by dispersion and receptor modelling for various towns in NCR

NCR-Towns	Season	Parameter	Dispersion Modelling					Receptor Modelling				
			Vehicle	Dust	Biomass	Industries	Others	Vehicle	Dust	Biomass	Industries	Others
Bahadurgarh	Summer	PM_{10}	17%	49%	13%	16%	5%	14%	31%	24%	19%	12%
		$PM_{2.5}$	22%	39%	15%	19%	5%	20%	32%	21%	17%	10%
	Winter	PM_{10}	21%	40%	11%	22%	6%	20%	28%	13%	25%	14%
		$PM_{2.5}$	28%	26%	12%	27%	7%	24%	19%	23%	24%	10%
Panipat	Summer	PM_{10}	21%	31%	18%	25%	5%	10%	37%	21%	18%	14%
		$PM_{2.5}$	22%	33%	17%	23%	5%	20%	34%	18%	15%	13%
	Winter	PM_{10}	22%	25%	16%	31%	6%	18%	26%	16%	28%	14%
		$PM_{2.5}$	27%	12%	18%	35%	8%	29%	8%	16%	32%	15%
Ghaziabad	Summer	PM_{10}	8%	41%	12%	35%	4%	18%	42%	16%	17%	7%
		$PM_{2.5}$	10%	37%	14%	34%	5%	21%	36%	12%	23%	8%
	Winter	PM_{10}	13%	31%	16%	35%	5%	22%	27%	16%	24%	11%
		$PM_{2.5}$	18%	19%	18%	39%	6%	26%	16%	29%	18%	11%
Noida	Summer	PM_{10}	13%	47%	12%	22%	6%	15%	44%	10%	23%	8%
		$PM_{2.5}$	15%	46%	13%	20%	6%	20%	31%	12%	26%	11%
	Winter	PM_{10}	25%	29%	12%	25%	9%	21%	23%	12%	26%	18%
		$PM_{2.5}$	30%	20%	12%	28%	10%	23%	10%	22%	24%	21%
Gurgaon	Summer	PM_{10}	14%	52%	13%	13%	8%	19%	32%	19%	24%	6%
		$PM_{2.5}$	16%	49%	14%	13%	8%	26%	29%	16%	19%	10%
	Winter	PM_{10}	23%	30%	14%	26%	7%	16%	23%	20%	26%	15%
		$PM_{2.5}$	27%	20%	15%	30%	8%	26%	15%	27%	17%	15%
Faridabad	Summer	PM_{10}	9%	46%	18%	18%	9%	21%	42%	14%	16%	8%
		$PM_{2.5}$	10%	46%	18%	17%	9%	19%	41%	12%	21%	7%
	Winter	PM_{10}	21%	19%	18%	32%	10%	18%	23%	17%	24%	19%
		$PM_{2.5}$	24%	13%	18%	34%	11%	27%	23%	19%	18%	14%

Note: Share of sources vary across cities because of sources and also because of changing meteorology as the period monitoring varied across three months within a season.

E9. Geographical contributions

This study also estimated the contribution of various regions towards $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR Towns. The average contribution of Delhi's own emissions in Delhi's $PM_{2.5}$ concentrations was found to be 36% in winters and 26% in summers. However, there are variations across different places in the city (Figure E.9). This finding is in-line with other recent studies for Delhi (Marrapu *et al.*, 2014; IITK, 2015; Kiesewetter *et al.*, 2017). In summers, the contribution of outside sources is higher on account of higher wind speeds and enhanced atmospheric transport of pollutants. In the NCR Towns, the contribution of emissions from Delhi city varies as per their location with respect to Delhi and prevailing wind directions. NOIDA city which is downwind of Delhi receives 28% and 40% of its $PM_{2.5}$ concentrations from Delhi-based sources, in summer and winter seasons, respectively. On the other hand, Panipat which is upwind of Delhi receives only 1% contribution from Delhi, and shows 56%–70% contribution from the remaining NCR regions. Ghaziabad also receives its major (61%–70%) contribution from NCR only.

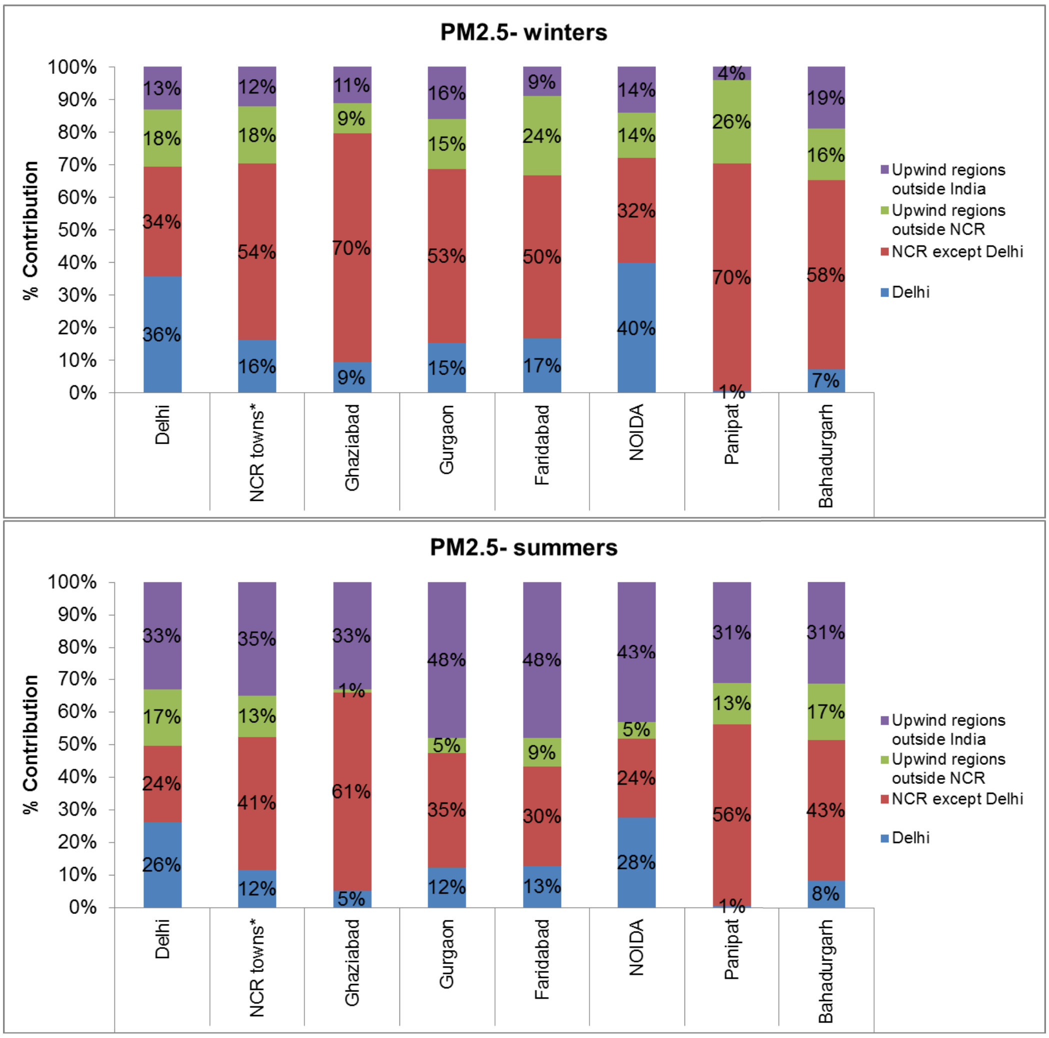


Figure E.9: contribution of various geographical regions in $PM_{2.5}$ concentrations in different towns during winter and summer seasons

Note: Share of different regions vary across different cities because of sources and also because of changing meteorology as the period monitoring varied across three months within a season.

* Average of NCR towns excluding Delhi. The contribution of nearby districts like Gurgaon, Faridabad, Noida, Ghaziabad, Jhajjar, and Sonipat in Delhi's $PM_{2.5}$ concentration was 23%-24%.

E10. Future projections

In order to understand the growth in different sectors contributing to air pollution in the region, future scenario analysis was also carried out. In this regard, possible future growth scenarios have been prepared for the year 2025 (medium term) and 2030 (long term). A Business as usual (BAU) scenario has been developed which takes into account the growth trajectories in various sectors and also the policies and interventions which have already been notified for control of pollution. A No-Further-Control (NFR) scenario has been analysed, in which impacts of these already planned interventions have been discounted. In order to assess the potential of various strategies for control of PM_{10} and $PM_{2.5}$ concentrations, about 27 interventions in different sectors have been tested on the model. Strategies which could provide significant air quality benefits have been identified and by combing them an alternative scenario (ALT) has been developed with the aim of meeting the prescribed air quality standards.

The BAU scenario shows that the total PM_{10} emissions will increase from 1,017 to 1,549 kt/yr during 2016–2030 (+54%), $PM_{2.5}$ emissions will grow from 528 to 791 kt/yr, by 50%. NO_x emissions will stabilize to about 913 kt/yr and SO_2 emissions will decrease from 892 kt/yr to 430 kt/yr. The increase in total PM emissions can be attributed to increase in industrial emissions which are projected to double and in the road dust and construction sector where the increase is 69%–82% by 2030. Emissions of NO_x are expected to stabilize during 2016 and 2030, mainly due to introduction of BS-VI emission norms in the vehicles sector, stringent NO_x and SO_2 standards in industries, and reduced usage of DG sets by 2030. The emissions of SO_2 are projected to decrease mainly due to banning of petcoke and FO (which are high sulphur fuels), and introduction of stringent standards for industries and power plants. With introduction of BS-VI norms, the PM emissions from the vehicle sector are expected to be 49% lower in 2030. Despite introduction of some controls, the industrial sector, due to its growth, will become the major sector contributing to $PM_{2.5}$ emissions in NCR. Contribution of residential sector in emissions reduces due to penetration of LPG and elimination of kerosene use for lighting. The share of agriculture residue burning in emissions is expected to reduce slightly considering the present focus on technologies and strategies for control. On the other hand, the contribution of road dust and construction activities in emissions is projected to increase in the BAU scenario.

Feeding the projected emissions for different sectors in the model, the BAU scenario still depicts an increase in PM_{10} concentrations (two season average) from 134 $\mu g/m^3$ in 2016 to 156 and 165 $\mu g/m^3$ in 2025 and 2030, respectively in NCR including Delhi. The $PM_{2.5}$ concentrations will increase from 109 $\mu g/m^3$ in 2016 to 114 and 118 $\mu g/m^3$ in 2025 and 2030, respectively. The increase could have been higher if the emissions control strategies (like BS-VI norms) envisaged in BAU are not implemented. These strategies are expected to contribute significantly towards reducing (30%) concentration of PM_{10} and $PM_{2.5}$ by the year 2030. Despite this, the BAU scenario shows slightly more pollutant concentrations in future than present, and hence, additional strategies will be required for control. In order to construct an alternative future scenario, intervention analysis is performed to estimate the emissions and concentrations reduction potential of different control strategies in transport, biomass, industries, road and construction dust and others sectors. The share of transport, industries, biomass , dust and others in $PM_{2.5}$ concentrations (winters) in 2030 is found to be 16%, 44%, 13%, 19%, and 8%, respectively.

The reductions have been estimated for various strategies across different sectors for the winter season (Table E.4). In the biomass burning sector, it was found that a 6%–7% reduction in ambient concentration of $PM_{2.5}$ and PM_{10}, respectively in 2030 may be achieved by using agricultural residues as pellets in households. However, when agricultural residues are burnt in power plants by replacing coal, it leads to a reduction of 7%–8% in PM_{10} and $PM_{2.5}$ concentrations. The main reduction is by eliminating the agricultural burning activity. Additional benefits of pelleting in households (improved cooking efficiency) and reduced use of sulphur-based coal in power plants have also been accounted for. LPG penetration leads to a reduction of 6% in $PM_{2.5}$ and PM_{10} concentrations in 2030.

As the projected share of transport in 2030 is low (16% in winter season), the impact of strategies in this sector is found to be somewhat lower than other sectors. Higher penetration of electric vehicles in transport such as 2-wheelers, buses and cars shows the reduction of 5%–6% in $PM_{2.5}$ and PM10 concentrations in 2025-2030. Reducing real world emissions by congestion management can lead to 4%–3% reduction in $PM_{2.5}$ and PM_{10} concentrations in 2030. Fleet modernization leads to 8%–6% reduction in 2025 and 3%–2% reduction in $PM_{2.5}$ and PM_{10} concentrations in 2030.

On the other hand, the projected share of industries is high (44% in winters) in 2030, and hence the impact of strategies on PM concentrations is found to be higher than other sectors. Fuel switch to gaseous fuels can lead to a massive reduction of 12% in PM_{10} and $PM_{2.5}$ concentrations in 2025. The reduction grows to 23% in 2030. Alternatively, the implementation of a stringent standard for $PM_{2.5}$/PM_{10} in industries can lead to 8%–10% reductions in PM concentrations in 2025, and 11%–12% in 2030. Better enforcement with continuous monitoring of industrial emissions will result in lower industrial emissions and a reduction of 9%–10% may be achieved in PM concentrations in 2025 and 2030. The impact of other strategies, such as zig-zag technology in brick kilns, and introduction of standards for gaseous pollutants is found to be less than 4%.

The share of dust in PM_{10} concentrations in 2030 is high, that is, 20% from road and construction activities. The strategy of enhanced vacuum cleaning of roads results in 6% and 2% reduction in PM_{10} and $PM_{2.5}$ concentrations, respectively in winters. Control of dust from C& D activities can reduce 2% and 1% of PM_{10} and $PM_{2.5}$ concentrations, respectively in NCR in 2030. Banning of open refuse burning and using it in waste to energy (WTE) plants reduces PM_{10} and $PM_{2.5}$ concentrations by 3% and 4%, respectively, in 2030. Supply of 24x7 electricity may reduce $PM_{2.5}$ concentrations by 2% in 2030 by reducing DG set usage. The rest of the strategies in others category having different reduction potentials are shown in Table E.4.

Table E.4 : Concentration reduction potential of various strategies (winter seasons) in 2025 and 2030.

S.N0	Strategies	2025		2030	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Biomass				
1	Increase in LPG penetration in residential sectors in NCR by 75% in 2025- 100% in 2030	-6%	-6%	-6%	-6%
2	Supply and use of improved biomass cook-stoves 75% in 2025 and 100% in 2030 to households using biomass	-6%	-6%	-4%	-4%
3	Supply and use of improved induction cook-stoves 75% in 2025 and 100% in 2030 to households using biomass	-6%	-6%	-6%	-6%
4	Use of agricultural residues in WTE (With adequate tail-pipe controls) *	-4%	-5%	-4%	-4%
5	Use of agricultural residues in power plants *	-8%	-8%	-8%	-7%
6	Use of agricultural residues pellets in local households *	-7%	-7%	-6%	-6%
	Transport				
7	Electrification of vehicular fleet (Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%)	-6%	-5%	-6%	-5%
7a	Public transportation -25% and 50% electric buses in 2025 and 2030	*-1%*	*-1%*	*-1%*	*-1%*
7b	Private electric vehicles- 20% in 2025 and 40% in 2030 electric two-wheelers, and 100% three-wheelers	*-4.7%*	*-3.5%*	*-3.9%*	*-2.8%*
7c	Private electric vehicles- 20% in 2025 and 40% in 2030 electric cars	*-0.24%*	*-0.17%*	*-1.4%*	*-1%*
8	Fleet modernization - Restricted entry/movement of pre-BS-VI vehicles	-8%	-6%	-3%	-2%
9	Banning entry of pre BS-IV trucks and buses - to be modernized/retrofitted to be BS-VI equivalent	-3%	-2%	-1%	-1%
10	Improved inspection and maintenance system- High emitters go down from 5% to 2% (2025) and 1% in 2030	-2%	-1%	-1%	-1%
11	Reducing real world emissions from vehicles by 50% through congestion management	-5%	-4%	-4%	-3%
12	Shift of 50% cars and 2-w users to shared commuter transport (public/private) (based on EVs)	-2%	-1%	-1%	-1%
13	Increase penetration of biodiesel to12% by 2025 and 20% by 2030	-0.5%	-0.3%	-0.7%	-0.5%
14	Increased penetration of hybrid and EV cars: 35% hybrid and 15% EV cars by 2025 and 70% hybrid and 30% EV by 2030	-0.7%	-0.5%	-2.1%	-1.5%

S.N0	Strategies	2025		2030	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Industries				
15	Power plant controls -implement stricter NO_x and SO_2 standards with continuous monitoring	-4%	-3%	-4%	-3%
16	Stricter enforcement of standards in industries through continuous monitoring and other mechanisms	-9%	-10%	-9%	-10%
17	Enforcement of SO_2/NO_x standards in industries 50% and 100% in 2025 and 2030	-1%	-1%	-2%	-2%
18	Enforcement (75-100%) of zig-zag brick kiln technology in 2025 and 2030	-4%	-4%	-4%	-3%
19	100% fuel switch from solid to gaseous fuels	-12%	-12%	-23%	-23%
20	Stricter dust control on stone crushers	-0.1%	-1%	-0.1%	-2%
21	Introduce and implement stringent PM_{10} and $PM_{2.5}$ norms in industries through installations of wet scrubbers	-8%	-10%	-11%	-12%
	Road dust and construction				
22	Vacuum cleaning of roads - silt load reduction of 25% and 50% in 2025 and 2030	-0.3%	-2%	-2%	-6%
23	Wall to wall paving- silt load reduction of 25% and 50% in 2025 and 2030	-0.3%	-2%	-2%	-6%
24	Control of dust from construction activities- barriers and fogging based controls -30% and 60% in 2025 and 2030.	-0.3%	-1%	-1%	-2%
	Others				
25	Full ban on refuse burning activities and combustion in WTE	-4%	-3%	-4%	-3%
26	Landfill fire control	-0.1%	-0.2%	-0.5%	-0.4%
27	Stricter standards for DG sets using innovative PM and NO_x emissions control technologies	-2%	-2%	-1%	-1%
28	Supply 24x7 electricity leading to 90–95% reduction in DG set usage by 2025 and 2030,	-2%	-2%	-2%	-1%

The table shows the reduction potential of different strategies and detailed techno-economic feasibility studies will be required for some of the strategies before actual implementation.

* This only shows the average effect over the whole season but in addition it will also help in reducing the peak of pollution during post-harvesting season.

After conducting the intervention analysis, a set of interventions, which are most feasible to implement and also have substantial impact on PM concentrations are selected for constructing the alternative scenario. Figure E.10 shows the change in concentrations of

$PM_{2.5}$ and PM_{10} in BAU and alternative scenario. In alternative scenario, in 2030, $PM_{2.5}$ emissions have reduced by 72% and PM_{10} emissions have reduced by 77% and the corresponding reduction in average concentration (of both seasons) was 58% in $PM_{2.5}$ and 61% in PM_{10}. The alternative scenario envisages meeting the prescribed daily standards in the winter season and hence, it may be safely assumed that annual average standards may be met considering lower concentrations during other seasons.

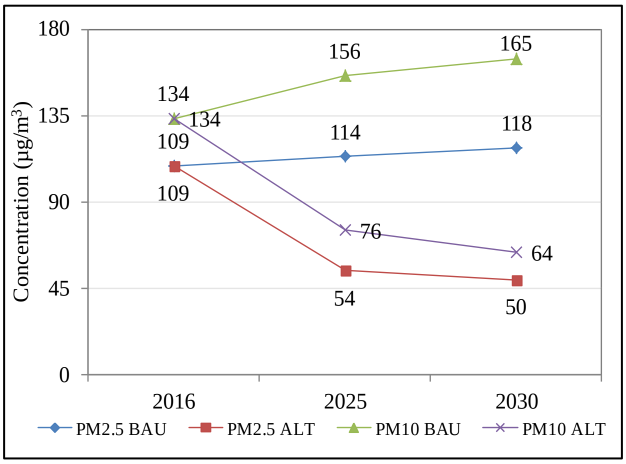


Figure E.10: Average of two seasons (winter and summer) PM_{10} and $PM_{2.5}$ concentrations in Delhi-NCR in seasons in BAU and ALT scenarios

E11. Proposed Action Plan

An action plan including all the selected strategies in the alternative scenario has been presented in Table E.5. The time frames and possible implementing agencies of these strategies are also suggested.

Table E.5.: Action plans with the list of interventions selected for reduction of pollutant concentrations in Delhi-NCR

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
	Biomass Burning ($PM_{2.5}$ and PM_{10} concentration reduction in 2030 winter season: 14% and 10%, respectively.)			
1	Increase in LPG penetration in NCR by 75% in 2025- 100% in 2030	Convert 75% and 100% biomass to LPG in 2025 and 2030, respectively	100% LPG penetration by 2026	MoPNG
2	Use of agricultural residues as briquettes in power plants	Zero-open burning and use of residue briquettes in power plants	Agricultural residue to be used in power plants by 2020	MoP, MoA
	Transport ($PM_{2.5}$ and PM_{10} concentration reduction in 2030 winter season: 9% and 7%, respectively.)			
3	Public transportation system on electric vehicles; followed by private vehicles	25% and 50% electric buses in 2025 and 2030, respectively	25% and 50% electric buses in 2025 and 2030, respectively	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
4	Improved inspection and maintenance system	Setting up OBD/remote sensing based and advanced I&M centres. High emitter emissions go down from 25% to 10% (in 2025) and 25% to 5% in 2030	15 advanced I&M centres in NCR by 2021 and 30 by 2025. To support, existing PUCs to be upgraded for OBD-based testing.	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
5	Fleet modernization	All vehicles to be BS-VI	Fleet modernisation mechanisms along with scrappage centres by 2025	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
6	Reducing real world emissions from vehicles by congestion management	Reduce real world emissions by 50% by congestions management strategies	Introduce congestion pricing schemes in Delhi by 2019 and expand to NCR by 2021to shift from private to public modes of transportation*	MoUD and states urban development and transport departments
7	Shift of 50% cars and 2-w to shared commuter transport	Shift 50% of personal transport on shared taxis in 2025 and 2030	Promote private players to enhance shared transport modes by 2019	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
	Industries ($PM_{2.5}$ and PM_{10} concentration reduction in 2030 winter season: 32% and 31%, respectively.)			
8	Power plant controls with continuous monitoring	Implement stricter NO_x and SO_2 standards	Install tailpipe control devices by 2020.	Power plant companies, MoP, SPCBs, and CPCB
9	Introduction and enforcement of new SO_2 and NO_x standards	75% and 100% enforcement of SO_2/NO_x standards in industries in 2025 and 2030, respectively	Install tailpipe control devices in 75% of industries by 2021 and 100% by 2026	Industries, SPCBs, and CPCB
10	Enforcement of zig-zag brick kiln technology	75% and 100% enforcement of zig-zag brick kiln technology in 2025 and 2030, respectively	75% and 100% enforcement of zig-zag brick kiln technology in 2021 and 2026, respectively	SPCBs and CPCB
11	Strict PM control on stone crushers	Increase PM_{10} control efficiency to 80% and $PM_{2.5}$ 40% in both 2025 and 2030	Install wet dust suppression system and dry collection techniques in all stone crushers by 2021.	SPCBs and CPCB
12	Fuel switch to gas from solid fuels	50% and 100% fuel switch to gas from solid fuels in 2025 and 2030, respectively	Fuel switch to gas from solid fuels in 50% and 100% industries in 2025 and 2030, respectively	MoPNG, State Industrial departments

S.No.	Strategies	Description	Desired Time frame	Suggested implementation agencies
	Road dust and Construction ($PM_{2.5}$ and PM_{10} concentration reduction in 2030 winter season: 4% and 11%, respectively.)			
13	Vacuum cleaning of roads	Silt load reduction 25% and 50% in 2025 and 2030, respectively	Mechanized road cleaning at 25% and 50% roads in 2025 and 2030, respectively	Municipal corporations
14	Wall to wall paving of roads	Silt load reduction 25% and 50% in 2025 and 2030, respectively	Wall to wall paving of 25% and 50% roads in 2025 and 2030, respectively	PWD
15	Control of dust from construction activities	Barriers and water controls (30% and 60% control on PM emissions in 2025 and 2030, respectively)	Mandatory implementation of barriers and water controls in major construction sites by 2021 and all by 2026.	PWD, NHAI, Municipal bodies, PCBs
	Others ($PM_{2.5}$ and PM_{10} concentration reduction in 2030 winter season: 6% and 6%, respectively.)			
16	Use of refuse in WTE	Reduced emissions from refuse burning in WTE plants fitted with controls	Immediate market mechanism for collection and transportation of refuse to WTE	Municipal corporations and panchayats
17	Supply 24x7 electricity	Supply 24x7 electricity , DG set emissions to reduce to 10% and 5% in 2025 and 2030, respectively	Immediate arrangements for regulatory and tariff structure to make use of the power surplus situation and thereby ensuring 24x7 power supply	State electricity departments

The table shows the reduction potential of different strategies and detailed techno-economic feasibility studies will be required for some of the strategies before actual implementation.

*the revenues collected from congestion pricing scheme should mandatorily be used for enhancement of public transport.

E12. Conclusions

- Air pollution levels are extremely high in Delhi and NCR, especially in winters.
- The assessment of both the scientific approaches reveals that transport, biomass burning, and industries are the three major contributors to $PM_{2.5}$ concentration in Delhi NCR during winter. In summer, the contributions of dust from inside and outside of India eclipses the shares of these three major sectors in the $PM_{2.5}$ concentrations, however, the contributions still remain significant.
- The assessment for PM_{10} shows that other than transport, biomass burning, and industries, road dust and construction dust also contribute significantly to concentrations. Like $PM_{2.5}$, during summers, the contributions of dust from outside of India reduce the shares of these local sectors in the PM_{10} concentrations.
- The study has quantified the contributions of different sources at present and in future time-frames (2025–2030). The $PM_{2.5}$ concentrations are expected to increase by 5% in 2025 and by 8% in 2030 with respect to 2016, in a BAU scenario. The PM_{10} concentrations are expected to increase by 16 and 23% in 2025 and 2030, respectively, in a BAU scenario. This is after accounting for growth in different sectors and also taking into account the possible enforcement of the interventions which have already been notified for control of air pollution. Discounting these planned interventions, the growth in $PM_{2.5}$ concentrations could be 30% higher in 2030.
- The study analysed various interventions and estimated their possible impacts over $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR. An alternative scenario has been developed considering the interventions which can provide maximum air quality benefits. The alternative scenario results in a reduction of 58% and 61% in $PM_{2.5}$ and PM_{10} concentrations in 2030, with respect to the BAU scenario, and achieves the daily ambient air quality standards for PM_{10} and $PM_{2.5}$.
- The interventions which have identified as the ones with highest impact on PM concentrations in 2030 are:
  - Complete phase out of biomass use in NCR by enhanced LPG penetration in rural households
  - Use of agricultural residues in power plants and other industries to replace high ash coal and open burning in fields
  - Introduction of gaseous fuels and enforcement of new and stringent $SO_2/NO_x/PM_{2.5}$ standards for industries using solid fuels
  - Strict implementation of BS-VI norms
  - Improvement and strengthening of inspection and maintenance system for vehicles
  - Fleet modernization and retro-fitment programmes with control devices
  - Enhanced penetration of electric and hybrid vehicles
  - Reducing real world emissions by congestion management
  - Stricter enforcement of standards in large industries through continuous monitoring
  - Full enforcement of zig-zag brick technology in brick kilns
  - Vacuum cleaning of roads, wall to wall paving of roads
  - Control of dust from construction activities using enclosures, fogging machines, and barriers
  - Elimination of DG set usage by provision of 24x7 electricity and control by innovative tail-pipe control technologies

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Chapter 1 Introduction

1.1 Background of the Study

The deteriorating ambient air quality (AAQ) in Indian cities is a matter of concern. Violation of ambient air-quality standards in about 80% of Indian cities presents a grim picture of the prevalent air quality across the country. The concern is even more serious in big cities like Delhi. Particulate matter is identified as the most critical pollutant, followed by other pollutants like NOx, CO, ozone, SO_2, NMVOCs, and ammonia. Due to growth in population, transportation demands, industrialisation, there is a steady growth in energy based air pollutant emissions released in the atmosphere. Other than these, sources like refuse burning, road dust, construction activities, agricultural residue burning, also add to the pool of emissions in India. Urban air pollution is widely linked to different types of health impacts all across the world. In order to take pin-pointed actions for control of pollution, there is always a need for scientific source apportionment studies.

Being the capital city, Delhi's worsening air quality has not only concerned the residents but also attracted significant regional and global attention. Over the last several years, PM_{10} and $PM_{2.5}$ concentrations in Delhi have remained well above the prescribed national standards. The annual average concentrations of PM generally violate the standards by about 3 times. Several source apportionment studies conducted in the past (ESMAP, 2004; NEERI, 2010; and IITK 2015) attempted to quantify the contribution of different sources towards PM_{10} and $PM_{2.5}$ concentrations in the city. All the studies provided significant inputs in providing estimates of source contributions in different years. However, most of these took into account sources within the city limits only, while there are contributions from outside the city also. Moreover, the source apportionments were derived mainly using receptor models only, which could not fully explain several aspects of the contributors (e.g. secondary particulate and geographical contributions).

There are a number of towns like Ghaziabad, Gurugram, Faridabad, NOIDA, and so on in the vicinity of Delhi, which have grown at a rapid pace and have shown very high air-pollutant levels. Hence, there is a need to inventorise the pollutants from sources not only within Delhi's limits, but also in the surrounding National Capital Region (NCR). Moreover, international studies have shown significant contributions from regional and trans-boundary sources in urban air pollution, and hence these need to be accounted while deriving source apportionment for a city like Delhi. Conclusively, the issue of deteriorating air quality in Delhi and several other neighboring towns need to be addressed through a comprehensive air-quality assessment carried out for a wider region than Delhi.

For development of an effective air-quality management plan, scientific apportionment of contributing sources is the essential step to draft specific strategies for their control. Apart from source apportionment in present, air quality projections are to be carried out, in order to take into account sectoral growth patterns in near future. This is essential for evaluation of the effectiveness of control options listed in the air quality management plan. This calls for an integrated approach towards air-quality management involving air quality monitoring, emission inventorisation, source apportionment, future projections and intervention testing. A database built using all the relevant scientific tools (for designing an air-quality management plan) is required for decision support.

Air quality models complements the ground based observations by representing a wider area and provides an economically viable option for future scenario analysis. In addition to pollutant information, air-quality models give a deterministic approach with an integrated analysis of emissions, meteorology, and the spatial and temporal variation of the current and controlled scenarios, making them an important tool for air-quality management and research. Further, a detailed control scenario analysis acts as a valuable tool to design policies based on

- Projected future growth in emissions from various source categories
- Impact scenarios with and without controls in different sectors.
- Impact of implementation of short-/medium-term interventions on ambient pollution levels for the various control options for different sources

In light of deteriorating air quality in Delhi, the Department of Heavy Industry (DHI), Ministry of Heavy Industries and Public Enterprises, Government of India, initiated a study titled 'Source Apportionment of $PM_{2.5}$ and PM_{10} of Delhi–NCR for Identification of Major Sources' with the Automotive Research Association of India (ARAI), Pune, and The Energy and Resources Institute (TERI), Delhi. The main objective of the study was to carry out the assessment of the current and future air-quality in Delhi–NCR. The focus of the study was on critical air pollutants like PM_{10} and $PM_{2.5}$ which impact human health and environment in several other ways. An integrated approach, with two different modelling techniques, namely, receptor modelling and dispersion modelling, was followed to identify the sources of $PM_{2.5}$ and PM_{10} in Delhi and several other towns in NCR. The study has relied upon results derived from both the receptor- and dispersion-modelling techniques to derive source contributions and arrived at more reliable and convergent conclusions. For the first approach using receptor modelling, the ARAI was assigned the tasks of monitoring air quality, chemical speciation, source profiling and receptor modelling. On the other hand, TERI prepared an emission inventory for the NCR (and also took into account contributions from regions beyond NCR), and conducted dispersion modelling using state-of-the-art chemical transport model for the entire NCR region.

Both the model results were compared to validate and derive meaningful conclusions. The key highlights of the study were:

a) Source apportionment results for several NCR towns other than Delhi
b) Wider NCR region considered for emission inventorisation and dispersion modelling to account for contributions from outside of Delhi
c) Boundary conditions from India scale modelling used to account for contributions from sources beyond NCR
d) Use of most advanced chemical transport modelling approach to also incorporate secondary particulate formation and its apportionment
e) Use of newly developed emission factors and source profiles for post-2005 vehicles

The study also projects future sectoral emissions and air quality and quantified the impact of several interventions which can reduce pollution in the region. This will assist in development and testing of appropriate strategies for control of air pollution in Delhi-NCR. A technical committee was formulated for providing reviews and directional inputs to the working teams in the ARAI and TERI. Moreover, the report was nationally and internationally peer-reviewed by renowned experts in the field.

1.2 About Delhi City

New Delhi, the national capital of India, is famous for its culture, tradition, and effervescent history.

Geography: Delhi is located in northern India between the latitudes of 28°-24'-17" and 28°-53'-00" North and longitudes of 76°-50'-24" and 77°-20'-37" East. Uttar Pradesh and Haryana are its border states. Delhi has an area of 1,483 sq. km. Its maximum length is 51.90 km and greatest width is 48.48 km.

Climate: Delhi receives an average annual rainfall of 714 mm, three-fourths of which falls in July, August, and September. Heavy rainfall in the catchment area of the Yamuna river can result in a dangerous flood situation in the city. During the summer months of April, May, and June, temperatures rise to 40–45 ℃; winters are typically cold with temperatures during December and January falling to 4–5 ℃. February and March, and October and November are climatically the best months.

Demographics: Delhi has been one of the country's most popular cities since ages and many kings and leaders have ruled the country from here. It has evolved as a metropolitan city and has shown great signs of development. The presence of places of national importance and of the governing body in the capital helps the overall development of Delhi as a city. As per the 2011 census, Delhi has a population of 1.68 crore, an increase from 1.39 crore as recorded in the 2001 census. The total population growth in this decade was 21.21%. Delhi's population accounted for 1.39% of India's population in 2011. The majority of people in Delhi (97.50%) live in urban regions.

Road transport: Delhi relies heavily on its transport infrastructure. The city has developed a highly efficient public transport system—the Delhi Metro—which is undergoing rapid modernization and expansion. There are 88,50,720 number of registered vehicles in the city as of 31.03.2015 (Ministry of Statistics and Program Implementation; http://mospi.nic.in). Therefore, serious efforts, including a number of transport infrastructure projects, are underway to encourage the usage of public transport in the city.

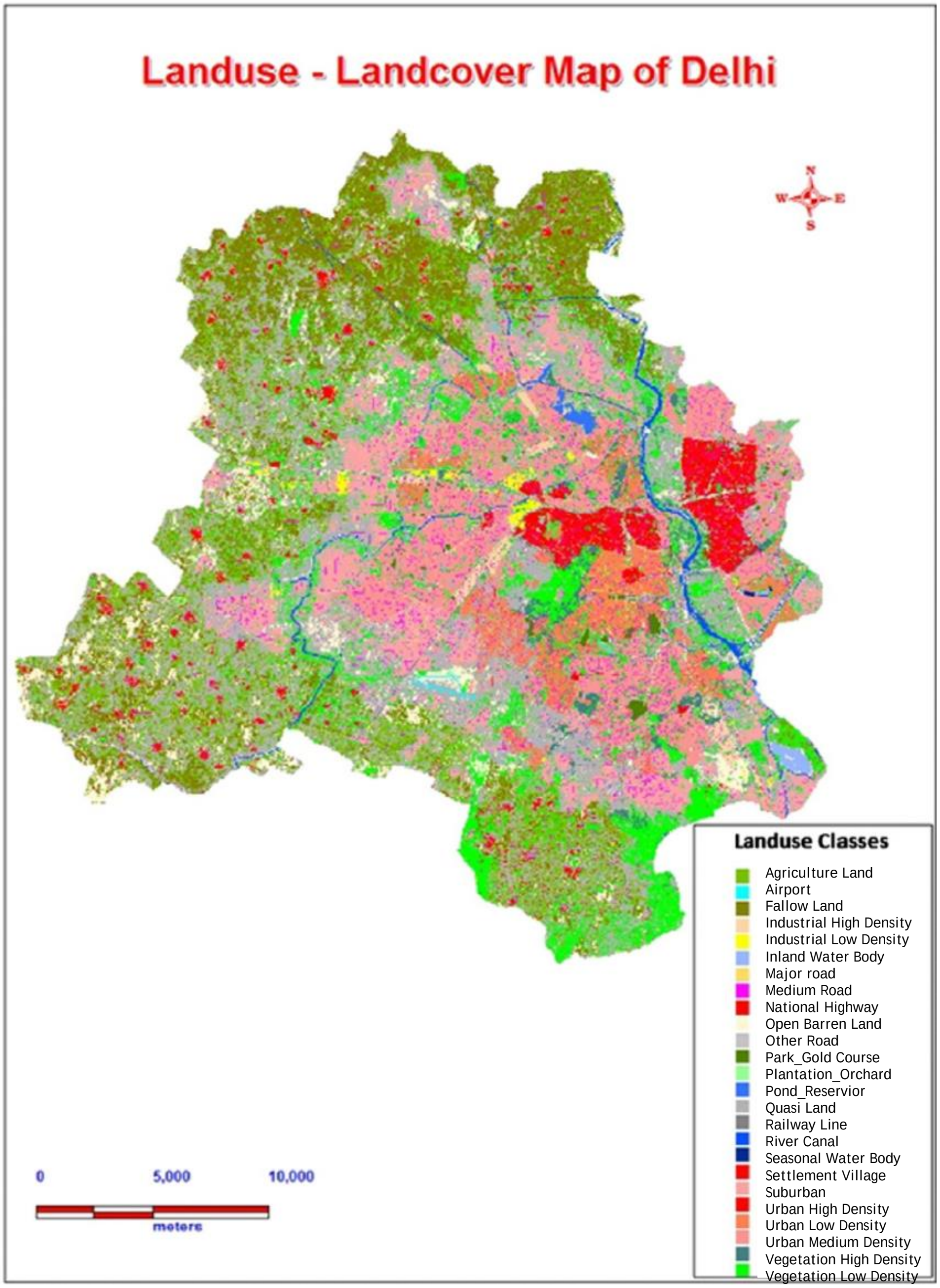


Figure 1.1 A Map of Delhi Depicting the **City's** Land-Use Pattern

Source: https://www.researchgate.net

1.3 General Description of the NCR

The NCR is a coordinated planning region centered upon the National Capital Territory (NCT) of Delhi in India. It encompasses the entire NCT of Delhi and several districts surrounding it from the states of Haryana, Uttar Pradesh, and Rajasthan. The area under NCR includes of the entire NCT of Delhi the Haryana districts of Karnal, Panipat, Sonipat, Jind, Bhiwani, Rohtak, Jhajjar, Mahendragrh, Rewari, Gurugram, and Faridabad; and the Uttar Pradesh districts of Meerut, Bhagpat, Ghaziabad, Bulandshahr, Hapur, Gautam Budh Nagar, and Muzzaffar Nagar; and two districts of Rajasthan, namely, Alwar and Bharatpur.

The area of the NCT of Delhi is 1484 km^2, while the NCR extends over an area of 58,332 km^2 excluding the union territory of Delhi (5%) and covering parts of Haryana (44%), Rajasthan (15%), and Uttar Pradesh (36%) as its constituents (Census 2011). The total population of Delhi as per the 2011 census is 16.8 million, while the NCR's population is 46 million. The density of the NCR's population is 790 per km^2, whereas that of Delhi is 11,297 per km^2. The NCR contains 7.6% of the total urban and 2.1% of the total rural population of India, whereas about 4.4% of India's urban population resides in the NCT of Delhi.

Delhi and its satellite urban communities, together known as the NCR, have the highest number of vehicles as compared to any other Indian city. The vehicle population growth has strongly expanded at a yearly rate of 7.40% for private vehicles and 9.15% for business vehicles. The total number of registered motor vehicles in Delhi by 2015–16 is 9,704,741, out of which 62.90% are motor cycles/scooters, 30.77% are cars and jeeps, and the rest are commercial vehicles such as auto rickshaw, taxis, buses, and goods vehicles. Other than the vehicles registered in the Delhi city, there is also a large in-and-out movement of vehicles from its surrounding towns like Gurugram, Faridabad, Sonipat, Ghaziabad, and Gautam Budh Nagar.

A variety of sources contribute to pollution in Delhi and NCR. On the one hand, the emissions related to economic growth such as those from coal-based power generation, industrial emissions, mobility demands, and the corresponding vehicular emissions are the causes; on the other hand, poverty-linked emissions from biomass-based cooking in the residential sector is contributing to both indoor and outdoor air pollution. About 3 million NCR households are still reliant on biomass for cooking purposes and use traditional cook stoves with minimal efficiency and high emission rates. Major industries are generally equipped with air-pollution-control installations, but medium- and small-scale industries are still dealing with limited controls. As per the data collected from State Pollution Control Boards (SPCBs) in the NCR, there are thousands of air-polluting industries in the whole of the NCR. Additionally, there are about 5,000 brick kilns operating in the NCR.

Currently, Delhi has one coal-based and three gas-based power plants, whereas the whole NCR accommodates five coal-based and five gas-based power plants. The only coal-based power plant in Delhi—the Badarpur power plant—which was operational and is expected to be shut down in near future. Furnace oil (FO), Light diesel oil (LDO), low sulphur high speed diesel (LSHS), natural gas (NG), and coal are the major fuels used by industries in Delhi, whereas the NCR shows an even wider variety of fuel usage in industries, which includes coal, wood, petcoke, bagasse, rice husk, high speed diesel (HSD), FO, NG, and others. Recently, the use of FO and petcoke was banned in Delhi–NCR.

Delhi's air quality is impacted by both local and regional sources. Vehicles, road dust, construction, and refuse burning are the sources which contribute locally; there are several other sources which are outside of the city but still contribute to Delhi' s air quality through atmospheric transport. Several towns surrounding the city of Delhi have grown at a faster rate with lesser controls in comparison to Delhi itself. While industries were moved out of Delhi, they still run and use solid fuels outside the city limits in these towns. Residential apartments and shopping malls which came up in big numbers in the surrounding towns contributed to emissions not only during the construction phase but also during their operations through the use of diesel generator (DG) sets to tackle the problem of frequent power cuts. Additionally, the burning of agricultural residues in the farms of Punjab, Haryana, and Uttar Pradesh also contribute significantly in specific seasons.

The NCR is India's biggest urban agglomeration and is known for its poor air quality. The AAQ monitoring in Delhi is conducted under the National Air Monitoring Programme (NAMP) through various organizations, including the CPCB, the DPCC, the National Environmental Engineering Research Institute (NEERI), and others, whereas the AAQ monitoring in other parts of the NCR is managed by the respective state pollution control boards. Under the NAMP, there are currently 10 manual monitoring and 38 continuous air-quality monitoring stations in Delhi, out of which 20 new continuous stations started operating from 2017. There are only 11 manual monitoring stations in the NCR—three of them are in the Alwar district and two each in Faridabad, Noida, Ghaziabad, and Meerut. Additionally, there are nine continuous air-quality monitoring stations operating in the NCR, one each in Faridabad, Gurugram, Rohtak, Bulandshahr, Greater Noida, Ghaziabad, and two in Noida. Figure 1.2 shows the results of air-quality monitoring carried out in different cities under the NAMP. Evidently, all the NCR towns including Delhi are violating the annual average standards for PM_{10}—and that too by 2–4 times. NOx concentrations consistently surpass the annual average standards in Delhi, and are close to the standards in many other towns. SO_2 concentrations are well below the annual average standards at all the places. Ghaziabad shows the highest SO_2 concentrations owing to the local industrial activities.

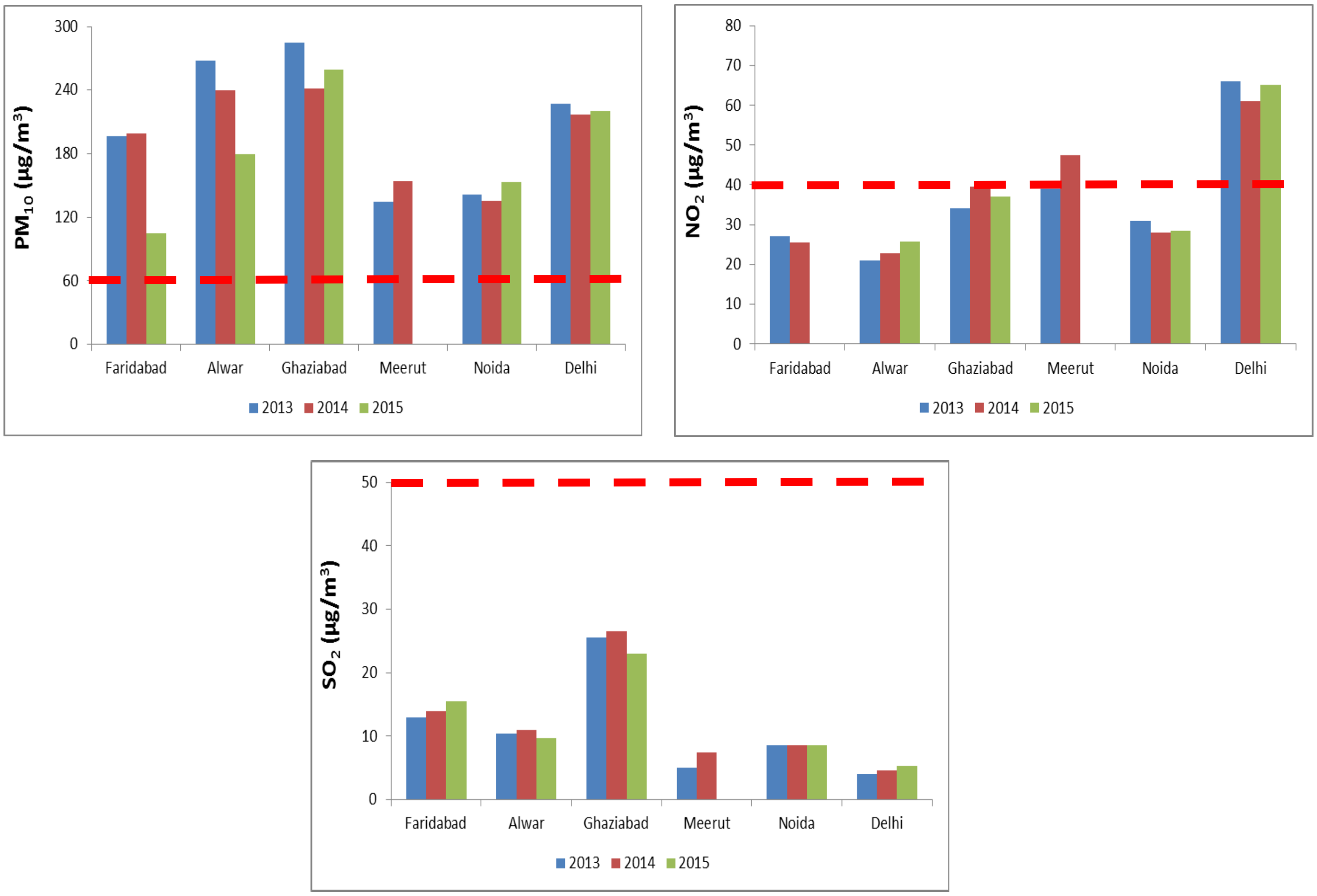


Figure 1.2 Comparison of Air-Pollutant Concentrations in Delhi and NCR Towns during 2013–15

Source: National Ambient Air Quality Monitoring Programme (NAMP)

The major sources responsible for the deteriorating AAQ in Delhi have been assessed through various source apportionment studies. The 2010 source apportionment study conducted by the Central Pollution Control Board (CPCB) reported re-suspended dust (45%) as the largest source of PM_{10} in the city, followed by waste burning (14%), transport (14%), DG sets (9%), industries (8%), and domestic cooking (7%). The data collected during 2013-2014 study conducted by IIT Kanpur reported that in Winter Season the three major sources of $PM_{2.5}$ were secondary particulates (30%), biomass burning (26%), and transport (25%); while in summers, the major source was found to be soil and road dust (28%), followed by coal and fly ash (26%) and secondary particulates (15%). Though these studies provided important information on source contributions, there still remained issues related to the apportionment of secondary particulates, geographical contributions (from local, regional, and international sources), and sub-sectoral contributions.

The central and state governments have taken several steps to curb the rising air-pollution levels in Delhi–NCR. However, despite their efforts pollutant levels have remained high in the region. This calls for further investigation of sources and their geographical locations. Moreover, we need proactive planning to draft strategies after accounting for future growth in different sectors.

1.4 Representative Windroses

Wind rose during monitoring period showing the distribution of wind direction in Delhi is presented in Figure 1.3. Most predominant wind directions were observed to be West and North-West.

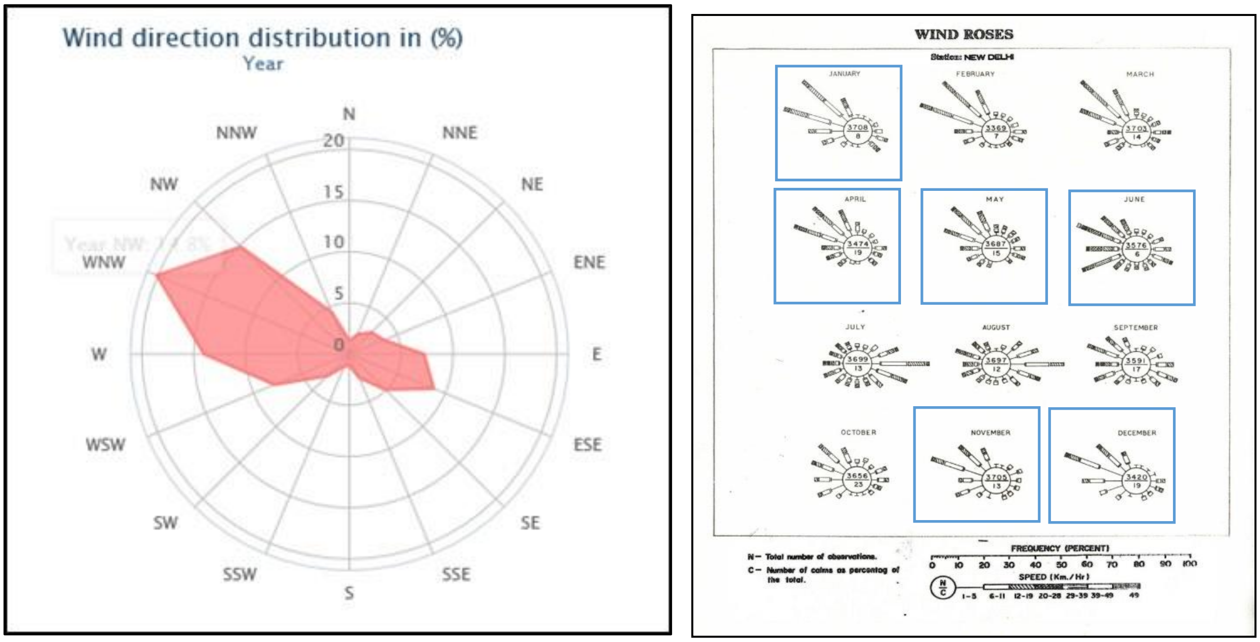


Figure 1.3 Windroses of Delhi City during Monitoring

1.5 Need for the Study

- PM is one of the most critical pollutant in Delhi–NCR.
- There are multiple emission sources of PM, including transportation, construction, domestic, agricultural burning, dust sources and energy consumption in industry.
- For an effective air-quality management plan, identification of major pollutant sources is very essential. Moreover, there is a need to understand the growth patterns to draft control strategies after taking into account future growth in different sectors.

1.6 Objectives and Scope of Work

The following were the broad objectives of the study:

- AAQ monitoring for PM_{10} and $PM_{2.5}$ in Delhi and NCR Towns in Summer and Winter seasons
- Chemical speciation of PM_{10} and $PM_{2.5}$ samples for Carbon Fractions, Ions and Elements
- Identification of major sources contributing to $PM_{2.5}$ and PM_{10} using receptor modeling
- To develop a multi-sectoral, multi-pollutant emissions inventory of PM and gaseous pollutants
- To simulate pollutant concentrations using WRF–CMAQ models for the baseline year 2016 and for future energy and emission scenarios for the medium (2020) and long terms (2030)

- To assess and quantify the potential of different strategies for controlling pollution in the NCR
- Generation of emission factors and source profiles for post-2005 technology vehicles

PM_{10} and $PM_{2.5}$ were monitored and inventoried during this project with the study's overall scope of work, as given below:

ARAI

- AAQ monitoring for PM_{10} and $PM_{2.5}$ in Delhi–NCR. Air-quality monitoring at 20 locations in the NCR in summer and winter. A ten-day monitoring at each location in each season.
- Chemical characterization of PM_{10} and $PM_{2.5}$ for elements, ions, and organic and elemental carbon
- Development of emission factors
- Generation of source profiles for post-2005 technology (BSIII and BSIV) vehicles
- Identification of major sources contributing to $PM_{2.5}$ and PM_{10} using receptor modelling.

TERI

- To identify major sources of air pollution
- To develop a multi-sectoral, multi-pollutant emissions inventory of PM and gaseous pollutants
- To simulate pollutant concentrations using WRF–CMAQ models for the baseline year 2016 and carry out source apportionment
- To validate the model with actual observations and source apportionment derived using receptor model
- To develop future energy and emission scenarios for the medium (2025) and long terms (2030)
- To assess and quantify the potential of different strategies for controlling pollution in the NCR

Chapter 2 Air-Quality Monitoring

2.1 Introduction

The main objective of AAQ monitoring was to generate the baseline data of ambient concentration of PM_{10} and $PM_{2.5}$ and to identify the major sources contributing to it. Monitoring was conducted in two critical seasons, summer and winter, to capture the seasonal variation. A comprehensive exercise to monitor air quality was carried out during summer in April 2016 and June 2016 and during winter seasons in November 2016- Feb 2017at 20 representative locations as per the monitoring protocol mentioned ahead, including kerbside, industrial, commercial, and residential sites, which have different land-use patterns and sources of activity.

2.2 Methodology

2.2.1 Monitoring Protocol

The following monitoring protocol was followed:

- No. of sites: A total of 20 AAQ monitoring locations were identified in Delhi–NCR: 9 in Delhi City, 4 in Uttar Pradesh, and 7 in Haryana (including 3 in the upwind direction).
- Seasons: The AAQ monitoring was carried out in the summer and winter seasons.
- Parameters: A 24-hour manual air-quality sampling was carried out for PM_{10} and $PM_{2.5}$.
- Samplers: Thermo Make 4-channel Speciation samplers (Partisol® 2300) were used to collect PM_{10} and $PM_{2.5}$ samples on Teflon and Quartz filter paper (see Figure 2.1) Refer Annexure A.
- Filter paper used for sampling: (Refer Annexure B)
  - Teflon filter paper: 2 μm PTFE 47 mm filter with PP Ring supported (Whatman make)
  - Quartz filter paper: Tissuequartz 2500QAT-UP (Pall Make)
- No. of days: Monitoring was carried out for about 10 days at each location in each season for the aforementioned parameters. It was conducted in different sets with 3–4 locations in a set at a time.
- Start time of monitoring at a location: 9 to10 in the morning

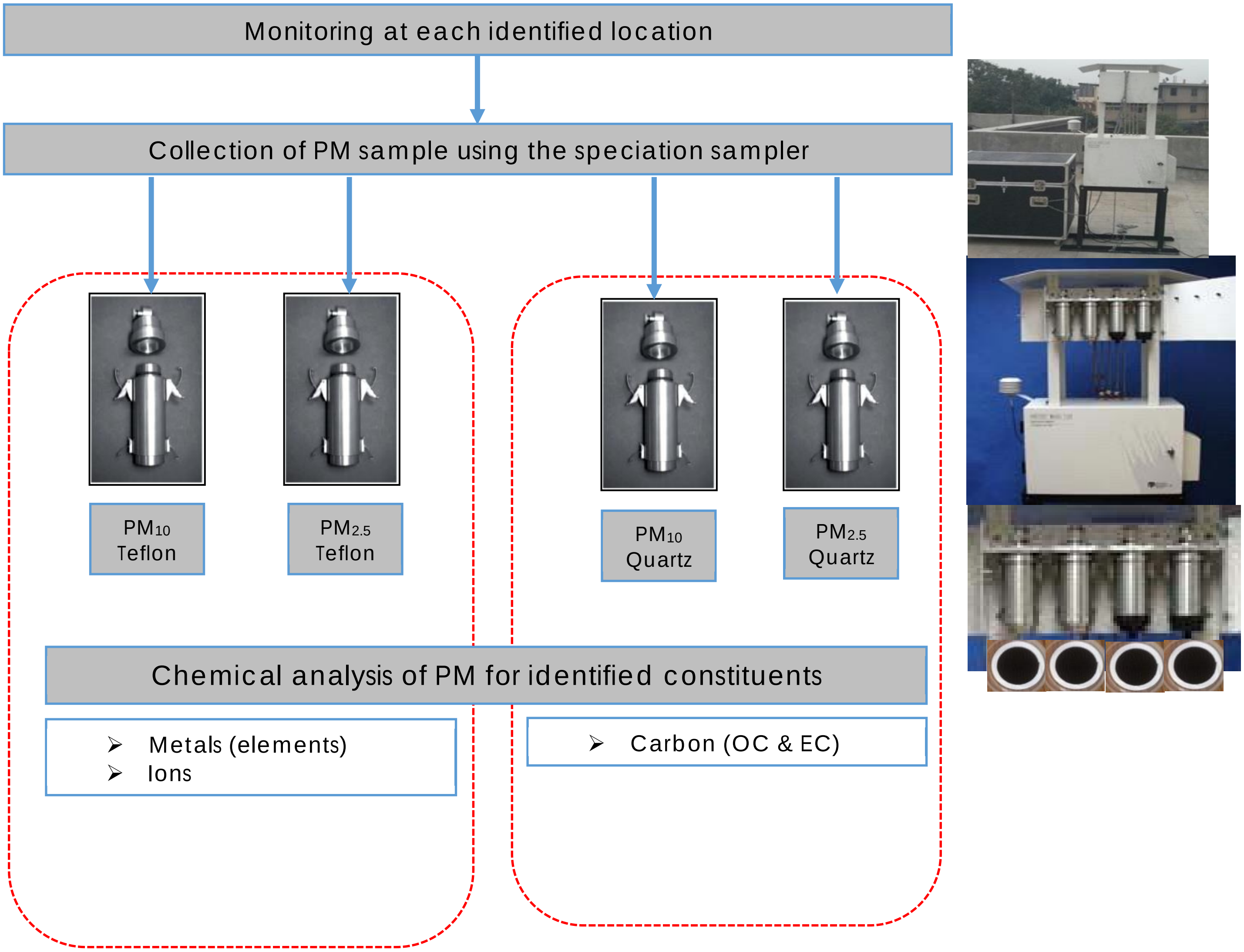


Figure 2.1 Ambient PM Sample Collection Protocol

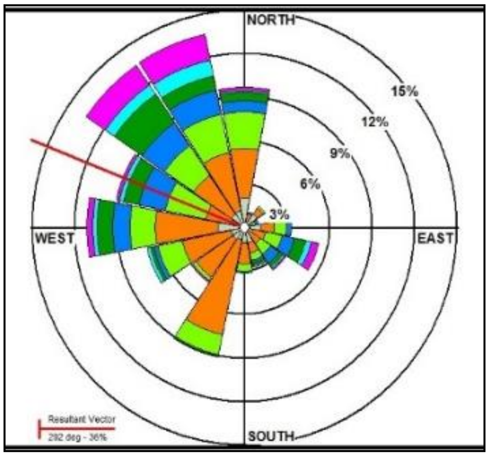
2.2.2 Sampling Sites

The details of monitoring locations with their types are tabulated in Table 2.1.

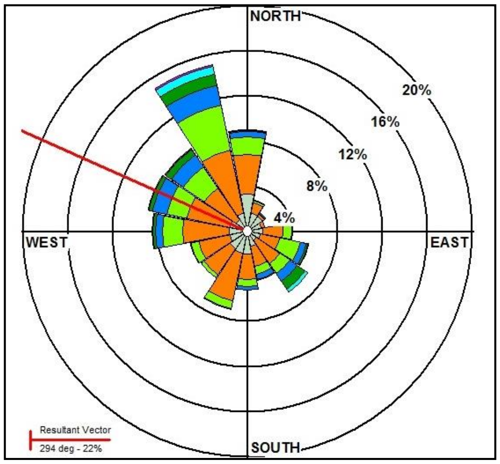
Table 2.1 Details of Monitoring Locations and Type of Air-Quality Monitoring Sites

Site ID	Location	Site ID	State	Location Type	Latitude# (Dir Deg Min Sec)	Longitude# (Dir Deg Min Sec)
1.	ITO square	ITO	Delhi City	Kerbside	28.6286°N	77.2411°E
2.	R.K. Puram, Sector 2	RKP	Delhi City	Residential	28.5627°N	77.1870°E
3.	Bahadurgrah	BHG	Haryana	Residential	28.6840°N	76.9189°E
4.	East Arjun Nagar, Shahdara	SHD	Delhi City	Commercial	28.6558°N	77.2942°E
5.	Mayur Vihar, Phase 1	MYR	Delhi City	Residential	28.6041°N	77.2943°E
6.	Janakpuri	JNP	Delhi City	Kerbside	28.6198°N	77.0789°E
7.	Chandni Chowk	CHN	Delhi City	Commercial	28.6585°N	77.2264°E
8.	Panipat	PNP	Haryana	Residential	29.4261°N	76.9799°E
9.	Naraina Industrial Sector	NRN	Delhi City	Industrial	28.6338°N	77.1349°E
10.	Wazirpur Industrial Sector	WZP	Delhi City	Industrial	28.6996°N	77.1662°E
11.	Rohini, Sector 6	RHN	Delhi City	Kerbside	28.7083°N	77.1098°E
12.	Sonipat	SNP	Haryana	Residential	28.9989°N	77.0417°E
13.	Lohia Nagar, Ghaziabad 1	GHZ-1	Uttar Pradesh	Residential	28.6755°N	77.4327°E
14.	Ghaziabad 2 Industrial Site	GHZ-2	Uttar Pradesh	Industrial	28.6594°N	77.4661°E
15.	Noida Industrial Site, Sector 6	NOI-1	Uttar Pradesh	Industrial	28.5950°N	77.3206°E
16.	Noida, Sector 1, UPPCB office	NOI-2	Uttar Pradesh	Industrial	28.5897°N	77.3101°E
17.	Huda Sector, Gurgaon1	GRG-1	Haryana	Residential	28.4547 N	77.0922°E
18.	Palam Vihar, Gurgaon 2	GRG-2	Haryana	Residential	28.4947°N	77.0176°E
19.	Faridabad 1, Sector 21 D	FBD-1	Haryana	Residential	28.4144°N	77.2904°E
20.	Faridabad 2, near DAV College	FBD-2	Haryana	Mixed (residential + industrial)	28.3985°N	77.2923°E

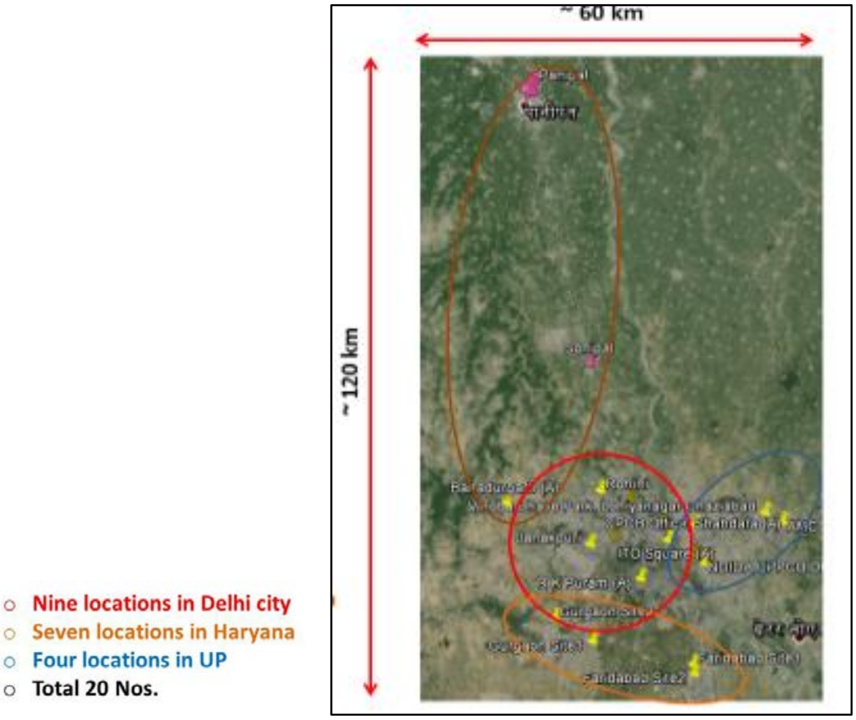
Twenty monitoring sites, as given below (Figure 2.2), were selected in Delhi–NCR based on land-use type and the prominent wind direction to capture air-quality levels under different activity profiles.



Windroses for summer season:
April 2016–June 2016



Windroses for winter season:
November 2016- Feb 2017



1) ITO square
2) R.K.Puram, Sector 2
3) Bahadurgrah
4) East Arjun Nagar, Shahdara
5) Mayur Vihar, Phase 1
6) Janakpuri
7) Chandani Chowk
8) Panipat
9) Narayana Industrial Area
10) Wazirpur
11) Rohini, Sector 6
12) Sonipat
13) Lohia Nagar, Ghaziabad
14) Ind. Site, Ghaziabad 2
15) Noida Ind. site, Sector 6
16) Noida, Sector 1
17) Huda Sector, Gurgaon 1
18) Palam Vihar, Gurgaon 2
19) Faridabad 1, Sector 21 D
20) Faridabad 2, near DAV College

Figure 2.2 Location of Air-Monitoring Sites in Delhi–NCR

Source: Google earth

Figure 2.3(a) Delhi–NCR with 20 Monitoring Locations

Figure 2.3(b): Delhi City with 9 Monitoring Locations

2.2.3 Chemical Analysis of Samples

The chemical speciation analysis of PM samples collected on filter papers can be broken into the three most common categories elements, ions (sulphates, nitrates, ammonium, and others), and carbon fractions for identifying the sources of pollutants in Delhi–NCR. Figure 2.4 depicts the overall scheme of chemical speciation of particulate samples.

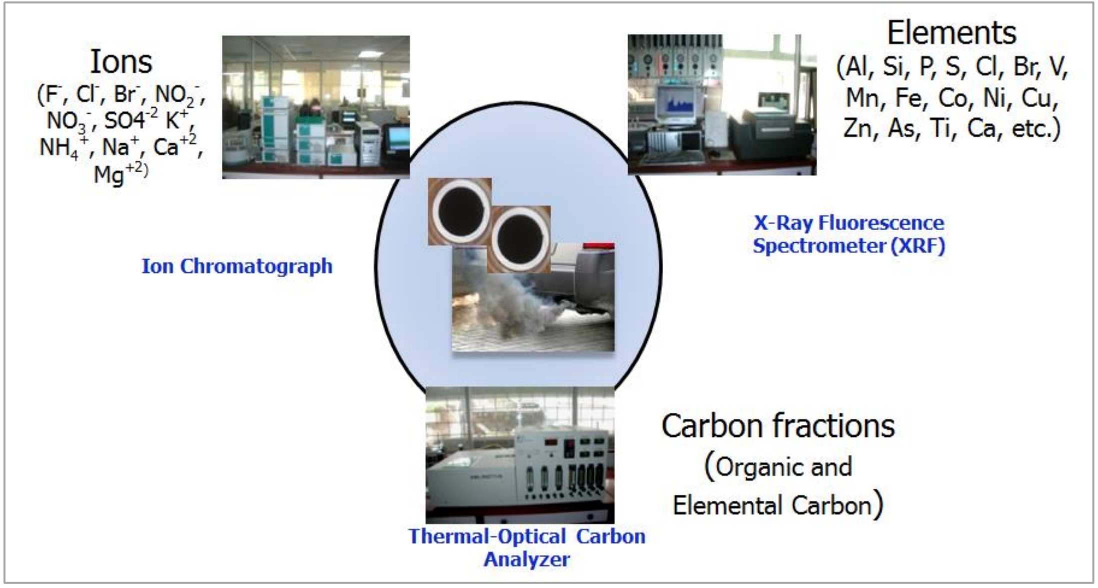


Figure 2.4 Chemical speciation of PM samples

The details of the instrumental techniques utilized for analysing PM are given ahead.

2.2.3.1 Elemental/Organic Carbon

Two classes of carbon are commonly measured in aerosol samples collected on quartz fibre filters: 1) organic, volatilized, or non-light absorbing carbon and 2) elemental or light-absorbing carbon.

'Organic carbon' and 'elemental carbon' generally refer to particles that appear black and are also called 'soot', 'graphitic carbon', or 'black carbon'. Various methods include thermal/optical reflectance (TOR), thermal/optical transmission (TOT), and thermal manganese oxidation (TMO) methods for organic and elemental carbon. TOR method of analysis was used for carbon fractions. DRI 2001 Model Carbon Analyzer was used for the carbon-measurement study. Pre-baked filters were used for carrying out blank analysis (detailed procedure given in Annexure-C: Carbon Analysis).

2.2.3.2 Elements

The energy dispersive X-ray fluorescence (ED-XRF) technique was used for the quantification of elements present in PM_{10} and $PM_{2.5}$ collected on Teflon paper. It is a non-destructive technique of inorganic speciation analysis; XRF does not require sample preparation or long operator time after it is loaded into the analyzer. Details of the procedure is given in Annexure-E: Analysis of Elements. Filters remain intact after analysis and were used for analysis of ions.

2.2.2.3 Ions

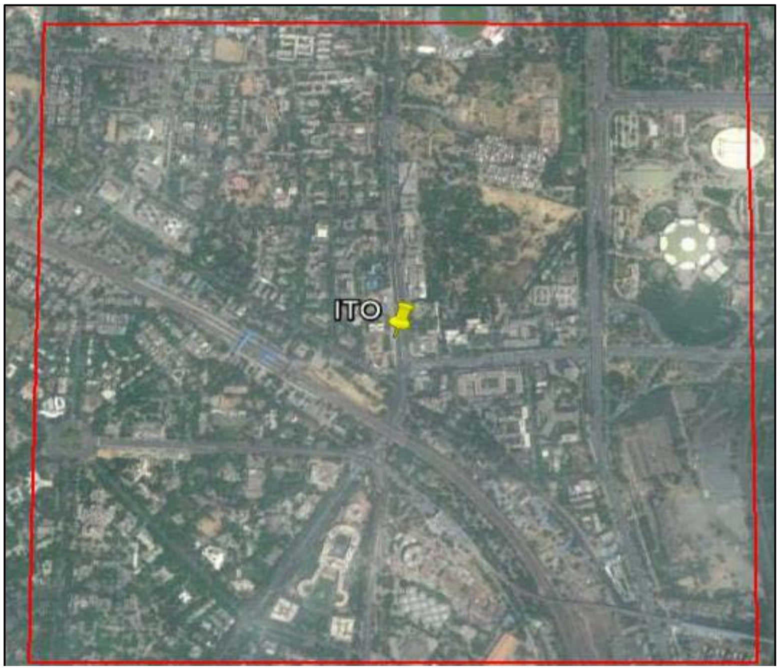
Ionic species are those that are soluble in water. Anions and cations were analyzed using an ion chromatograph with conductivity detector. In PM_{10} and $PM_{2.5}$ dust samples, ions that are analysed on an ion chromatograph are grouped under anions such as fluoride, chloride, bromide, nitrite, nitrate, sulphate and under cations such as sodium, ammonium, potassium, calcium, and magnesium. Sample preparation was done by using the ultrasonication method. Milli-Q grade water, freshly produced from the Gradient A10 Millipore system and having resistivity of 18 M-Ohm, was used for sample preparation and analysis. Laboratory blank, field blank, and samples were always filtered through 0.2 micron nylon membrane filters to avoid background matrix interference. Details of procedure is given in Annexure-D: Analysis of Ions.

2.3 Information of Sites

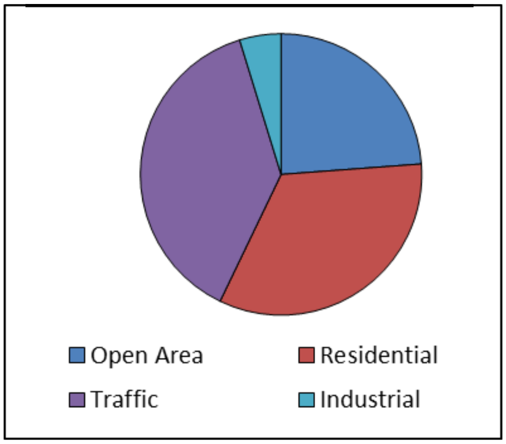
2.3.1 Site 1: ITO Square

GPS Coordinates of the Site: 28.6286°N, 77.2411°E

Site Location in Delhi–NCR



2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Site type: Kerbside

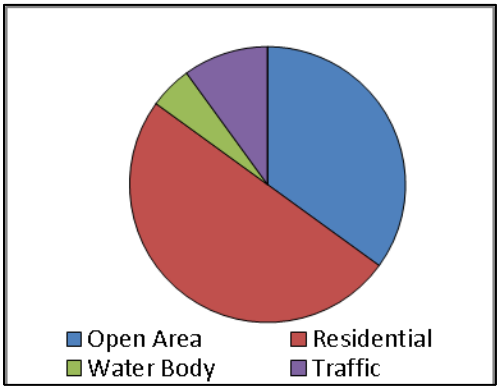
Activities around the site:

- Heavy traffic
- Restaurants
- Road-side food stalls

Sampler Installed at the ITO Square Site

2.3.2 Site 2: R. K. Puram

Site Location in Delhi–NCR



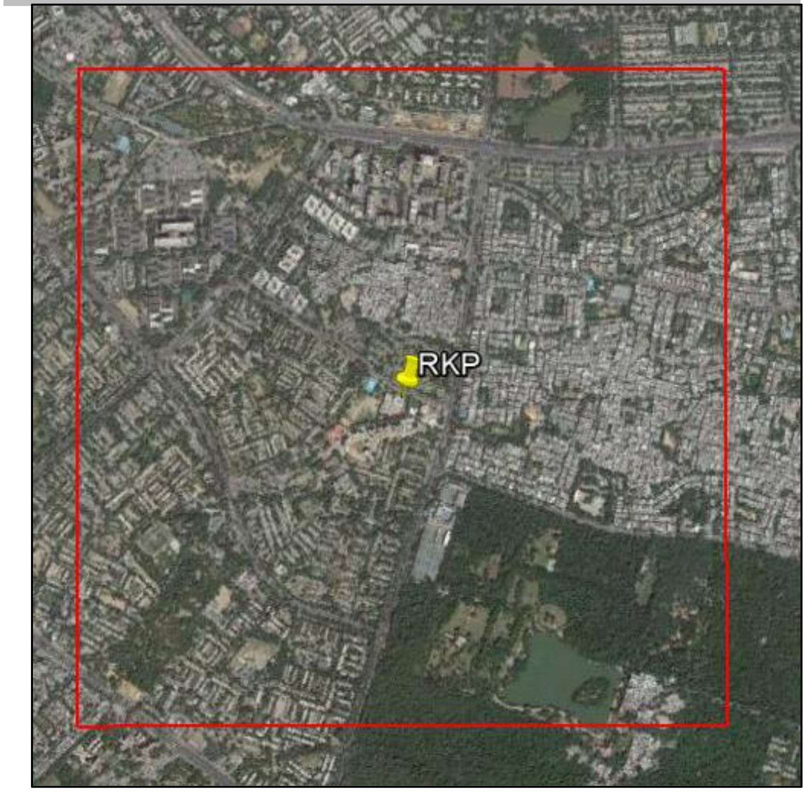
Land-Use Pattern

Site type: Residential

Activities around the site :

- Light traffic
- Densely populated area
- Small industries

GPS Coordinates of the site: 28.5627°N, 77.187°E



2X2 km^2 Area around the Monitoring Site

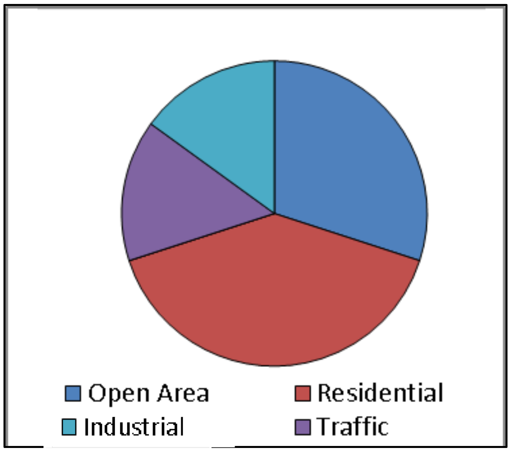
Sampler Installed at the R. K. Puram Site

2.3.3 Site 3: Bahadurgarh

GPS Coordinates of the Site: 28.6840°N, 76.9189°E

Site Location in Delhi–NCR

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Site type: Residential

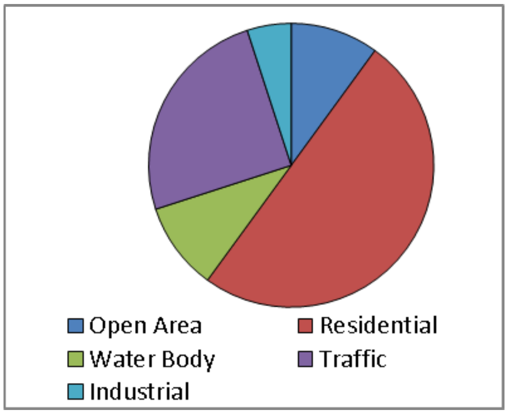
Activities around the site:

- Open space
- Densely populated area
- Construction activities
- Light traffic
- Garbage burning near the site
- Agricultural activities
- DG sets
- Industrial area

Sampler Installed at the Bahadurgarh Site

2.3.4 Site 4: Shahdara

Site Location in Delhi–NCR



Land-Use Pattern

Site type: Residential/Kerbside

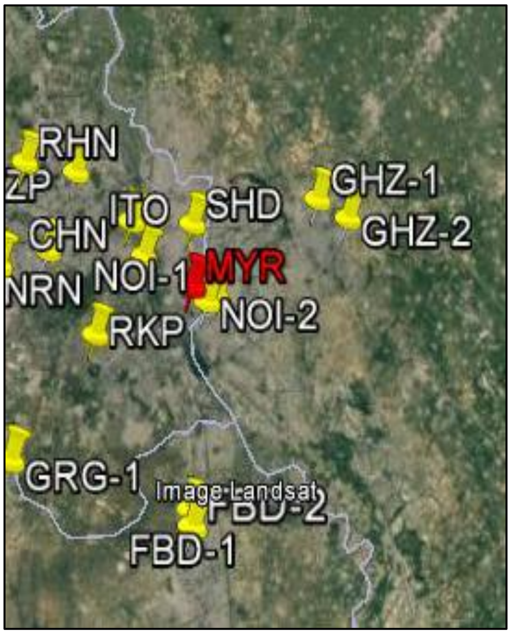
Activities around the site:
- Densely populated area
- Open drain
- Construction of an overbridge and metro work
- Small indoor shops
- Heavy traffic
- Tile and ceramic shop cutting activities nearby

GPS Coordinates of the Site: 28.6558°N, 77.2942°E

2X2 km^2 Area around the Monitoring Site

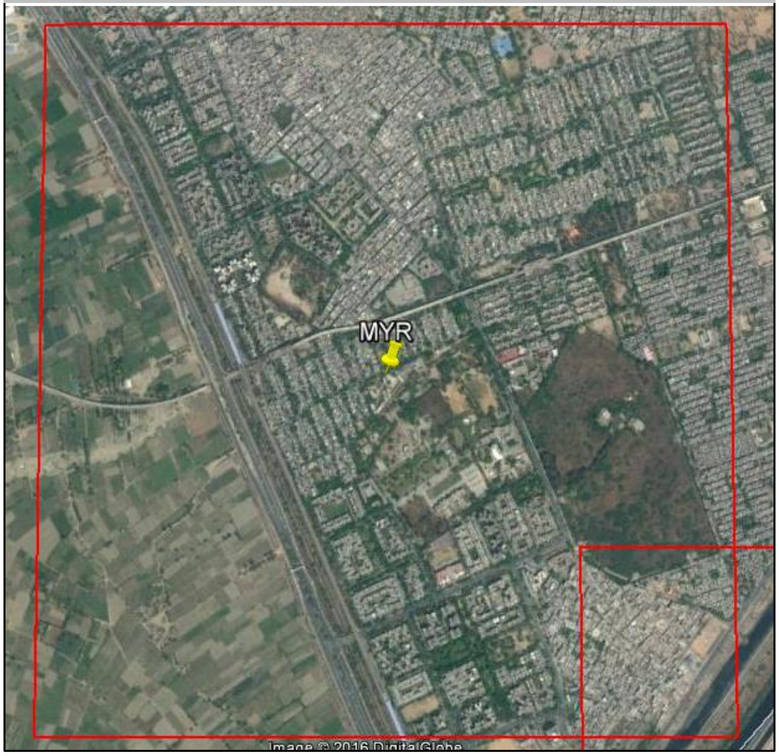
Sampler Installed at the Shahdara Site

2.3.5 Site 5: Mayur Vihar

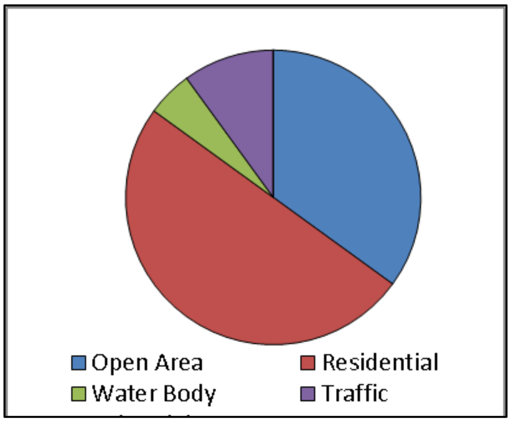


Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.6041°N, 77.2943°E



2X2 km² Area around the Monitoring Site



Land-Use Pattern

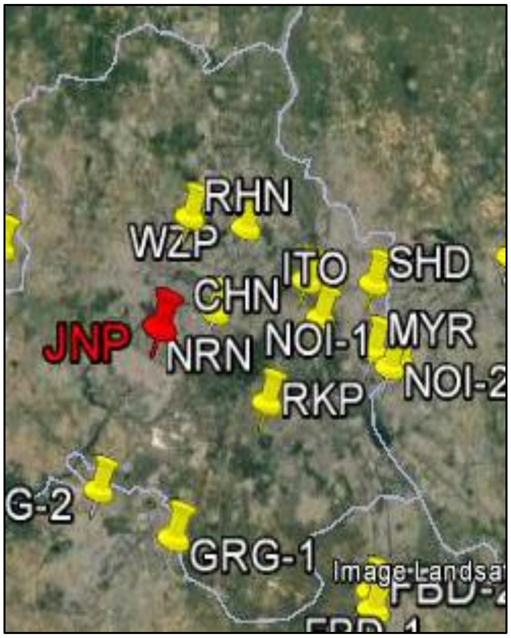
Site type: Residential

Activities around the site:

- Construction of metro work
- Light traffic
- National Highway nearby
- Agricultural activities in the riverbed
- Open burning
- Slum area nearby

Sampler Installed at the Mayur Vihar Site

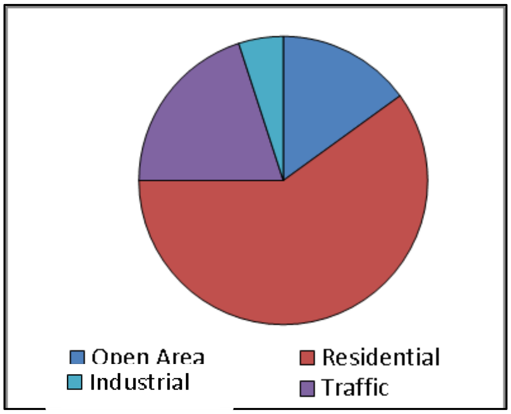
2.3.6 Site 6: Janak Puri



Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.6198°N, 77.0789°E

2X2 km² Area around the Monitoring Site



Land-Use Pattern

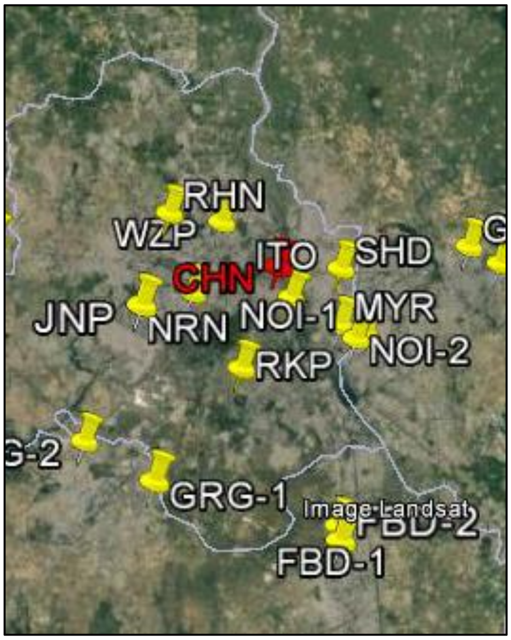
Site type: Residential, Kerbside

Activities around the site:

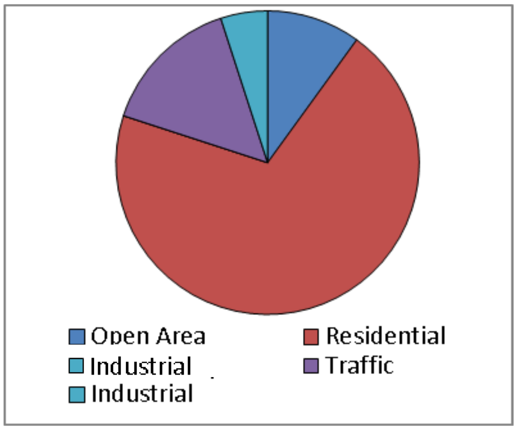
- Heavy traffic
- Garbage burning near the site
- Slum area
- Small bakeries/restaurant

Sampler Installed at the Janak Puri Site

2.3.7 Site 7: Chandni Chowk



Site Location in Delhi–NCR



Land-Use Pattern

Site type: Commercial

Activities around the site:

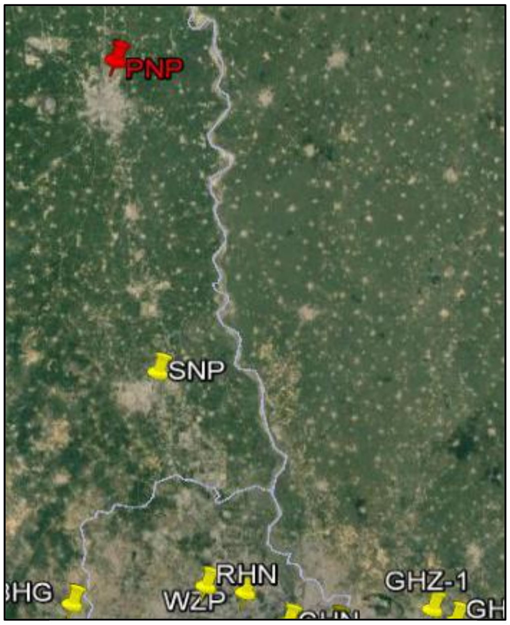
- Heavy traffic on the road nearby
- Bakery, restaurants, dhabas, and cooking activity
- Diesel locomotive (trains)
- Densely crowded
- Paper industry and small shops
- DG sets in shops

GPS Coordinates of the Site: 28.6585°N, 77.2264°E

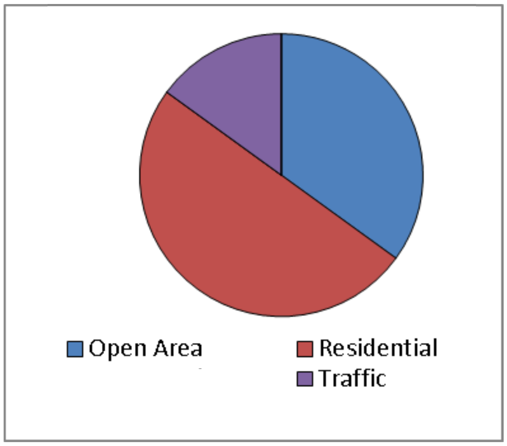
2X2 km^2 Area around the Monitoring Site

Sampler Installed at the Chandni Chowk Site

2.3.8 Site 8: Huda Colony, Panipat



Site Location in Delhi–NCR



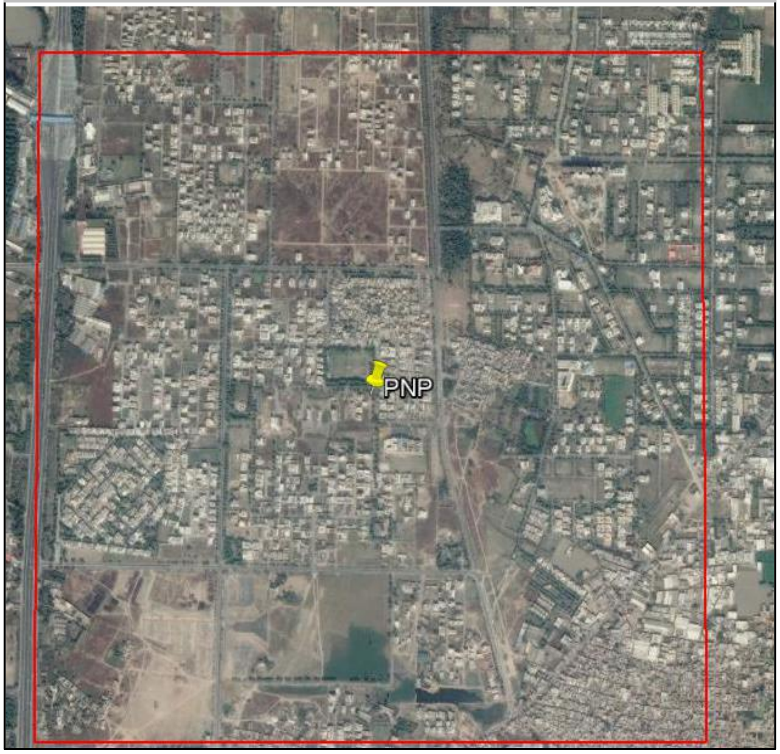
Land-Use Pattern

Site type: Residential (upwind)

Activities around the site:

- Building construction
- Unpaved roads
- Highway in close vicinity
- Institutional area
- Open area
- Coal combustion
- DG sets for residential use

GPS Coordinates of the Site: 29.4261°N, 76.9799°E



2X2 km^2 Area around the Monitoring Site

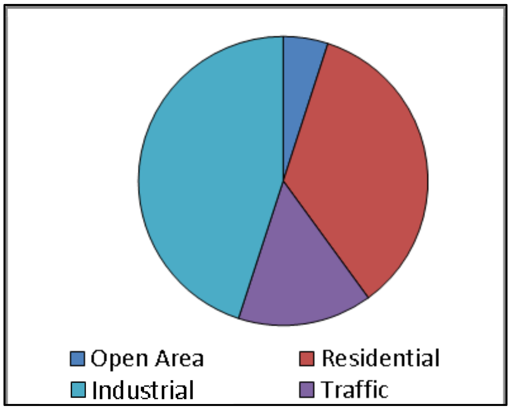
Sampler Installed at HUDA Colony, Panipat

2.3.9 Site 9: Naraina, Industrial Sector

Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.6338°N, 77.1349°E

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

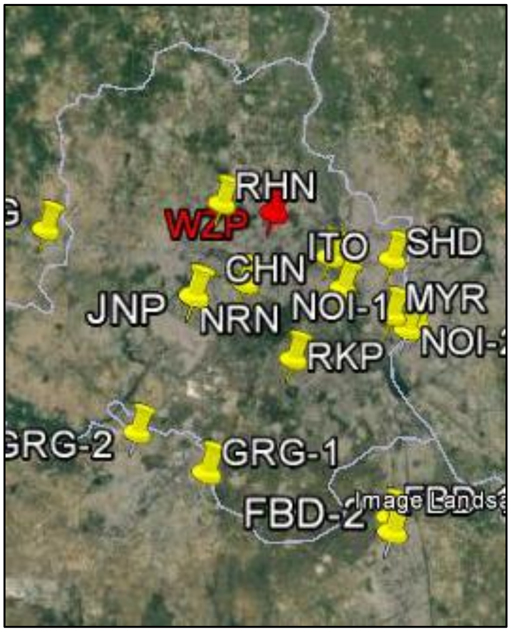
Site type: Industrial

Activities around the site:

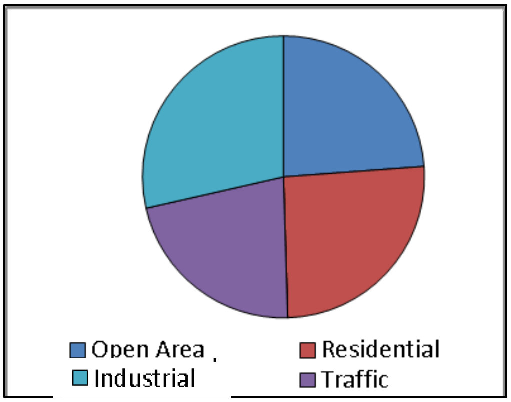
- Diesel locomotive track
- Garbage burning near the site
- Road construction near the area
- Slum area
- Construction of road
- Densely crowded
- Power DG sets
- Medium traffic on Ring Road

Sampler Installed at the Naraina Site

2.3.10 Site 10: Wazirpur, Industrial Sector



Site Location in Delhi–NCR



Land-Use Pattern

Site type: Industrial

Activities around the site:

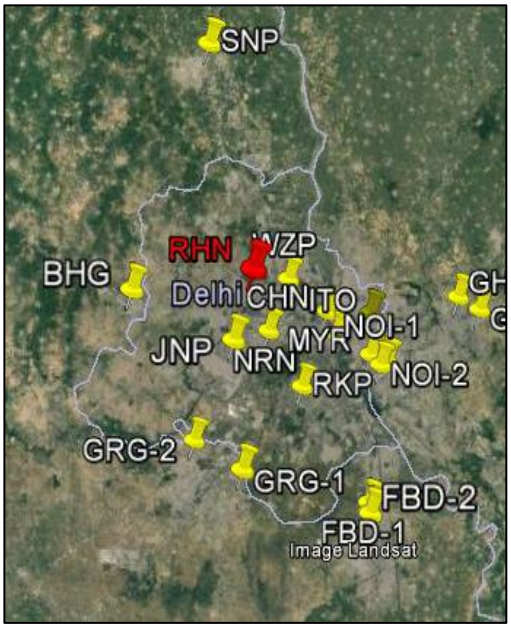
- Traffic
- Road and DMRC construction
- Industrial smoke from nearby factories
- Slum area nearby
- DG sets

GPS Coordinates of the Site: 28.6996°N, 77.1662°E

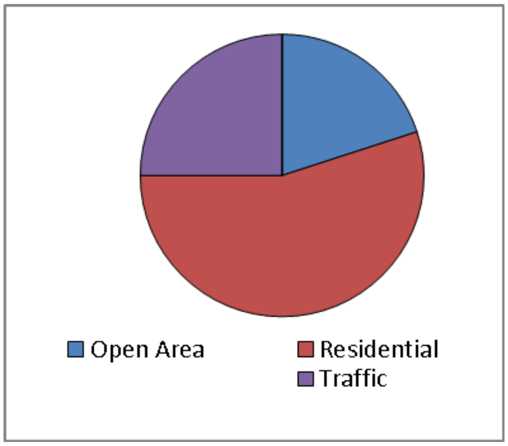
2X2 km² Area around the Monitoring Site

Sampler Installed at the Wazirpur Site

2.3.11 Site 11: Rohini, Sector 6



Site Location in Delhi–NCR



Land-Use Pattern

Site type: Residential

Activities around the site:

- Traffic
- Restaurants and bakeries nearby
- Densely populated
- Wood burning

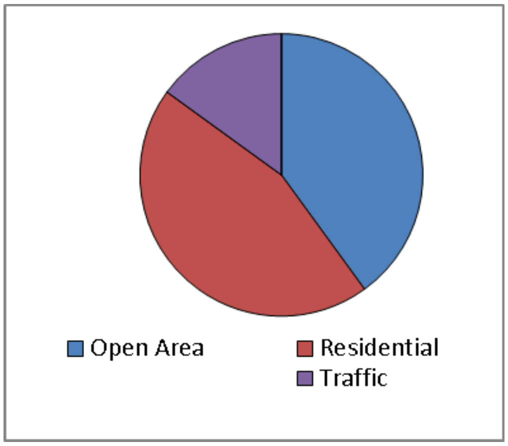
GPS Coordinates of the Site: 28.7083°N, 77.1098°E

2X2 km^2 Area around the Monitoring Site

Sampler Installed at the Rohini Site

2.3.12 Site 12: Sonipat, Sector 15

Site Location in Delhi–NCR



Land-Use Pattern

Site type: Residential

Activities around the site:

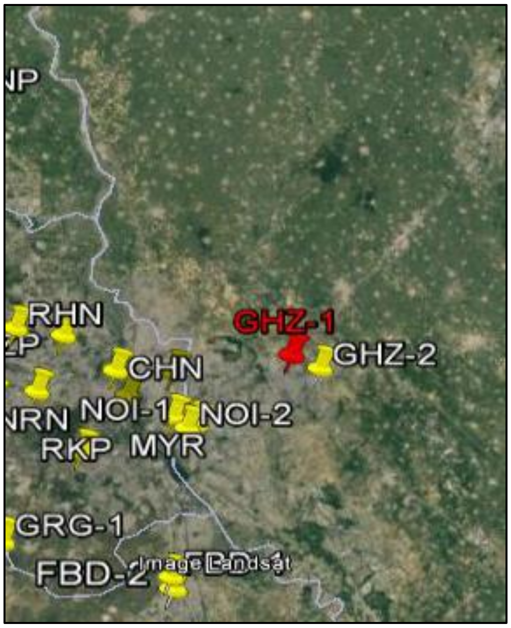
- Building construction
- Street sweeping
- Agricultural activities
- DG sets

GPS Coordinates of the Site: 28.9989°N, 77.0417°E

2X2 km^2 Area around the Monitoring Site

Sampler Installed at Sector 15, Sonipat Site

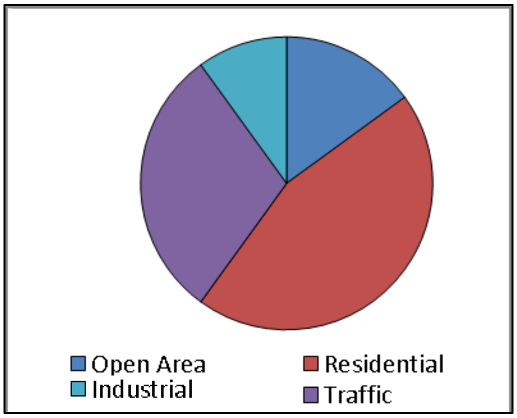
2.3.13 Site 13: Ghaziabad 1, Lohia Nagar



Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.6755°N, 77.4327°E

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Site type: Residential

Activities around the site:

- Groundwater treatment plant
- Building construction
- DG sets
- Small- and medium-scale industries

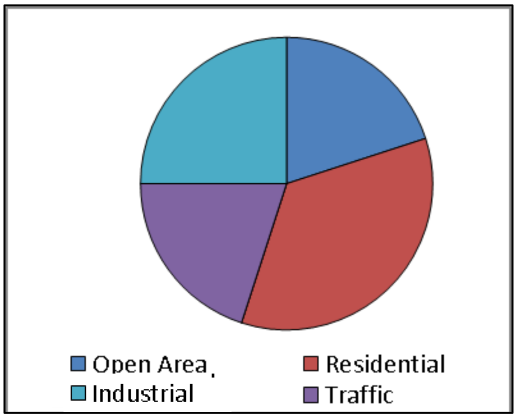
Sampler Installed at Lohia Nagar, Ghaziabad Site

2.3.14 Site 14: Ghaziabad 2, Industrial Site

Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.6594°N, 77.4661°E

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Sampler Installed at the Ghaziabad Site 2

Site type: Industrial

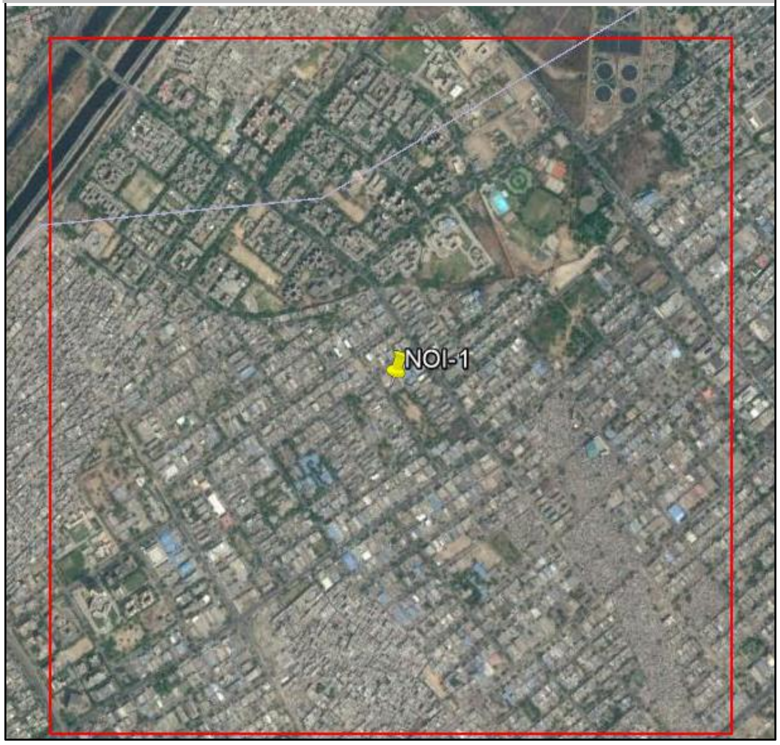
Activities around the site:

- Traffic
- Smoke from industries
- Construction
- Diesel locomotives
- Fuel-oil burning
- Traffic on NH24
- DG Sets
- Chemical and dye industries

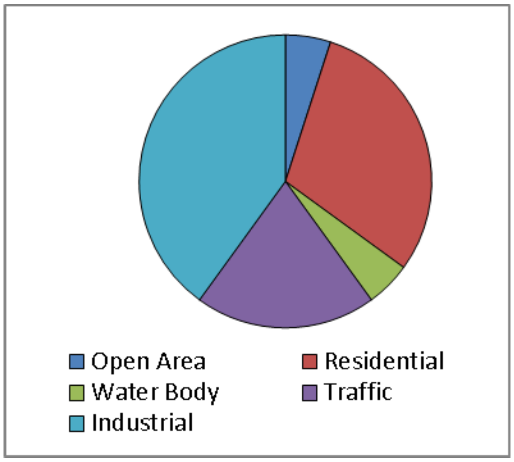
2.3.15 Site 15: Noida, Sector 6

GPS Coordinates of the Site: 28.5950°N, 77.3206°E

Site Location in Delhi–NCR



2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Site type: Industrial

Activities around the site:

- Densely crowded industries
- Slum area
- Light traffic
- DG sets
- Open drainage
- Open industrial areas
- Open burning

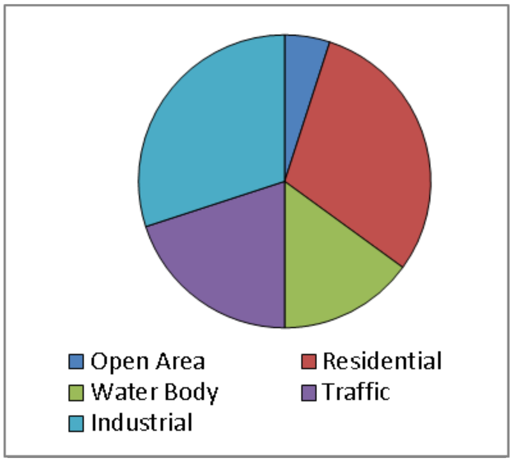
Sampler Installed at Sector 6, Noida Site

2.3.16 Site 16: Noida, Sector 1

Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.5897°N, 77.3101°E

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

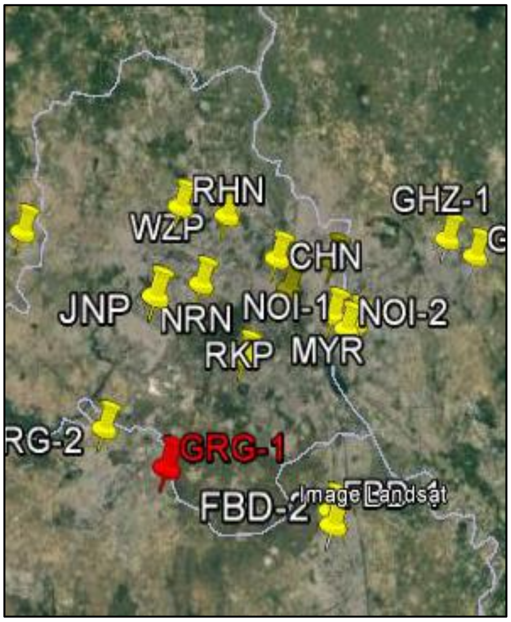
Site type: Residential

Activity around the site:

- Building construction
- Smoke from industries
- Institutional area
- Open burning
- Slum area nearby
- Open drainage

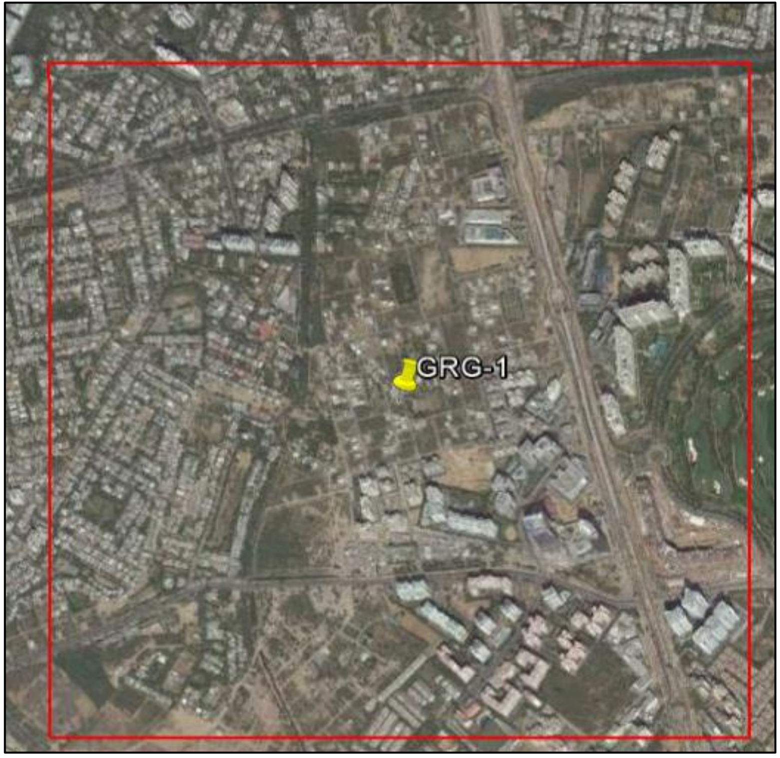
Sampler Installed at Sector 1, Noida Site

2.3.17 Site 17: Gurgaon, HUDA, Sector 43

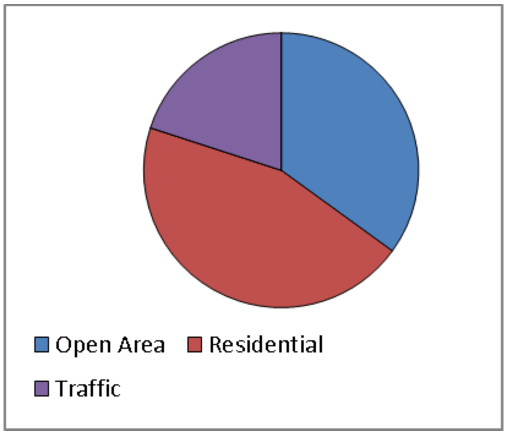


Site Location in Delhi–NCR

GPS Coordinates of the Site: 28.4547°N, 77.0922°E



2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Sampler Installed at HUDA, Sector 43, Gurgaon Site

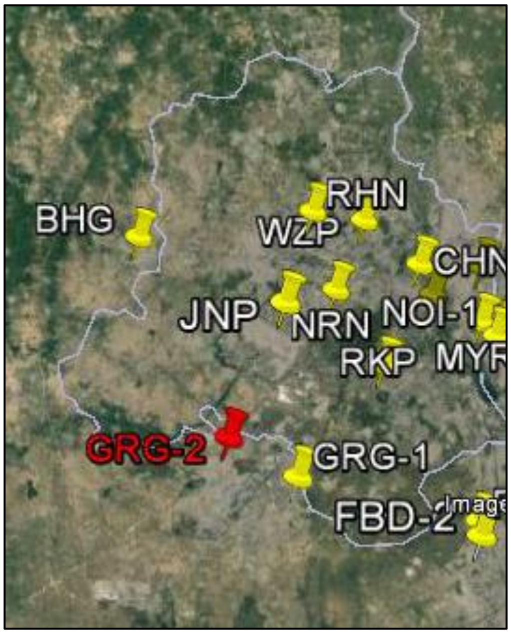
Site type: Residential

Activities around the site:

- Building construction
- Unpaved roads
- Large open areas
- Highway traffic

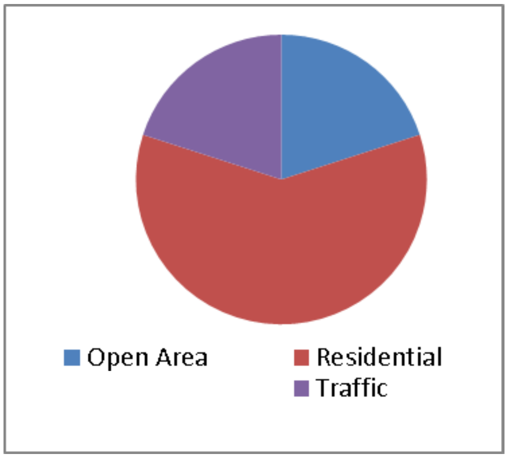
2.3.18 Site 18: Palam Vihar, Gurgaon

GPS Coordinates of the Site: 28.4947°N, 77.0176°E



Site Location in Delhi–NCR

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

Sampler Installed at Palam Vihar, Gurgaon Site

Site type: Residential

Activities around the site:

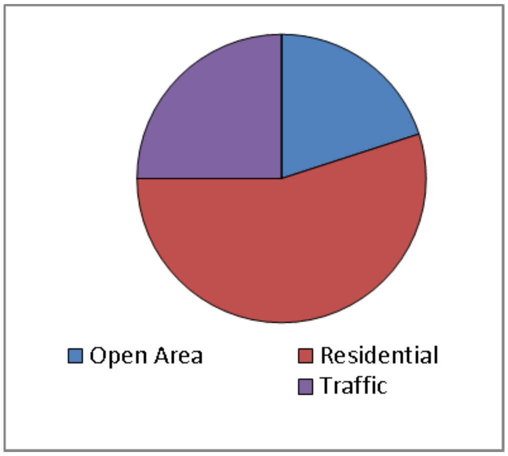
- Light traffic
- Rail locomotive track nearby
- Open green parks
- Densely populated
- DG sets

2.3.19 Site 19: Faridabad, Sector 21D

GPS Coordinates of the Site: 28.4144°N, 77.2904°E

Site Location in Delhi–NCR

2X2 km^2 Area around the Monitoring Site



Land-Use Pattern

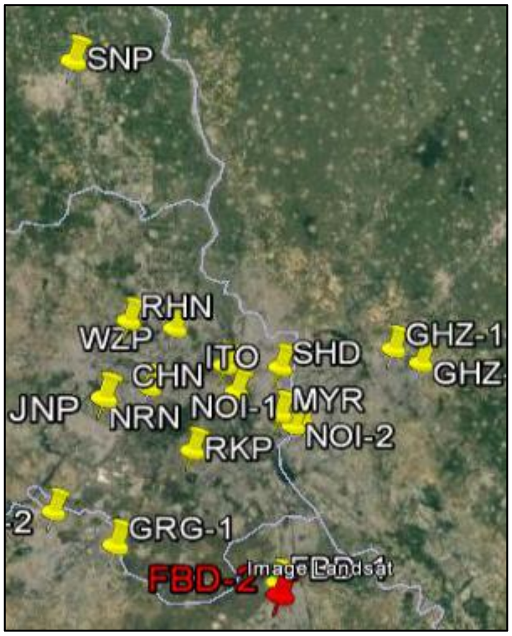
Site type: Residential

Activities around the site:

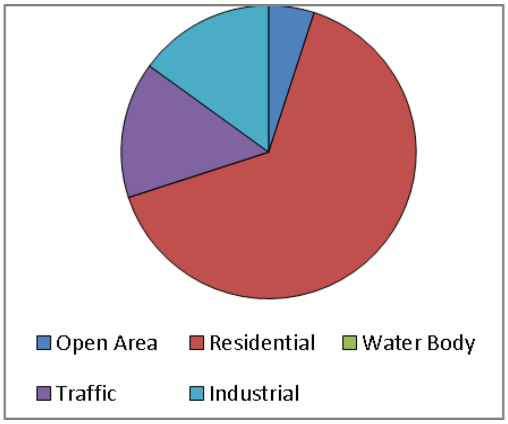
- Unpaved roads
- Street sweeping
- Garbage burning
- Densely populated
- Open space nearby

Sampler Installed at Sector 21D, Faridabad Site

2.3.20 Site 20: Faridabad, Near DAV College



Site Location in Delhi–NCR



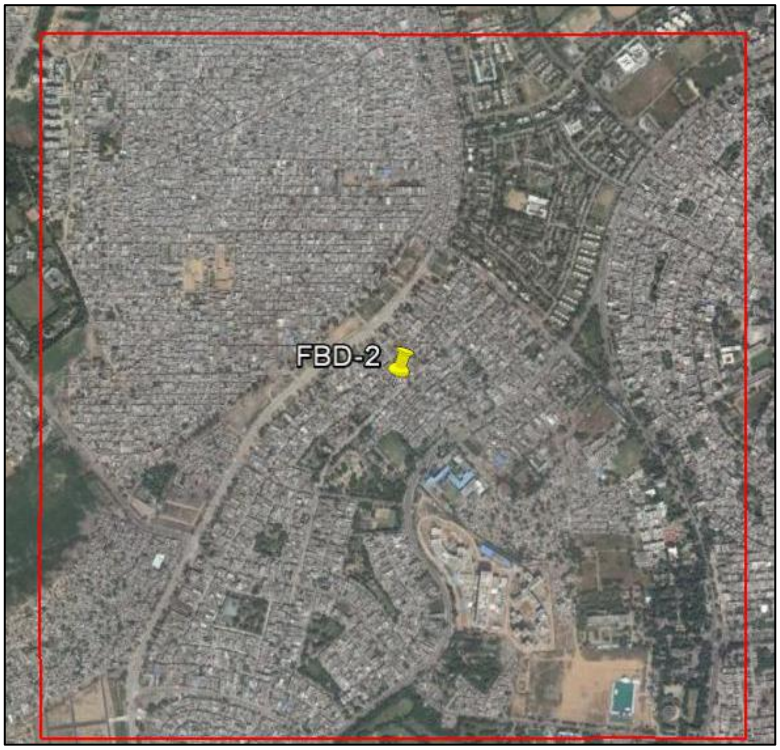
Land-Use Pattern

Site type: Residential

Activities around the site:

- Small restaurants nearby
- Densely populated
- Slum area nearby
- Open burning
- Gensets

GPS Coordinates of the Site: 28.3985°N, 77.2923°E



2X2 km^2 Area around the Monitoring Site

Sampler Installed at Faridabad, Near DAV College

2.4 Monitoring Schedule

The AAQ monitoring was conducted during April '16 to July '16 in Summer Season and November '16 to February '17 in Winter Season at 20 locations in Delhi–NCR.

2.4.1 The sampling schedule for the summer season is presented in Figure 2.5. It represents the dates of sampling during the monitoring period on which the technically valid samples were collected.

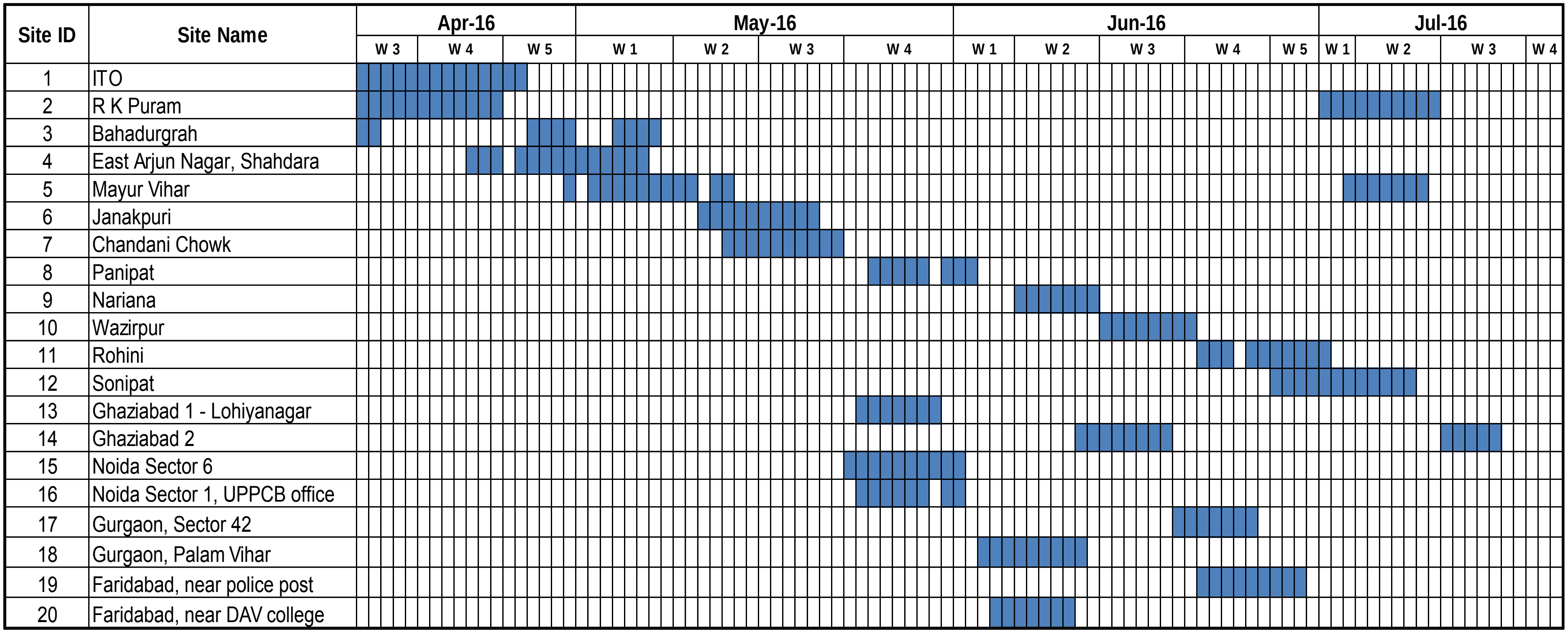


Figure 2.5 Schedule of Sampling at Various Locations in the Summer Season

2.4.2 The sampling schedule for the winter season is presented in Figure 2.6 below. It represents the valid dates of sampling during the monitoring period.

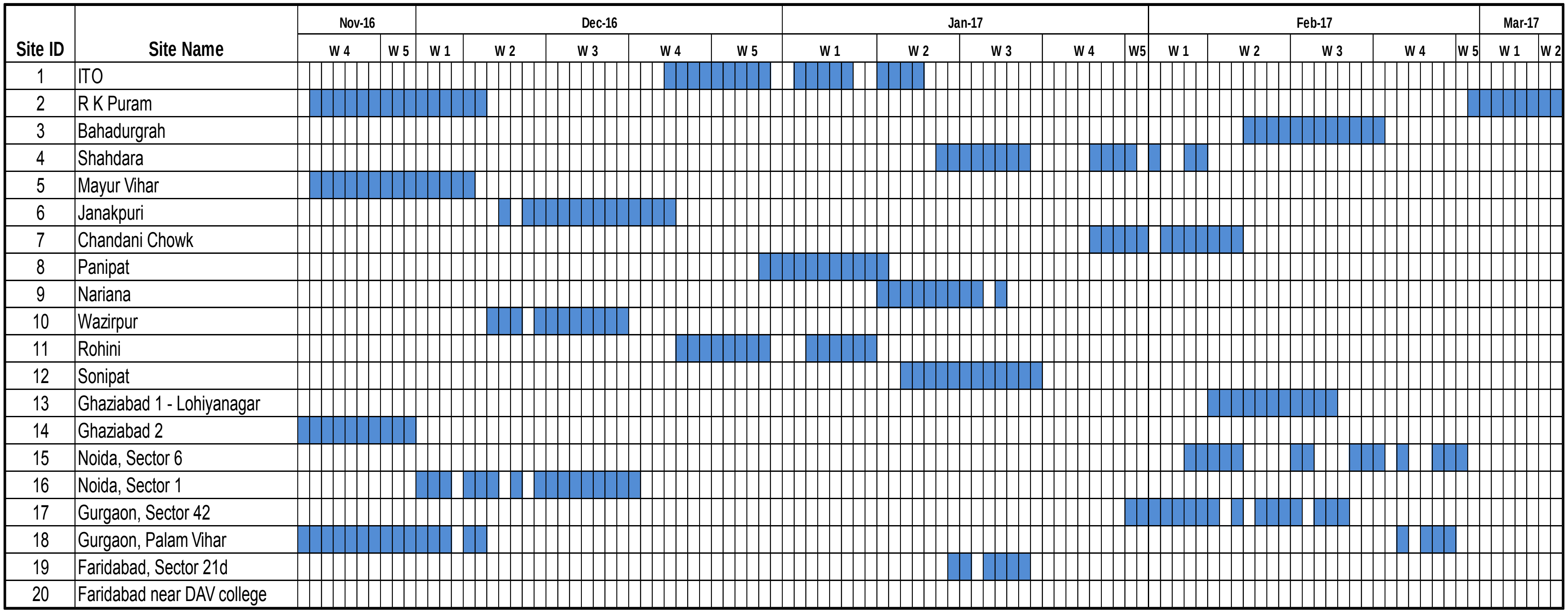


Figure 2.6: Schedule of Sampling at Various Locations in Winter Season

Table 2.2 Sampling and Analytical Protocol for PM Samples

Particulars	Parameters			
	PM_{10} and $PM_{2.5}$	OC/EC	Ions	Elements
Sampling instrument	Multichannel (4 channel) Speciation Sampler	PM_{10} and $PM_{2.5}$ samples collected on Quartz filter	PM_{10} and $PM_{2.5}$ samples collected on Teflon filter	PM_{10} and $PM_{2.5}$ samples collected on Teflon filter
Sampling principle	Filtration of aerodynamic sizes with a size cut by impaction	--	--	--
Flow rate	16.7 LPM	--	--	--
Sampling period	10 days continuous in each season. The technically valid samples were processed further.	--	--	--
Sampling frequency	Hourly	--	--	--
Analytical instrument	Electronic Microbalance	OC/EC Analyser	Ion chromatograph	ED-XRF
Analytical method	Gravimetric	TOR/TOT Method CARB/ MLD No. 065	Ion chromatography CARB/ MLD No. 064	Compendium Method IO-3.3
Minimum reportable value	5 $\mu g/m^3$	TOC 1 $\mu g/cm^2$, TEC 0.5 $\mu g/cm^2$, TC 1.5 $\mu g/cm^2$	0.020 ppm	Detection limits of elements

2.5 Quality Assurance/Quality Control

2.5.1 Air Sampling

Quality assurance (QA)/quality control (QC) is an essential part of any monitoring system. It is a programme of activities that ensures that the measurements meet the defined and appropriate standards of quality, with a stated level of confidence. Each sample to be sent to the field for monitoring was prepared carefully by following the QA/QC system (see Table 3). A unique sample ID was given to each sample collected for future reference and database generation.

The Partisol Model 2300 were used for particulate sampling during summer and winter seasons over a period of one year. SOPs can be viewed in 'Annexure A (A1–A6)'. The field staff, handling the sample kit, were trained for specific tasks like the handling of filters and ChemComb cartridges. Proper training was provided to the field staff and supervisors for conducting intermediate performance checks.

Speciation sampling was carried out with Partisol 2300 samplers with PM_{10} and $PM_{2.5}$ ChemComb cartridges with impactor heads at a flow rate of 16.7 lpm. Teflon and Quartz filter papers were used for sample collection.

PM was collected on pre-baked Quartz fibre filter. Teflon filters were conditioned before and after sample collection. Please refer to 'Annexure B' for details of sample conditioning, handling, and weighing.

2.5.2 Analysis

Details of analytical techniques/ instrumentation, calibration standard, SOPs used for conducting the aforementioned analysis and an outline of field and laboratory performance audits are given in Table 2.3.

The typical analytical technique/methodology applicable for each of the speciation categories is described below. Refer to 'Annexure C' for the procedure followed for the analysis of carbon fractions. The detailed procedure followed for ion analysis is given in 'Annexure D'. The standard operating procedure for elemental analysis is given in 'Annexure E'.

Table 2.3 Outlines of Field and Laboratory Performance Audits

Sr. No.	Parameter	Standard Ref. Method	Test procedure/ SOP	Analytical technique/ method	Calibration standard details	Performance test method	Perform. test frequency	Calibration periodicity	Primary standard
1	Sample flow	ERT/DRI modified	TP-AQM-Samp-AML	Partisol 2300 samplers	Calibrated rotameter	Calibrated rotameter	Once a day	At the beginning or when the performance tests out of specifications	Certified root meter
2	PM_{10}	CARB/MLD NO.031	TP-AQM-PM10-AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
3	$PM_{2.5}$	CARB/MLD NO.055	TP-AQM-PM2.5-AML	Gravimetric	NBS Class M standards weights	NBS Class M standards weights	Once a day	At the beginning of weighing session	NBS Class M standards weights
4	Elements	Method IO –3.3 for XRF CARB	TP-AQM-Elements-AML	Energy dispersive - X-Ray fluorescence (ED-XRF)	Micromatter thin film standards	Replicate thin film standard	1/10th sample	Once in two months or when the performance test not met	Micromatter thin film standards
5	Ions	CARB/MLD NO.064	TP-155-AML	Ion Chromatograph with conductivity detector	NIST Traceable MERCK make Certipur Standards	Standard solution	1/10th sample	At the beginning of each run	Certified NIST traceable standards
6	EC/OC	CARB/MLD NO.065	TP-156-AML	Thermal optical reflectance carbon analyzer	Methane, CO_2 gas, and ACS-certified KHP	Replicate methane gas run	1/10th sample	Once in two months or when performance test not met	ACS certified chemicals

Chapter 3 Observation and Results

Observations of AAQ monitoring exercise conducted at 20 locations in Delhi–NCR for $PM_{2.5}$ and PM_{10} in Summer Season for daily variations in mass concentrations and chemical composition of PM with respect to various chemical species including carbon fraction (organic and elemental carbon), crustal elements (Al, Si, Ca, Ti and Fe), other elements, and ions (cations and anions) are presented in the following sections.

3.1 Site-Wise Monitoring Results in the Summer and Winter Seasons

3.1.1 Site 1: ITO Square

3.1.1.1 Summer Season

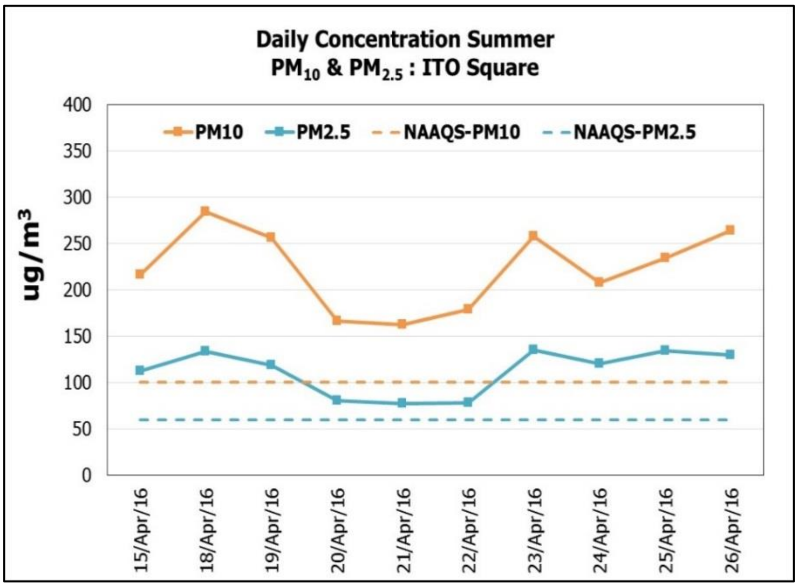


Figure 3.1: Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at the ITO Square in the Summer Season

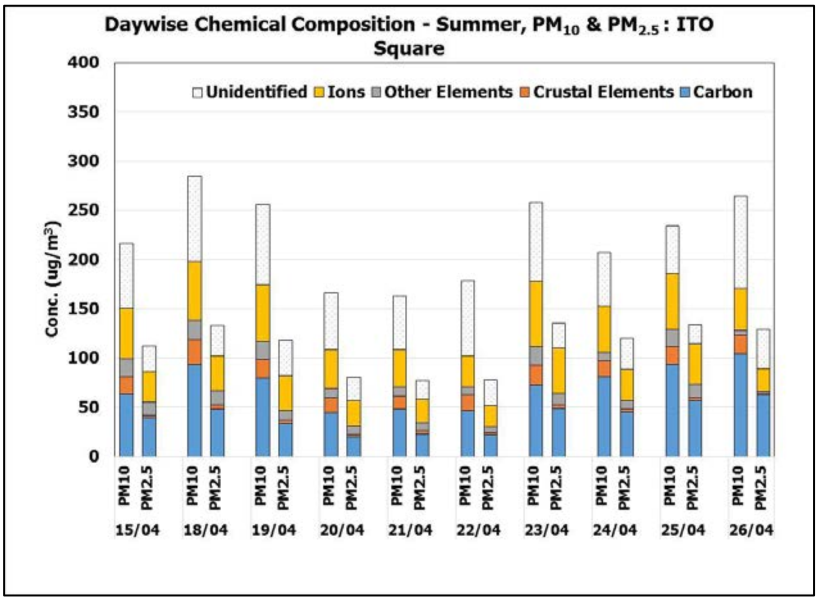


Figure 3.2 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at the ITO Square in the Summer Season

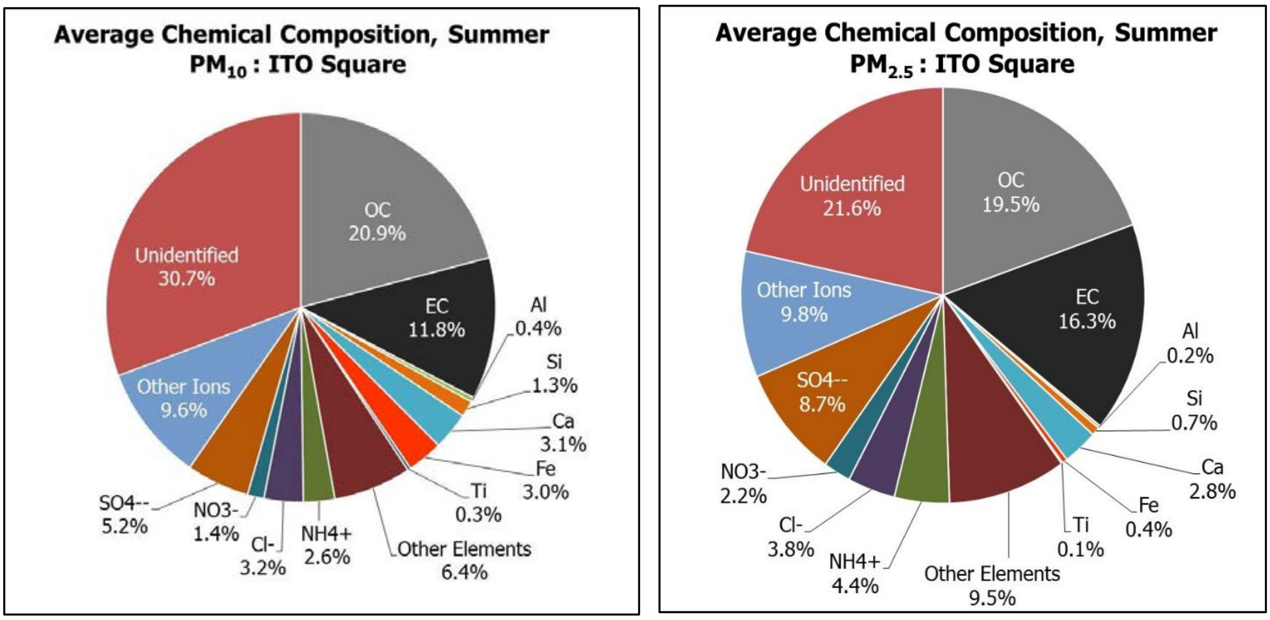


Figure 3.3: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at the ITO Square in the Summer Season

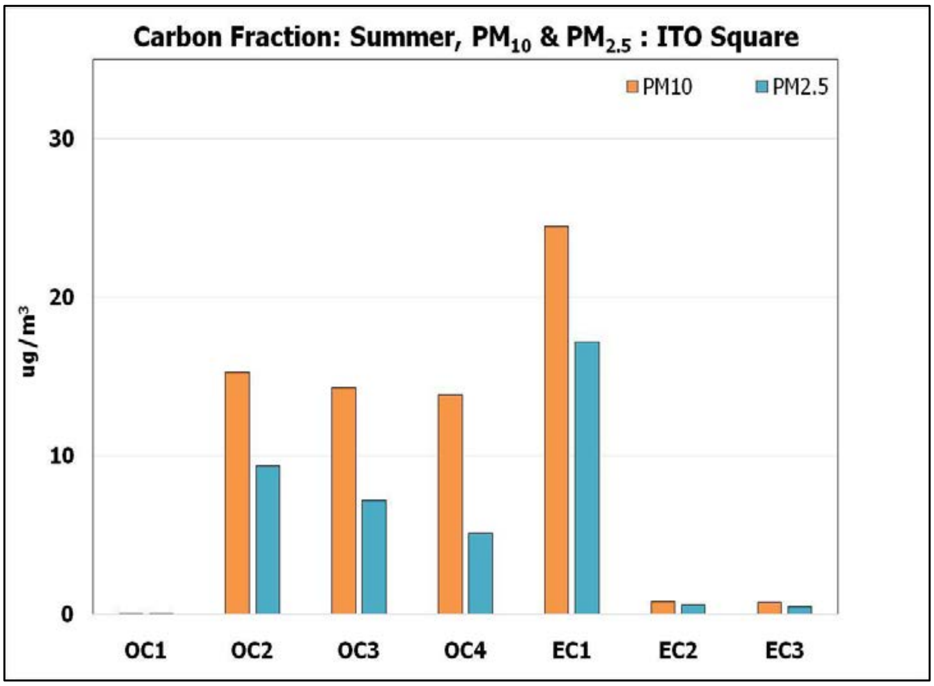


Figure 3.4: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at the ITO Square in the Summer Season

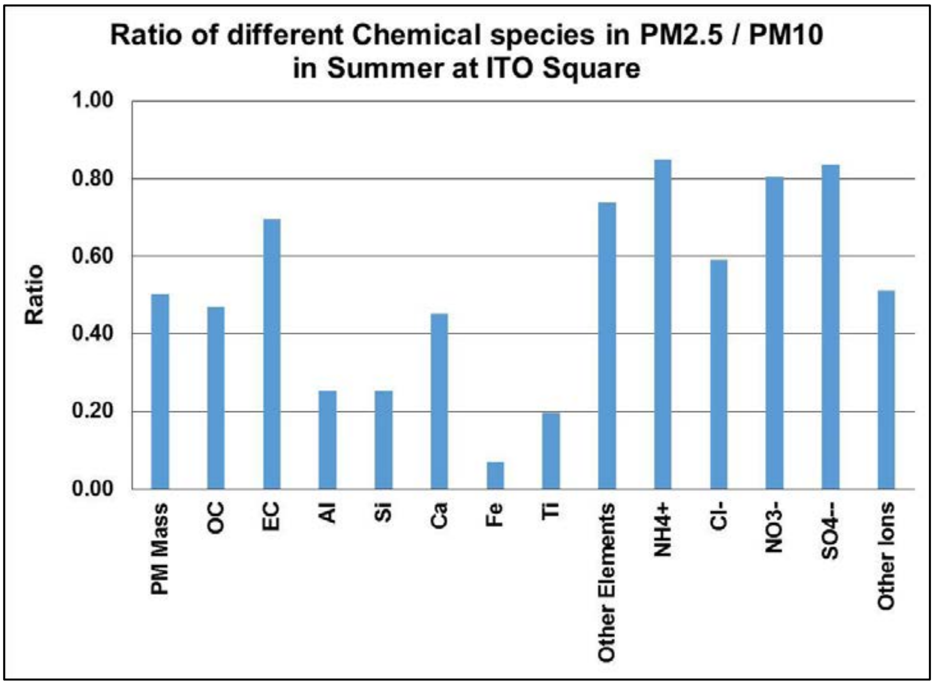


Figure 3.5: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at the ITO Square in the Summer Season

Average concentration of PM10 at the ITO square (ITO) was found to be 223±44 µg/m^3, which is 2.2 times the permissible limit of 100 µg/m^3 as per the NAAQS. Average concentration for PM2.5 was found to be 112±24 µg/m^3. Concentration of PM_{10} varied from 163 to 285 µg/m^3 and similarly, for $PM_{2.5}$, it varied from 77 to 135 µg/m^3 (See Figure 3.1).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.2. The average chemical composition (see Figure 3.3) shows that the major component of PM_{10} and $PM_{2.5}$ is carbon fraction, namely, organic carbon (OC) and elemental carbon (EC). Average concentration of carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 73 µg/m^3 and 40 µg/m^3, respectively. The percentage mass distribution showed that the organic carbon component is similar in both PM_{10} and $PM_{2.5}$. However, the elemental carbon component in $PM_{2.5}$ was higher than that in PM_{10}. The second major component observed was crustal elements contributing 8% of PM_{10}. But In case of $PM_{2.5}$, its contribution is very less, that is, only 3%. The ions prominently observed were SO_4^{--}, NO_3^-, and NH_4^+ and their contribution was more In case of $PM_{2.5}$ than in that of PM10, which may be attributed to the secondary particulates.

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, Pb) was found to be 6% in PM_{10} and 10% in $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 31% and 22% for PM_{10} and $PM_{2.5}$, respectively.

Concentration of OC2, OC3, and OC4 was found to be higher in PM_{10} than in $PM_{2.5}$. Also, EC1 was found in higher concentrations than the other carbon fractions (see Figure 3.4). Ratio of concentration of mass and major species of PM2.5 to PM10 is presented in Figure 3.5

Table 3.1 Statistical evaluatio**n of concentrations (µg/m**^{3}) of mass and major species of PM_{10} at the ITO Square in Summer Season

µg/m3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	223	46.57	26.30	0.89	2.99	6.96	6.60	0.61	10.20	1.18	0.55	0.65	7.24	3.06	11.69	5.73	5.80	6.56	6.30
SD	44	12.12	10.95	0.37	0.65	1.74	1.38	0.09	4.17	0.22	0.32	0.26	2.60	1.11	3.11	3.84	1.58	1.85	2.19
Min	163	31.40	11.67	0.58	2.09	4.79	4.22	0.48	4.82	0.88	0.20	0.31	3.28	0.87	6.74	1.91	3.26	3.94	4.12
Max	285	70.11	44.22	1.79	4.23	9.64	9.20	0.74	14.99	1.57	1.10	1.05	12.91	4.34	17.19	14.32	8.49	9.48	11.31
C.V.	0.20	0.26	0.42	0.41	0.22	0.25	0.21	0.15	0.41	0.18	0.58	0.40	0.36	0.36	0.27	0.67	0.27	0.28	0.35
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	276	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	225	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	165	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.2 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM2.5 at the ITO Square in Summer Season

µg/m3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	112	21.83	18.29	0.23	0.75	3.14	0.46	0.12	8.12	0.90	0.34	0.33	4.28	2.46	9.77	2.67	4.93	3.83	2.35
SD	24	7.70	7.58	0.04	0.16	0.87	0.14	0.02	2.41	0.23	0.24	0.17	2.49	0.89	3.07	0.95	1.52	1.72	1.33
Min	77	12.13	7.84	0.18	0.57	1.40	0.31	0.10	3.77	0.69	0.08	0.14	2.57	0.55	4.61	1.05	2.48	1.17	1.18
Max	135	34.38	28.40	0.31	1.02	4.46	0.74	0.15	11.28	1.33	0.83	0.64	10.49	3.42	15.07	3.64	7.73	5.95	5.86
C.V.	0.22	0.35	0.41	0.16	0.21	0.28	0.29	0.15	0.30	0.26	0.69	0.50	0.58	0.36	0.31	0.36	0.31	0.45	0.57
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	135	32.70	27.47	0.28	0.98	4.24	0.69	0.15	11.12	1.28	0.68	0.61	8.46	3.35	14.38	3.59	7.35	5.95	4.48
50 %ile	119	22.43	18.30	0.22	0.73	3.14	0.46	0.11	8.55	0.87	0.37	0.26	3.30	2.54	9.51	3.03	4.59	3.69	1.91
5 %ile	78	12.45	8.60	0.19	0.58	1.85	0.31	0.10	4.86	0.69	0.09	0.18	2.61	1.07	5.99	1.19	3.03	1.48	1.30

Table 3.3 Correlation Matrix for PM_{10} and Its major constituent at the ITO Square in Summer Season

	PM_{10}	OC	EC	TC	Cl^{-}	NO_3^{-}	SO_4^{--}	Na^{+}	NH_4^{+}	K^{+}	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.75																			
	0.02																			
EC	0.84	0.80																		
	0.00	*0.01*																		
TC	0.85	0.94	0.96																	
	0.00	*0.00*	*0.00*																	
Cl^{-}	0.62	0.63	0.29	0.47																
	0.08	*0.07*	*0.46*	*0.21*																
NO_3^{-}	0.74	0.68	0.69	0.72	0.31															
	0.02	*0.04*	*0.04*	*0.03*	*0.42*															
SO_4^{--}	0.66	0.85	0.57	0.73	0.62	0.80														
	0.06	*0.00*	*0.11*	*0.03*	*0.08*	*0.01*														
Na^{+}	0.82	0.44	0.80	0.67	0.16	0.73	0.35													
	0.01	*0.23*	*0.01*	*0.05*	*0.67*	*0.03*	*0.36*													
NH_4^{+}	0.68	0.67	0.50	0.61	0.50	0.88	0.78	0.59												
	0.04	*0.05*	*0.17*	*0.08*	*0.17*	*0.00*	*0.01*	*0.10*												
K^{+}	0.62	0.63	0.27	0.46	0.89	0.54	0.80	0.24	0.74											
	0.08	*0.07*	*0.48*	*0.22*	*0.00*	*0.13*	*0.01*	*0.53*	*0.02*											
Ca^{++}	0.76	0.65	0.48	0.59	0.89	0.36	0.46	0.40	0.52	0.70										
	0.02	*0.06*	*0.19*	*0.10*	*0.00*	*0.35*	*0.21*	*0.29*	*0.15*	*0.04*										
Si	0.64	0.24	0.59	0.45	-0.04	0.76	0.29	0.92	0.62	0.17	0.16									
	0.07	*0.53*	*0.10*	*0.22*	*0.92*	*0.02*	*0.44*	*0.00*	*0.07*	*0.67*	*0.68*									
Al	0.72	0.23	0.68	0.50	0.13	0.48	0.09	0.89	0.25	0.04	0.40	0.77								
	0.03	*0.55*	*0.05*	*0.17*	*0.74*	*0.20*	*0.82*	*0.00*	*0.52*	*0.93*	*0.29*	*0.01*								
Ca	0.78	0.57	0.47	0.54	0.68	0.56	0.47	0.57	0.69	0.64	0.85	0.50	0.51							
	0.01	*0.11*	*0.21*	*0.13*	*0.04*	*0.12*	*0.20*	*0.11*	*0.04*	*0.07*	*0.00*	*0.18*	*0.16*							
Fe	0.76	0.45	0.81	0.68	0.08	0.54	0.26	0.77	0.31	0.02	0.38	0.61	0.79	0.41						
	0.02	*0.22*	*0.01*	*0.04*	*0.84*	*0.13*	*0.51*	*0.02*	*0.42*	*0.97*	*0.31*	*0.08*	*0.01*	*0.28*						
Ti	0.78	0.64	0.76	0.74	0.27	0.75	0.65	0.78	0.66	0.46	0.34	0.76	0.58	0.59	0.51					
	0.01	*0.07*	*0.02*	*0.02*	*0.49*	*0.02*	*0.06*	*0.01*	*0.05*	*0.21*	*0.37*	*0.02*	*0.11*	*0.10*	*0.16*					
K	0.88	0.63	0.58	0.63	0.70	0.76	0.71	0.73	0.85	0.83	0.71	0.65	0.53	0.78	0.43	0.74				
	0.00	*0.07*	*0.10*	*0.07*	*0.04*	*0.02*	*0.03*	*0.03*	*0.00*	*0.01*	*0.03*	*0.06*	*0.15*	*0.01*	*0.25*	*0.02*				
S	0.64	0.43	0.71	0.61	-0.11	0.78	0.44	0.84	0.60	0.12	0.08	0.90	0.65	0.44	0.67	0.87	0.55			
	0.06	*0.25*	*0.03*	*0.08*	*0.78*	*0.01*	*0.24*	*0.01*	*0.09*	*0.76*	*0.83*	*0.00*	*0.06*	*0.24*	*0.05*	*0.00*	*0.13*			
Ni	0.51	-0.04	0.47	0.25	-0.10	0.33	-0.03	0.78	0.08	-0.07	0.06	0.76	0.89	0.24	0.59	0.58	0.40	0.64		
	0.16	*0.91*	*0.20*	*0.52*	*0.80*	*0.39*	*0.94*	*0.01*	*0.85*	*0.85*	*0.88*	*0.02*	*0.00*	*0.54*	*0.09*	*0.11*	*0.28*	*0.06*		
Pb	0.65	0.54	0.44	0.51	0.41	0.70	0.57	0.60	0.89	0.64	0.51	0.66	0.30	0.79	0.25	0.76	0.81	0.66	0.19	
	0.06	*0.13*	*0.24*	*0.16*	*0.27*	*0.04*	*0.11*	*0.09*	*0.00*	*0.06*	*0.16*	*0.05*	*0.43*	*0.01*	*0.52*	*0.02*	*0.01*	*0.06*	*0.62*	
Zn	0.50	0.44	0.62	0.57	-0.14	0.83	0.48	0.70	0.59	0.07	0.02	0.81	0.54	0.39	0.54	0.75	0.42	0.92	0.47	0.56
	0.17	*0.24*	*0.08*	*0.11*	*0.72*	*0.01*	*0.19*	*0.04*	*0.10*	*0.85*	*0.97*	*0.01*	*0.14*	*0.30*	*0.14*	*0.02*	*0.26*	*0.00*	*0.20*	*0.12*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

Table 3.4 Correlation Matrix for $PM_{2.5}$ and Its major constituent at the ITO Square in Summer Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.89																			
	0.00																			
EC	0.96	0.89																		
	0.00	*0.00*																		
TC	0.95	0.97	0.97																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.57	0.49	0.40	0.46																
	0.11	*0.18*	*0.28*	*0.21*																
NO_3^-	0.85	0.65	0.78	0.74	0.23															
	0.00	*0.06*	*0.01*	*0.02*	*0.56*															
SO_4^{--}	0.77	0.78	0.76	0.79	0.56	0.56														
	0.01	*0.01*	*0.02*	*0.01*	*0.12*	*0.12*														
Na^+	0.36	0.23	0.30	0.27	0.01	0.55	0.19													
	0.35	*0.56*	*0.43*	*0.48*	*0.99*	*0.12*	*0.62*													
NH_4^+	0.90	0.87	0.86	0.89	0.42	0.83	0.85	0.57												
	0.00	*0.00*	*0.00*	*0.00*	*0.27*	*0.01*	*0.00*	*0.11*												
K^+	0.88	0.83	0.88	0.88	0.44	0.73	0.74	0.54	0.90											
	0.00	*0.01*	*0.00*	*0.00*	*0.24*	*0.03*	*0.02*	*0.14*	*0.00*											
Ca^{++}	0.40	0.22	0.46	0.35	0.33	0.17	0.28	0.32	0.27	0.35										
	0.29	*0.58*	*0.22*	*0.36*	*0.39*	*0.67*	*0.47*	*0.41*	*0.48*	*0.36*										
Si	0.40	0.70	0.42	0.57	0.36	0.13	0.58	-0.19	0.47	0.48	-0.34									
	0.29	*0.04*	*0.26*	*0.11*	*0.34*	*0.73*	*0.10*	*0.63*	*0.20*	*0.19*	*0.37*									
Al	0.30	-0.06	0.30	0.13	-0.12	0.47	0.02	0.56	0.24	0.35	0.56	-0.62								
	0.44	*0.87*	*0.43*	*0.74*	*0.77*	*0.20*	*0.96*	*0.12*	*0.54*	*0.36*	*0.12*	*0.07*								
Ca	0.45	0.27	0.52	0.41	0.29	0.26	0.37	0.44	0.39	0.44	0.98	-0.29	0.59							
	0.22	*0.48*	*0.15*	*0.27*	*0.44*	*0.50*	*0.33*	*0.24*	*0.30*	*0.24*	*0.00*	*0.45*	*0.10*							
Fe	0.44	0.19	0.52	0.37	-0.17	0.53	-0.02	0.35	0.25	0.29	0.63	-0.47	0.72	0.63						
	0.24	*0.63*	*0.15*	*0.33*	*0.66*	*0.15*	*0.96*	*0.36*	*0.52*	*0.46*	*0.07*	*0.20*	*0.03*	*0.07*						
Ti	0.54	0.46	0.62	0.56	0.20	0.44	0.58	0.69	0.68	0.73	0.59	0.15	0.39	0.72	0.34					
	0.14	*0.21*	*0.07*	*0.12*	*0.60*	*0.23*	*0.10*	*0.04*	*0.04*	*0.03*	*0.10*	*0.69*	*0.30*	*0.03*	*0.37*					
K	0.76	0.61	0.71	0.68	0.17	0.85	0.37	0.80	0.78	0.75	0.41	-0.01	0.57	0.49	0.64	0.59				
	0.02	*0.08*	*0.03*	*0.04*	*0.67*	*0.00*	*0.33*	*0.01*	*0.01*	*0.02*	*0.27*	*0.97*	*0.11*	*0.18*	*0.06*	*0.09*				
S	0.83	0.66	0.87	0.79	0.11	0.88	0.56	0.60	0.82	0.83	0.38	0.16	0.53	0.50	0.65	0.73	0.85			
	0.01	*0.05*	*0.00*	*0.01*	*0.77*	*0.00*	*0.12*	*0.09*	*0.01*	*0.01*	*0.31*	*0.68*	*0.14*	*0.17*	*0.06*	*0.03*	*0.00*			
Ni	0.33	0.08	0.44	0.27	-0.30	0.54	0.01	0.64	0.32	0.38	0.50	-0.42	0.73	0.59	0.84	0.64	0.67	0.76		
	0.38	*0.83*	*0.24*	*0.48*	*0.44*	*0.14*	*0.97*	*0.06*	*0.40*	*0.32*	*0.17*	*0.27*	*0.03*	*0.10*	*0.01*	*0.07*	*0.05*	*0.02*		
Pb	0.57	0.55	0.53	0.55	0.07	0.72	0.18	0.72	0.63	0.62	-0.01	0.22	0.20	0.10	0.37	0.46	0.84	0.72	0.53	
	0.11	*0.13*	*0.15*	*0.12*	*0.87*	*0.03*	*0.65*	*0.03*	*0.07*	*0.07*	*0.99*	*0.56*	*0.60*	*0.81*	*0.33*	*0.22*	*0.00*	*0.03*	*0.14*	
Zn	0.52	0.40	0.67	0.55	-0.27	0.64	0.40	0.58	0.62	0.67	0.33	0.04	0.59	0.47	0.60	0.76	0.65	0.88	0.82	0.52
	0.15	*0.28*	*0.05*	*0.12*	*0.48*	*0.07*	*0.28*	*0.10*	*0.08*	*0.05*	*0.39*	*0.93*	*0.10*	*0.20*	*0.09*	*0.02*	*0.06*	*0.00*	*0.01*	*0.15*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.1 and Table 3.2 for PM mass and the major species, respectively.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is presented in Table 3.3 and Table 3.4 for PM mass and the major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3-, & SO_4^{--}) show better correlation with each other.

3.1.1.2 Winter Season

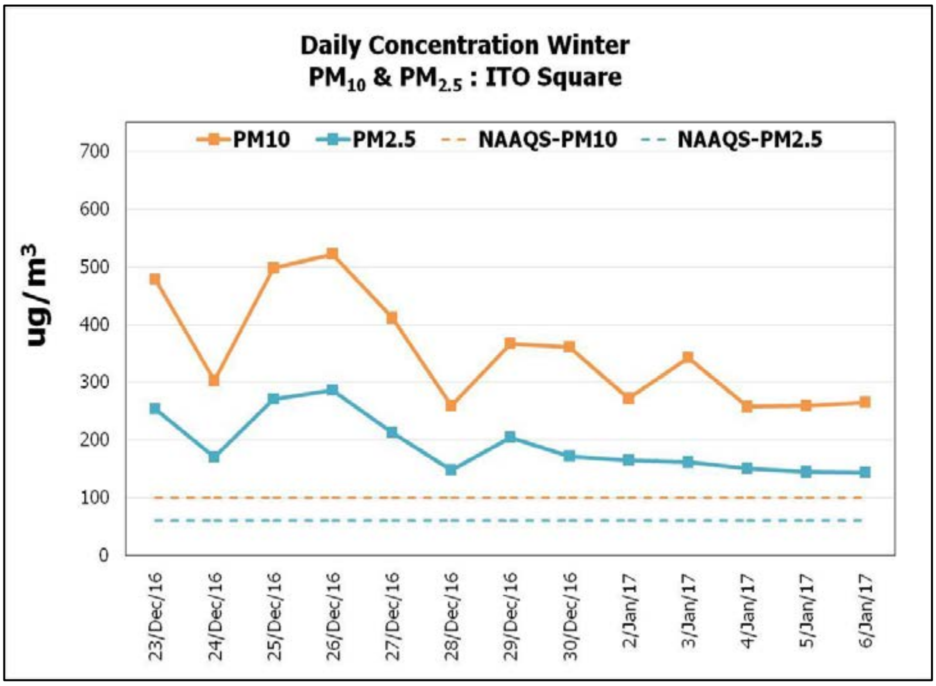


Figure 0-10 Variation in the 24 hourly Concentrations of PM_{10} and $PM_{2.5}$ at the ITO Square in Winter Season

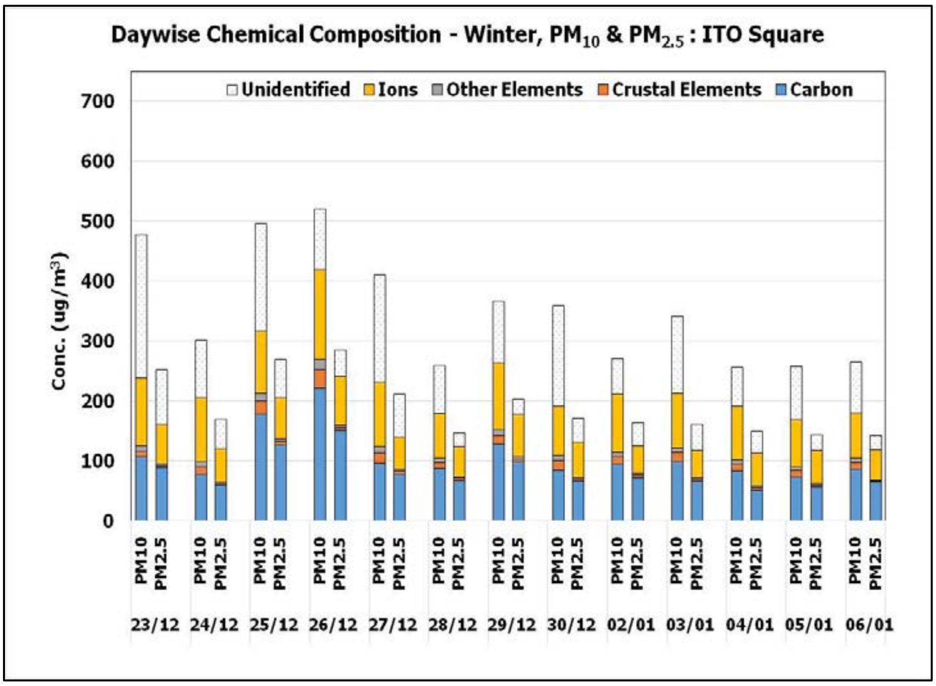


Figure 3.7 Variation in the Chemical Compositions of PM_{10} and $PM_{2.5}$ at the ITO square in Winter Season

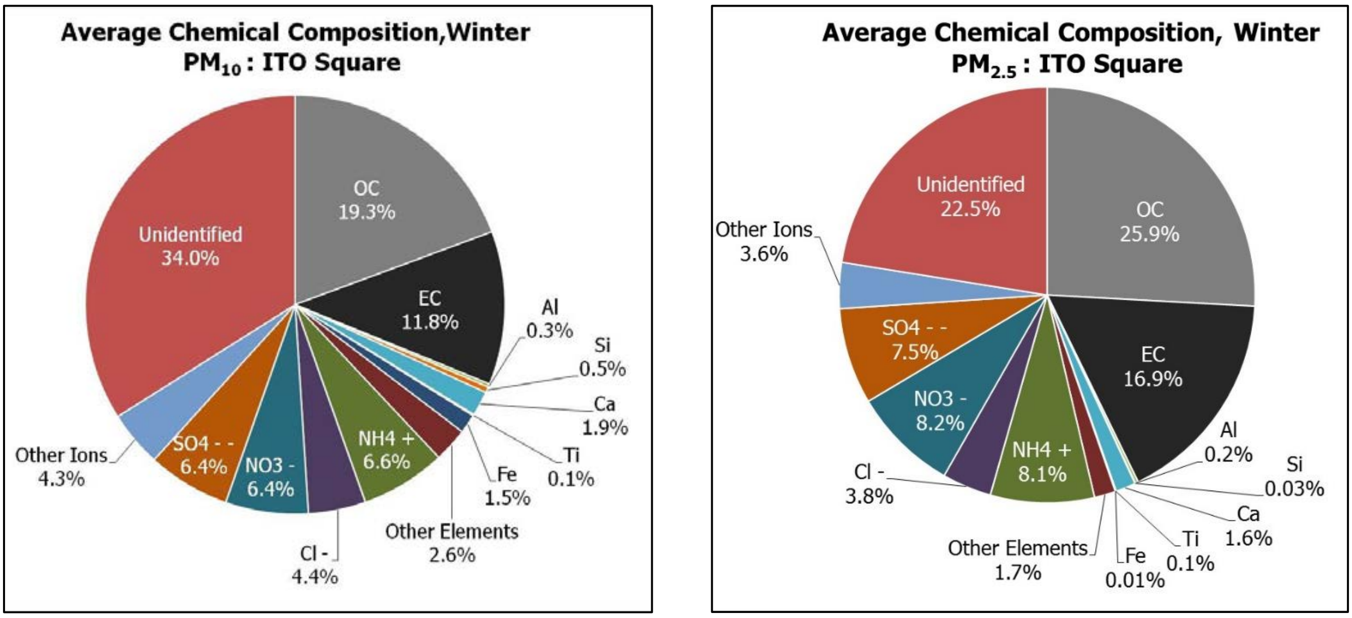


Figure 3.8: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at the ITO Square in Winter Season

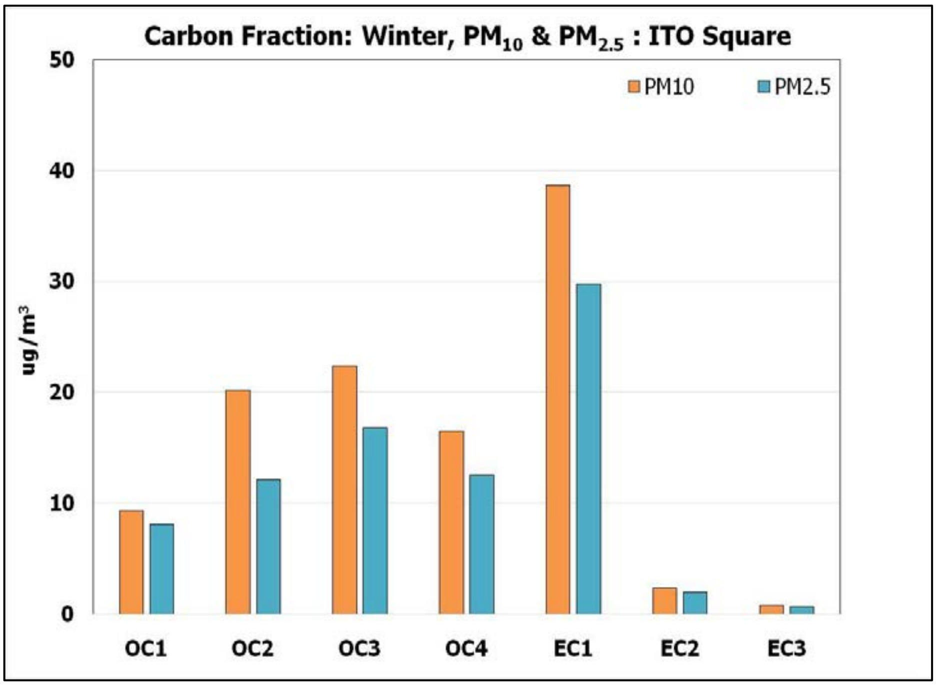


Figure 3.9: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at the ITO Square in Winter Season

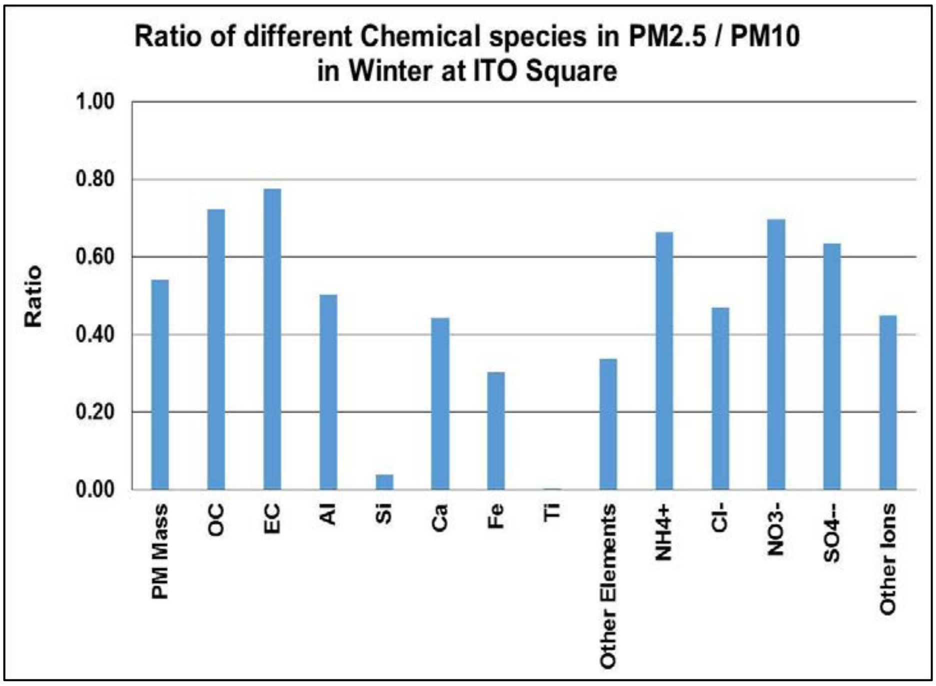


Figure 3.10: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at the ITO Square

At the ITO Square (ITO), the average concentration of PM_{10} was found to be 354±97 μg/m^3, which is 3.5 times higher than the NAAQS's permissible limit of 100 μg/m^3 , while $PM_{2.5}$ was found to be 191±50 μg/m^3. Concentration of PM_{10} varied from 257 to 522 μg/m^3 and In case of $PM_{2.5}$, it varied from 143 to 286 μg/m^3 (see Figure 3.6).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.7.

Average concentration of carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 110 μg/m^3 and 82 μg/m^3, respectively. The percentage mass distribution of the organic carbon and elemental carbon of $PM_{2.5}$ is higher than that of PM_{10}. The crustal element was found to be 4% for PM_{10} and 2% for PM2.5. The total ion concentration was found to be 28% for PM_{10} and 31% for $PM_{2.5}$ (see Figure 3.8).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% and 2% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, were found to be 34% and 23%, in PM_{10} and $PM_{2.5}$ respectively.

OC3 was found to be higher in PM_{10} as compared to that in $PM_{2.5}$, followed by OC2, OC4, and OC1 in PM_{10}. And in $PM_{2.5}$, OC3 was found to be higher, followed by OC4, OC2, and OC1. In PM_{10}, EC1 was found to be higher than in $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.9). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.10.

Table 3.5 Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of PM_{10} at the ITO Square in Winter Season

μg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	354	68.41	41.78	0.91	1.62	6.74	5.20	0.38	3.19	3.28	0.46	1.21	15.63	22.56	22.48	1.46	23.22	3.24	7.70
SD	97	26.93	17.65	0.39	0.48	3.02	1.96	0.14	1.26	1.37	0.16	0.50	7.54	5.37	5.05	1.24	3.83	0.88	5.06
Min	257	42.54	25.70	0.59	1.02	3.35	2.72	0.19	1.99	1.27	0.22	0.77	5.72	14.83	15.34	0.16	17.75	2.21	3.21
Max	522	130.04	92.37	1.84	2.69	15.11	10.12	0.71	6.45	6.15	0.84	2.49	31.39	31.05	32.72	4.38	30.67	5.31	20.27
C.V.	0.27	0.39	0.42	0.43	0.30	0.45	0.38	0.37	0.39	0.42	0.35	0.42	0.48	0.24	0.22	0.85	0.17	0.27	0.66
N	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
95 %ile	507	123.49	72.38	1.66	2.47	12.41	8.58	0.62	5.35	5.51	0.75	2.19	28.26	29.84	30.72	3.89	29.27	4.66	15.86
50 %ile	348	62.11	38.68	0.75	1.53	5.95	5.03	0.33	2.72	3.05	0.46	1.06	13.76	22.69	22.47	1.14	23.18	3.14	5.48
5 %ile	209	37.86	23.28	0.53	0.86	3.25	2.49	0.17	1.77	1.34	0.20	0.69	7.00	11.99	12.25	0.27	13.57	1.81	3.39

Table 3.6 Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of $PM_{2.5}$ at the ITO Square in Winter Season

μg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	191	49.43	32.37	0.46	0.06	2.98	0.02	0.11	2.09	0.11	0.01	0.13	7.34	15.70	14.31	0.36	15.43	1.78	2.52
SD	50	17.04	13.50	0.10	0.03	0.70	0.01	0.04	0.59	0.04	0.01	0.03	4.05	1.87	2.59	0.30	2.55	0.49	0.71
Min	143	30.86	20.74	0.26	0.02	1.55	0.00	0.04	1.04	0.07	0.00	0.10	2.05	13.52	11.09	0.04	11.70	1.26	1.39
Max	286	82.93	69.03	0.58	0.09	3.96	0.03	0.16	3.06	0.20	0.03	0.18	16.44	19.02	21.24	0.86	19.84	2.79	3.54
C.V.	0.26	0.34	0.42	0.22	0.42	0.23	0.54	0.35	0.28	0.32	0.64	0.20	0.55	0.12	0.18	0.83	0.17	0.28	0.28
N	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
95 %ile	277	81.67	56.24	0.57	0.09	3.89	0.03	0.16	3.05	0.19	0.03	0.17	14.89	18.46	18.61	0.82	19.64	2.70	3.38
50 %ile	171	40.76	27.72	0.47	0.07	3.05	0.02	0.12	2.06	0.10	0.01	0.12	7.16	15.09	13.95	0.30	15.19	1.61	2.32
5 %ile	144	32.56	21.36	0.29	0.02	1.98	0.00	0.05	1.10	0.08	0.00	0.10	2.58	13.64	11.77	0.04	12.53	1.28	1.62

Table 3.7 Correlation Matrix for PM_{10} and Its major constituent at the ITO Square in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.82																			
	0.00																			
EC	0.73	0.89																		
	0.01	*0.00*																		
TC	0.81	0.98	0.96																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.37	0.43	0.49	0.47																
	0.22	*0.14*	*0.09*	*0.11*																
NO_3^-	0.52	0.41	0.39	0.41	0.21															
	0.07	*0.16*	*0.19*	*0.16*	*0.49*															
SO_4^{--}	0.51	0.43	0.39	0.43	0.10	0.64														
	0.07	*0.14*	*0.19*	*0.15*	*0.76*	*0.02*														
Na^+	0.37	0.52	0.58	0.56	0.95	0.31	0.04													
	0.22	*0.07*	*0.04*	*0.05*	*0.00*	*0.31*	*0.90*													
NH_4^+	0.90	0.75	0.72	0.76	0.42	0.69	0.72	0.39												
	0.00	*0.00*	*0.01*	*0.00*	*0.15*	*0.01*	*0.01*	*0.19*												
K^+	0.63	0.69	0.63	0.69	0.06	0.49	0.41	0.18	0.55											
	0.02	*0.01*	*0.02*	*0.01*	*0.85*	*0.09*	*0.17*	*0.57*	*0.05*											
Ca^{++}	0.57	0.63	0.81	0.72	0.31	0.22	0.21	0.31	0.56	0.40										
	0.04	*0.02*	*0.00*	*0.01*	*0.31*	*0.48*	*0.49*	*0.31*	*0.05*	*0.18*										
Si	0.70	0.79	0.75	0.80	0.16	0.46	0.47	0.29	0.56	0.72	0.52									
	0.01	*0.00*	*0.00*	*0.00*	*0.60*	*0.11*	*0.11*	*0.34*	*0.05*	*0.01*	*0.07*									
Al	0.76	0.91	0.88	0.92	0.34	0.45	0.51	0.46	0.67	0.66	0.63	0.93								
	0.00	*0.00*	*0.00*	*0.00*	*0.26*	*0.13*	*0.08*	*0.12*	*0.01*	*0.01*	*0.02*	*0.00*								
Ca	0.65	0.89	0.89	0.91	0.30	0.47	0.50	0.45	0.61	0.70	0.63	0.91	0.95							
	0.02	*0.00*	*0.00*	*0.00*	*0.32*	*0.11*	*0.08*	*0.12*	*0.03*	*0.01*	*0.02*	*0.00*	*0.00*							
Fe	0.65	0.81	0.82	0.83	0.31	0.51	0.56	0.46	0.62	0.61	0.49	0.91	0.92	0.96						
	0.02	*0.00*	*0.00*	*0.00*	*0.30*	*0.07*	*0.05*	*0.12*	*0.02*	*0.03*	*0.09*	*0.00*	*0.00*	*0.00*						
Ti	0.64	0.85	0.82	0.86	0.30	0.45	0.52	0.44	0.58	0.69	0.49	0.93	0.96	0.96	0.95					
	0.02	*0.00*	*0.00*	*0.00*	*0.32*	*0.12*	*0.07*	*0.13*	*0.04*	*0.01*	*0.09*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.83	0.89	0.87	0.91	0.46	0.57	0.65	0.52	0.79	0.72	0.61	0.88	0.95	0.91	0.89	0.90				
	0.00	*0.00*	*0.00*	*0.00*	*0.11*	*0.04*	*0.02*	*0.07*	*0.00*	*0.01*	*0.03*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.95	0.79	0.71	0.78	0.37	0.62	0.58	0.36	0.93	0.73	0.53	0.66	0.69	0.66	0.65	0.64	0.80			
	0.00	*0.00*	*0.01*	*0.00*	*0.22*	*0.02*	*0.04*	*0.22*	*0.00*	*0.01*	*0.06*	*0.01*	*0.01*	*0.02*	*0.02*	*0.02*	*0.00*			
Ni	0.59	0.62	0.36	0.53	0.25	0.48	0.50	0.28	0.61	0.36	0.18	0.39	0.56	0.42	0.38	0.52	0.54	0.56		
	0.03	*0.02*	*0.23*	*0.06*	*0.40*	*0.10*	*0.08*	*0.35*	*0.03*	*0.22*	*0.56*	*0.19*	*0.05*	*0.16*	*0.21*	*0.07*	*0.06*	*0.05*		
Pb	0.75	0.83	0.79	0.84	0.41	0.36	0.50	0.45	0.68	0.52	0.68	0.80	0.89	0.85	0.83	0.86	0.86	0.72	0.57	
	0.00	*0.00*	*0.00*	*0.00*	*0.17*	*0.22*	*0.08*	*0.12*	*0.01*	*0.07*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.04*	
Zn	0.81	0.95	0.90	0.96	0.50	0.44	0.51	0.58	0.75	0.64	0.65	0.84	0.96	0.93	0.90	0.91	0.95	0.78	0.56	0.94
	0.00	*0.00*	*0.00*	*0.00*	*0.09*	*0.14*	*0.07*	*0.04*	*0.00*	*0.02*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.05*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.8 Correlation Matrix for $PM_{2.5}$ and Its major constituent at the ITO Square in Winter Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.94																			
	0.00																			
EC	0.79	0.84																		
	0.00	*0.00*																		
TC	0.91	0.97	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.51	0.56	0.60	0.60																
	0.08	*0.05*	*0.03*	*0.03*																
NO_3^-	0.94	0.88	0.74	0.85	0.44															
	0.00	*0.00*	*0.00*	*0.00*	*0.13*															
SO_4^{--}	0.72	0.73	0.77	0.78	0.49	0.58														
	0.01	*0.01*	*0.00*	*0.00*	*0.09*	*0.04*														
Na^+	0.46	0.41	0.51	0.47	0.83	0.52	0.22													
	0.15	*0.22*	*0.11*	*0.15*	*0.00*	*0.10*	*0.53*													
NH_4^+	0.91	0.85	0.71	0.82	0.42	0.82	0.75	0.31												
	0.00	*0.00*	*0.01*	*0.00*	*0.16*	*0.00*	*0.00*	*0.36*												
K^+	0.65	0.62	0.62	0.65	0.85	0.64	0.60	0.69	0.54											
	0.02	*0.02*	*0.02*	*0.02*	*0.00*	*0.02*	*0.03*	*0.02*	*0.06*											
Ca^{++}	0.25	0.34	0.48	0.41	0.21	0.51	0.21	0.42	0.15	0.14										
	0.55	*0.40*	*0.24*	*0.31*	*0.61*	*0.19*	*0.62*	*0.31*	*0.72*	*0.74*										
Si	0.70	0.72	0.41	0.61	0.43	0.66	0.25	0.39	0.61	0.48	0.06									
	0.01	*0.01*	*0.17*	*0.03*	*0.14*	*0.01*	*0.42*	*0.24*	*0.03*	*0.10*	*0.89*									
Al	0.62	0.63	0.31	0.51	0.38	0.63	0.20	0.22	0.50	0.54	0.15	0.84								
	0.02	*0.02*	*0.30*	*0.07*	*0.20*	*0.02*	*0.52*	*0.52*	*0.09*	*0.06*	*0.72*	*0.00*								
Ca	0.43	0.56	0.30	0.46	0.36	0.47	0.09	0.16	0.27	0.38	0.35	0.69	0.87							
	0.14	*0.05*	*0.32*	*0.11*	*0.22*	*0.11*	*0.78*	*0.65*	*0.38*	*0.20*	*0.40*	*0.01*	*0.00*							
Fe	0.65	0.70	0.47	0.62	0.42	0.59	0.27	0.37	0.64	0.39	0.10	0.94	0.64	0.51						
	0.02	*0.01*	*0.11*	*0.02*	*0.15*	*0.03*	*0.38*	*0.27*	*0.02*	*0.19*	*0.81*	*0.00*	*0.02*	*0.07*						
Ti	0.70	0.72	0.39	0.60	0.42	0.68	0.23	0.38	0.58	0.50	0.10	0.99	0.90	0.77	0.88					
	0.01	*0.01*	*0.18*	*0.03*	*0.16*	*0.01*	*0.46*	*0.25*	*0.04*	*0.08*	*0.82*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.59	0.59	0.60	0.62	0.56	0.71	0.37	0.65	0.39	0.81	0.53	0.43	0.59	0.47	0.29	0.49				
	0.03	*0.03*	*0.03*	*0.02*	*0.05*	*0.01*	*0.22*	*0.03*	*0.19*	*0.00*	*0.17*	*0.15*	*0.03*	*0.10*	*0.34*	*0.09*				
S	0.55	0.53	0.55	0.56	0.51	0.38	0.65	0.22	0.52	0.55	-0.38	0.33	0.23	0.25	0.30	0.32	0.17			
	0.05	*0.06*	*0.05*	*0.05*	*0.08*	*0.21*	*0.02*	*0.52*	*0.07*	*0.05*	*0.35*	*0.27*	*0.45*	*0.41*	*0.32*	*0.29*	*0.59*			
Ni	0.42	0.55	0.61	0.60	0.34	0.49	0.56	0.27	0.34	0.33	0.61	0.05	0.07	0.34	0.05	0.09	0.35	0.44		
	0.16	*0.05*	*0.03*	*0.03*	*0.25*	*0.09*	*0.05*	*0.42*	*0.25*	*0.28*	*0.11*	*0.88*	*0.82*	*0.25*	*0.87*	*0.78*	*0.24*	*0.13*		
Pb	0.67	0.68	0.68	0.71	0.57	0.62	0.58	0.47	0.58	0.65	0.32	0.21	0.41	0.29	0.15	0.26	0.70	0.28	0.34	
	0.01	*0.01*	*0.01*	*0.01*	*0.04*	*0.02*	*0.04*	*0.15*	*0.04*	*0.02*	*0.43*	*0.49*	*0.17*	*0.35*	*0.64*	*0.39*	*0.01*	*0.35*	*0.25*	
Zn	0.87	0.90	0.71	0.85	0.59	0.82	0.67	0.29	0.79	0.73	0.24	0.64	0.65	0.51	0.61	0.65	0.61	0.49	0.44	0.71
	0.00	*0.00*	*0.01*	*0.00*	*0.03*	*0.00*	*0.01*	*0.38*	*0.00*	*0.01*	*0.58*	*0.02*	*0.02*	*0.07*	*0.03*	*0.02*	*0.03*	*0.09*	*0.13*	*0.01*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For the winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.5 and Table 3.6, respectively for PM mass and the major species. For the secondary ions, C.V. observed in PM_{10} and $PM_{2.5}$ was very less, which represents less variation in concentration during the monitoring period.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.7 and Table 3.8, respectively for PM mass and its major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3- & SO_4^{--}) show better correlation with each other in $PM_{2.5}$.

3.1.2 Site 2: RK Puram

3.1.2.1 Summer Season

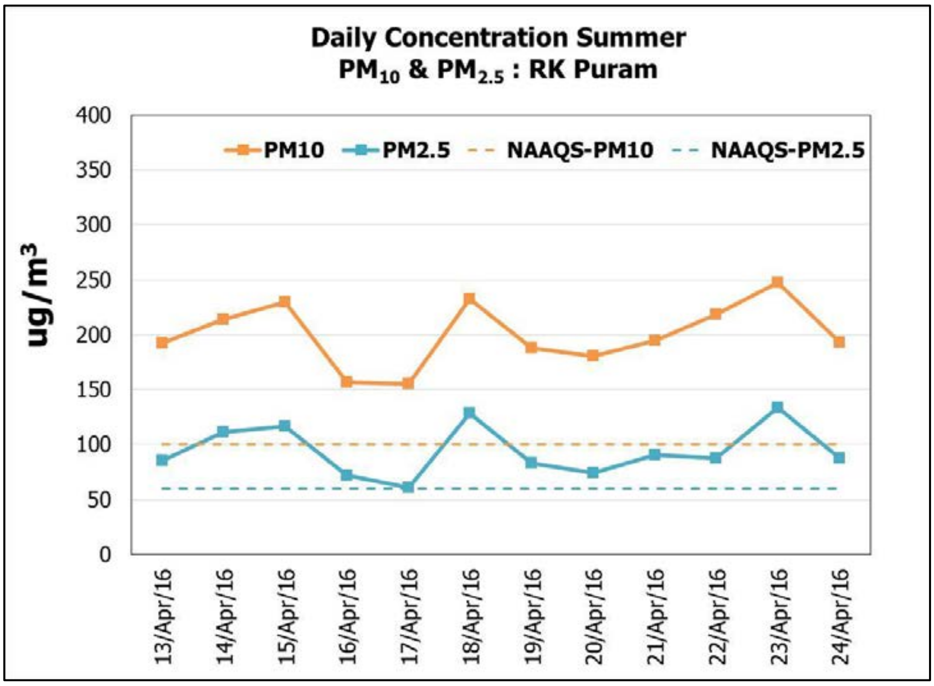


Figure 3.11 Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at R.K. Puram in the Summer Season

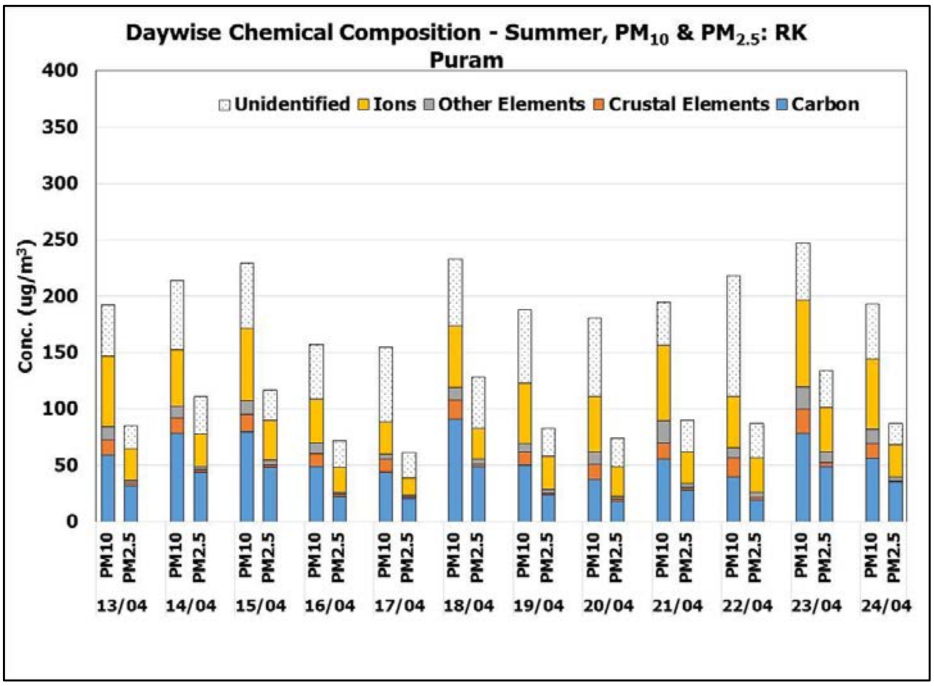


Figure 3.12: Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at R.K. Puram in the Summer Season

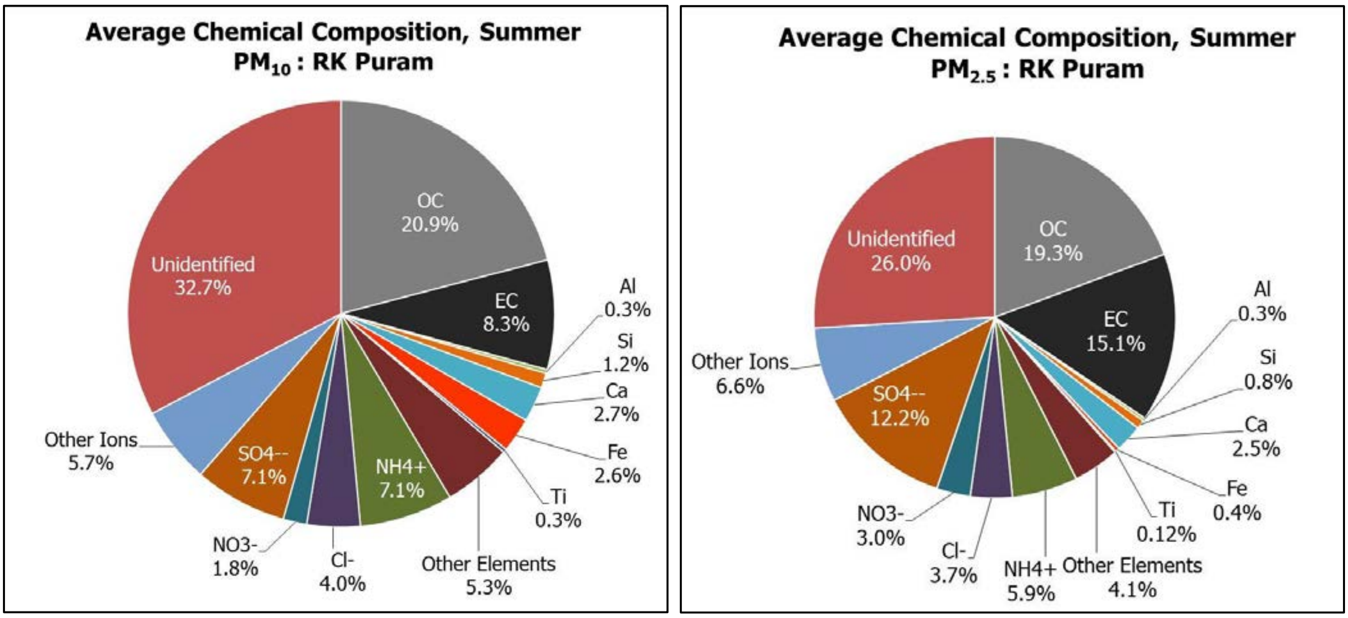


Figure 3.13: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at R.K. Puram in the Summer Season

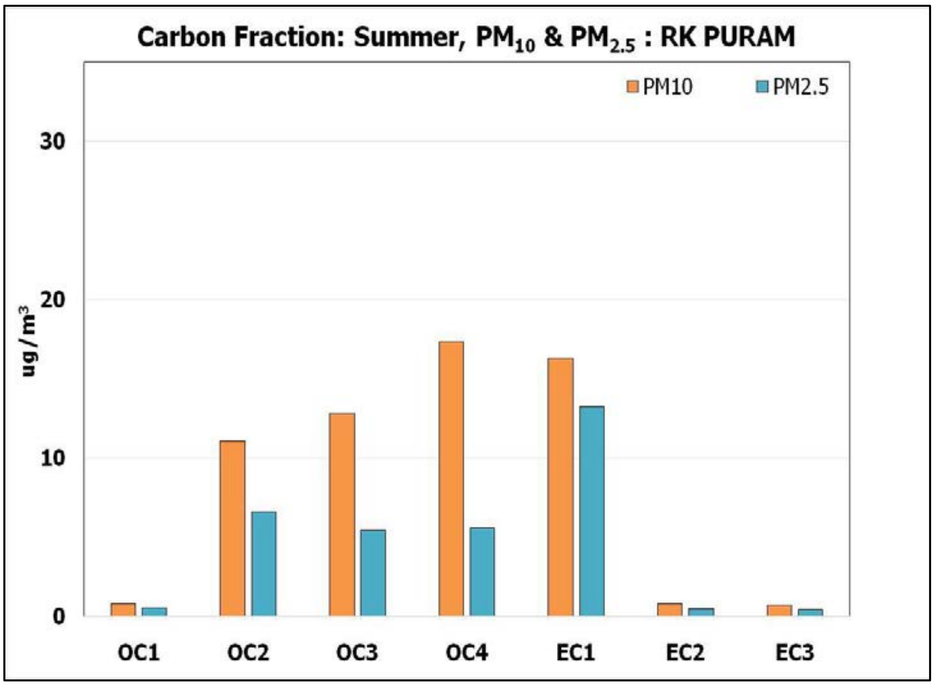


Figure 3.14: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at R.K. Puram in the Summer Season

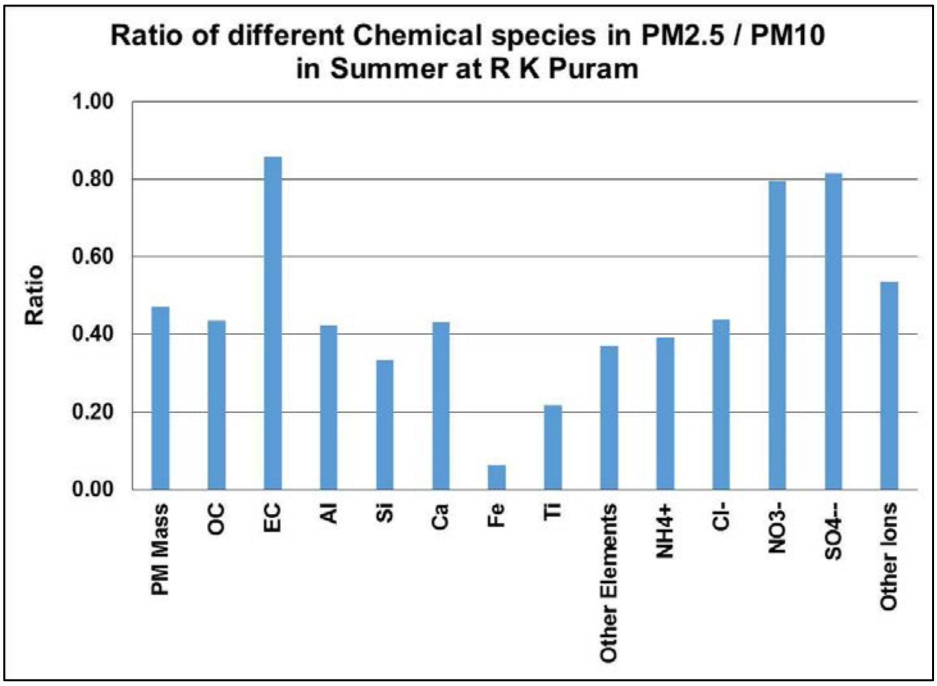


Figure 3.15: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at R.K. Puram

It was found that Daily variation in concentrations of PM_{10} and $PM_{2.5}$ followed the trend with an average value of 200±28 µg/m^3 and 94±23 µg/m^3, respectively, at R.K. Puram (RKP). The maximum concentration of PM_{10} was found to be 233 µg/m^3 and it was 134 µg/m^3 for $PM_{2.5}$. All concentrations of PM_{10} and $PM_{2.5}$ are well above the NAAQS, varying from 155 to 233 µg/m^3 and 61 to 134 µg/m^3, respectively (see Figure 3.11).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.12.

Contribution to PM_{10} and $PM_{2.5}$ is mainly from carbon fraction, followed by ions and then the crustal elements. Average concentration of carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 59 µg/m^3 and 33 µg/m^3, respectively. However, the percentage mass distribution showed that the elemental carbon component is much higher in $PM_{2.5}$ than in PM_{10}. The total ion concentration was found to be higher in $PM_{2.5}$ as compared to that in PM_{10}, that is, 31% and 25%, respectively. The crustal element contribution was found to be 7% from PM_{10} and was much less from $PM_{2.5}$ (2%) (see Figure 3.13).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% in PM_{10} and 4% in $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 33% for PM_{10} and 29% for $PM_{2.5}$.

In PM_{10}, Concentration of OC4 (17 µg/m^3) was the highest, followed by EC1 (16 µg/m^3). On the other hand, In case of $PM_{2.5}$, EC1 is the highest, followed by OC2 (see Figure 3.14).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.15.

Table 3.9 Statistical **evaluation of concentrations (µ**g/m^3) of mass and major species of PM_{10} at R.K. Puram in Summer Season

µg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	200	41.94	16.62	0.59	2.25	5.39	5.28	0.52	8.12	0.81	0.27	0.21	8.06	3.59	14.16	2.63	14.18	4.75	1.93
SD	28	13.66	5.10	0.16	0.58	0.75	0.91	0.08	3.44	0.16	0.15	0.09	4.96	0.52	3.39	0.87	3.34	1.04	0.53
Min	155	26.23	11.26	0.36	1.47	4.50	4.05	0.40	2.72	0.52	0.04	0.06	2.68	2.90	7.77	1.73	8.49	2.46	1.02
Max	233	64.99	26.17	0.87	3.25	6.37	6.87	0.64	15.53	1.10	0.52	0.36	19.18	4.46	17.73	3.93	20.80	6.11	2.76
C.V.	0.14	0.33	0.31	0.27	0.26	0.14	0.17	0.16	0.42	0.20	0.57	0.44	0.62	0.14	0.24	0.33	0.24	0.22	0.27
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95 %ile	239	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	194	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	156	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.10 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at R.K. Puram in Summer Season

µg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	94	18.24	14.25	0.25	0.75	2.32	0.34	0.11	2.40	0.75	0.10	0.08	3.52	2.85	11.54	1.77	5.55	1.72	0.96
SD	23	7.04	5.23	0.03	0.07	0.40	0.12	0.02	1.71	0.15	0.12	0.06	0.99	0.47	2.75	0.83	1.13	1.14	0.27
Min	61	10.70	7.56	0.21	0.62	1.83	0.11	0.08	0.32	0.49	0.01	0.01	1.51	2.18	5.73	0.89	3.02	0.71	0.43
Max	134	28.29	21.70	0.30	0.85	3.44	0.58	0.14	7.19	0.99	0.38	0.17	5.33	3.39	16.74	3.23	7.50	4.97	1.37
C.V.	0.24	0.39	0.37	0.11	0.10	0.17	0.35	0.13	0.71	0.20	1.23	0.70	0.28	0.16	0.24	0.47	0.20	0.66	0.28
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95 %ile	131	27.93	21.49	0.29	0.85	2.90	0.49	0.13	4.80	0.99	0.34	0.15	4.94	3.35	15.54	3.11	7.08	3.60	1.34
50 %ile	87	16.94	12.93	0.25	0.77	2.29	0.35	0.11	2.32	0.76	0.04	0.09	3.70	2.93	11.59	1.51	5.44	1.55	1.00
5 %ile	67	10.78	8.29	0.21	0.63	1.85	0.18	0.09	0.74	0.55	0.01	0.01	2.00	2.22	7.59	0.89	3.89	0.77	0.53

Table 3.11 Correlation Matrix for PM_{10} and Its major constituents at R.K. Puram in Summer Season

	PM10	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.68																			
	0.02																			
EC	0.76	0.79																		
	0.00	*0.00*																		
TC	0.74	0.98	0.89																	
	0.01	*0.00*	*0.00*																	
Cl^-	*0.43*	*0.26*	*0.31*	*0.29*																
	0.17	*0.42*	*0.33*	*0.37*																
NO_3^-	0.63	0.55	0.64	0.61	0.38															
	0.03	*0.06*	*0.02*	*0.04*	*0.22*															
SO_4^{--}	0.57	0.55	0.55	0.58	0.57	0.80														
	0.05	*0.06*	*0.07*	*0.05*	*0.05*	*0.00*														
Na^+	0.51	-0.03	0.23	0.05	0.65	0.15	0.09													
	0.09	*0.94*	*0.48*	*0.87*	*0.02*	*0.65*	*0.77*													
NH_4^+	0.73	0.66	0.69	0.70	0.46	0.93	0.87	0.20												
	0.01	*0.02*	*0.01*	*0.01*	*0.13*	*0.00*	*0.00*	*0.53*												
K^+	0.58	0.15	0.53	0.27	0.73	0.54	0.50	0.74	0.58											
	0.05	*0.64*	*0.08*	*0.39*	*0.01*	*0.07*	*0.10*	*0.01*	*0.05*											
Ca^{++}	0.71	0.39	0.55	0.46	0.51	0.55	0.57	0.56	0.61	0.72										
	0.01	*0.22*	*0.07*	*0.14*	*0.09*	*0.07*	*0.06*	*0.06*	*0.04*	*0.01*										
Si	0.70	0.24	0.54	0.35	0.67	0.38	0.30	0.87	0.36	0.75	0.54									
	0.01	*0.45*	*0.07*	*0.27*	*0.02*	*0.23*	*0.35*	*0.00*	*0.25*	*0.01*	*0.07*									
Al	0.72	0.26	0.50	0.35	0.70	0.36	0.30	0.89	0.37	0.74	0.54	0.99								
	0.01	*0.41*	*0.10*	*0.27*	*0.01*	*0.25*	*0.35*	*0.00*	*0.24*	*0.01*	*0.07*	*0.00*								
Ca	0.79	0.57	0.58	0.60	0.49	0.41	0.32	0.63	0.48	0.59	0.83	0.64	0.67							
	0.00	*0.05*	*0.05*	*0.04*	*0.11*	*0.19*	*0.31*	*0.03*	*0.12*	*0.04*	*0.00*	*0.03*	*0.02*							
Fe	0.78	0.32	0.43	0.37	0.37	0.19	0.10	0.69	0.22	0.50	0.48	0.78	0.81	0.70						
	0.00	*0.30*	*0.16*	*0.23*	*0.24*	*0.57*	*0.77*	*0.01*	*0.49*	*0.10*	*0.12*	*0.00*	*0.00*	*0.01*						
Ti	0.78	0.54	0.51	0.55	0.71	0.25	0.47	0.59	0.40	0.50	0.52	0.74	0.78	0.67	0.75					
	0.00	*0.07*	*0.09*	*0.06*	*0.01*	*0.44*	*0.12*	*0.04*	*0.19*	*0.10*	*0.08*	*0.01*	*0.00*	*0.02*	*0.01*					
K	0.46	0.29	0.50	0.37	0.89	0.45	0.55	0.64	0.53	0.85	0.47	0.70	0.70	0.43	0.41	0.58				
	0.14	*0.36*	*0.10*	*0.24*	*0.00*	*0.14*	*0.07*	*0.02*	*0.07*	*0.00*	*0.13*	*0.01*	*0.01*	*0.17*	*0.19*	*0.05*				
S	0.86	0.37	0.48	0.42	0.46	0.48	0.51	0.49	0.58	0.63	0.65	0.60	0.63	0.68	0.72	0.75	0.41			
	0.00	*0.24*	*0.11*	*0.18*	*0.14*	*0.11*	*0.09*	*0.11*	*0.05*	*0.03*	*0.02*	*0.04*	*0.03*	*0.02*	*0.01*	*0.01*	*0.18*			
Ni	0.56	0.68	0.32	0.60	0.51	0.53	0.56	0.18	0.56	0.17	0.51	0.28	0.33	0.61	0.37	0.57	0.30	0.39		
	0.06	*0.01*	*0.32*	*0.04*	*0.09*	*0.08*	*0.06*	*0.57*	*0.06*	*0.60*	*0.09*	*0.38*	*0.29*	*0.04*	*0.24*	*0.05*	*0.35*	*0.21*		
Pb	0.89	0.66	0.57	0.67	0.65	0.57	0.59	0.58	0.67	0.52	0.56	0.73	0.78	0.73	0.74	0.87	0.58	0.74	0.73	
	0.00	*0.02*	*0.05*	*0.02*	*0.02*	*0.06*	*0.04*	*0.05*	*0.02*	*0.08*	*0.06*	*0.01*	*0.00*	*0.01*	*0.01*	*0.00*	*0.05*	*0.01*	*0.01*	
Zn	0.69	0.10	0.35	0.18	0.44	0.15	0.05	0.82	0.22	0.59	0.47	0.82	0.84	0.54	0.88	0.68	0.49	0.64	0.19	0.64
	0.01	*0.75*	*0.26*	*0.57*	*0.15*	*0.65*	*0.87*	*0.00*	*0.50*	*0.04*	*0.12*	*0.00*	*0.00*	*0.07*	*0.00*	*0.02*	*0.11*	*0.03*	*0.55*	*0.03*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.12 Correlation Matrix for $PM_{2.5}$ and Its major constituents at R.K. Puram in Summer Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.93																			
	0.00																			
EC	0.91	0.98																		
	0.00	*0.00*																		
TC	0.92	1.00	1.00																	
	0.00	0.00	0.00																	
Cl^-	0.53	0.27	0.31	0.29																
	0.08	0.39	0.33	0.37																
NO_3^-	0.76	0.72	0.72	0.72	0.43															
	0.00	0.01	0.01	0.01	0.16															
SO_4^{--}	0.71	0.70	0.67	0.69	0.55	0.48														
	0.01	0.01	0.02	0.01	0.06	0.12														
Na^+	0.43	0.21	0.22	0.22	0.63	0.31	0.18													
	0.16	0.51	0.49	0.50	0.03	0.33	0.57													
NH_4^+	0.94	0.93	0.90	0.92	0.46	0.83	0.81	0.34												
	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.29												
K^+	0.61	0.43	0.44	0.44	0.78	0.47	0.52	0.72	0.55											
	0.04	0.16	0.15	0.15	0.00	0.13	0.09	0.01	0.06											
Ca^{++}	0.48	0.26	0.18	0.23	0.35	0.52	0.19	0.51	0.43	0.49										
	0.11	0.41	0.57	0.48	0.27	0.08	0.56	0.09	0.17	0.11										
Si	0.50	0.36	0.31	0.34	0.34	0.51	-0.04	0.47	0.37	0.38	0.57									
	0.10	0.26	0.33	0.28	0.28	0.09	0.90	0.12	0.24	0.22	0.06									
Al	0.69	0.67	0.60	0.64	0.17	0.52	0.27	0.34	0.58	0.46	0.67	0.63								
	0.01	0.02	0.04	0.02	0.59	0.09	0.40	0.28	0.05	0.14	0.02	0.03								
Ca	0.63	0.46	0.41	0.44	0.59	0.56	0.37	0.34	0.54	0.73	0.71	0.61	0.74							
	0.03	0.14	0.19	0.15	0.05	0.06	0.24	0.28	0.07	0.01	0.01	0.04	0.01							
Fe	0.47	0.42	0.36	0.39	0.08	0.29	0.04	0.05	0.32	0.39	0.46	0.66	0.75	0.77						
	0.12	0.18	0.25	0.21	0.81	0.36	0.91	0.88	0.32	0.21	0.13	0.02	0.01	0.00						
Ti	0.48	0.46	0.49	0.47	0.22	0.70	-0.07	0.39	0.41	0.47	0.42	0.73	0.59	0.53	0.54					
	0.12	0.14	0.11	0.12	0.49	0.01	0.82	0.22	0.19	0.13	0.17	0.01	0.04	0.08	0.07					
K	0.73	0.55	0.56	0.55	0.81	0.49	0.57	0.71	0.62	0.96	0.51	0.39	0.56	0.75	0.41	0.45				
	0.01	0.07	0.06	0.06	0.00	0.10	0.05	0.01	0.03	0.00	0.09	0.22	0.06	0.01	0.18	0.15				
S	0.73	0.54	0.54	0.54	0.74	0.68	0.64	0.69	0.77	0.76	0.47	0.38	0.28	0.51	0.12	0.32	0.73			
	0.01	0.07	0.07	0.07	0.01	0.01	0.03	0.01	0.00	0.00	0.12	0.22	0.38	0.09	0.71	0.32	0.01			
Ni	0.80	0.81	0.77	0.79	0.24	0.90	0.46	0.16	0.84	0.41	0.58	0.55	0.77	0.69	0.57	0.67	0.46	0.52		
	0.00	0.00	0.00	0.00	0.45	0.00	0.13	0.62	0.00	0.18	0.05	0.06	0.00	0.01	0.05	0.02	0.13	0.08		
Pb	0.86	0.77	0.79	0.78	0.49	0.76	0.45	0.32	0.74	0.66	0.49	0.51	0.73	0.78	0.67	0.69	0.76	0.55	0.82	
	0.00	0.00	0.00	0.00	0.10	0.00	0.14	0.31	0.01	0.02	0.11	0.09	0.01	0.00	0.02	0.01	0.00	0.07	0.00	
Zn	0.90	0.78	0.76	0.77	0.55	0.71	0.58	0.72	0.85	0.66	0.59	0.59	0.64	0.52	0.32	0.51	0.73	0.82	0.66	0.68
	0.00	0.00	0.00	0.00	0.07	0.01	0.05	0.01	0.00	0.02	0.04	0.05	0.03	0.08	0.31	0.09	0.01	0.00	0.02	0.02

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.9 and Table 3.10, respectively for PM mass and the major species. PM_{10} mass has lesser C.V. than $PM_{2.5}$ mass. The secondary ions in both PM_{10} and $PM_{2.5}$ have a similar C.V.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.11 and Table 3.12, respectively for PM mass and the major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other in $PM_{2.5}$.

3.1.2.2 Winter Season

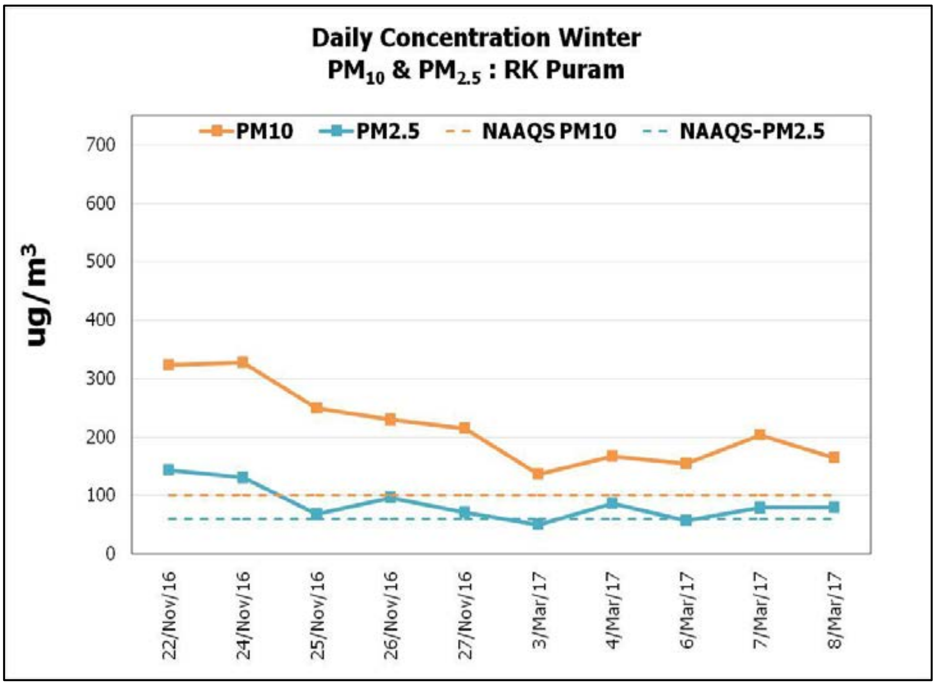


Figure 3.16: Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at R.K. Puram in Winter Season

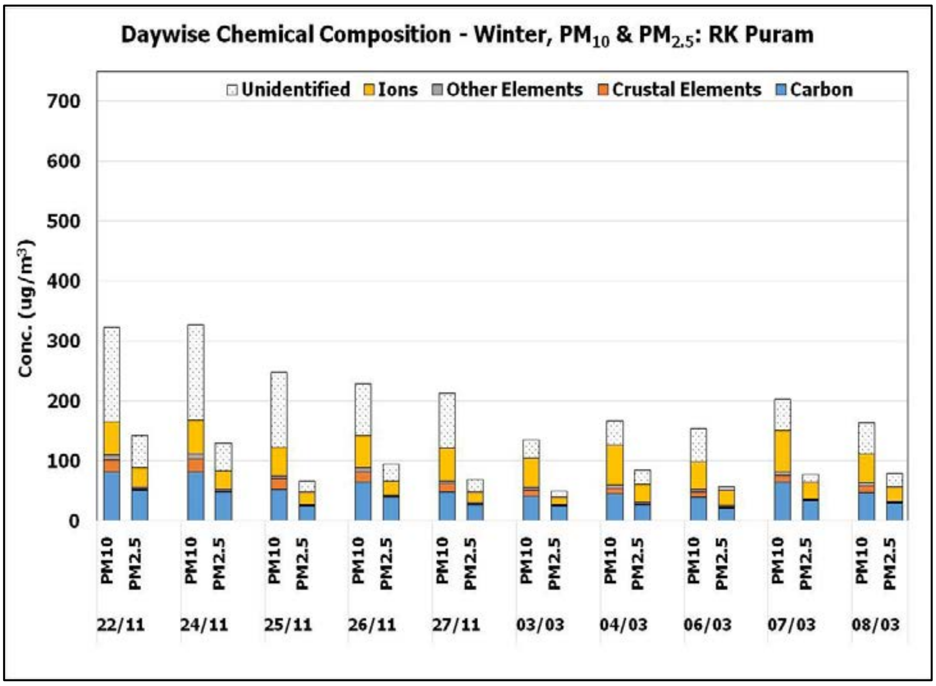


Figure 3.17: Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at R.K. Puram in Winter Season

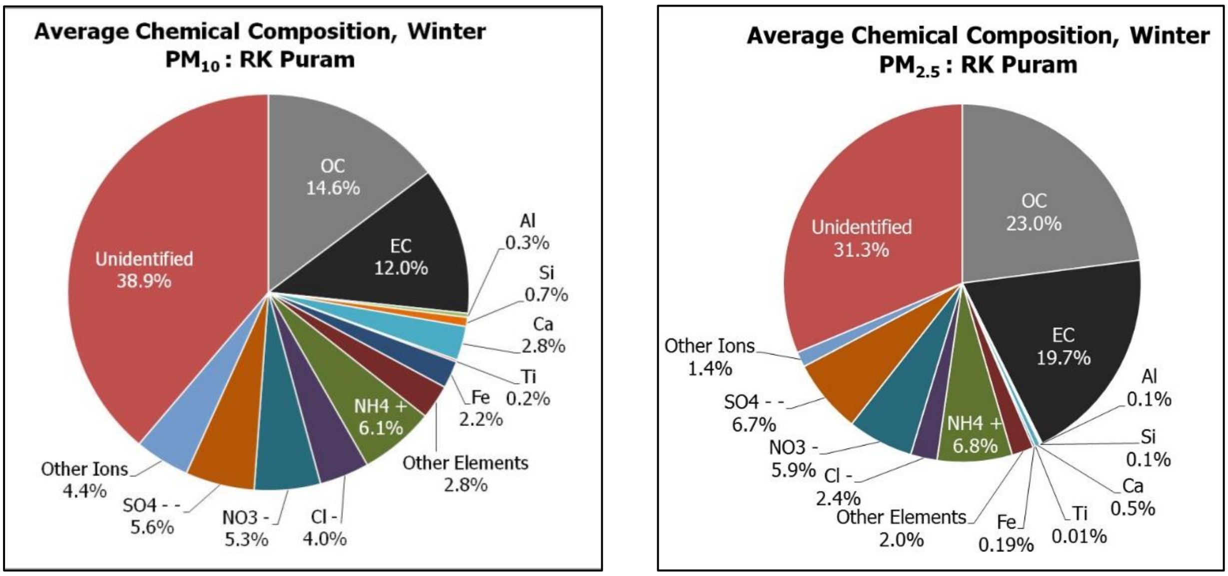


Figure 3.18: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at R.K. Puram in Winter Season

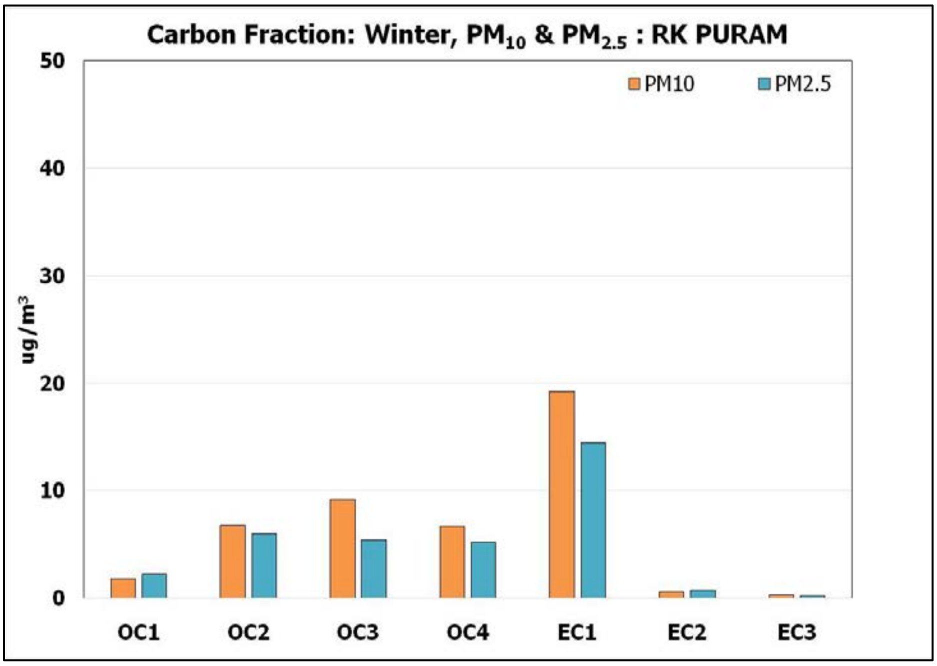


Figure 3.19: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at R.K. Puram in Winter Season

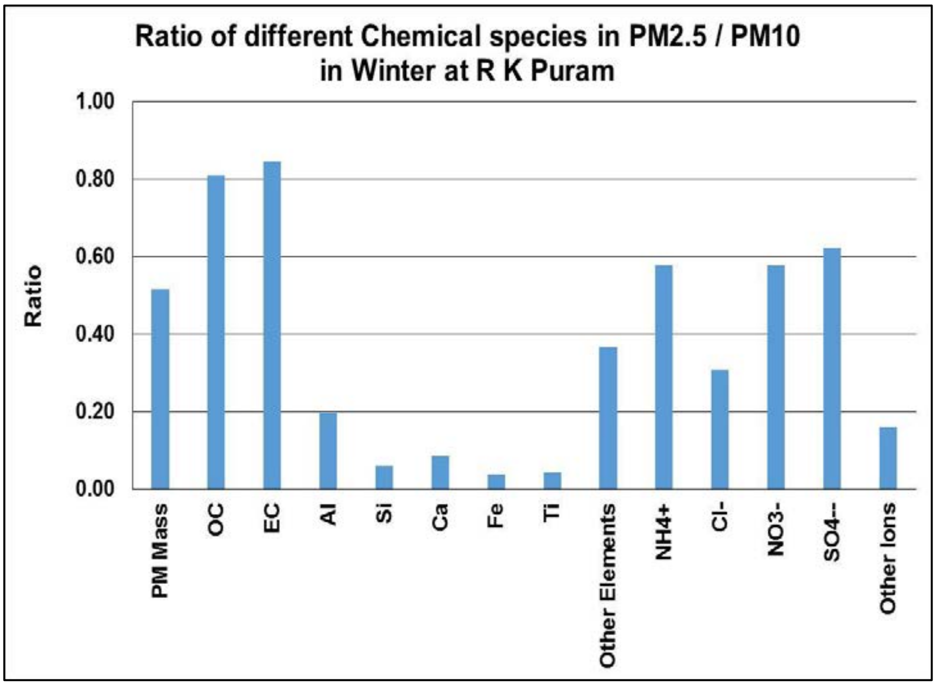


Figure 3.20: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at R.K. Puram in Winter Season

Average concentration of PM_{10} in R.K. Puram was found to be 217±67 µg/m³ and was 112±40 µg/m³ for PM 2.5. Concentration of PM_{10} varied from 137 to 328 µg/m³, while $PM_{2.5}$ varied from 68 to 165 µg/m³ (see Figure 3.16).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.17.

Contribution of carbon fraction from PM_{10} was found to be 58 µg/m³, while from $PM_{2.5}$, it was found to be 48 µg/m³. The percentage mass distribution showed that the organic carbon and elemental carbon of $PM_{2.5}$ is higher than that of PM_{10}. The total ion concentration was found to be 25% in PM_{10} and 23% in $PM_{2.5}$,. The crustal element in PM_{10} and $PM_{2.5}$ was found to be 6% and 1%, respectively (see Figure 3.18).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% and 2% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 39% in PM_{10} and that in $PM_{2.5}$ was 31%. OC3 in PM_{10} was found to be higher as compared to that in $PM_{2.5}$, followed by OC2, OC4, and OC1. Similarly, EC1 was found to be higher in PM_{10} as compared to that in $PM_{2.5}$, followed by EC2 and EC (see Figure 3.19).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.20.

Table 3.13 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at R.K. Puram in Winter Season

µg/m^3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	217	31.84	26.20	0.72	1.62	6.04	4.86	0.36	3.03	1.34	0.38	0.71	8.72	11.56	12.08	0.76	13.20	1.54	4.99
SD	67	11.02	7.02	0.24	0.56	1.72	1.94	0.11	1.28	0.39	0.24	0.43	1.43	1.84	3.25	0.35	3.25	0.43	0.94
Min	137	19.21	18.93	0.34	0.76	4.23	2.81	0.20	1.69	0.64	0.11	0.35	5.54	8.47	9.13	0.34	9.70	1.11	3.11
Max	328	54.53	38.97	0.99	2.27	8.77	7.74	0.51	4.63	1.88	0.94	1.56	10.67	15.06	18.35	1.29	19.62	2.23	6.69
C.V.	0.31	0.35	0.27	0.34	0.35	0.28	0.40	0.32	0.42	0.29	0.65	0.60	0.16	0.16	0.27	0.46	0.25	0.28	0.19
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	326	49.91	37.83	0.99	2.25	8.71	7.53	0.51	4.58	1.86	0.75	1.49	10.62	14.42	17.46	1.27	18.98	2.23	6.22
50 %ile	214	29.87	23.65	0.72	1.62	5.59	4.66	0.36	3.03	1.27	0.35	0.55	8.72	11.32	10.47	0.76	13.06	1.53	4.97
5 %ile	106	15.53	13.57	0.30	0.67	3.10	2.42	0.16	1.50	0.53	0.13	0.39	3.69	5.48	6.48	0.35	6.80	0.81	2.13

Table 3.14 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at R.K. Puram in Winter Season

µg/m^3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	112	25.80	22.12	0.14	0.10	0.52	0.21	0.01	1.08	0.60	0.11	0.25	2.69	6.68	7.52	0.19	7.61	0.91	0.11
SD	40	10.64	12.22	0.05	0.06	0.53	0.09	0.01	0.25	0.10	0.04	0.19	1.73	1.33	1.78	0.06	2.68	0.49	0.08
Min	68	14.72	11.03	0.08	0.03	0.11	0.12	0.01	0.77	0.47	0.06	0.10	0.76	4.61	5.36	0.14	3.48	0.14	0.05
Max	165	44.55	44.85	0.20	0.17	1.19	0.36	0.03	1.45	0.77	0.16	0.50	5.67	8.22	9.60	0.27	10.62	1.62	0.22
C.V.	0.36	0.41	0.55	0.34	0.61	1.02	0.44	0.58	0.23	0.18	0.41	0.77	0.64	0.20	0.24	0.33	0.35	0.54	0.66
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	160	40.52	39.47	0.20	0.17	1.19	0.34	0.03	1.39	0.73	0.15	0.50	5.11	8.05	9.51	0.26	10.52	1.49	0.20
50 %ile	114	24.92	20.55	0.15	0.09	0.25	0.18	0.01	1.09	0.58	0.11	0.14	2.42	7.07	7.61	0.18	7.60	0.96	0.10
5 %ile	69	15.35	11.38	0.08	0.04	0.11	0.12	0.01	0.80	0.49	0.06	0.11	0.93	4.86	5.43	0.14	4.15	0.27	0.05

Table 3.15 Correlation Matrix for PM_{10} and Its major constituents at R.K. Puram in Winter Season

	PM10	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.96																			
	0.00																			
EC	0.58	0.55																		
	0.08	*0.10*																		
TC	0.91	0.93	0.82																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.76	0.68	0.61	0.73																
	0.01	*0.03*	*0.06*	*0.02*																
NO_3^-	-0.27	-0.25	0.22	-0.08	0.04															
	0.45	*0.48*	*0.55*	*0.83*	*0.91*															
SO_4^{--}	-0.21	-0.19	0.26	-0.01	0.10	0.79														
	0.56	*0.61*	*0.47*	*0.97*	*0.79*	*0.01*														
Na^+	0.90	0.89	0.80	0.97	0.75	-0.23	-0.11													
	0.00	*0.00*	*0.01*	*0.00*	*0.01*	*0.53*	*0.76*													
NH_4^+	-0.13	-0.10	0.23	0.03	0.08	0.78	0.80	-0.02												
	0.73	*0.78*	*0.52*	*0.94*	*0.84*	*0.01*	*0.01*	*0.96*												
K^+	0.65	0.67	0.76	0.79	0.71	0.22	-0.01	0.75	0.16											
	0.04	*0.04*	*0.01*	*0.01*	*0.02*	*0.55*	*0.98*	*0.01*	*0.66*											
Ca^{++}	0.81	0.78	0.58	0.79	0.93	-0.03	0.09	0.83	0.20	0.69										
	0.01	*0.01*	*0.08*	*0.01*	*0.00*	*0.95*	*0.80*	*0.00*	*0.58*	*0.03*										
Si	0.80	0.75	0.31	0.66	0.46	-0.29	-0.02	0.63	-0.12	0.17	0.53									
	0.01	*0.01*	*0.38*	*0.04*	*0.18*	*0.43*	*0.96*	*0.05*	*0.75*	*0.65*	*0.11*									
Al	0.73	0.73	0.14	0.57	0.32	-0.39	-0.21	0.55	-0.27	0.09	0.43	0.95								
	0.02	*0.02*	*0.69*	*0.09*	*0.36*	*0.26*	*0.56*	*0.10*	*0.45*	*0.80*	*0.22*	*0.00*								
Ca	0.95	0.94	0.46	0.85	0.61	-0.46	-0.41	0.85	-0.34	0.58	0.67	0.78	0.78							
	0.00	*0.00*	*0.18*	*0.00*	*0.06*	*0.18*	*0.24*	*0.00*	*0.33*	*0.08*	*0.04*	*0.01*	*0.01*							
Fe	0.91	0.90	0.29	0.75	0.51	-0.54	-0.36	0.75	-0.31	0.35	0.62	0.87	0.87	0.95						
	0.00	*0.00*	*0.42*	*0.01*	*0.13*	*0.11*	*0.31*	*0.01*	*0.38*	*0.32*	*0.06*	*0.00*	*0.00*	*0.00*						
Ti	0.81	0.82	0.30	0.70	0.45	-0.53	-0.43	0.75	-0.35	0.40	0.57	0.80	0.85	0.91	0.90					
	0.00	*0.00*	*0.39*	*0.03*	*0.20*	*0.11*	*0.22*	*0.01*	*0.32*	*0.25*	*0.08*	*0.01*	*0.00*	*0.00*	*0.00*					
K	0.64	0.71	0.89	0.88	0.61	0.09	0.19	0.86	0.13	0.73	0.68	0.44	0.36	0.58	0.44	0.52				
	0.05	*0.02*	*0.00*	*0.00*	*0.06*	*0.81*	*0.61*	*0.00*	*0.73*	*0.02*	*0.03*	*0.20*	*0.30*	*0.08*	*0.20*	*0.13*				
S	0.75	0.84	0.41	0.76	0.38	-0.23	-0.08	0.67	-0.22	0.46	0.45	0.77	0.76	0.84	0.83	0.78	0.60			
	0.01	*0.00*	*0.24*	*0.01*	*0.27*	*0.52*	*0.82*	*0.04*	*0.54*	*0.19*	*0.19*	*0.01*	*0.01*	*0.00*	*0.00*	*0.01*	*0.07*			
Ni	0.03	0.12	0.42	0.27	-0.06	0.10	0.05	0.32	0.13	0.31	0.10	0.05	0.12	0.10	-0.02	0.35	0.58	0.18		
	0.94	*0.74*	*0.23*	*0.45*	*0.88*	*0.79*	*0.89*	*0.36*	*0.71*	*0.38*	*0.78*	*0.89*	*0.75*	*0.78*	*0.95*	*0.33*	*0.08*	*0.62*		
Pb	0.45	0.33	0.58	0.48	0.69	0.16	0.00	0.43	-0.11	0.68	0.42	0.05	-0.11	0.36	0.16	0.06	0.35	0.21	-0.24	
	0.20	*0.36*	*0.08*	*0.16*	*0.03*	*0.67*	*0.99*	*0.22*	*0.75*	*0.03*	*0.23*	*0.89*	*0.77*	*0.31*	*0.66*	*0.88*	*0.32*	*0.56*	*0.51*	
Zn	0.80	0.78	0.51	0.76	0.76	-0.25	-0.40	0.75	-0.27	0.79	0.71	0.31	0.29	0.77	0.62	0.52	0.52	0.50	-0.13	0.70
	0.01	*0.01*	*0.13*	*0.01*	*0.01*	*0.49*	*0.26*	*0.01*	*0.45*	*0.01*	*0.02*	*0.38*	*0.43*	*0.01*	*0.06*	*0.13*	*0.12*	*0.15*	*0.72*	*0.02*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.16 Correlation Matrix for $PM_{2.5}$ and Its major constituents at R.K. Puram in Winter Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.96																			
	0.00																			
EC	0.92	0.95																		
	0.00	*0.00*																		
TC	0.95	0.99	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	-0.20	-0.21	-0.19	-0.20																
	0.61	*0.58*	*0.63*	*0.60*																
NO_3^-	0.79	0.66	0.54	0.61	-0.12															
	0.01	*0.04*	*0.11*	*0.06*	*0.76*															
SO_4^{--}	0.92	0.85	0.86	0.87	-0.30	0.66														
	0.00	*0.00*	*0.00*	*0.00*	*0.43*	*0.04*														
Na^+	-0.07	-0.10	-0.19	-0.14	0.80	0.29	-0.35													
	0.87	*0.81*	*0.65*	*0.73*	*0.03*	*0.49*	*0.40*													
NH_4^+	0.95	0.87	0.81	0.85	-0.18	0.90	0.85	0.09												
	0.00	*0.00*	*0.01*	*0.00*	*0.64*	*0.00*	*0.00*	*0.84*												
K^+	0.77	0.79	0.76	0.79	0.13	0.38	0.72	-0.30	0.66											
	0.01	*0.01*	*0.01*	*0.01*	*0.74*	*0.28*	*0.02*	*0.47*	*0.04*											
Ca^{++}	0.65	0.48	0.43	0.46	0.34	0.94	0.48	1.00	0.71	0.34										
	0.55	*0.69*	*0.72*	*0.70*	*0.78*	*0.22*	*0.68*	*	*0.50*	*0.78*										
Si	0.80	0.68	0.73	0.71	0.01	0.64	0.77	-0.08	0.75	0.60	0.98									
	0.01	*0.03*	*0.02*	*0.02*	*0.97*	*0.05*	*0.01*	*0.85*	*0.01*	*0.07*	*0.14*									
Al	0.75	0.70	0.65	0.68	0.41	0.62	0.69	0.18	0.77	0.85	0.45	0.63								
	0.01	*0.02*	*0.04*	*0.03*	*0.28*	*0.06*	*0.03*	*0.67*	*0.01*	*0.00*	*0.71*	*0.05*								
Ca	0.71	0.67	0.74	0.71	0.05	0.56	0.58	0.34	0.70	0.40	0.93	0.75	0.55							
	0.02	*0.03*	*0.01*	*0.02*	*0.90*	*0.09*	*0.08*	*0.41*	*0.02*	*0.25*	*0.23*	*0.01*	*0.10*							
Fe	0.63	0.50	0.46	0.49	0.45	0.79	0.50	0.60	0.69	0.32	0.80	0.63	0.63	0.61						
	0.05	*0.14*	*0.18*	*0.15*	*0.22*	*0.01*	*0.14*	*0.12*	*0.03*	*0.37*	*0.42*	*0.05*	*0.05*	*0.06*						
Ti	0.82	0.78	0.66	0.73	-0.08	0.79	0.76	-0.05	0.81	0.64	0.95	0.68	0.76	0.55	0.58					
	0.00	*0.01*	*0.04*	*0.02*	*0.83*	*0.01*	*0.01*	*0.91*	*0.00*	*0.05*	*0.19*	*0.03*	*0.01*	*0.10*	*0.08*					
K	0.87	0.81	0.74	0.79	-0.12	0.73	0.85	-0.31	0.82	0.76	0.73	0.75	0.72	0.37	0.54	0.83				
	0.00	*0.00*	*0.02*	*0.01*	*0.76*	*0.02*	*0.00*	*0.46*	*0.00*	*0.01*	*0.48*	*0.01*	*0.02*	*0.30*	*0.11*	*0.00*				
S	0.83	0.79	0.69	0.75	-0.35	0.76	0.74	-0.27	0.85	0.67	0.70	0.61	0.62	0.36	0.36	0.76	0.90			
	0.00	*0.01*	*0.03*	*0.01*	*0.35*	*0.01*	*0.02*	*0.51*	*0.00*	*0.04*	*0.51*	*0.06*	*0.06*	*0.31*	*0.31*	*0.01*	*0.00*			
Ni	0.39	0.43	0.59	0.51	0.13	0.23	0.24	0.56	0.42	0.08	*	0.34	0.26	0.92	0.42	0.06	-0.15	-0.11		
	0.35	*0.29*	*0.13*	*0.20*	*0.78*	*0.59*	*0.56*	*0.24*	*0.30*	*0.86*	*	*0.41*	*0.53*	*0.00*	*0.30*	*0.88*	*0.72*	*0.80*		
Pb	0.86	0.83	0.73	0.80	-0.43	0.68	0.81	-0.38	0.77	0.67	0.87	0.68	0.51	0.35	0.36	0.80	0.92	0.90	-0.21	
	0.00	*0.00*	*0.02*	*0.01*	*0.25*	*0.03*	*0.01*	*0.35*	*0.01*	*0.03*	*0.33*	*0.03*	*0.13*	*0.32*	*0.31*	*0.01*	*0.00*	*0.00*	*0.62*	
Zn	0.66	0.59	0.51	0.56	0.32	0.66	0.57	0.27	0.69	0.59	0.96	0.70	0.83	0.69	0.65	0.87	0.59	0.48	0.31	0.47
	0.04	*0.07*	*0.13*	*0.09*	*0.41*	*0.04*	*0.08*	*0.51*	*0.03*	*0.07*	*0.19*	*0.02*	*0.00*	*0.03*	*0.04*	*0.00*	*0.07*	*0.16*	*0.45*	*0.17*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For the winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.13 and Table 3.14, respectively for PM mass and the major species. PM_{10} mass has lesser C.V. than $PM_{2.5}$ mass.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.15 and Table 3.16, respectively for PM mass and its major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other. '*' represents that the correlation coefficient or the P-value cannot be calculated for the given set of species.

3.1.3 Site 3: Bahadurgarh

3.1.3.1 Summer Season

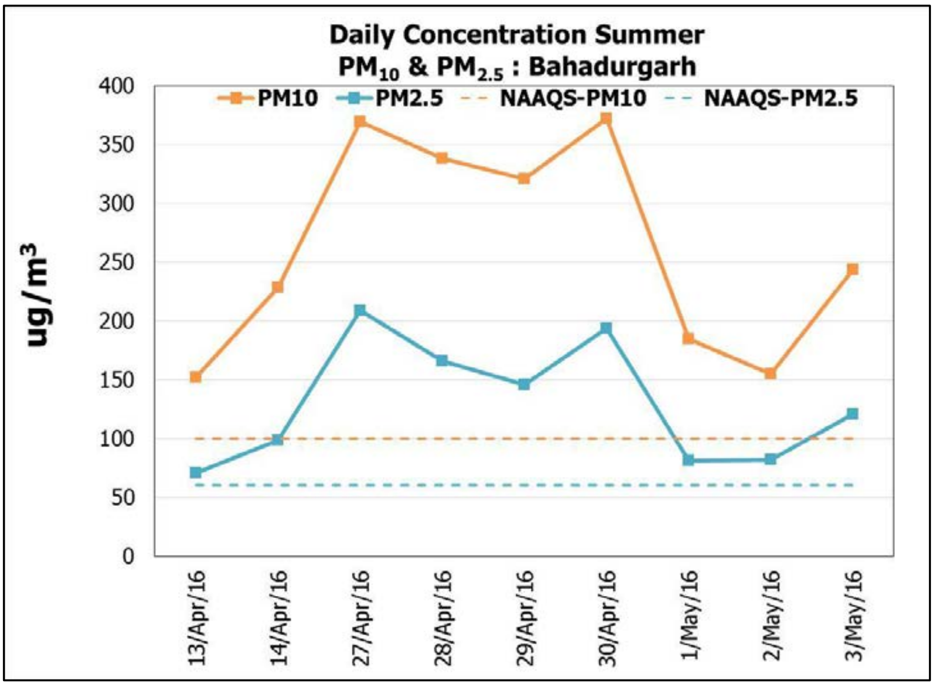


Figure 3.21: Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at Bahadurgarh in the Summer Season

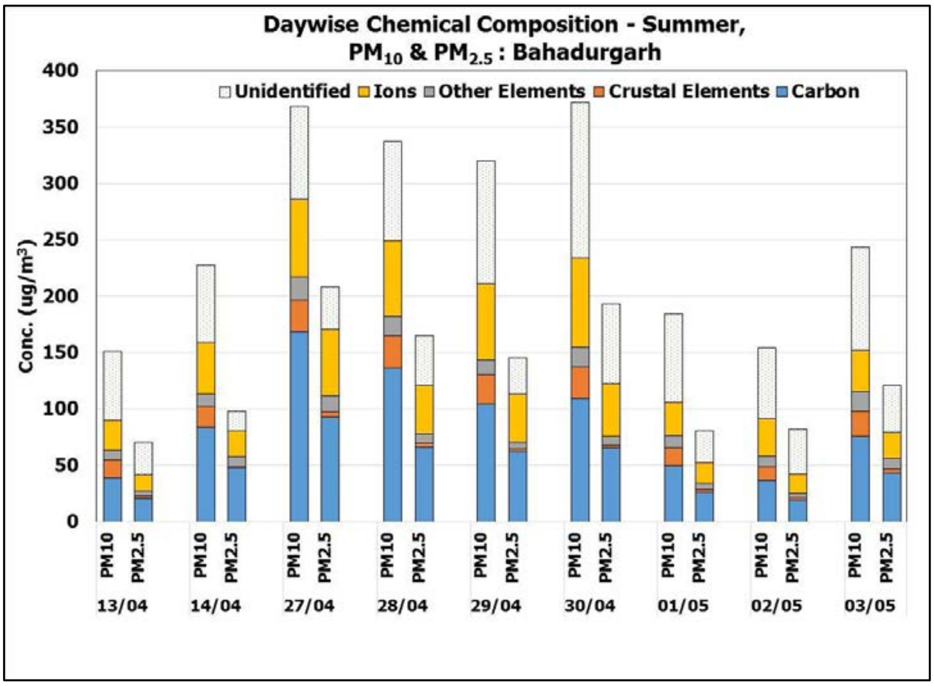


Figure 3.22 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at Bahadurgarh in the Summer Season

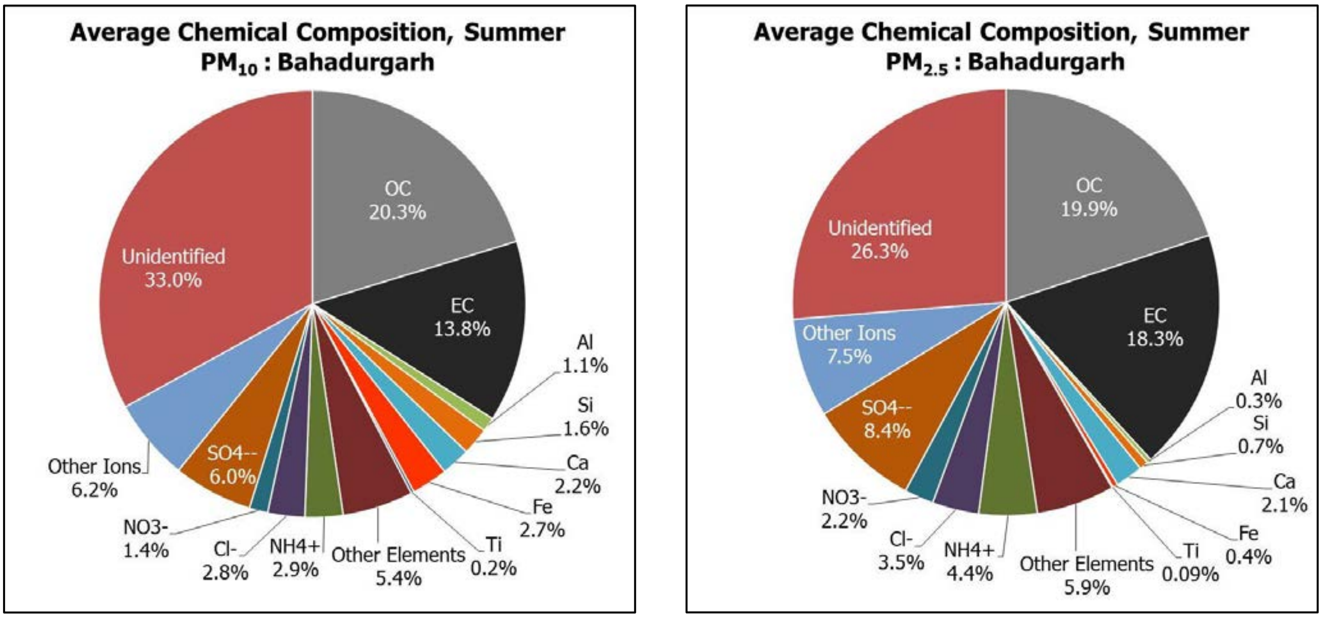


Figure 3.23: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Bahadurgarh in the Summer Season

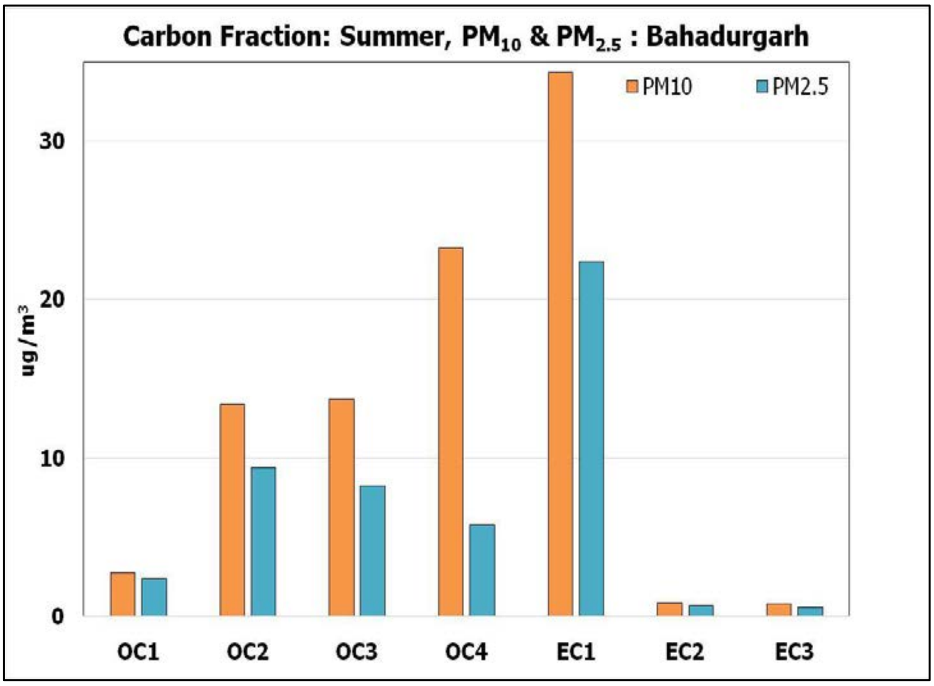


Figure 3.24: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Bahadurgarh in the Summer Season

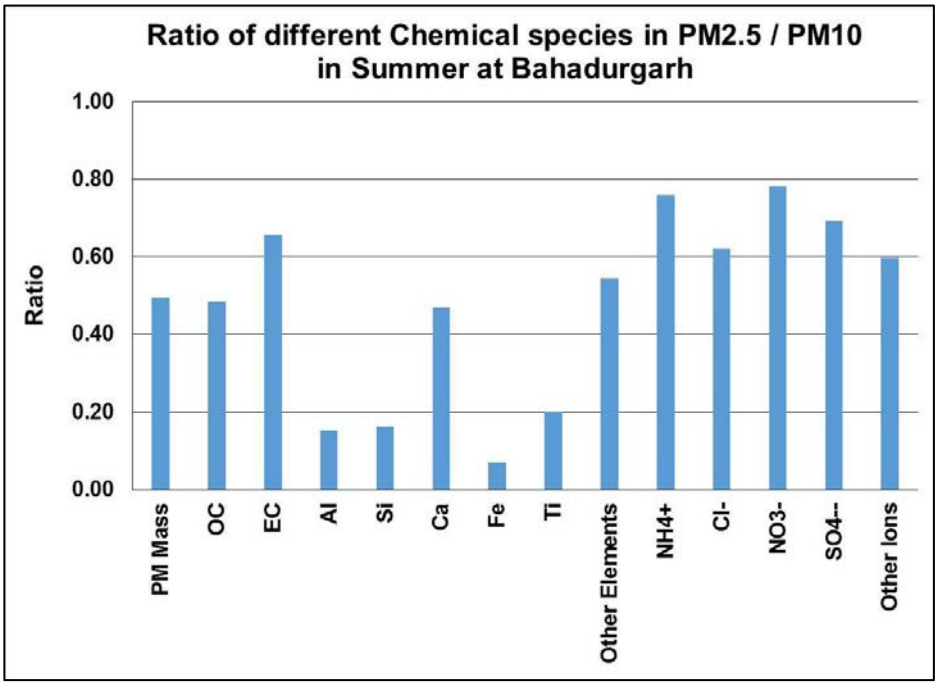


Figure 3.25 Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Bahadurgarh in Summer Season.

At Bahadurgarh (BHG), the average concentrations of PM_{10} and $PM_{2.5}$ were 263 µg/m^3 and 130 µg/m^3, respectively. The variation of concentration of PM_{10} and $PM_{2.5}$ is more with the standard deviation of 89 and 51 µg/m^3, respectively. The observed average concentrations of PM_{10} are 2.6 times than the NAAQS, while in $PM_{2.5}$ it is 2.2 times than the NAAQS. In PM_{10}, Daily concentration variation observed was significant, with variation from 152 to 372 µg/m^3. Similarly, for $PM_{2.5}$, Daily concentration variation was from 71 to 209 µg/m^3 (see Figure 3.21).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.22.

The average carbon fraction of PM_{10} is 89 µg/m^3 and 50 µg/m^3 In case of $PM_{2.5}$, which is a major portion of both PM_{10} and $PM_{2.5}$. The percentage mass distribution showed that organic carbon is similar in both PM_{10} and $PM_{2.5}$, while the elemental carbon component in $PM_{2.5}$ is higher than in PM_{10}. The total ions concentration of $PM_{2.5}$ was found to be higher (26%) than that of PM_{10} (19%). The crustal element contribution is 8% in PM_{10} and very less in case of $PM_{2.5}$ (2%) (see Figure 3.23).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% and 6% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be was 33% and 28% for PM_{10} and $PM_{2.5}$, respectively.

In PM_{10}, Concentration of EC1 was the highest, followed by OC4, while In case of $PM_{2.5}$, EC1 is the highest, followed by OC2. In PM_{10}, EC1 was found to be 34 µg/m^3, while OC4 is 23 µg/m^3 of the total carbon. Similarly, in $PM_{2.5}$, EC1 is 22 µg/m^3 and OC2 is 9 µg/m^3 of the total carbon (see Figure 3.24).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.25.

Table 3.17 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM$_{10}$ at Bahadurgarh in Summer Season

µg/m^3																			
	PM10 Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	262	53.20	36.11	2.84	5.43	5.76	7.20	0.59	9.61	1.21	0.63	0.93	7.36	3.68	15.79	3.66	7.53	5.06	5.00
SD	89	25.38	20.13	0.97	1.71	1.69	2.56	0.17	3.02	0.37	0.44	0.65	1.11	2.49	9.00	1.30	4.26	2.69	2.49
Min	152	19.91	14.60	1.45	2.25	3.63	4.03	0.33	6.60	0.67	0.05	0.21	5.42	0.69	5.60	1.96	2.87	1.85	2.14
Max	372	93.46	75.19	3.88	6.73	7.60	10.71	0.84	15.68	1.77	1.38	2.26	8.51	7.28	28.20	6.13	13.95	10.07	8.53
C.V.	0.34	0.48	0.56	0.34	0.31	0.29	0.36	0.29	0.31	0.30	0.69	0.71	0.15	0.68	0.57	0.35	0.57	0.53	0.50
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	371	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	244	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	153	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.18 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM$_{2.5}$ at Bahadurgarh in Summer Season

µg/m^3																			
	PM2.5 Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	130	25.80	23.66	0.43	0.88	2.70	0.51	0.12	4.99	0.79	0.30	0.38	4.56	2.88	10.93	2.62	5.71	3.62	0.29
SD	51	12.98	11.99	0.17	0.11	0.49	0.23	0.02	2.89	0.23	0.21	0.19	1.59	2.39	8.01	0.82	3.86	2.37	0.06
Min	71	10.29	9.05	0.26	0.71	2.12	0.15	0.09	2.24	0.47	0.01	0.10	2.16	0.56	2.47	1.67	1.66	1.47	0.17
Max	209	49.56	43.75	0.82	1.07	3.31	0.88	0.14	11.03	1.03	0.64	0.64	7.05	6.43	21.31	4.44	10.63	8.54	0.35
C.V.	0.40	0.50	0.51	0.40	0.13	0.18	0.46	0.13	0.58	0.29	0.72	0.49	0.35	0.83	0.73	0.31	0.68	0.65	0.22
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	203	43.41	39.17	0.72	1.05	3.30	0.86	0.14	9.48	1.02	0.59	0.62	6.69	5.93	20.47	3.88	10.37	7.27	0.35
50 %ile	121	25.12	22.96	0.37	0.86	2.57	0.43	0.12	4.48	0.92	0.30	0.39	4.26	1.46	5.94	2.54	3.37	2.69	0.32
5 %ile	75	10.87	9.18	0.28	0.74	2.18	0.24	0.10	2.40	0.50	0.01	0.11	2.57	0.61	2.86	1.70	1.85	1.56	0.19

Table 3.19 Correlation Matrix for PM_{10} and Its major constituents at Bahadurgarh in Summer Season

	PM_{10}	OC	EC	TC	Cl-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.95																			
	0.00																			
EC	0.88	0.96																		
	0.00	*0.00*																		
TC	0.93	0.99	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.30	0.14	0.26	0.19																
	0.43	*0.72*	*0.50*	*0.62*																
NO_3^-	0.91	0.80	0.72	0.77	0.35															
	0.00	*0.01*	*0.03*	*0.02*	*0.36*															
SO_4^{--}	0.95	0.86	0.78	0.83	0.33	0.99														
	0.00	*0.00*	*0.01*	*0.01*	*0.39*	*0.00*														
Na^+	0.71	0.56	0.45	0.52	0.15	0.78	0.78													
	0.03	*0.12*	*0.22*	*0.15*	*0.69*	*0.01*	*0.01*													
NH_4^+	0.93	0.88	0.82	0.86	0.31	0.96	0.98	0.72												
	0.00	*0.00*	*0.01*	*0.00*	*0.41*	*0.00*	*0.00*	*0.03*												
K^+	0.15	0.24	0.36	0.30	0.17	-0.17	-0.10	-0.03	-0.14											
	0.69	*0.53*	*0.35*	*0.44*	*0.67*	*0.67*	*0.80*	*0.94*	*0.71*											
Ca^{++}	0.94	0.85	0.78	0.83	0.31	0.99	0.99	0.74	0.97	-0.10										
	0.00	*0.00*	*0.01*	*0.01*	*0.42*	*0.00*	*0.00*	*0.02*	*0.00*	*0.79*										
Si	0.81	0.78	0.63	0.72	-0.01	0.66	0.70	0.70	0.68	0.18	0.64									
	0.01	*0.01*	*0.07*	*0.03*	*0.98*	*0.05*	*0.04*	*0.04*	*0.04*	*0.65*	*0.07*									
Al	0.92	0.85	0.72	0.80	0.18	0.81	0.83	0.67	0.79	0.15	0.80	0.93								
	0.00	*0.00*	*0.03*	*0.01*	*0.64*	*0.01*	*0.01*	*0.05*	*0.01*	*0.70*	*0.01*	*0.00*								
Ca	0.87	0.80	0.75	0.79	0.43	0.85	0.86	0.44	0.89	-0.12	0.87	0.56	0.77							
	0.00	*0.01*	*0.02*	*0.01*	*0.24*	*0.00*	*0.00*	*0.23*	*0.00*	*0.75*	*0.00*	*0.12*	*0.02*							
Fe	0.92	0.94	0.91	0.94	0.27	0.83	0.87	0.53	0.92	0.07	0.88	0.65	0.78	0.93						
	0.00	*0.00*	*0.00*	*0.00*	*0.49*	*0.01*	*0.00*	*0.14*	*0.00*	*0.86*	*0.00*	*0.06*	*0.01*	*0.00*						
Ti	0.81	0.76	0.61	0.70	0.01	0.73	0.80	0.60	0.75	-0.07	0.80	0.63	0.71	0.74	0.76					
	0.01	*0.02*	*0.08*	*0.04*	*0.98*	*0.03*	*0.01*	*0.09*	*0.02*	*0.87*	*0.01*	*0.07*	*0.03*	*0.02*	*0.02*					
K	0.85	0.89	0.91	0.91	0.28	0.60	0.66	0.38	0.66	0.57	0.68	0.63	0.76	0.72	0.85	0.60				
	0.00	*0.00*	*0.00*	*0.00*	*0.46*	*0.09*	*0.05*	*0.31*	*0.05*	*0.11*	*0.05*	*0.07*	*0.02*	*0.03*	*0.00*	*0.09*				
S	0.68	0.56	0.40	0.49	0.11	0.53	0.54	0.57	0.48	0.22	0.50	0.89	0.90	0.51	0.48	0.51	0.56			
	0.05	*0.12*	*0.29*	*0.18*	*0.78*	*0.14*	*0.14*	*0.11*	*0.20*	*0.58*	*0.17*	*0.00*	*0.00*	*0.16*	*0.19*	*0.17*	*0.11*			
Ni	0.37	0.55	0.47	0.52	-0.44	0.07	0.15	-0.14	0.19	0.29	0.19	0.39	0.42	0.36	0.49	0.46	0.60	0.35		
	0.33	*0.13*	*0.20*	*0.15*	*0.23*	*0.85*	*0.70*	*0.72*	*0.63*	*0.45*	*0.63*	*0.30*	*0.26*	*0.35*	*0.19*	*0.22*	*0.09*	*0.36*		
Pb	0.52	0.35	0.21	0.29	0.22	0.45	0.40	0.32	0.33	0.11	0.43	0.57	0.73	0.53	0.37	0.37	0.46	0.86	0.31	
	0.15	*0.35*	*0.59*	*0.45*	*0.56*	*0.23*	*0.28*	*0.41*	*0.39*	*0.79*	*0.25*	*0.11*	*0.02*	*0.15*	*0.33*	*0.33*	*0.21*	*0.00*	*0.42*	
Zn	0.51	0.53	0.39	0.47	-0.38	0.47	0.44	0.30	0.47	-0.15	0.48	0.57	0.64	0.51	0.55	0.41	0.45	0.59	0.65	0.60
	0.16	*0.14*	*0.30*	*0.20*	*0.31*	*0.21*	*0.24*	*0.43*	*0.20*	*0.70*	*0.19*	*0.11*	*0.06*	*0.16*	*0.13*	*0.27*	*0.23*	*0.10*	*0.06*	*0.09*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.20 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Bahadurgarh in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.94																			
	0.00																			
EC	0.96	0.99																		
	0.00	*0.00*																		
TC	0.95	1.00	1.00																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.60	0.73	0.67	0.70																
	0.09	*0.03*	*0.05*	*0.04*																
NO_3^-	0.96	0.92	0.91	0.92	0.51															
	0.00	*0.00*	*0.00*	*0.00*	*0.17*															
SO_4^{--}	0.92	0.87	0.87	0.87	0.40	0.99														
	0.00	*0.00*	*0.00*	*0.00*	*0.28*	*0.00*														
Na^+	0.53	0.41	0.45	0.43	0.56	0.36	0.29													
	0.15	*0.27*	*0.23*	*0.25*	*0.12*	*0.34*	*0.44*													
NH_4^+	0.91	0.92	0.91	0.92	0.59	0.95	0.94	0.44												
	0.00	*0.00*	*0.00*	*0.00*	*0.10*	*0.00*	*0.00*	*0.24*												
K^+	0.47	0.57	0.56	0.57	0.67	0.29	0.17	0.28	0.23											
	0.20	*0.11*	*0.12*	*0.11*	*0.05*	*0.45*	*0.67*	*0.46*	*0.55*											
Ca^{++}	-0.39	-0.36	-0.47	-0.41	0.00	-0.30	-0.27	-0.01	-0.20	-0.32										
	0.30	*0.34*	*0.21*	*0.27*	*1.00*	*0.44*	*0.48*	*0.99*	*0.61*	*0.40*										
Si	0.40	0.46	0.48	0.47	0.11	0.45	0.42	-0.24	0.24	0.38	-0.53									
	0.29	*0.21*	*0.20*	*0.20*	*0.77*	*0.22*	*0.26*	*0.53*	*0.53*	*0.31*	*0.14*									
Al	0.35	0.50	0.47	0.49	0.12	0.53	0.60	-0.21	0.53	-0.06	-0.06	0.51								
	0.36	*0.17*	*0.20*	*0.19*	*0.76*	*0.14*	*0.09*	*0.59*	*0.15*	*0.88*	*0.89*	*0.16*								
Ca	0.27	0.28	0.28	0.28	0.21	0.29	0.24	-0.24	0.12	0.27	-0.60	0.48	0.03							
	0.49	*0.47*	*0.47*	*0.47*	*0.58*	*0.46*	*0.54*	*0.54*	*0.76*	*0.49*	*0.09*	*0.19*	*0.94*							
Fe	0.78	0.77	0.79	0.78	0.34	0.74	0.71	0.07	0.71	0.45	-0.57	0.45	0.19	0.39						
	0.01	*0.02*	*0.01*	*0.01*	*0.38*	*0.02*	*0.03*	*0.86*	*0.03*	*0.23*	*0.11*	*0.23*	*0.62*	*0.31*						
Ti	0.82	0.71	0.74	0.72	0.25	0.80	0.81	0.19	0.76	0.26	-0.44	0.18	0.20	0.37	0.85					
	0.01	*0.03*	*0.02*	*0.03*	*0.52*	*0.01*	*0.01*	*0.62*	*0.02*	*0.50*	*0.24*	*0.65*	*0.61*	*0.33*	*0.00*					
K	0.59	0.70	0.71	0.71	0.66	0.43	0.32	0.23	0.39	0.95	-0.53	0.50	0.06	0.37	0.65	0.41				
	0.10	*0.04*	*0.03*	*0.03*	*0.06*	*0.25*	*0.40*	*0.56*	*0.31*	*0.00*	*0.14*	*0.17*	*0.87*	*0.33*	*0.06*	*0.28*				
S	0.89	0.79	0.86	0.83	0.29	0.86	0.85	0.38	0.76	0.32	-0.68	0.51	0.40	0.39	0.71	0.80	0.49			
	0.00	*0.01*	*0.00*	*0.01*	*0.45*	*0.00*	*0.00*	*0.31*	*0.02*	*0.40*	*0.04*	*0.16*	*0.29*	*0.30*	*0.03*	*0.01*	*0.18*			
Ni	0.41	0.38	0.40	0.39	-0.07	0.42	0.39	-0.28	0.26	0.28	-0.48	0.78	0.19	0.29	0.71	0.37	0.44	0.42		
	0.28	*0.31*	*0.28*	*0.30*	*0.86*	*0.26*	*0.30*	*0.47*	*0.50*	*0.47*	*0.19*	*0.01*	*0.63*	*0.46*	*0.03*	*0.32*	*0.24*	*0.26*		
Pb	0.64	0.45	0.55	0.50	0.10	0.53	0.50	0.44	0.34	0.37	-0.65	0.42	0.03	0.38	0.40	0.55	0.41	0.83	0.29	
	0.07	*0.23*	*0.13*	*0.17*	*0.80*	*0.14*	*0.17*	*0.23*	*0.38*	*0.32*	*0.06*	*0.26*	*0.93*	*0.32*	*0.29*	*0.12*	*0.27*	*0.01*	*0.45*	
Zn	0.70	0.56	0.62	0.59	0.27	0.64	0.59	0.36	0.42	0.49	-0.52	0.49	0.18	0.47	0.42	0.60	0.49	0.81	0.27	0.94
	0.04	*0.11*	*0.07*	*0.09*	*0.49*	*0.07*	*0.09*	*0.34*	*0.26*	*0.18*	*0.15*	*0.18*	*0.64*	*0.20*	*0.27*	*0.09*	*0.18*	*0.01*	*0.49*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.17 and Table 3.18, respectively for PM mass and the major species. PM_{10} has better C.V. than $PM_{2.5}$. In $PM_{2.5}$, secondary ions (NH_4^+, NO_3-, and SO_4^{--}) also show better C.V. than in PM_{10}.

Correlation Matrix for PM_{10} and $PM_{2.5}$ are tabulated in Table 3.19 and Table 3.20, respectively for PM mass and the major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) and (NH_4^+, NO_3-, & SO_4^{--}) show better correlation with PM_{10} mass. In both PM_{10} and $PM_{2.5}$, the secondary ions show better correlation with each other. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass.

3.1.3.2 Winter Season

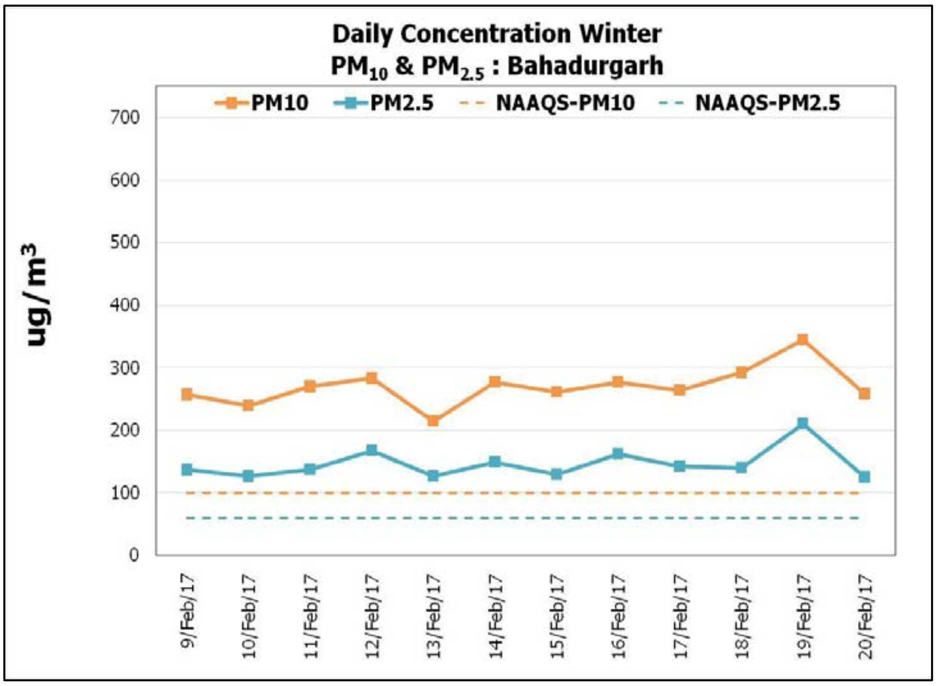


Figure 3.26: Variation in 24 hourly Concentration of PM_{10} and $PM_{2.5}$ at Bahadurgarh in Winter Season

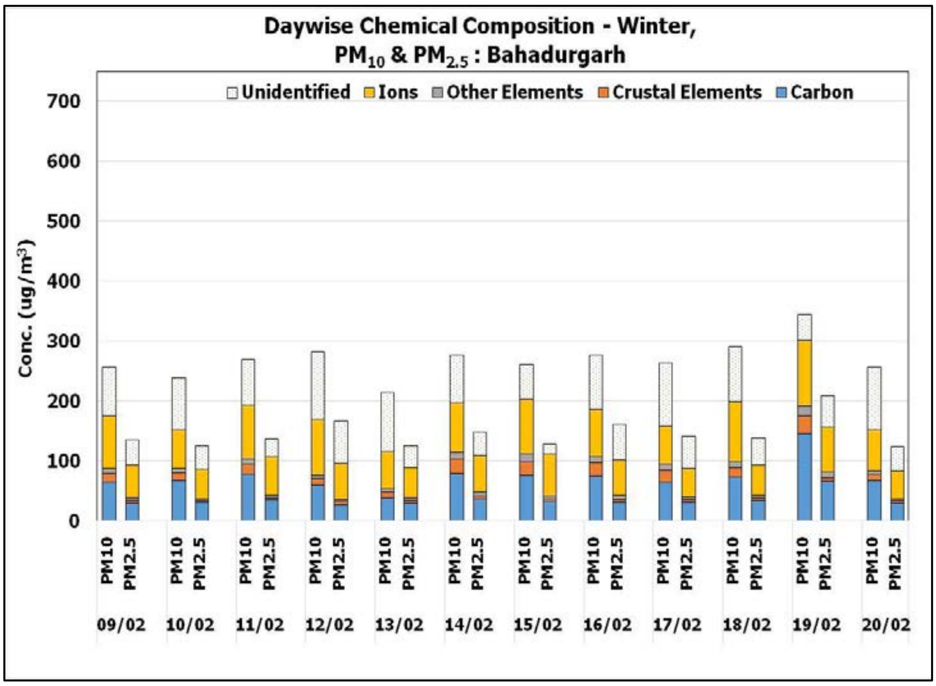


Figure 3.27 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at Bahadurgarh in Winter Season

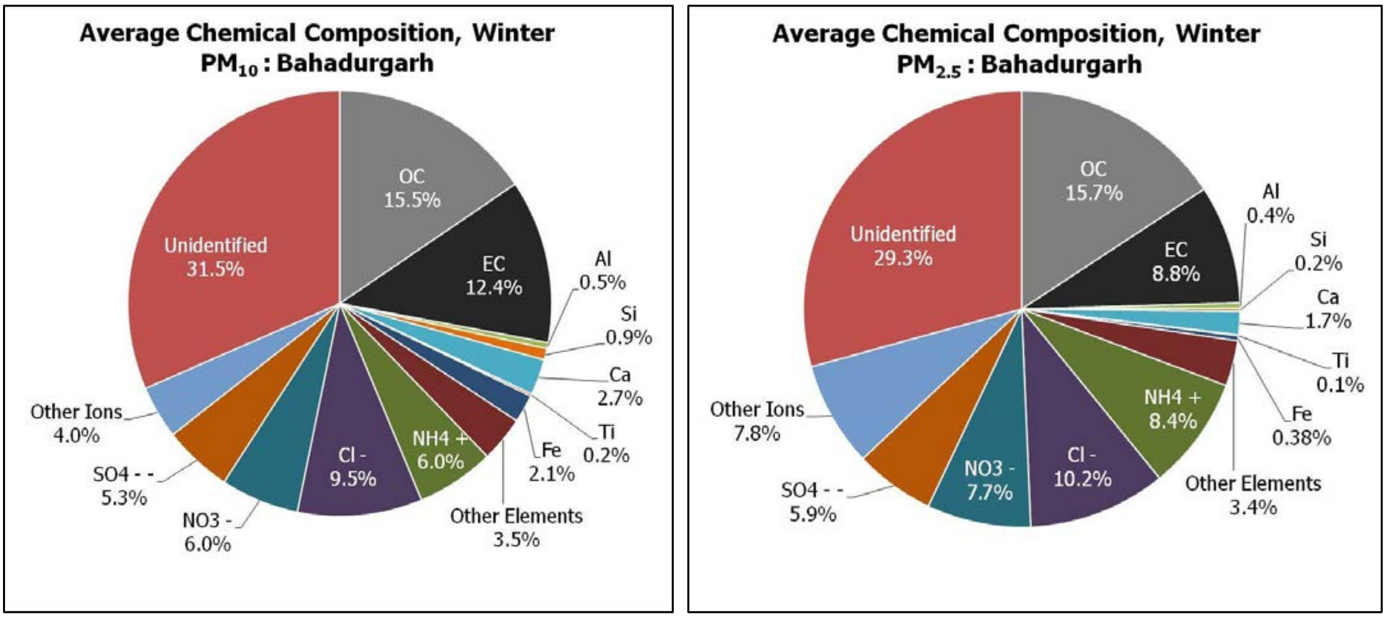


Figure 3.28 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Bahadurgarh in Winter Season

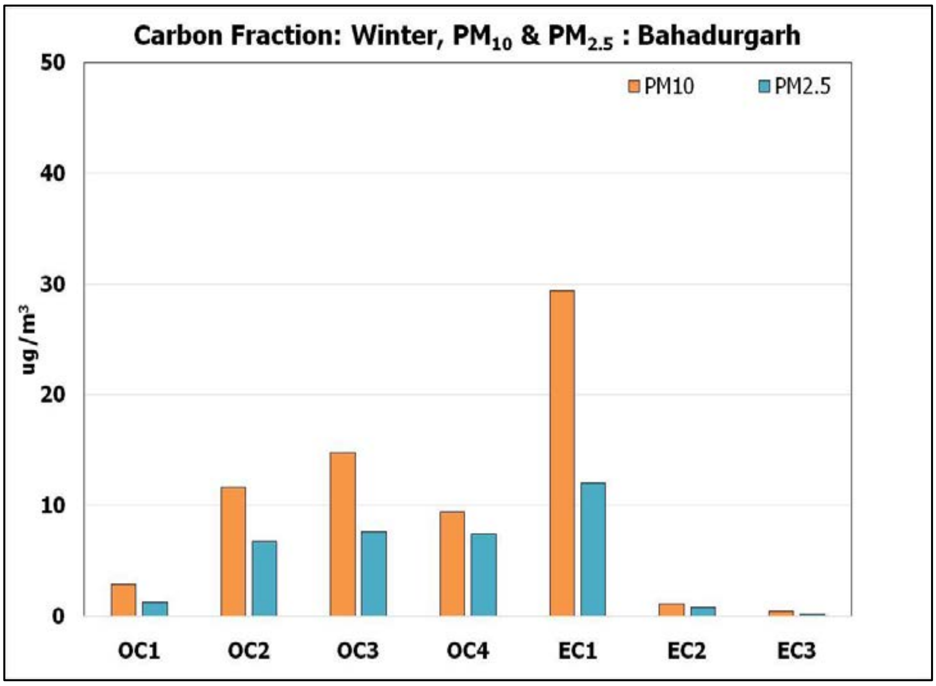


Figure 3.29 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Bahadurgarh in Winter Season

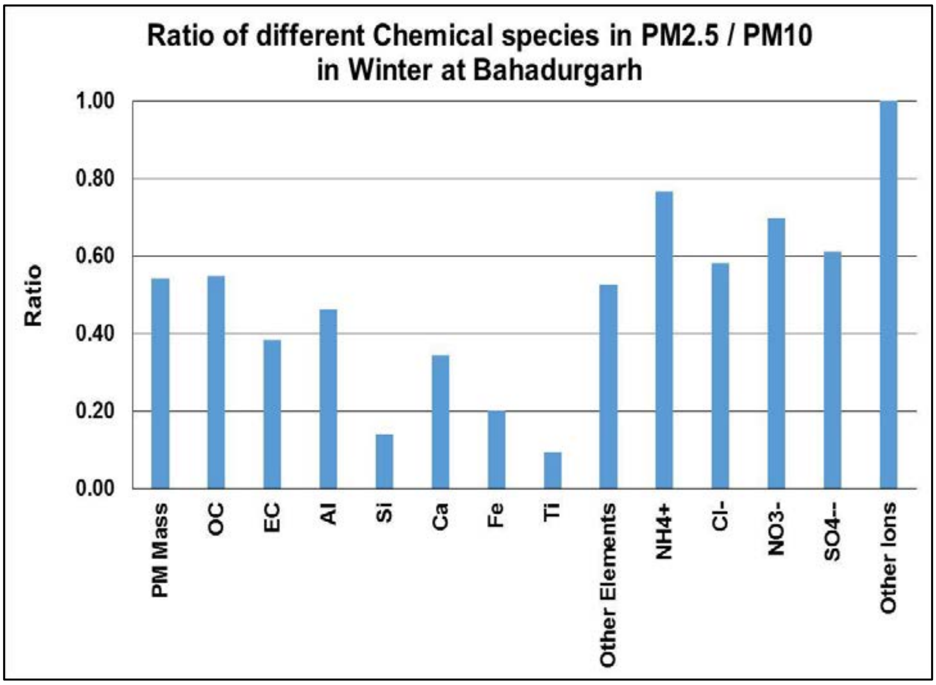


Figure 3.30 The Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Bahadurgarh in Winter Season

Average concentration of PM_{10} and $PM_{2.5}$ in Bahadurgadh was found to be 270±31 µg/m³ and 146 ± 24 µg/m³, respectively. The PM_{10} concentration varied from 215 to 345 µg/m³ and that of $PM_{2.5}$ varied from 125 to 210 µg/m³ (see Figure 3.26).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.27.

Carbon fraction for PM_{10} was found to be 75 µg/m³ and was 36 µg/m³ for $PM_{2.5}$. The crustal element for PM_{10} was found to be 6%, while it was 3% for $PM_{2.5}$. The percentage of total ions for $PM_{2.5}$ was found to be higher (40%) than for PM_{10} (31%) (See Figure 3.28).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% and 3% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 32% in PM_{10} and 29% in $PM_{2.5}$.

In PM_{10}, OC3 was found to be higher, followed by OC2, OC4, and OC1. In case of $PM_{2.5}$, OC3 was found to be higher, followed by OC4, OC2, and OC1. EC1 was found to be higher in both PM_{10} and $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.29).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.30.

Table 3.21 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Bahadurgarh in Winter Season

	µg/m^3																		
	PM10 Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	270	41.89	33.55	1.23	2.33	7.35	5.77	0.46	3.84	2.27	1.10	1.15	25.70	16.12	14.18	1.06	16.07	3.03	5.68
SD	31	10.99	14.40	0.56	0.75	3.03	1.79	0.18	1.37	1.01	0.91	0.41	7.59	3.93	2.19	0.61	2.55	0.92	2.33
Min	215	27.10	12.55	0.49	1.22	3.90	3.10	0.23	1.97	1.19	0.19	0.88	12.67	11.43	10.31	0.49	12.11	2.13	2.71
Max	345	73.32	73.20	2.69	3.54	14.04	8.37	0.82	6.49	4.51	2.91	2.28	35.97	21.29	17.48	2.67	19.62	5.23	9.99
C.V.	0.12	0.26	0.43	0.46	0.32	0.41	0.31	0.39	0.36	0.45	0.83	0.36	0.30	0.24	0.15	0.57	0.16	0.30	0.41
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95 %ile	316	57.35	54.98	2.12	3.51	11.80	8.12	0.73	5.73	3.87	2.58	1.87	35.33	21.27	17.03	2.14	19.25	4.38	9.54
50 %ile	270	41.26	32.65	1.23	2.26	7.35	5.77	0.46	3.63	2.27	0.77	0.98	26.08	16.12	14.53	0.89	16.93	2.99	5.68
5 %ile	151	21.46	13.75	0.54	1.06	3.60	2.64	0.21	1.76	1.13	0.23	0.71	10.89	8.80	7.47	0.57	8.77	1.70	2.58

Table 3.22 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Bahadurgarh in Winter Season

	µg/m^3																		
	PM2.5 Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	146	23.02	12.89	0.57	0.33	2.53	0.55	0.09	1.72	1.71	0.24	0.58	14.95	11.26	8.68	0.38	12.31	2.23	1.51
SD	24	4.93	5.48	0.22	0.19	0.49	0.23	0.05	0.57	0.82	0.04	0.21	4.30	2.47	2.27	0.18	3.10	0.64	0.26
Min	125	20.04	8.46	0.32	0.07	2.04	0.29	0.02	1.31	1.10	0.19	0.32	6.72	9.59	6.00	0.17	8.02	1.66	1.08
Max	210	37.98	29.27	0.95	0.64	3.81	1.10	0.18	3.30	3.41	0.35	1.11	20.14	17.99	13.48	0.84	17.86	3.94	2.13
C.V.	0.17	0.21	0.43	0.38	0.57	0.19	0.42	0.50	0.33	0.48	0.18	0.36	0.29	0.22	0.26	0.49	0.25	0.29	0.17
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95 %ile	187	30.64	21.87	0.90	0.59	3.36	0.95	0.16	2.71	3.15	0.32	0.93	20.13	15.72	12.07	0.67	16.52	3.44	1.92
50 %ile	139	21.75	10.80	0.55	0.31	2.43	0.49	0.09	1.52	1.30	0.24	0.53	15.47	10.06	7.77	0.35	11.43	2.05	1.48
5 %ile	126	20.10	9.41	0.33	0.09	2.08	0.33	0.02	1.32	1.10	0.19	0.37	8.81	9.60	6.30	0.20	8.56	1.71	1.16

Table 3.23 Correlation Matrix for PM10 and Its major constituents at Bahadurgarh in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.84																			
	0.00																			
EC	0.89	0.94																		
	0.00	*0.00*																		
TC	0.88	0.98	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.63	0.41	0.49	0.46																
	0.03	*0.19*	*0.11*	*0.13*																
NO_3^-	0.56	0.58	0.43	0.50	0.32															
	0.06	*0.05*	*0.16*	*0.10*	*0.31*															
SO_4^{--}	0.66	0.59	0.47	0.53	0.43	0.83														
	0.02	*0.04*	*0.13*	*0.08*	*0.16*	*0.00*														
Na^+	0.72	0.82	0.80	0.82	0.58	0.42	0.58													
	0.01	*0.00*	*0.00*	*0.00*	*0.05*	*0.18*	*0.05*													
NH_4^+	0.69	0.52	0.46	0.49	0.54	0.74	0.88	0.64												
	0.01	*0.08*	*0.14*	*0.11*	*0.07*	*0.01*	*0.00*	*0.03*												
K^+	0.77	0.81	0.87	0.86	0.62	0.45	0.32	0.68	0.41											
	0.00	*0.00*	*0.00*	*0.00*	*0.03*	*0.15*	*0.32*	*0.02*	*0.18*											
Ca^{++}	0.56	0.65	0.75	0.72	0.39	0.18	0.31	0.80	0.46	0.67										
	0.06	*0.02*	*0.01*	*0.01*	*0.21*	*0.57*	*0.34*	*0.00*	*0.14*	*0.02*										
Si	0.70	0.56	0.71	0.66	0.44	0.20	0.12	0.43	0.39	0.78	0.61									
	0.01	*0.06*	*0.01*	*0.02*	*0.15*	*0.53*	*0.71*	*0.16*	*0.21*	*0.00*	*0.04*									
Al	0.88	0.81	0.85	0.84	0.71	0.37	0.41	0.74	0.53	0.89	0.63	0.77								
	0.00	*0.00*	*0.00*	*0.00*	*0.01*	*0.23*	*0.19*	*0.01*	*0.08*	*0.00*	*0.03*	*0.00*								
Ca	0.71	0.78	0.88	0.85	0.38	0.32	0.21	0.65	0.35	0.88	0.82	0.87	0.78							
	0.01	*0.00*	*0.00*	*0.00*	*0.23*	*0.31*	*0.52*	*0.02*	*0.26*	*0.00*	*0.00*	*0.00*	*0.00*							
Fe	0.62	0.62	0.74	0.69	0.16	0.30	0.13	0.39	0.27	0.68	0.63	0.87	0.57	0.90						
	0.03	*0.03*	*0.01*	*0.01*	*0.63*	*0.34*	*0.69*	*0.22*	*0.41*	*0.02*	*0.03*	*0.00*	*0.06*	*0.00*						
Ti	0.65	0.67	0.81	0.76	0.34	0.26	0.08	0.47	0.22	0.82	0.67	0.85	0.72	0.95	0.89					
	0.02	*0.02*	*0.00*	*0.00*	*0.29*	*0.42*	*0.80*	*0.12*	*0.49*	*0.00*	*0.02*	*0.00*	*0.01*	*0.00*	*0.00*					
K	0.69	0.70	0.82	0.78	0.33	0.26	0.17	0.60	0.35	0.77	0.80	0.89	0.71	0.97	0.95	0.91				
	0.01	*0.01*	*0.00*	*0.00*	*0.30*	*0.41*	*0.60*	*0.04*	*0.26*	*0.00*	*0.00*	*0.00*	*0.01*	*0.00*	*0.00*	*0.00*				
S	0.75	0.71	0.84	0.79	0.43	0.22	0.16	0.66	0.38	0.78	0.74	0.91	0.76	0.92	0.88	0.88	0.95			
	0.01	*0.01*	*0.00*	*0.00*	*0.16*	*0.50*	*0.61*	*0.02*	*0.22*	*0.00*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*			
Ni	0.86	0.79	0.81	0.81	0.76	0.65	0.57	0.66	0.54	0.81	0.41	0.58	0.81	0.65	0.53	0.64	0.59	0.66		
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.02*	*0.06*	*0.02*	*0.07*	*0.00*	*0.18*	*0.05*	*0.00*	*0.02*	*0.08*	*0.03*	*0.04*	*0.02*		
Pb	0.66	0.74	0.70	0.73	0.32	0.67	0.50	0.54	0.51	0.70	0.53	0.51	0.69	0.72	0.58	0.74	0.63	0.54	0.67	
	0.02	*0.01*	*0.01*	*0.01*	*0.31*	*0.02*	*0.10*	*0.07*	*0.09*	*0.01*	*0.08*	*0.09*	*0.01*	*0.01*	*0.05*	*0.01*	*0.03*	*0.07*	*0.02*	
Zn	0.77	0.87	0.82	0.85	0.40	0.60	0.47	0.77	0.50	0.71	0.56	0.57	0.76	0.75	0.65	0.69	0.74	0.76	0.81	0.78
	0.00	*0.00*	*0.00*	*0.00*	*0.20*	*0.04*	*0.12*	*0.00*	*0.10*	*0.01*	*0.06*	*0.05*	*0.01*	*0.01*	*0.02*	*0.01*	*0.01*	*0.00*	*0.00*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.24 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Bahadurgarh in Winter Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.76																			
	0.00																			
EC	0.79	0.94																		
	0.00	*0.00*																		
TC	0.79	0.98	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.47	0.25	0.32	0.29																
	0.12	*0.43*	*0.32*	*0.36*																
NO_3^-	0.68	0.93	0.84	0.90	0.22															
	0.02	*0.00*	*0.00*	*0.00*	*0.49*															
SO_4^{--}	0.77	0.55	0.65	0.61	0.21	0.52														
	0.00	*0.07*	*0.02*	*0.04*	*0.52*	*0.09*														
Na^+	0.75	0.92	0.83	0.88	0.25	0.88	0.38													
	0.01	*0.00*	*0.00*	*0.00*	*0.49*	*0.00*	*0.29*													
NH_4^+	0.71	0.56	0.52	0.55	0.49	0.53	0.61	0.60												
	0.01	*0.06*	*0.08*	*0.06*	*0.11*	*0.08*	*0.04*	*0.07*												
K^+	0.85	0.75	0.83	0.80	0.37	0.71	0.72	0.70	0.59											
	0.00	*0.01*	*0.00*	*0.00*	*0.23*	*0.01*	*0.01*	*0.02*	*0.04*											
Ca^{++}	0.64	0.75	0.65	0.71	0.00	0.70	0.30	0.72	0.13	0.48										
	0.03	*0.01*	*0.02*	*0.01*	*0.99*	*0.01*	*0.34*	*0.02*	*0.70*	*0.11*										
Si	0.66	0.36	0.50	0.44	0.09	0.32	0.60	0.59	0.57	0.64	0.17									
	0.02	*0.25*	*0.10*	*0.16*	*0.78*	*0.31*	*0.04*	*0.07*	*0.05*	*0.03*	*0.59*									
Al	0.80	0.35	0.35	0.35	0.37	0.38	0.55	0.47	0.41	0.52	0.55	0.54								
	0.00	*0.27*	*0.27*	*0.26*	*0.23*	*0.22*	*0.06*	*0.18*	*0.18*	*0.08*	*0.07*	*0.07*								
Ca	0.67	0.72	0.72	0.73	-0.09	0.56	0.46	0.63	0.22	0.61	0.79	0.35	0.40							
	0.02	*0.01*	*0.01*	*0.01*	*0.78*	*0.06*	*0.13*	*0.05*	*0.50*	*0.03*	*0.00*	*0.26*	*0.20*							
Fe	0.90	0.66	0.78	0.73	0.44	0.61	0.75	0.73	0.66	0.91	0.42	0.84	0.68	0.51						
	0.00	*0.02*	*0.00*	*0.01*	*0.15*	*0.03*	*0.01*	*0.02*	*0.02*	*0.00*	*0.17*	*0.00*	*0.02*	*0.09*						
Ti	0.71	0.38	0.53	0.46	0.14	0.33	0.70	0.58	0.52	0.76	0.18	0.88	0.58	0.49	0.86					
	0.01	*0.23*	*0.08*	*0.13*	*0.65*	*0.29*	*0.01*	*0.08*	*0.08*	*0.00*	*0.57*	*0.00*	*0.05*	*0.10*	*0.00*					
K	0.83	0.85	0.95	0.92	0.32	0.75	0.69	0.78	0.50	0.82	0.63	0.65	0.47	0.68	0.86	0.61				
	0.00	*0.00*	*0.00*	*0.00*	*0.31*	*0.01*	*0.01*	*0.01*	*0.10*	*0.00*	*0.03*	*0.02*	*0.12*	*0.01*	*0.00*	*0.04*				
S	0.76	0.64	0.79	0.72	0.50	0.65	0.71	0.60	0.45	0.80	0.41	0.64	0.57	0.35	0.88	0.61	0.88			
	0.00	*0.03*	*0.00*	*0.01*	*0.10*	*0.02*	*0.01*	*0.07*	*0.14*	*0.00*	*0.19*	*0.03*	*0.05*	*0.27*	*0.00*	*0.04*	*0.00*			
Ni	0.84	0.50	0.60	0.56	0.27	0.50	0.80	0.60	0.66	0.76	0.38	0.83	0.73	0.50	0.88	0.85	0.71	0.71		
	0.00	*0.10*	*0.04*	*0.06*	*0.40*	*0.10*	*0.00*	*0.07*	*0.02*	*0.01*	*0.22*	*0.00*	*0.01*	*0.10*	*0.00*	*0.00*	*0.01*	*0.01*		
Pb	0.72	0.81	0.86	0.85	0.51	0.81	0.53	0.79	0.62	0.78	0.46	0.53	0.37	0.43	0.79	0.45	0.88	0.85	0.58	
	0.01	*0.00*	*0.00*	*0.00*	*0.09*	*0.00*	*0.08*	*0.01*	*0.03*	*0.00*	*0.13*	*0.08*	*0.24*	*0.17*	*0.00*	*0.14*	*0.00*	*0.00*	*0.05*	
Zn	0.68	0.76	0.86	0.83	0.37	0.75	0.59	0.67	0.43	0.91	0.44	0.49	0.30	0.52	0.80	0.57	0.84	0.84	0.54	0.89
	0.02	*0.00*	*0.00*	*0.00*	*0.24*	*0.01*	*0.05*	*0.03*	*0.16*	*0.00*	*0.16*	*0.11*	*0.34*	*0.08*	*0.00*	*0.06*	*0.00*	*0.00*	*0.07*	*0.00*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.21 and Table 3.22 for PM mass and the major species, respectively. PM_{10} mass and $PM_{2.5}$ mass show similar C.V. For the secondary ions, C.V. observed in PM_{10} and $PM_{2.5}$ was very less, which represents less variation in concentration during the monitoring period.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.23 and Table 3.24 for PM mass and its major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3-, & SO_4^{--}) show better correlation with each other.

3.1.4 Site 4: Shahdara

3.1.4.1 Summer Season

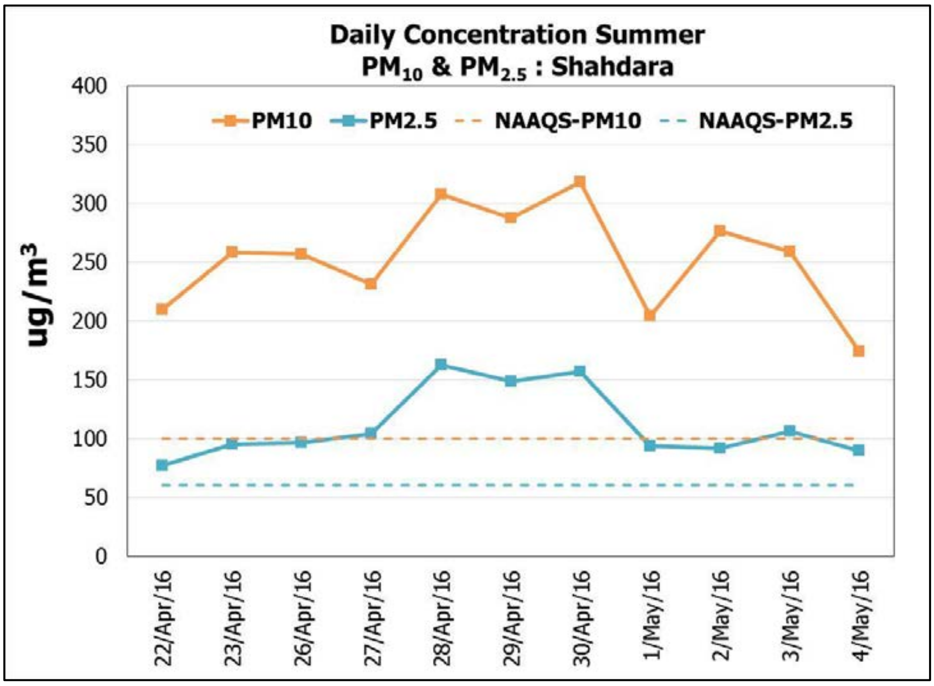


Figure 0-11 Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at Shahdara in the Summer Season

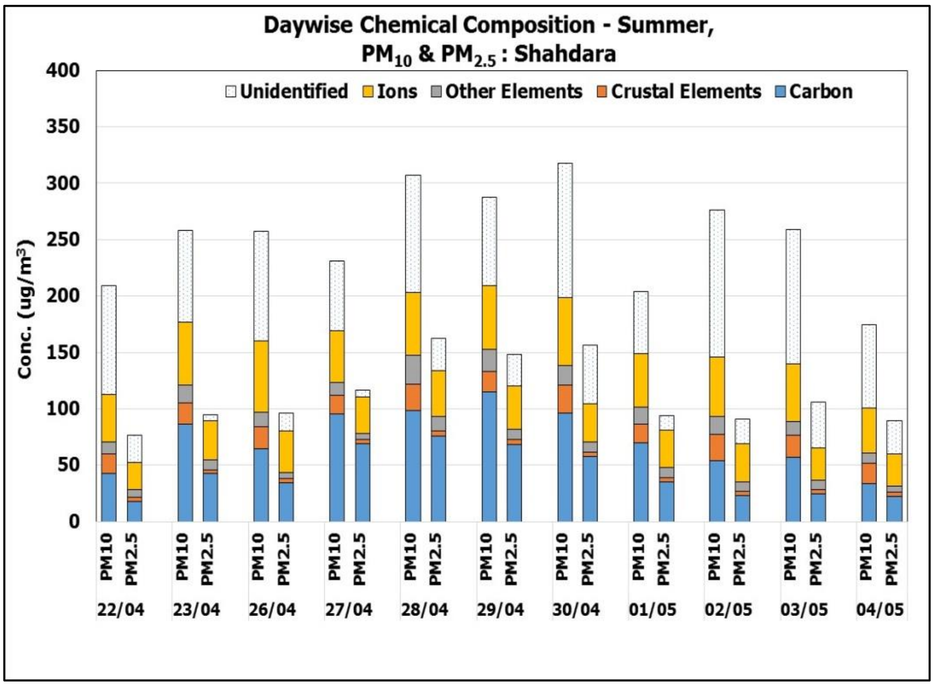


Figure 3.32 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at Shahdara in the Summer Season

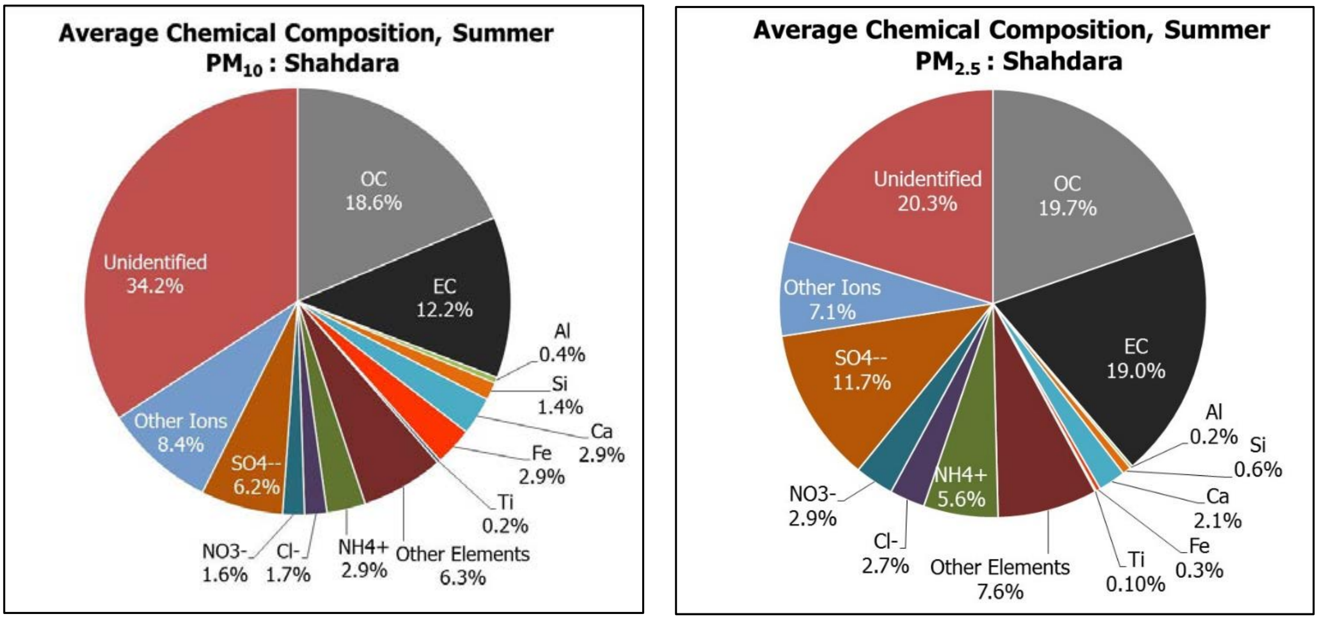


Figure 3.33: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Shahdara in the Summer Season

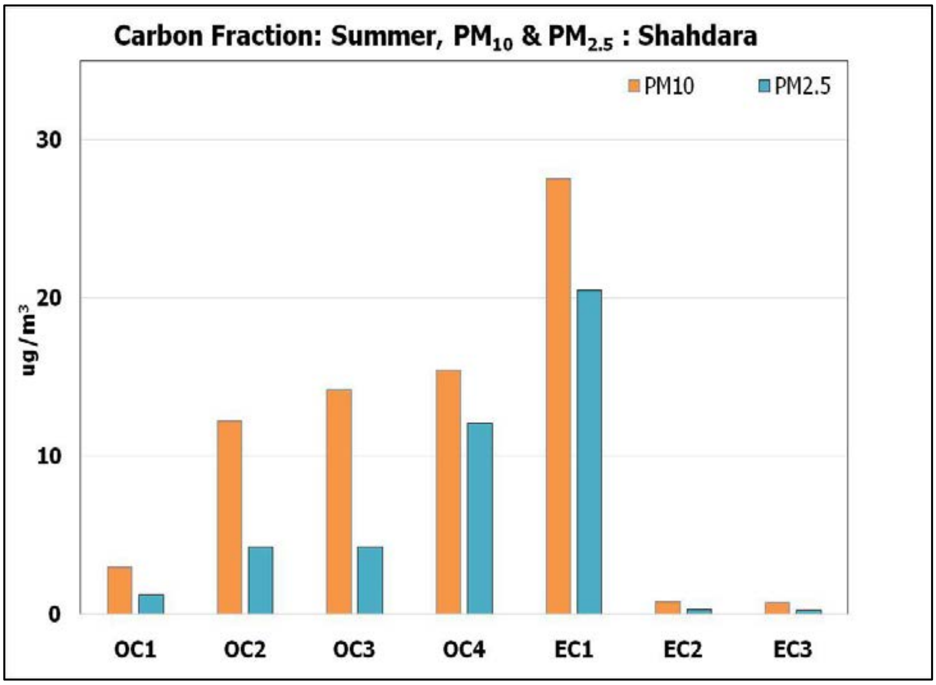


Figure 3.34: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Shahdara in the Summer Season

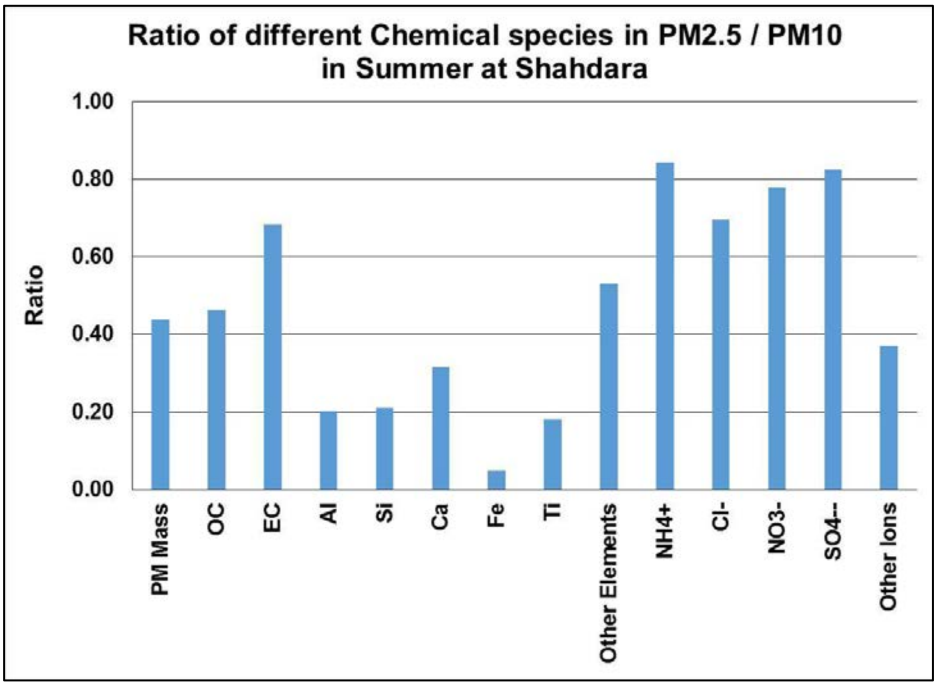


Figure 3.35: Ratio of Different Chemical Species in $PM_{2.5}$/PM_{10} at Shahdara

Average concentration of PM_{10} and $PM_{2.5}$ at Shahdara (SHD) was 253±38 µg/m^3 and 111±30 µg/m^3, respectively. The observed average concentration of PM_{10} is 2.5 times the NAAQS, while in $PM_{2.5}$, it is almost 1.9 times the NAAQS. In PM_{10}, the observed daily concentration variation was from 204 to 318 µg/m^3. Similarly, for $PM_{2.5}$, Daily concentration variation is 77 to 162 µg/m^3 (see Figure 3.31).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.32.

The carbon fraction contributes 78 µg/m^3 of PM_{10}, while the same is 43 µg/m^3 In case of $PM_{2.5}$. The percentage mass distribution shows that both organic carbon and elemental carbon are higher in $PM_{2.5}$ than in PM_{10}. The total Ion concentration of PM_{10} and $PM_{2.5}$ is 21% and 30%, respectively. The crustal elements are 8% in PM_{10} and almost 3% in $PM_{2.5}$ (see Figure 3.33).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 6% and 8% in PM_{10} and $PM_{2.5}$, respectively.
The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be was 34% and 20% for PM_{10} and $PM_{2.5}$, respectively.

In both PM_{10} and $PM_{2.5}$, the EC1 concentration was the highest, followed by OC4. EC1 was found to be 28 µg/m^3 and 21 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively, and OC4 was found to be 15 µg/m^3 and 14 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively (see Figure 3.34).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.35.

Table 3.25 Statistical **evaluation of concentrations (µg/m³)** of mass and major species of PM_{10} at Shahdara in Summer Season

	µg/m³																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	253	47.02	30.88	1.13	3.42	7.29	7.31	0.62	10.19	1.38	0.66	1.16	4.25	4.17	15.77	5.97	7.42	8.41	4.18
SD	38	12.38	13.31	0.36	0.78	1.43	0.81	0.14	2.59	0.26	0.47	1.01	2.91	0.66	1.81	2.90	0.76	2.93	0.66
Min	204	28.66	12.80	0.67	2.09	5.79	5.89	0.44	6.95	0.90	0.21	0.58	2.07	3.44	11.68	2.63	5.85	4.54	3.47
Max	318	71.03	48.61	1.64	4.57	9.57	8.94	0.86	14.24	1.77	1.80	3.89	11.54	5.01	18.16	11.88	8.47	12.76	5.79
C.V.	0.15	0.26	0.43	0.32	0.23	0.20	0.11	0.22	0.25	0.19	0.70	0.87	0.68	0.16	0.11	0.49	0.10	0.35	0.16
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	313	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	258	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	189	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.26 Statistical **evaluation of concentrations (µg/m³)** of mass and major species of $PM_{2.5}$ at Shahdara in Summer Season

	µg/m³																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	111	21.81	21.08	0.23	0.72	2.30	0.37	0.11	5.22	1.15	0.30	0.45	2.95	3.25	12.99	1.57	6.25	3.77	0.98
SD	30	9.65	12.13	0.08	0.08	0.11	0.16	0.02	1.09	0.24	0.26	0.40	1.32	0.48	2.51	1.21	1.04	0.92	0.13
Min	77	10.00	7.78	0.15	0.58	2.08	0.08	0.08	3.74	0.79	0.01	0.01	1.94	2.69	7.21	0.28	3.95	2.27	0.80
Max	162	37.16	38.69	0.37	0.87	2.52	0.57	0.17	7.12	1.44	0.82	1.39	6.40	4.21	16.80	4.15	7.51	5.63	1.17
C.V.	0.27	0.44	0.58	0.37	0.11	0.05	0.45	0.20	0.21	0.21	0.86	0.89	0.45	0.15	0.19	0.77	0.17	0.24	0.13
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	159	34.68	37.84	0.36	0.83	2.47	0.56	0.14	6.82	1.44	0.72	1.15	5.18	3.97	16.26	3.61	7.46	5.06	1.16
50 %ile	96	20.29	21.09	0.18	0.73	2.30	0.38	0.12	5.39	1.21	0.27	0.37	2.45	3.18	12.65	1.01	6.37	3.56	0.99
5 %ile	83	11.62	8.30	0.16	0.61	2.15	0.11	0.08	3.82	0.81	0.01	0.02	1.94	2.69	9.22	0.45	4.56	2.51	0.80

Table 3.27 Correlation Matrix for PM_{10} and Its Composition in Summer Season at Shahdara

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.72																			
	0.01																			
EC	0.55	0.76																		
	0.08	*0.01*																		
TC	0.68	0.94	0.94																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.14	-0.17	-0.27	-0.23																
	0.69	*0.63*	*0.42*	*0.49*																
NO_3^-	0.50	0.49	0.45	0.50	0.31															
	0.12	*0.12*	*0.17*	*0.12*	*0.35*															
SO_4^{--}	0.40	0.47	0.50	0.52	-0.23	0.44														
	0.22	*0.14*	*0.12*	*0.10*	*0.49*	*0.18*														
Na^+	0.28	-0.09	0.07	-0.01	0.43	0.18	-0.09													
	0.41	*0.79*	*0.84*	*0.98*	*0.19*	*0.61*	*0.79*													
NH_4^+	0.42	0.25	0.34	0.32	0.17	0.60	0.77	0.30												
	0.20	*0.46*	*0.31*	*0.35*	*0.62*	*0.05*	*0.01*	*0.37*												
K^+	0.68	0.86	0.73	0.85	-0.11	0.34	0.57	-0.24	0.25											
	0.02	*0.00*	*0.01*	*0.00*	*0.76*	*0.31*	*0.07*	*0.47*	*0.45*											
Ca^{++}	0.79	0.61	0.54	0.61	0.12	0.14	0.24	0.17	0.34	0.64										
	0.00	*0.05*	*0.09*	*0.05*	*0.72*	*0.68*	*0.48*	*0.61*	*0.30*	*0.04*										
Si	0.65	0.15	0.03	0.09	0.11	0.18	-0.09	0.02	0.09	0.19	0.56									
	0.03	*0.66*	*0.94*	*0.78*	*0.76*	*0.60*	*0.80*	*0.95*	*0.79*	*0.58*	*0.08*									
Al	0.69	0.25	0.05	0.16	0.13	0.38	0.34	-0.04	0.51	0.29	0.55	0.84								
	0.02	*0.46*	*0.89*	*0.64*	*0.71*	*0.25*	*0.30*	*0.92*	*0.11*	*0.39*	*0.08*	*0.00*								
Ca	0.76	0.27	0.18	0.24	0.27	0.23	0.16	0.36	0.47	0.25	0.76	0.73	0.80							
	0.01	*0.42*	*0.60*	*0.48*	*0.42*	*0.51*	*0.65*	*0.28*	*0.14*	*0.45*	*0.01*	*0.01*	*0.00*							
Fe	0.52	0.14	0.00	0.07	0.16	-0.07	0.39	-0.09	0.36	0.39	0.64	0.56	0.70	0.58						
	0.10	*0.69*	*1.00*	*0.83*	*0.64*	*0.84*	*0.23*	*0.80*	*0.28*	*0.24*	*0.03*	*0.07*	*0.02*	*0.06*						
Ti	0.61	0.18	0.11	0.16	0.03	0.09	0.17	-0.02	0.07	0.45	0.38	0.73	0.63	0.52	0.51					
	0.05	*0.59*	*0.74*	*0.65*	*0.92*	*0.79*	*0.63*	*0.95*	*0.83*	*0.16*	*0.26*	*0.01*	*0.04*	*0.10*	*0.11*					
K	0.80	0.75	0.50	0.66	0.00	0.35	0.57	-0.01	0.37	0.73	0.62	0.28	0.52	0.60	0.46	0.39				
	0.00	*0.01*	*0.12*	*0.03*	*1.00*	*0.29*	*0.07*	*0.97*	*0.26*	*0.01*	*0.04*	*0.40*	*0.11*	*0.05*	*0.16*	*0.24*				
S	0.51	0.65	0.77	0.75	-0.41	0.24	0.56	-0.11	0.22	0.81	0.37	0.12	0.13	0.10	0.12	0.54	0.46			
	0.11	*0.03*	*0.01*	*0.01*	*0.21*	*0.48*	*0.07*	*0.76*	*0.52*	*0.00*	*0.27*	*0.73*	*0.71*	*0.78*	*0.73*	*0.09*	*0.16*			
Ni	0.21	-0.19	-0.49	-0.37	0.17	0.22	0.02	0.04	0.26	-0.32	-0.08	0.50	0.69	0.51	0.23	0.27	0.21	-0.39		
	0.54	*0.57*	*0.12*	*0.27*	*0.63*	*0.51*	*0.95*	*0.90*	*0.43*	*0.33*	*0.82*	*0.12*	*0.02*	*0.11*	*0.50*	*0.42*	*0.53*	*0.24*		
Pb	0.55	0.39	0.78	0.62	-0.12	0.55	0.51	0.14	0.46	0.45	0.37	0.29	0.33	0.33	0.16	0.33	0.43	0.58	-0.11	
	0.08	*0.24*	*0.01*	*0.04*	*0.73*	*0.08*	*0.11*	*0.67*	*0.16*	*0.16*	*0.27*	*0.39*	*0.32*	*0.32*	*0.64*	*0.32*	*0.18*	*0.06*	*0.75*	
Zn	0.45	0.19	0.63	0.44	-0.22	0.36	0.37	0.06	0.31	0.32	0.28	0.42	0.37	0.33	0.18	0.47	0.29	0.55	-0.03	0.95
	0.17	*0.58*	*0.04*	*0.18*	*0.51*	*0.27*	*0.27*	*0.86*	*0.35*	*0.33*	*0.40*	*0.20*	*0.26*	*0.32*	*0.61*	*0.14*	*0.39*	*0.08*	*0.92*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.28 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Shahdara in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.87																			
	0.00																			
EC	0.73	0.92																		
	0.01	*0.00*																		
TC	0.81	0.98	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	-0.07	-0.06	-0.28	-0.19																
	0.83	*0.85*	*0.41*	*0.58*																
NO_3^-	0.85	0.83	0.73	0.79	0.09															
	0.00	*0.00*	*0.01*	*0.00*	*0.78*															
SO_4^{--}	0.73	0.76	0.79	0.79	-0.13	0.81														
	0.01	*0.01*	*0.00*	*0.00*	*0.71*	*0.00*														
Na^+	-0.16	-0.03	-0.08	-0.06	0.57	-0.08	-0.27													
	0.63	*0.94*	*0.82*	*0.87*	*0.07*	*0.81*	*0.42*													
NH_4^+	0.87	0.85	0.74	0.80	0.07	0.79	0.81	0.06												
	0.00	*0.00*	*0.01*	*0.00*	*0.84*	*0.00*	*0.00*	*0.86*												
K^+	0.53	0.39	0.47	0.44	-0.15	0.31	0.40	0.27	0.58											
	0.10	*0.24*	*0.14*	*0.17*	*0.67*	*0.35*	*0.23*	*0.43*	*0.06*											
Ca^{++}	0.31	0.47	0.43	0.46	-0.18	0.50	0.52	-0.22	0.26	-0.29										
	0.35	*0.14*	*0.18*	*0.16*	*0.59*	*0.12*	*0.10*	*0.53*	*0.45*	*0.39*										
Si	0.56	0.79	0.72	0.77	0.31	0.64	0.50	0.26	0.49	0.19	0.42									
	0.07	*0.00*	*0.01*	*0.01*	*0.35*	*0.04*	*0.12*	*0.44*	*0.12*	*0.58*	*0.19*									
Al	0.85	0.63	0.53	0.58	-0.11	0.61	0.42	-0.15	0.56	0.56	0.00	0.46								
	0.00	*0.04*	*0.09*	*0.06*	*0.76*	*0.05*	*0.20*	*0.65*	*0.07*	*0.07*	*0.99*	*0.15*								
Ca	0.43	0.36	0.31	0.34	-0.35	0.44	0.41	-0.55	0.12	-0.15	0.77	0.29	0.32							
	0.18	*0.27*	*0.35*	*0.31*	*0.30*	*0.18*	*0.21*	*0.08*	*0.72*	*0.67*	*0.01*	*0.39*	*0.34*							
Fe	0.55	0.21	0.12	0.16	-0.40	0.37	0.36	-0.64	0.23	0.14	0.38	-0.07	0.53	0.80						
	0.08	*0.53*	*0.73*	*0.63*	*0.23*	*0.27*	*0.28*	*0.04*	*0.50*	*0.68*	*0.25*	*0.83*	*0.10*	*0.00*						
Ti	-0.09	-0.39	-0.40	-0.40	-0.09	-0.18	-0.04	-0.58	-0.14	0.04	-0.45	-0.58	0.03	-0.03	0.38					
	0.80	*0.23*	*0.22*	*0.22*	*0.80*	*0.61*	*0.91*	*0.06*	*0.68*	*0.92*	*0.17*	*0.06*	*0.92*	*0.93*	*0.25*					
K	0.66	0.37	0.42	0.40	-0.24	0.45	0.52	-0.11	0.57	0.88	-0.16	0.08	0.67	0.17	0.52	0.28				
	0.03	*0.27*	*0.20*	*0.22*	*0.47*	*0.17*	*0.10*	*0.75*	*0.07*	*0.00*	*0.65*	*0.81*	*0.03*	*0.61*	*0.10*	*0.40*				
S	0.84	0.81	0.76	0.79	-0.17	0.76	0.64	-0.09	0.73	0.40	0.37	0.54	0.63	0.39	0.36	-0.36	0.54			
	0.00	*0.00*	*0.01*	*0.00*	*0.62*	*0.01*	*0.03*	*0.79*	*0.01*	*0.22*	*0.27*	*0.09*	*0.04*	*0.24*	*0.28*	*0.28*	*0.09*			
Ni	0.48	0.36	0.16	0.25	-0.21	0.45	0.19	-0.41	0.17	-0.21	0.60	0.19	0.43	0.79	0.73	0.02	0.02	0.26		
	0.14	*0.27*	*0.64*	*0.45*	*0.54*	*0.17*	*0.59*	*0.21*	*0.61*	*0.53*	*0.05*	*0.57*	*0.19*	*0.00*	*0.01*	*0.96*	*0.96*	*0.44*		
Pb	0.54	0.42	0.52	0.49	-0.33	0.32	0.50	0.13	0.61	0.89	-0.08	0.13	0.55	-0.05	0.22	-0.01	0.76	0.34	-0.06	
	0.09	*0.20*	*0.10*	*0.13*	*0.32*	*0.34*	*0.12*	*0.71*	*0.05*	*0.00*	*0.82*	*0.71*	*0.08*	*0.89*	*0.51*	*0.97*	*0.01*	*0.31*	*0.86*	
Zn	0.55	0.42	0.42	0.43	-0.28	0.24	0.32	0.20	0.57	0.82	-0.07	0.14	0.59	0.00	0.27	-0.07	0.66	0.29	0.13	0.93
	0.08	*0.19*	*0.19*	*0.19*	*0.40*	*0.48*	*0.33*	*0.57*	*0.07*	*0.00*	*0.85*	*0.69*	*0.06*	*0.99*	*0.42*	*0.84*	*0.03*	*0.40*	*0.71*	*0.00*

Bold values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.25 and Table 3.26 for PM mass and the major species, respectively. PM_{10} mass and the secondary ions (NH_4^+, NO_3-, and SO_4^{--}) have lesser C.V. than $PM_{2.5}$.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.27 and Table 3.28 for PM mass and the major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than they show with PM_{10} mass. Also, the secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other in $PM_{2.5}$.

3.1.4.2 Winter Season

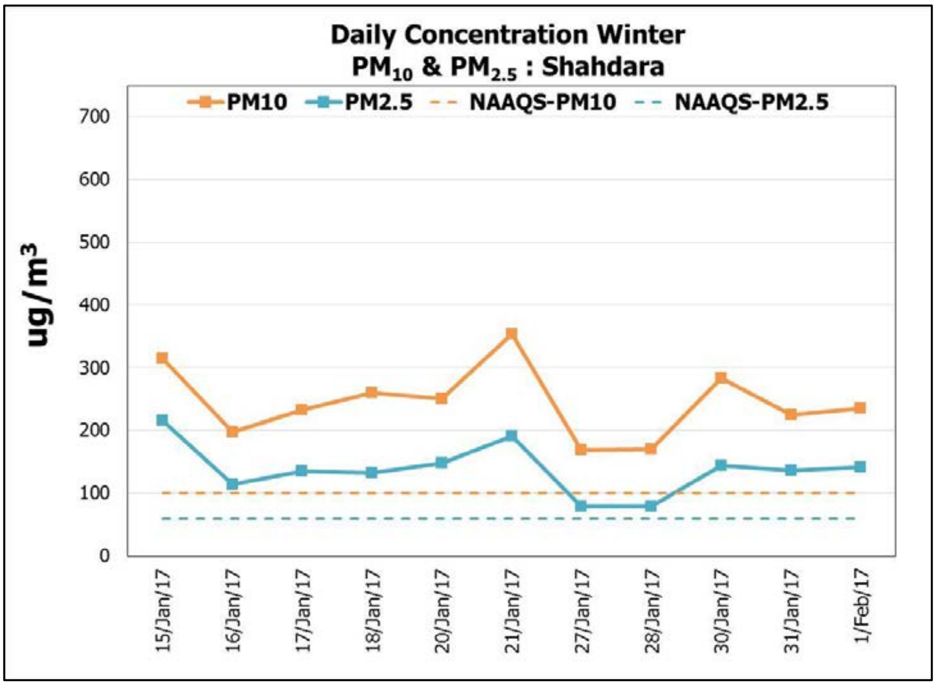


Figure 3.*6*: Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at Shahdara in Winter Season

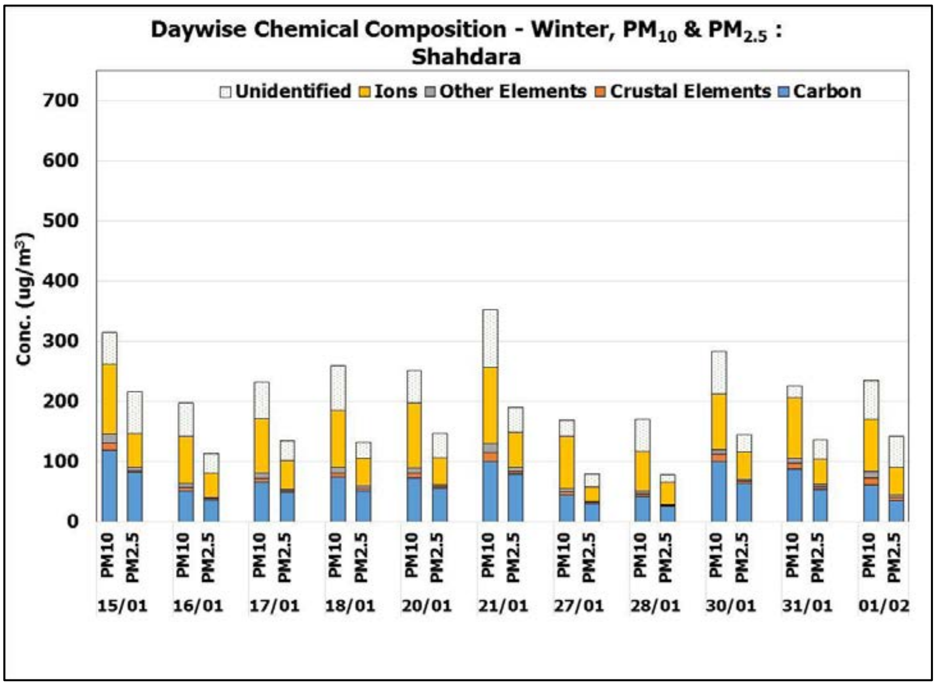


Figure 3.37 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at Shahdara in Winter Season

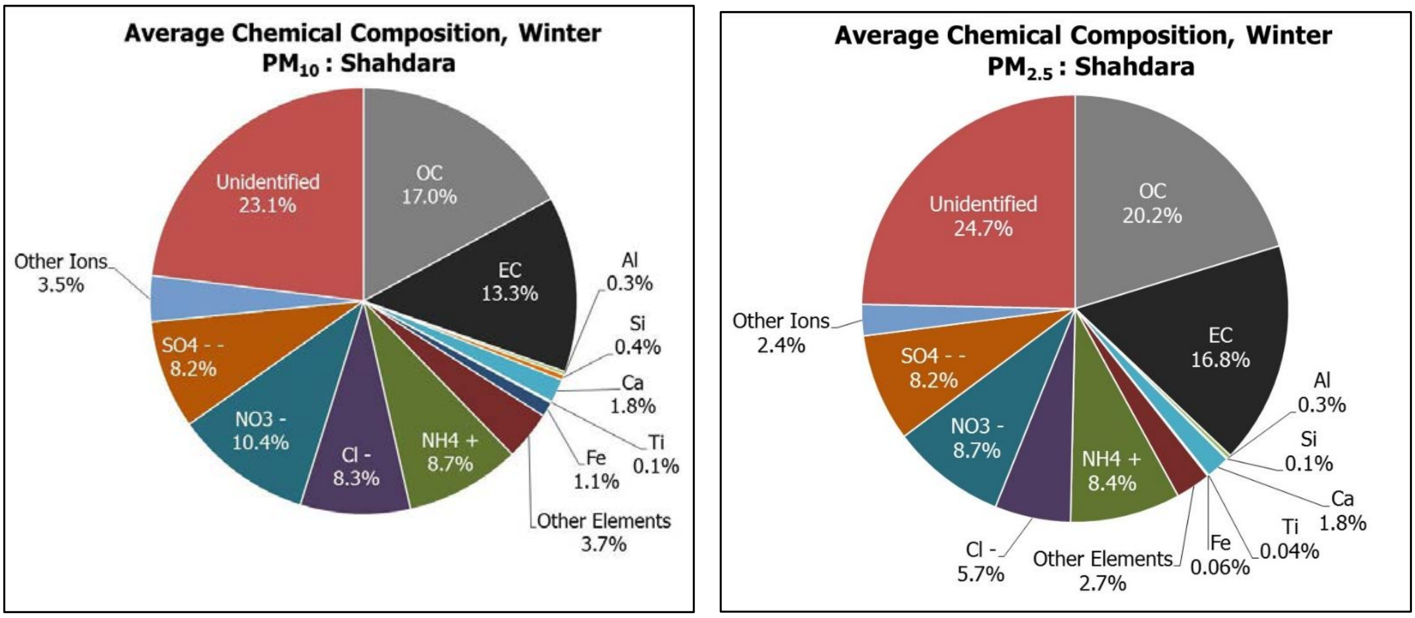


Figure 3.38 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Shahdara in Winter Season

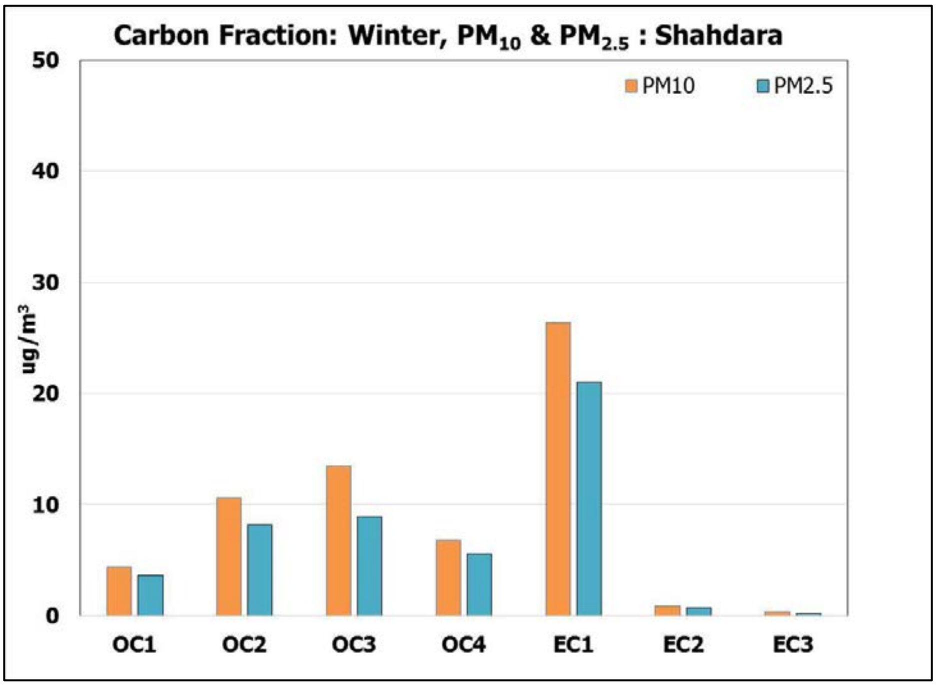


Figure 3.39 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Shahdara in Winter Season

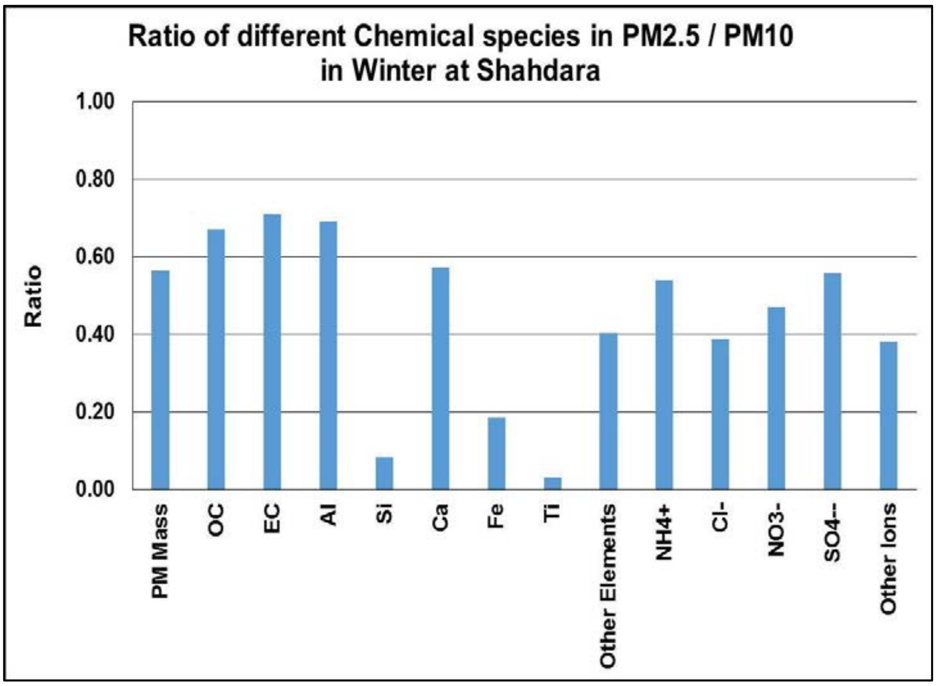


Figure 3.40: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Shahdara

Average concentration for PM_{10} was found to be 245±57 µg/m^3 and was 138±41 µg/m^3 for $PM_{2.5}$. The concentration variation for PM_{10} showed 169 to 354 µg/m^3 and it was 79 to 216 µg/m^3 for $PM_{2.5}$ (see Figure 3.36).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.37.

The carbon fraction in $PM_{2.5}$ and PM_{10} was found to be 51 µg/m^3 and 74 µg/m^3. The percentage mass distribution showed that both organic carbon and elemental carbon in $PM_{2.5}$ is higher as compared to that in PM_{10}. The crustal element in PM_{10} was found to be 4% and was 2% in $PM_{2.5}$. The total ion concentration was found to be 39% in PM_{10} and 33% in $PM_{2.5}$ (see Figure 3.38).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% and 3% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 23% in PM_{10}, while it was a little higher in $PM_{2.5}$ (25%).

The carbon fraction of PM_{10} showed that OC3 was higher than $PM_{2.5}$, followed by OC2, OC4, and OC1. Also, EC1 was found to be higher in PM_{10} than in $PM_{2.5}$, followed by EC2 and EC1 (see Figure 3.39).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.40.

Table 3.29 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Shahdara in Winter Season

	µg/m3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	245	41.70	32.64	0.63	1.02	4.35	2.75	0.26	2.31	3.54	0.66	1.49	20.39	25.48	20.15	0.63	21.33	2.28	3.59
SD	57	14.69	10.38	0.30	0.37	1.91	1.03	0.12	0.95	1.52	0.30	0.60	8.37	4.45	2.48	0.37	2.66	0.83	2.27
Min	168	21.87	19.64	0.21	0.44	2.30	1.34	0.11	0.87	1.96	0.22	0.60	7.34	19.12	15.09	0.18	18.01	1.19	1.05
Max	354	66.47	52.21	1.22	1.80	8.00	4.40	0.48	4.39	7.14	1.27	2.78	37.28	33.77	24.16	1.18	27.00	3.27	8.33
C.V.	0.23	0.35	0.32	0.48	0.36	0.44	0.38	0.45	0.41	0.43	0.46	0.40	0.41	0.17	0.12	0.59	0.12	0.36	0.63
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	334	62.22	47.23	1.10	1.54	6.98	4.24	0.43	3.67	6.09	1.17	2.51	33.14	33.31	23.73	1.15	25.72	3.22	7.31
50 %ile	240	41.21	31.94	0.62	0.98	3.98	2.68	0.25	2.34	3.24	0.65	1.48	19.72	24.84	20.09	0.65	21.24	2.44	3.28
5 %ile	124	19.00	15.94	0.26	0.41	2.14	1.22	0.11	0.91	1.78	0.27	0.60	7.96	13.25	10.05	0.19	11.87	1.05	1.20

Table 3.30 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Shahdara in Winter Season

	µg/m3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	138	27.93	23.18	0.44	0.09	2.50	0.09	0.05	0.94	1.58	0.21	0.42	7.92	12.01	11.26	0.16	11.52	0.98	0.52
SD	41	9.63	9.28	0.32	0.12	0.91	0.04	0.06	0.40	0.49	0.14	0.22	3.67	4.07	2.44	0.16	2.15	0.31	0.37
Min	79	13.91	11.37	0.10	0.01	1.16	0.03	0.00	0.36	0.99	0.01	0.16	2.11	4.89	5.09	0.01	7.98	0.44	0.13
Max	216	44.12	41.29	1.12	0.43	3.67	0.16	0.16	1.54	2.44	0.47	0.85	14.11	17.59	14.76	0.48	14.37	1.47	0.93
C.V.	0.30	0.34	0.40	0.72	1.36	0.36	0.42	1.22	0.42	0.31	0.65	0.52	0.46	0.34	0.22	1.00	0.19	0.32	0.71
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	204	42.51	38.23	0.97	0.26	3.65	0.14	0.15	1.43	2.35	0.44	0.79	12.92	17.38	14.14	0.40	14.07	1.39	0.90
50 %ile	136	27.59	24.42	0.27	0.05	2.52	0.09	0.01	0.88	1.63	0.21	0.39	8.02	12.78	11.45	0.08	11.33	1.03	0.50
5 %ile	79	14.98	12.85	0.13	0.02	1.18	0.04	0.00	0.36	1.01	0.04	0.16	3.24	5.74	7.69	0.02	8.15	0.47	0.15

Table 3.31 Correlation Matrix for PM_{10} and Its major constituents at Shahdara in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.90																			
	0.00																			
EC	0.86	0.97																		
	0.00	*0.00*																		
TC	0.89	1.00	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.60	0.52	0.55	0.54																
	0.05	*0.10*	*0.08*	*0.09*																
NO_3^-	0.95	0.86	0.84	0.86	0.70															
	0.00	*0.00*	*0.00*	*0.00*	*0.02*															
SO_4^{--}	0.55	0.58	0.58	0.58	0.33	0.66														
	0.08	*0.06*	*0.06*	*0.06*	*0.32*	*0.03*														
Na^+	0.76	0.75	0.77	0.76	0.40	0.71	0.34													
	0.01	*0.01*	*0.01*	*0.01*	*0.22*	*0.02*	*0.31*													
NH_4^+	0.43	0.61	0.64	0.63	0.14	0.51	0.83	0.34												
	0.18	*0.05*	*0.03*	*0.04*	*0.69*	*0.11*	*0.00*	*0.30*												
K^+	0.31	0.32	0.31	0.32	0.38	0.16	-0.15	0.58	-0.20											
	0.35	*0.34*	*0.35*	*0.34*	*0.26*	*0.64*	*0.66*	*0.06*	*0.55*											
Ca^{++}	0.59	0.53	0.46	0.50	0.10	0.53	0.52	0.29	0.22	-0.04										
	0.06	*0.09*	*0.16*	*0.11*	*0.77*	*0.09*	*0.10*	*0.39*	*0.52*	*0.91*										
Si	0.93	0.81	0.72	0.78	0.58	0.89	0.55	0.57	0.29	0.25	0.73									
	0.00	*0.00*	*0.01*	*0.01*	*0.06*	*0.00*	*0.08*	*0.07*	*0.39*	*0.46*	*0.01*									
Al	0.77	0.70	0.63	0.68	0.47	0.77	0.56	0.41	0.22	0.10	0.91	0.90								
	0.01	*0.02*	*0.04*	*0.02*	*0.15*	*0.01*	*0.07*	*0.21*	*0.51*	*0.78*	*0.00*	*0.00*								
Ca	0.80	0.80	0.73	0.77	0.47	0.76	0.45	0.52	0.21	0.21	0.85	0.89	0.96							
	0.00	*0.00*	*0.01*	*0.01*	*0.14*	*0.01*	*0.17*	*0.10*	*0.53*	*0.54*	*0.00*	*0.00*	*0.00*							
Fe	0.89	0.86	0.77	0.83	0.35	0.81	0.56	0.51	0.52	0.09	0.67	0.90	0.75	0.77						
	0.00	*0.00*	*0.01*	*0.00*	*0.29*	*0.00*	*0.07*	*0.11*	*0.11*	*0.78*	*0.03*	*0.00*	*0.01*	*0.01*						
Ti	0.89	0.83	0.75	0.80	0.40	0.80	0.49	0.55	0.30	0.22	0.85	0.95	0.93	0.95	0.92					
	0.00	*0.00*	*0.01*	*0.00*	*0.22*	*0.00*	*0.13*	*0.08*	*0.37*	*0.52*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.91	0.74	0.65	0.70	0.52	0.83	0.50	0.59	0.20	0.32	0.77	0.97	0.89	0.86	0.83	0.93				
	0.00	*0.01*	*0.03*	*0.02*	*0.10*	*0.00*	*0.11*	*0.06*	*0.56*	*0.33*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.62	0.58	0.64	0.61	0.25	0.72	0.55	0.65	0.43	-0.08	0.49	0.51	0.58	0.54	0.45	0.52	0.50			
	0.04	*0.06*	*0.03*	*0.05*	*0.45*	*0.01*	*0.08*	*0.03*	*0.19*	*0.83*	*0.13*	*0.11*	*0.06*	*0.09*	*0.16*	*0.10*	*0.12*			
Ni	0.54	0.56	0.60	0.58	0.44	0.63	0.46	0.48	0.18	0.09	0.71	0.58	0.81	0.80	0.38	0.64	0.58	0.77		
	0.09	*0.07*	*0.05*	*0.06*	*0.17*	*0.04*	*0.16*	*0.13*	*0.60*	*0.79*	*0.01*	*0.06*	*0.00*	*0.00*	*0.25*	*0.04*	*0.06*	*0.01*		
Pb	0.75	0.69	0.76	0.73	0.53	0.84	0.65	0.60	0.50	-0.03	0.55	0.65	0.70	0.66	0.56	0.63	0.64	0.89	0.80	
	0.01	*0.02*	*0.01*	*0.01*	*0.09*	*0.00*	*0.03*	*0.05*	*0.12*	*0.93*	*0.08*	*0.03*	*0.02*	*0.03*	*0.07*	*0.04*	*0.04*	*0.00*	*0.00*	
Zn	0.86	0.83	0.86	0.85	0.49	0.91	0.67	0.63	0.64	-0.09	0.56	0.74	0.69	0.70	0.78	0.74	0.68	0.80	0.64	0.91
	0.00	*0.00*	*0.00*	*0.00*	*0.12*	*0.00*	*0.03*	*0.04*	*0.04*	*0.79*	*0.07*	*0.01*	*0.02*	*0.02*	*0.01*	*0.01*	*0.02*	*0.00*	*0.03*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.32 Correlation Matrix for PM$_{2.5}$ and Its major constituents at Shahdara in Winter Season

	PM$_{2.5}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.90																			
	0.00																			
EC	0.90	0.95																		
	0.00	*0.00*																		
TC	0.91	0.99	0.99																	
	0.00	*0.00*	*0.00*																	
Cl$^-$	0.65	0.79	0.82	0.82																
	0.04	*0.01*	*0.00*	*0.00*																
NO$_3^-$	0.73	0.49	0.53	0.52	0.45															
	0.02	*0.15*	*0.12*	*0.13*	*0.19*															
SO$_4^{--}$	0.14	0.09	-0.03	0.03	-0.04	0.33														
	0.70	*0.81*	*0.94*	*0.94*	*0.92*	*0.35*														
Na$^+$	0.80	0.56	0.56	0.57	0.19	0.68	0.29													
	0.02	*0.15*	*0.15*	*0.14*	*0.65*	*0.06*	*0.48*													
NH$_4^+$	0.81	0.78	0.63	0.71	0.28	0.44	0.32	0.73												
	0.00	*0.01*	*0.05*	*0.02*	*0.44*	*0.21*	*0.38*	*0.04*												
K$^+$	0.88	0.85	0.85	0.86	0.72	0.69	0.22	0.52	0.68											
	0.00	*0.00*	*0.00*	*0.00*	*0.02*	*0.03*	*0.54*	*0.19*	*0.03*											
Ca^{++}	0.85	-0.83	-0.90	-0.87	-0.84	0.53	0.54	0.90	0.83	-0.79										
	0.35	*0.37*	*0.29*	*0.32*	*0.37*	*0.65*	*0.64*	*0.29*	*0.37*	*0.42*										
Si	0.17	0.43	0.24	0.33	0.17	0.03	0.13	0.42	0.44	0.14	0.97									
	0.63	*0.22*	*0.51*	*0.35*	*0.63*	*0.93*	*0.72*	*0.31*	*0.20*	*0.70*	*0.17*									
Al	0.49	0.20	0.23	0.22	-0.25	0.29	-0.12	0.62	0.54	0.26	0.93	-0.25								
	0.15	*0.58*	*0.52*	*0.54*	*0.48*	*0.42*	*0.75*	*0.10*	*0.11*	*0.46*	*0.25*	*0.49*								
Ca	0.39	0.45	0.20	0.33	0.03	0.22	0.34	0.05	0.72	0.41	0.99	0.58	0.30							
	0.27	*0.20*	*0.58*	*0.36*	*0.94*	*0.55*	*0.34*	*0.90*	*0.02*	*0.24*	*0.11*	*0.08*	*0.40*							
Fe	0.57	0.72	0.52	0.63	0.43	0.40	0.33	0.55	0.77	0.58	0.53	0.80	0.02	0.83						
	0.11	*0.03*	*0.15*	*0.07*	*0.25*	*0.28*	*0.38*	*0.20*	*0.01*	*0.10*	*0.64*	*0.01*	*0.96*	*0.01*						
Ti	0.27	0.18	0.17	0.18	-0.30	-0.16	0.01	0.16	0.47	0.14	0.97	-0.18	0.78	0.36	0.00					
	0.44	*0.62*	*0.64*	*0.63*	*0.40*	*0.65*	*0.98*	*0.70*	*0.17*	*0.71*	*0.17*	*0.61*	*0.01*	*0.31*	*0.99*					
K	0.76	0.67	0.64	0.66	0.36	0.54	0.24	0.44	0.72	0.85	0.55	0.08	0.55	0.65	0.61	0.51				
	0.01	*0.03*	*0.05*	*0.04*	*0.30*	*0.11*	*0.50*	*0.28*	*0.02*	*0.00*	*0.63*	*0.84*	*0.10*	*0.04*	*0.08*	*0.14*				
S	0.67	0.40	0.55	0.48	0.13	0.56	0.06	0.75	0.49	0.65	0.58	-0.31	0.73	0.06	0.04	0.51	0.70			
	0.03	*0.25*	*0.10*	*0.16*	*0.71*	*0.09*	*0.88*	*0.03*	*0.15*	*0.04*	*0.61*	*0.38*	*0.02*	*0.88*	*0.92*	*0.13*	*0.03*			
Ni	0.41	0.32	0.31	0.32	-0.25	-0.03	-0.12	0.38	0.62	0.17	0.94	0.13	0.90	0.44	0.17	0.95	0.49	0.60		
	0.27	*0.40*	*0.43*	*0.41*	*0.51*	*0.95*	*0.75*	*0.36*	*0.08*	*0.66*	*0.22*	*0.75*	*0.00*	*0.24*	*0.69*	*0.00*	*0.18*	*0.09*		
Pb	0.74	0.53	0.65	0.60	0.52	0.88	-0.09	0.70	0.34	0.64	-0.24	-0.03	0.37	-0.04	0.21	-0.13	0.42	0.64	0.09	
	0.01	*0.12*	*0.04*	*0.07*	*0.13*	*0.00*	*0.81*	*0.05*	*0.34*	*0.05*	*0.84*	*0.93*	*0.30*	*0.91*	*0.58*	*0.73*	*0.23*	*0.05*	*0.82*	
Zn	0.77	0.66	0.73	0.70	0.52	0.76	-0.20	0.71	0.47	0.62	1.00	0.29	0.39	0.20	0.50	-0.02	0.50	0.53	0.28	0.90
	0.01	*0.04*	*0.02*	*0.02*	*0.13*	*0.01*	*0.59*	*0.05*	*0.18*	*0.05*	*0.06*	*0.42*	*0.27*	*0.57*	*0.17*	*0.95*	*0.14*	*0.12*	*0.47*	*0.00*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.29 and Table 3.30 for PM mass and the major species, respectively. PM_{10} mass shows lesser C.V. than $PM_{2.5}$ mass. For the secondary ions, the C.V. observed in PM_{10} and $PM_{2.5}$ was very less, which represents less variation in concentration during the monitoring period.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.31 and Table 3.32 for PM mass and its major species. In PM_{10}, the crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass.

3.1.5 Site 5: Mayur Vihar

3.1.5.1 Summer Season

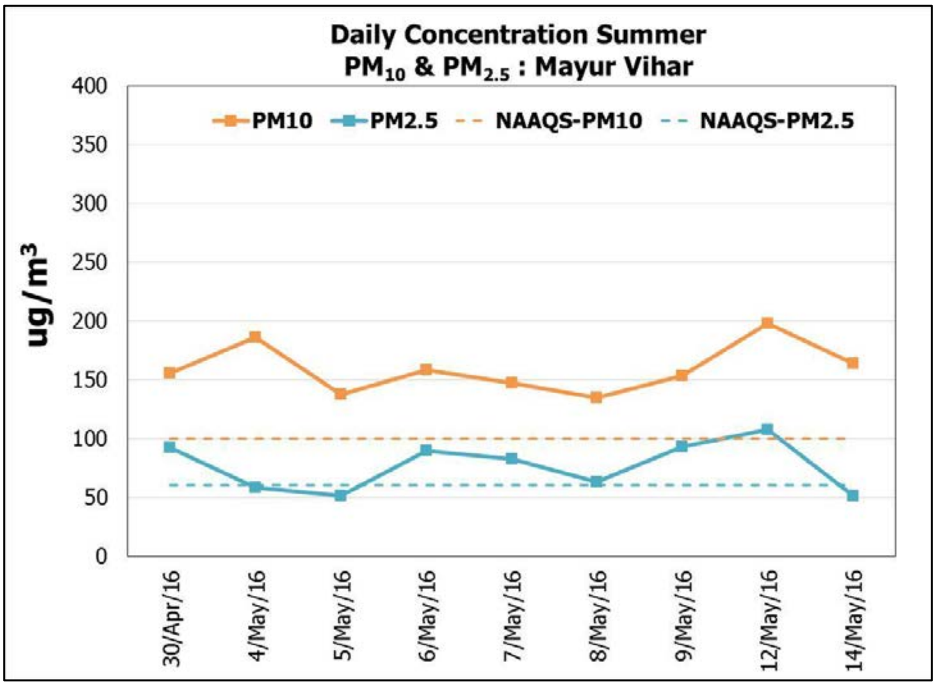


Figure 3.41: Variation in the Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Mayur Vihar in the Summer Season

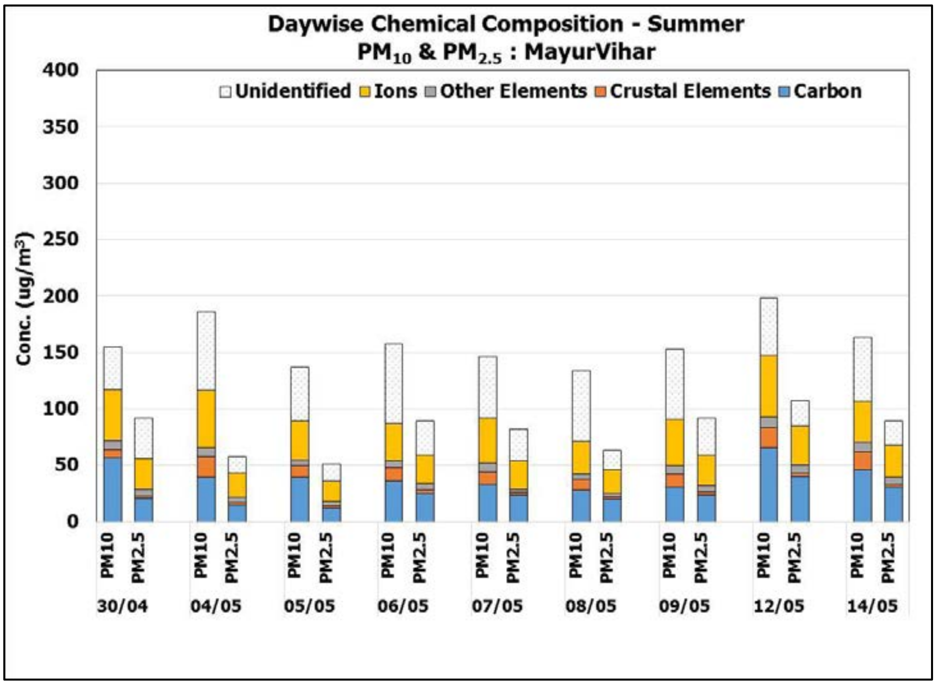


Figure 3.42 Variation in the Chemical Composition of PM_{10} and $PM_{2.5}$ at Mayur Vihar in the Summer Season

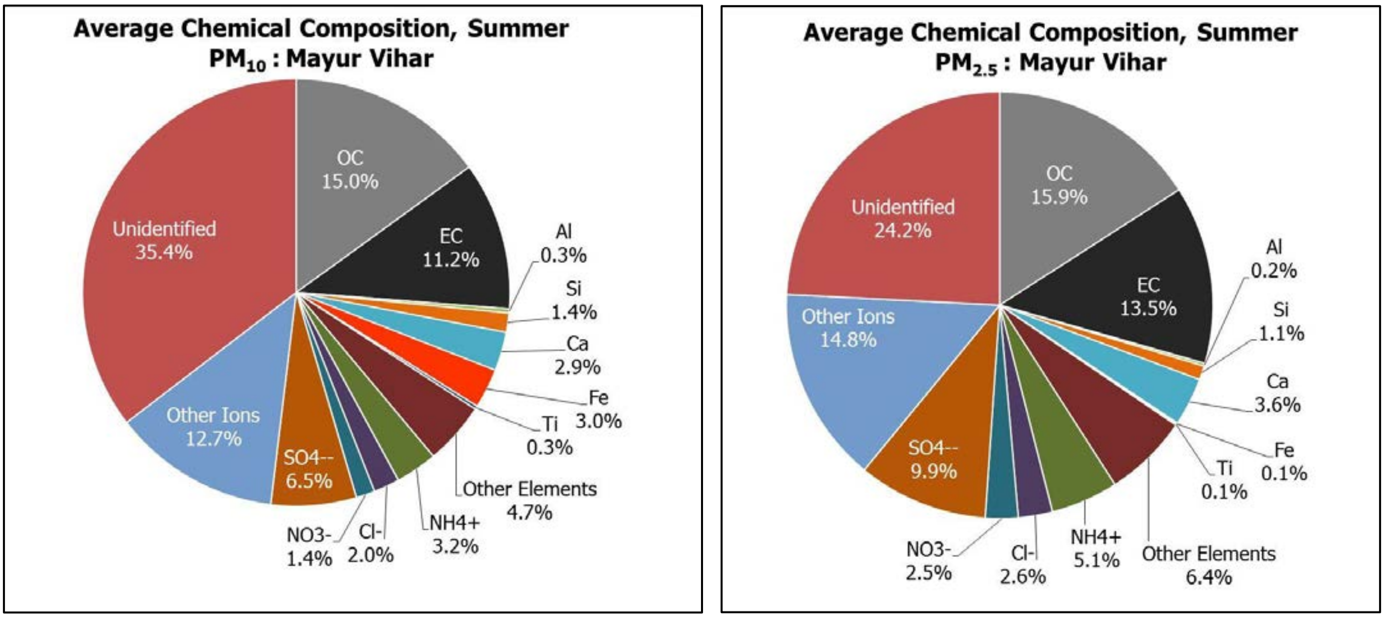


Figure 3.43 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Mayur Vihar in the summer season

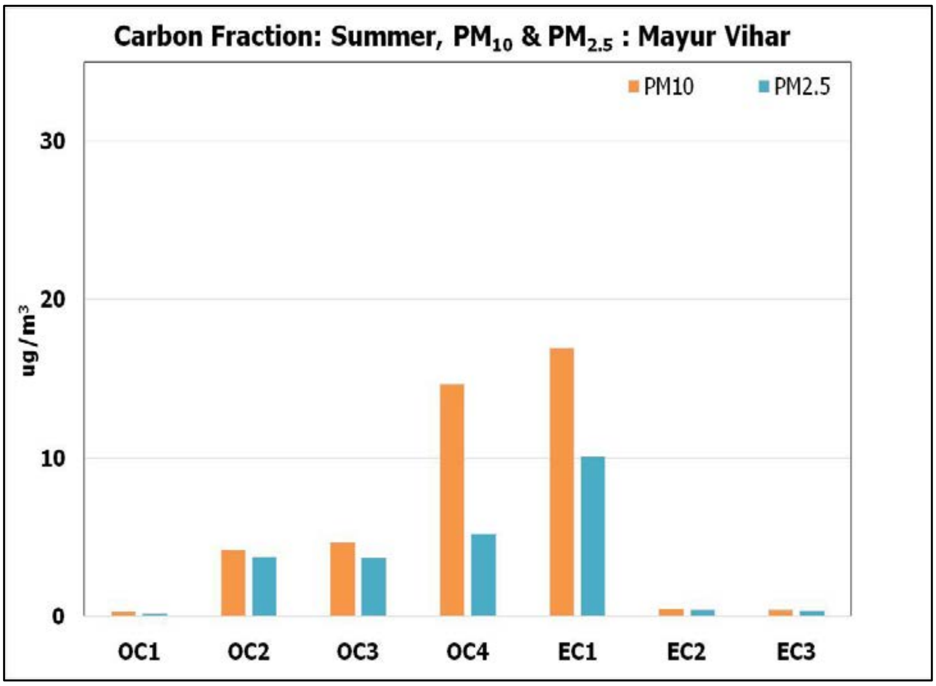


Figure 3.44: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Mayur Vihar in the Summer Season

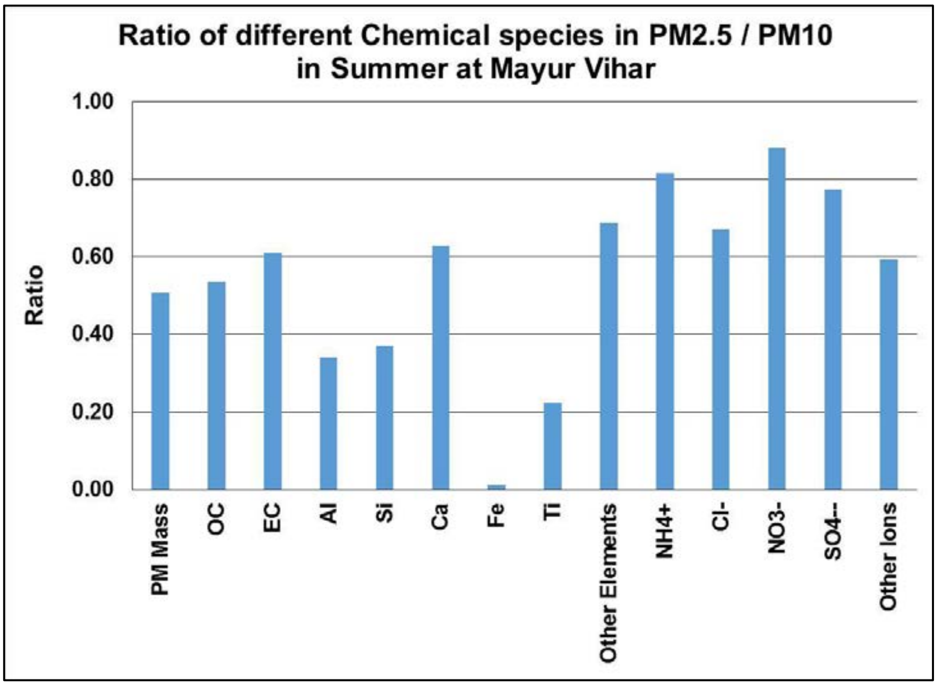


Figure 3.45 Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Mayur Vihar in the Summer Season

At Mayur Vihar (MYR), observed average concentration of PM_{10} and $PM_{2.5}$ was 159±21 µg/m^3 and 81±19 µg/m^3, respectively. Daily concentration of PM_{10} was higher than NAAQS, but in some cases for $PM_{2.5}$, it was nearer to NAAQS. In PM_{10}, variation observed was from 134 to 198 µg/m^3. Similarly, for $PM_{2.5}$, daily concentration variation is 51 to 107 µg/m^3 (see Figure 3.41)..

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.42.

The observed major portion of PM_{10} and $PM_{2.5}$ is carbon fraction, which is almost 42 µg/m^3 and 24 µg/m^3, respectively. The total ion concentration of PM_{10} is 26% and is 33% in $PM_{2.5}$. The crustal elements are 8% in PM_{10} and almost 3% in $PM_{2.5}$. Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% and 6% in PM_{10} and $PM_{2.5}$, respectively. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 35% and 29% for PM_{10} and $PM_{2.5}$, respectively. (See Figure 3.43)

In both PM_{10} and $PM_{2.5}$, EC1 contribution is higher than the other fractions, followed by OC4. EC1 was found to be 17 µg/m^3 and 10 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively, and OC4 was found to be 15 µg/m^3 and 5 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively (see Figure 3.44).Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.45.

Table 3.33 Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM_{10} at Mayur Vihar in Summer Season

µg/m3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	159	23.87	17.86	0.51	2.30	4.68	4.78	0.41	4.44	1.10	0.16	0.40	3.11	2.27	10.27	9.75	5.04	3.63	3.91
SD	21	8.41	4.70	0.28	0.83	1.50	1.37	0.12	1.14	0.28	0.06	0.11	1.10	0.46	2.88	4.78	1.37	0.76	1.35
Min	134	16.56	11.20	0.27	1.39	3.07	2.55	0.21	2.45	0.86	0.08	0.28	1.79	1.65	5.90	4.50	2.95	2.30	2.04
Max	198	42.68	26.89	1.06	3.90	7.06	7.23	0.63	5.95	1.60	0.24	0.59	5.15	3.17	14.97	19.20	7.30	4.95	6.61
C.V.	0.13	0.35	0.26	0.54	0.36	0.32	0.29	0.28	0.26	0.26	0.36	0.29	0.35	0.20	0.28	0.49	0.27	0.21	0.35
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	193	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	155	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	136	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.34 Statistical evaluation **of concentrations ($\mu g/m^3$)** of mass and major species of $PM_{2.5}$ at Mayur Vihar in Summer Season

µg/m3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	81	12.81	10.89	0.17	0.85	2.94	0.06	0.09	3.41	0.79	0.09	0.18	2.09	2.00	7.95	4.93	4.11	2.57	1.85
SD	19	4.23	4.29	0.02	0.16	0.31	0.03	0.01	1.17	0.18	0.04	0.06	0.46	0.40	1.88	0.68	0.95	1.09	0.34
Min	51	7.15	5.12	0.15	0.61	2.59	0.04	0.08	1.54	0.58	0.03	0.10	1.64	1.54	4.76	4.12	2.50	0.83	1.17
Max	107	22.00	18.27	0.21	1.06	3.45	0.12	0.12	5.43	1.16	0.14	0.24	2.86	2.73	10.88	5.95	5.68	4.24	2.32
C.V.	0.23	0.33	0.39	0.13	0.19	0.10	0.46	0.14	0.34	0.23	0.45	0.32	0.22	0.20	0.24	0.14	0.23	0.42	0.18
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	101	19.34	17.30	0.20	1.04	3.43	0.11	0.11	5.01	1.09	0.14	0.24	2.78	2.60	10.46	5.82	5.39	3.95	2.29
50 %ile	89	12.29	11.42	0.16	0.89	2.88	0.05	0.09	3.57	0.78	0.07	0.20	1.91	2.05	7.72	4.76	3.92	2.84	1.87
5 %ile	54	7.79	5.52	0.15	0.62	2.63	0.04	0.08	1.75	0.58	0.04	0.10	1.66	1.56	5.32	4.17	2.79	0.91	1.36

Table 3.35 Correlation Matrix for PM_{10} and Its major constituents at Mayur Vihar in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.73																			
	0.03																			
EC	0.44	0.76																		
	0.24	*0.02*																		
TC	0.67	0.97	0.90																	
	0.05	*0.00*	*0.00*																	
Cl^-	0.66	0.90	0.73	0.89																
	0.05	*0.00*	*0.03*	*0.00*																
NO_3^-	0.44	0.58	0.16	0.45	0.70															
	0.24	*0.10*	*0.68*	*0.22*	*0.04*															
SO_4^{--}	0.49	0.56	0.36	0.52	0.64	0.67														
	0.18	*0.12*	*0.34*	*0.15*	*0.07*	*0.05*														
Na^+	0.51	0.29	0.44	0.36	0.07	-0.45	0.04													
	0.16	*0.45*	*0.24*	*0.34*	*0.85*	*0.22*	*0.93*													
NH_4^+	0.56	0.51	0.25	0.44	0.67	0.91	0.66	-0.28												
	0.12	*0.16*	*0.52*	*0.24*	*0.05*	*0.00*	*0.05*	*0.48*												
K^+	0.93	0.71	0.48	0.66	0.74	0.50	0.61	0.42	0.62											
	0.00	*0.03*	*0.19*	*0.05*	*0.02*	*0.18*	*0.08*	*0.26*	*0.08*											
Ca^{++}	0.82	0.33	0.11	0.27	0.30	0.05	0.08	0.59	0.21	0.79										
	0.01	*0.39*	*0.77*	*0.49*	*0.44*	*0.90*	*0.84*	*0.10*	*0.58*	*0.01*										
Si	0.86	0.71	0.33	0.61	0.66	0.56	0.24	0.20	0.59	0.82	0.74									
	0.00	*0.03*	*0.38*	*0.08*	*0.05*	*0.12*	*0.54*	*0.61*	*0.10*	*0.01*	*0.02*									
Al	0.86	0.75	0.27	0.61	0.65	0.55	0.44	0.22	0.49	0.83	0.68	0.90								
	0.00	*0.02*	*0.49*	*0.08*	*0.06*	*0.12*	*0.24*	*0.58*	*0.18*	*0.01*	*0.04*	*0.00*								
Ca	0.89	0.54	0.16	0.43	0.45	0.24	0.22	0.51	0.29	0.83	0.93	0.85	0.88							
	0.00	*0.13*	*0.69*	*0.25*	*0.23*	*0.53*	*0.57*	*0.16*	*0.46*	*0.01*	*0.00*	*0.00*	*0.00*							
Fe	0.73	0.24	-0.20	0.09	0.19	0.17	0.06	0.33	0.20	0.64	0.90	0.71	0.75	0.93						
	0.03	*0.53*	*0.60*	*0.82*	*0.62*	*0.66*	*0.87*	*0.38*	*0.60*	*0.06*	*0.00*	*0.03*	*0.02*	*0.00*						
Ti	0.65	0.12	-0.32	-0.04	0.02	0.07	0.00	0.32	0.10	0.54	0.84	0.62	0.69	0.87	0.98					
	0.06	*0.76*	*0.40*	*0.92*	*0.95*	*0.86*	*1.00*	*0.40*	*0.80*	*0.14*	*0.01*	*0.08*	*0.04*	*0.00*	*0.00*					
K	0.84	0.66	0.46	0.62	0.73	0.41	0.61	0.37	0.47	0.95	0.73	0.71	0.81	0.78	0.61	0.52				
	0.00	*0.06*	*0.22*	*0.08*	*0.02*	*0.27*	*0.08*	*0.33*	*0.20*	*0.00*	*0.03*	*0.03*	*0.01*	*0.01*	*0.08*	*0.16*				
S	0.34	0.52	0.67	0.61	0.45	0.27	0.76	0.30	0.37	0.39	-0.11	0.03	0.17	-0.03	-0.30	-0.32	0.36			
	0.37	*0.15*	*0.05*	*0.08*	*0.22*	*0.49*	*0.02*	*0.43*	*0.33*	*0.30*	*0.77*	*0.94*	*0.66*	*0.93*	*0.43*	*0.41*	*0.34*			
Ni	0.72	0.21	-0.21	0.07	0.20	0.21	0.04	0.28	0.28	0.66	0.91	0.75	0.73	0.91	0.99	0.95	0.61	-0.34		
	0.03	*0.58*	*0.60*	*0.86*	*0.61*	*0.58*	*0.93*	*0.47*	*0.47*	*0.05*	*0.00*	*0.02*	*0.03*	*0.00*	*0.00*	*0.00*	*0.08*	*0.38*		
Pb	0.37	0.73	0.58	0.72	0.72	0.43	0.62	0.00	0.25	0.44	-0.02	0.31	0.56	0.22	-0.01	-0.05	0.60	0.57	-0.08	
	0.33	*0.03*	*0.10*	*0.03*	*0.03*	*0.25*	*0.07*	*0.99*	*0.51*	*0.24*	*0.96*	*0.42*	*0.12*	*0.56*	*0.98*	*0.89*	*0.09*	*0.11*	*0.85*	
Zn	0.31	0.58	0.23	0.48	0.56	0.51	0.05	-0.25	0.29	0.38	0.21	0.69	0.67	0.43	0.29	0.22	0.40	-0.16	0.32	0.52
	0.41	*0.10*	*0.56*	*0.19*	*0.12*	*0.16*	*0.90*	*0.51*	*0.46*	*0.32*	*0.59*	*0.04*	*0.05*	*0.25*	*0.45*	*0.58*	*0.28*	*0.68*	*0.40*	*0.15*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.36 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Mayur Vihar in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.00																			
EC	0.85	0.93																		
	0.00	*0.00*																		
TC	0.87	0.98	0.98																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.42	0.20	0.41	0.31																
	0.26	*0.62*	*0.28*	*0.42*																
NO_3^-	0.76	0.85	0.90	0.89	0.22															
	0.02	*0.00*	*0.00*	*0.00*	*0.57*															
SO_4^{--}	0.80	0.77	0.77	0.78	0.31	0.73														
	0.01	*0.02*	*0.02*	*0.01*	*0.42*	*0.03*														
Na^+	0.85	0.77	0.72	0.76	0.43	0.48	0.55													
	0.00	*0.02*	*0.03*	*0.02*	*0.25*	*0.19*	*0.13*													
NH_4^+	0.80	0.75	0.68	0.73	0.10	0.83	0.72	0.45												
	0.01	*0.02*	*0.04*	*0.03*	*0.81*	*0.01*	*0.03*	*0.22*												
K^+	0.57	0.61	0.53	0.58	0.06	0.40	0.18	0.81	0.27											
	0.11	*0.08*	*0.14*	*0.10*	*0.88*	*0.29*	*0.64*	*0.01*	*0.49*											
Ca^{++}	0.71	0.70	0.62	0.67	-0.05	0.74	0.68	0.42	0.90	0.37										
	0.03	*0.04*	*0.08*	*0.05*	*0.91*	*0.02*	*0.05*	*0.26*	*0.00*	*0.33*										
Si	0.57	0.36	0.35	0.36	0.05	0.19	0.10	0.69	0.24	0.79	0.29									
	0.11	*0.34*	*0.35*	*0.34*	*0.90*	*0.62*	*0.80*	*0.04*	*0.54*	*0.01*	*0.45*									
Al	0.62	0.87	0.87	0.89	0.20	0.75	0.47	0.69	0.43	0.74	0.46	0.38								
	0.08	*0.00*	*0.00*	*0.00*	*0.62*	*0.02*	*0.20*	*0.04*	*0.25*	*0.02*	*0.21*	*0.32*								
Ca	0.68	0.73	0.64	0.69	-0.18	0.85	0.57	0.38	0.91	0.43	0.89	0.33	0.53							
	0.04	*0.03*	*0.07*	*0.04*	*0.65*	*0.00*	*0.11*	*0.31*	*0.00*	*0.25*	*0.00*	*0.39*	*0.14*							
Fe	0.57	0.84	0.72	0.80	-0.07	0.77	0.40	0.58	0.62	0.70	0.59	0.28	0.87	0.76						
	0.11	*0.00*	*0.03*	*0.01*	*0.86*	*0.02*	*0.29*	*0.11*	*0.08*	*0.04*	*0.09*	*0.46*	*0.00*	*0.02*						
Ti	0.51	0.53	0.32	0.43	-0.20	0.25	0.38	0.70	0.33	0.79	0.49	0.58	0.45	0.45	0.54					
	0.16	*0.15*	*0.40*	*0.25*	*0.61*	*0.51*	*0.32*	*0.04*	*0.38*	*0.01*	*0.19*	*0.10*	*0.23*	*0.22*	*0.13*					
K	0.63	0.71	0.60	0.66	0.01	0.42	0.28	0.86	0.33	0.97	0.41	0.78	0.78	0.47	0.73	0.80				
	0.07	*0.03*	*0.09*	*0.05*	*0.99*	*0.26*	*0.47*	*0.00*	*0.38*	*0.00*	*0.27*	*0.01*	*0.01*	*0.21*	*0.03*	*0.01*				
S	0.89	0.86	0.80	0.84	0.16	0.72	0.89	0.77	0.70	0.52	0.64	0.44	0.62	0.65	0.58	0.65	0.62			
	0.00	*0.00*	*0.01*	*0.00*	*0.68*	*0.03*	*0.00*	*0.02*	*0.04*	*0.15*	*0.06*	*0.24*	*0.08*	*0.06*	*0.10*	*0.06*	*0.08*			
Ni	0.29	0.35	0.41	0.39	0.08	0.63	0.08	0.08	0.57	0.30	0.62	0.15	0.43	0.67	0.55	0.00	0.21	0.03		
	0.45	*0.36*	*0.27*	*0.31*	*0.83*	*0.07*	*0.85*	*0.85*	*0.11*	*0.44*	*0.08*	*0.69*	*0.25*	*0.05*	*0.13*	*0.99*	*0.58*	*0.93*		
Pb	0.63	0.68	0.70	0.70	0.46	0.37	0.61	0.82	0.14	0.57	0.14	0.38	0.69	0.06	0.39	0.49	0.64	0.71	-0.24	
	0.07	*0.05*	*0.04*	*0.04*	*0.22*	*0.33*	*0.08*	*0.01*	*0.72*	*0.11*	*0.72*	*0.31*	*0.04*	*0.88*	*0.30*	*0.18*	*0.06*	*0.03*	*0.53*	
Zn	0.77	0.67	0.66	0.67	0.21	0.48	0.31	0.86	0.44	0.84	0.38	0.90	0.65	0.48	0.56	0.55	0.87	0.63	0.23	0.58
	0.02	*0.05*	*0.06*	*0.05*	*0.58*	*0.19*	*0.42*	*0.00*	*0.23*	*0.01*	*0.31*	*0.00*	*0.06*	*0.20*	*0.12*	*0.13*	*0.00*	*0.07*	*0.55*	*0.10*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.33 and Table 3.34 for PM mass and the major species, respectively. PM_{10} mass and secondary ions (NH_4^+, NO_3-, and SO_4^{--}) has lesser C.V. than $PM_{2.5}$. Also, C.V. (NH_4^+, NO_3- & SO_4^{--}) was found to be similar.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.35 and Table 3.36 for PM mass and major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation in PM_{10} mass. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other in $PM_{2.5}$.

3.1.5.2 Winter Season

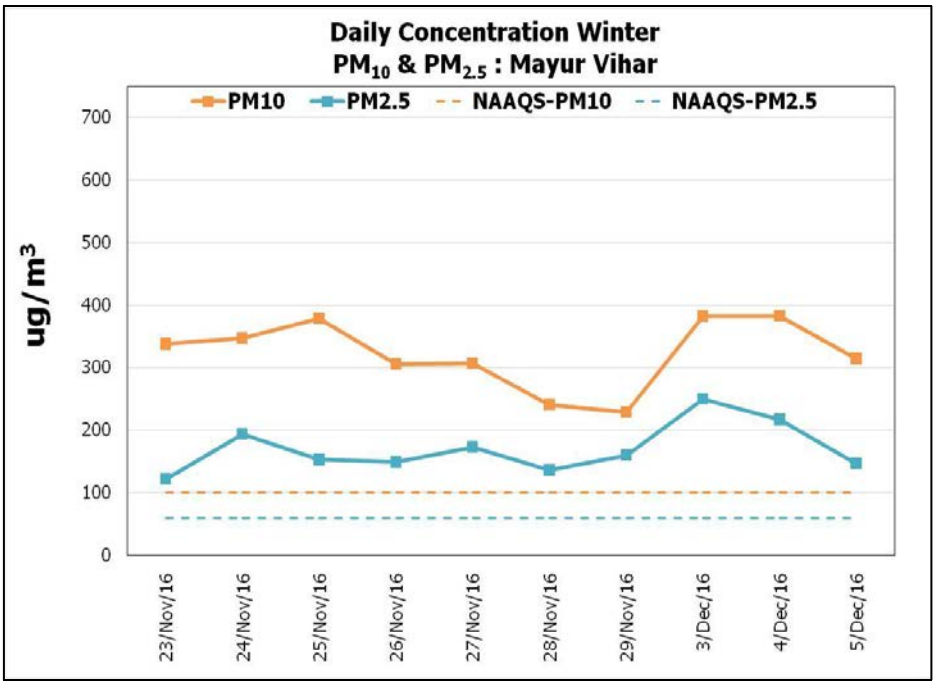


Figure 3.46: Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Mayur Vihar in Winter Season

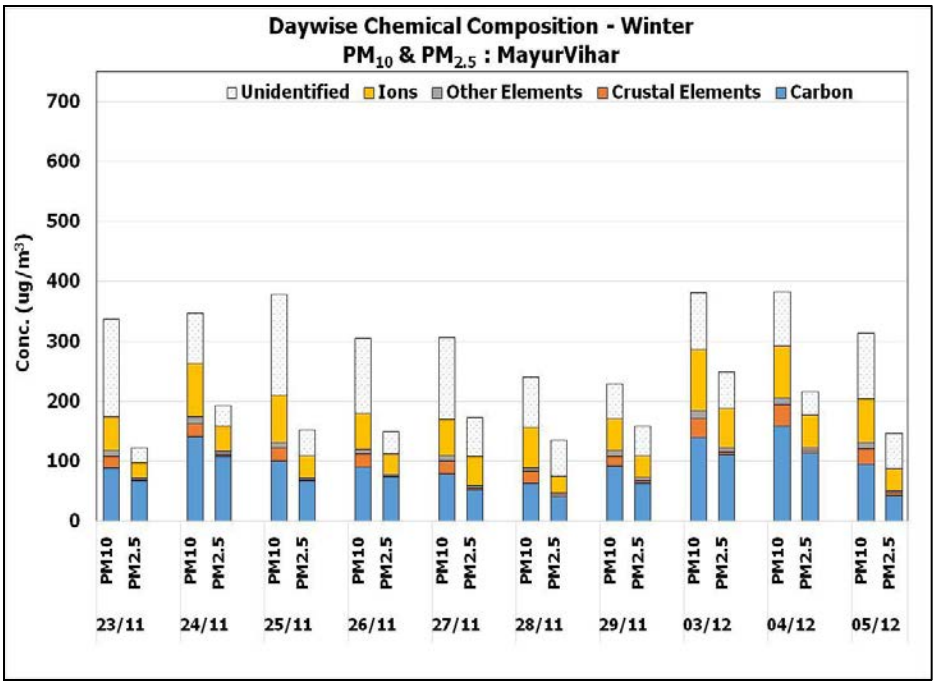


Figure 3.47 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Mayur Vihar in Winter Season

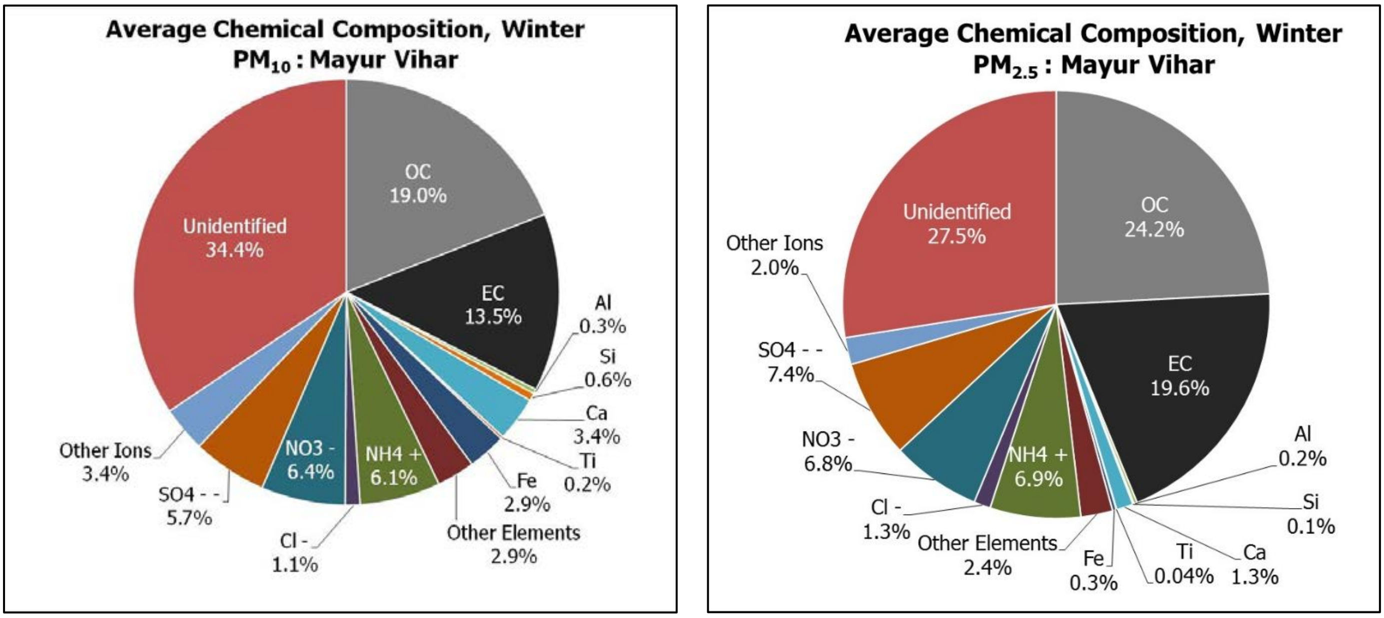


Figure 3.48: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Mayur Vihar in Winter Season

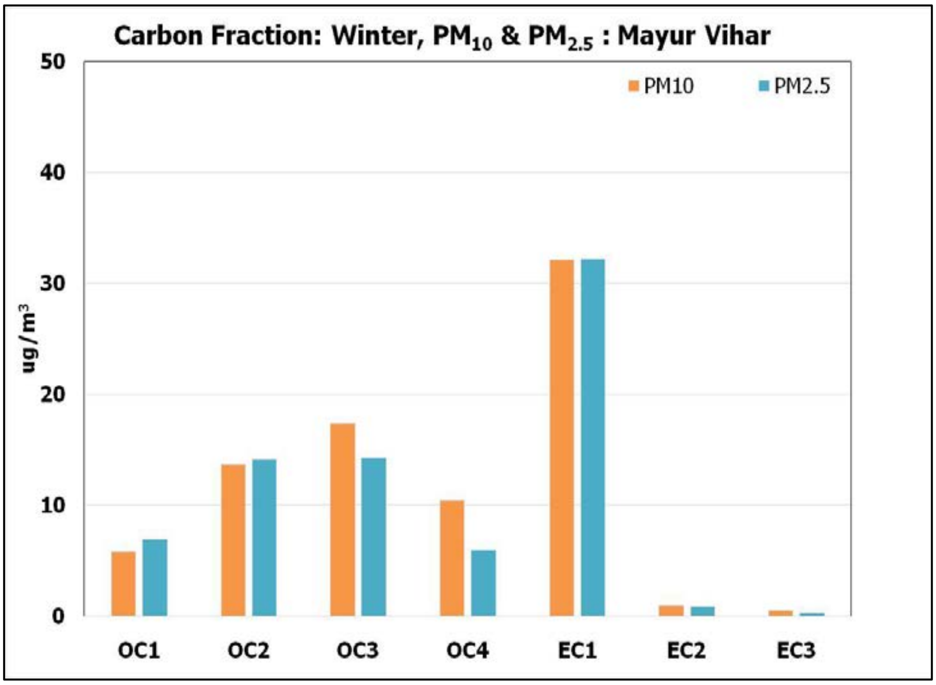


Figure 3.49: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Mayur Vihar in Winter Season

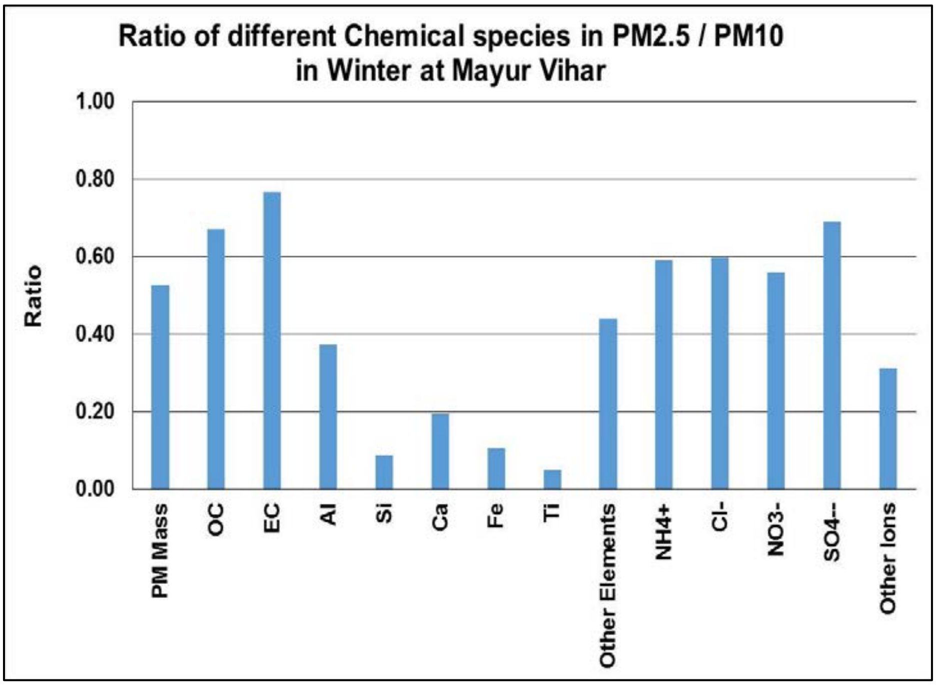


Figure 3.50: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Mayur Vihar in Winter Season

At Mayur Vihar, the average concentration for PM_{10} was found to be 323±55 µg/m^3, which is 3.2 times higher than that of NAAQS, and for $PM_{2.5}$, it was found to be 170±39 µg/m^3. Average concentration of PM_{10} varied from 229 to 383 µg/m^3, while $PM_{2.5}$ varied from 122 to 250 µg/m^3 (see Figure 3.46).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.47.

Carbon fraction was found to be the major portion, followed by the total ions and crustal elements. The carbon fraction for PM_{10} was found to be 105 µg/m^3, while it was found to be higher for $PM_{2.5}$ (74 µg/m^3). The percentage mass distribution of organic carbon and elemental carbon of $PM_{2.5}$ was found to be higher as compared to that of PM_{10}. The total ion concentration was found to be 23% in PM_{10} and 24% in $PM_{2.5}$. The crustal element of PM_{10} was found to be 7%, while it was 2 % for $PM_{2.5}$ (see Figure 3.48).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} and 2% in $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 34% in PM_{10} and 28% in $PM_{2.5}$.

OC3 was found to be higher in PM_{10}, followed by OC2, OC4, OC1, and In case of $PM_{2.5}$, OC2 and OC3 was found to be similar, followed by OC4 and OC1. EC1 was found to be higher in both PM_{10} and $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.49). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.50.

Table 3.37 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Mayur Vihar in Winter Season

µg/m3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	323	61.43	43.58	1.12	1.90	10.94	9.36	0.63	4.87	2.00	0.24	0.96	3.60	20.60	18.29	1.15	19.75	3.54	5.70
SD	55	17.60	14.30	0.21	0.81	2.79	1.99	0.13	1.15	0.49	0.05	0.28	1.21	5.64	3.71	0.56	4.68	1.16	2.41
Min	229	41.20	23.20	0.83	1.10	8.07	6.84	0.46	2.91	1.04	0.16	0.70	2.23	14.25	12.54	0.48	13.83	2.19	2.53
Max	383	98.40	65.11	1.55	3.53	16.90	13.07	0.89	6.50	2.91	0.30	1.67	5.90	32.14	24.41	1.89	27.92	5.75	9.54
C.V.	0.17	0.29	0.33	0.19	0.43	0.25	0.21	0.20	0.24	0.25	0.21	0.29	0.34	0.27	0.20	0.49	0.24	0.33	0.42
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	382	89.42	64.22	1.42	3.36	15.59	12.70	0.83	6.42	2.73	0.30	1.41	5.41	29.65	23.97	1.80	26.90	5.56	9.35
50 %ile	323	57.89	39.47	1.12	1.71	9.94	9.01	0.59	4.84	1.96	0.25	0.90	3.60	20.05	18.49	1.15	19.07	3.31	5.10
5 %ile	151	30.58	19.19	0.55	0.97	5.69	4.66	0.31	2.12	0.79	0.11	0.51	1.77	10.37	8.57	0.51	9.71	1.73	2.48

Table 3.38 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Mayur Vihar in Winter Season

µg/m3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	170	41.13	33.34	0.42	0.17	2.14	0.47	0.07	2.07	1.13	0.14	0.31	2.14	11.52	12.62	0.15	11.64	1.52	0.99
SD	39	15.56	13.34	0.29	0.05	0.84	0.21	0.05	0.85	0.35	0.04	0.11	0.96	4.44	3.62	0.04	3.94	0.66	0.83
Min	122	23.72	16.76	0.08	0.10	1.17	0.27	0.01	1.21	0.48	0.08	0.14	1.02	6.76	7.48	0.11	7.65	1.07	0.08
Max	250	70.07	54.28	0.78	0.23	3.22	0.86	0.15	3.72	1.59	0.21	0.52	3.71	21.06	17.82	0.22	18.63	3.10	2.29
C.V.	0.23	0.38	0.40	0.70	0.27	0.39	0.45	0.72	0.41	0.31	0.30	0.35	0.45	0.39	0.29	0.30	0.34	0.44	0.83
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	235	64.07	53.55	0.78	0.23	3.18	0.78	0.13	3.60	1.50	0.20	0.45	3.60	18.24	17.25	0.20	17.12	2.74	2.19
50 %ile	156	38.13	32.37	0.43	0.18	2.39	0.41	0.08	1.73	1.28	0.14	0.33	1.87	11.77	12.52	0.13	9.52	1.20	1.01
5 %ile	128	24.21	17.43	0.09	0.11	1.18	0.27	0.01	1.31	0.63	0.08	0.16	1.09	6.76	7.71	0.12	7.88	1.09	0.11

Table 3.39 Correlation Matrix for PM_{10} and Its major constituents at Mayur Vihar in Winter Season

	PM_{10}	OC	EC	TC	Cl-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.68																			
	0.03																			
EC	0.72	0.87																		
	0.02	*0.00*																		
TC	0.72	0.97	0.96																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.34	0.17	0.12	0.15																
	0.34	*0.64*	*0.74*	*0.68*																
NO_3^-	0.64	0.70	0.69	0.72	0.31															
	0.05	*0.03*	*0.03*	*0.02*	*0.39*															
SO_4^{--}	0.54	0.53	0.62	0.59	0.15	0.72														
	0.11	*0.12*	*0.06*	*0.07*	*0.67*	*0.02*														
Na^+	0.73	0.41	0.54	0.48	-0.18	0.40	0.18													
	0.04	*0.31*	*0.17*	*0.23*	*0.68*	*0.33*	*0.67*													
NH_4^+	0.65	0.73	0.78	0.78	-0.04	0.79	0.91	0.52												
	0.04	*0.02*	*0.01*	*0.01*	*0.92*	*0.01*	*0.00*	*0.18*												
K^+	0.57	0.62	0.85	0.74	0.05	0.75	0.85	0.34	0.85											
	0.09	*0.06*	*0.00*	*0.01*	*0.90*	*0.01*	*0.00*	*0.41*	*0.00*											
Ca^{++}	0.65	0.75	0.72	0.76	0.24	0.75	0.46	0.37	0.55	0.64										
	0.04	*0.01*	*0.02*	*0.01*	*0.51*	*0.01*	*0.18*	*0.36*	*0.10*	*0.05*										
Si	0.62	0.76	0.73	0.77	0.57	0.80	0.47	0.32	0.53	0.57	0.80									
	0.06	*0.01*	*0.02*	*0.01*	*0.08*	*0.01*	*0.17*	*0.44*	*0.11*	*0.09*	*0.01*									
Al	0.60	0.52	0.25	0.41	0.54	0.36	-0.06	0.44	0.04	-0.06	0.59	0.55								
	0.06	*0.13*	*0.49*	*0.24*	*0.11*	*0.31*	*0.87*	*0.28*	*0.91*	*0.88*	*0.07*	*0.10*								
Ca	0.64	0.77	0.59	0.72	0.49	0.74	0.45	0.31	0.48	0.46	0.87	0.83	0.78							
	0.05	*0.01*	*0.07*	*0.02*	*0.15*	*0.02*	*0.19*	*0.45*	*0.16*	*0.18*	*0.00*	*0.00*	*0.01*							
Fe	0.79	0.76	0.79	0.80	0.43	0.80	0.59	0.48	0.63	0.70	0.92	0.89	0.59	0.89						
	0.01	*0.01*	*0.01*	*0.01*	*0.21*	*0.01*	*0.07*	*0.23*	*0.05*	*0.03*	*0.00*	*0.00*	*0.07*	*0.00*						
Ti	0.73	0.82	0.80	0.84	0.04	0.68	0.53	0.71	0.70	0.61	0.76	0.71	0.48	0.78	0.85					
	0.02	*0.00*	*0.01*	*0.00*	*0.91*	*0.03*	*0.12*	*0.05*	*0.02*	*0.06*	*0.01*	*0.02*	*0.16*	*0.01*	*0.00*					
K	0.78	0.76	0.91	0.85	0.34	0.63	0.69	0.37	0.70	0.85	0.71	0.67	0.33	0.64	0.82	0.68				
	0.01	*0.01*	*0.00*	*0.00*	*0.33*	*0.05*	*0.03*	*0.37*	*0.02*	*0.00*	*0.02*	*0.03*	*0.36*	*0.05*	*0.00*	*0.03*				
S	0.72	0.70	0.85	0.80	0.40	0.58	0.34	0.45	0.45	0.64	0.79	0.84	0.48	0.65	0.86	0.68	0.83			
	0.02	*0.02*	*0.00*	*0.01*	*0.25*	*0.08*	*0.33*	*0.27*	*0.20*	*0.05*	*0.01*	*0.00*	*0.16*	*0.04*	*0.00*	*0.03*	*0.00*			
Ni	-0.18	0.33	0.15	0.26	0.29	0.27	-0.08	-0.48	-0.11	0.11	0.46	0.41	0.35	0.54	0.29	0.13	0.16	0.25		
	0.61	*0.35*	*0.68*	*0.47*	*0.42*	*0.45*	*0.83*	*0.23*	*0.76*	*0.76*	*0.18*	*0.24*	*0.32*	*0.11*	*0.41*	*0.72*	*0.67*	*0.50*		
Pb	0.74	0.45	0.53	0.50	0.43	0.18	0.24	0.58	0.27	0.24	0.35	0.49	0.51	0.46	0.62	0.62	0.62	0.65	-0.24	
	0.01	*0.20*	*0.11*	*0.14*	*0.22*	*0.62*	*0.51*	*0.13*	*0.46*	*0.50*	*0.32*	*0.16*	*0.13*	*0.18*	*0.06*	*0.06*	*0.06*	*0.04*	*0.51*	
Zn	0.38	0.62	0.77	0.71	-0.18	0.29	0.63	0.30	0.69	0.74	0.29	0.22	-0.19	0.19	0.35	0.49	0.74	0.41	-0.01	0.31
	0.28	*0.06*	*0.01*	*0.02*	*0.61*	*0.42*	*0.05*	*0.47*	*0.03*	*0.01*	*0.43*	*0.55*	*0.60*	*0.59*	*0.32*	*0.15*	*0.01*	*0.24*	*0.98*	*0.38*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.40 The Correlation Matrix for PM$_{2.5}$ and Its major constituents at Mayur Vihar in Winter Season

	PM$_{2.5}$	OC	EC	TC	Cl-	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.77																			
	0.01																			
EC	0.78	0.83																		
	0.01	*0.00*																		
TC	0.81	0.96	0.95																	
	0.01	*0.00*	*0.00*																	
Cl$^-$	0.54	0.33	0.25	0.30																
	0.11	*0.36*	*0.50*	*0.40*																
NO$_3^-$	0.77	0.39	0.35	0.39	0.64															
	0.01	*0.27*	*0.33*	*0.27*	*0.05*															
SO$_4^{--}$	0.91	0.70	0.79	0.78	0.42	0.66														
	0.00	*0.02*	*0.01*	*0.01*	*0.22*	*0.04*														
Na$^+$	0.81	0.31	0.68	0.53	0.56	0.70	0.70													
	0.09	*0.61*	*0.20*	*0.36*	*0.32*	*0.19*	*0.19*													
NH$_4^+$	0.93	0.61	0.77	0.71	0.37	0.67	0.93	0.80												
	0.00	*0.06*	*0.01*	*0.02*	*0.29*	*0.04*	*0.00*	*0.10*												
K$^+$	0.86	0.65	0.81	0.75	0.35	0.55	0.68	0.93	0.77											
	0.00	*0.04*	*0.01*	*0.01*	*0.32*	*0.10*	*0.03*	*0.02*	*0.01*											
Ca^{++}	0.54	0.40	0.05	0.25	0.68	0.68	0.38	-0.06	0.32	0.25										
	0.11	*0.25*	*0.88*	*0.49*	*0.03*	*0.03*	*0.27*	*0.92*	*0.36*	*0.48*										
Si	0.46	0.23	0.24	0.25	0.34	0.50	0.42	0.44	0.31	0.53	0.46									
	0.18	*0.52*	*0.51*	*0.49*	*0.33*	*0.14*	*0.22*	*0.46*	*0.39*	*0.12*	*0.19*									
Al	0.37	0.16	-0.21	-0.01	0.43	0.57	0.14	-0.27	0.20	0.13	0.83	0.27								
	0.30	*0.67*	*0.56*	*0.97*	*0.21*	*0.09*	*0.71*	*0.66*	*0.57*	*0.73*	*0.00*	*0.45*								
Ca	0.55	0.22	-0.02	0.11	0.52	0.72	0.30	0.26	0.44	0.34	0.73	0.21	0.92							
	0.10	*0.55*	*0.95*	*0.76*	*0.13*	*0.02*	*0.41*	*0.68*	*0.21*	*0.34*	*0.02*	*0.56*	*0.00*							
Fe	0.75	0.43	0.50	0.48	0.27	0.62	0.64	0.74	0.70	0.79	0.54	0.71	0.40	0.46						
	0.01	*0.22*	*0.14*	*0.16*	*0.45*	*0.05*	*0.05*	*0.15*	*0.02*	*0.01*	*0.10*	*0.02*	*0.25*	*0.18*						
Ti	0.32	0.00	-0.28	-0.14	0.41	0.58	0.09	-0.11	0.19	0.13	0.71	0.29	0.97	0.94	0.36					
	0.37	*1.00*	*0.43*	*0.71*	*0.24*	*0.08*	*0.81*	*0.86*	*0.59*	*0.73*	*0.02*	*0.43*	*0.00*	*0.00*	*0.30*					
K	0.75	0.50	0.77	0.65	0.12	0.37	0.67	0.79	0.78	0.92	0.10	0.46	-0.04	0.16	0.83	-0.04				
	0.01	*0.14*	*0.01*	*0.04*	*0.74*	*0.29*	*0.04*	*0.11*	*0.01*	*0.00*	*0.79*	*0.18*	*0.92*	*0.66*	*0.00*	*0.92*				
S	0.73	0.42	0.34	0.40	0.52	0.62	0.60	0.81	0.68	0.58	0.75	0.50	0.71	0.71	0.81	0.66	0.56			
	0.02	*0.23*	*0.34*	*0.25*	*0.12*	*0.06*	*0.07*	*0.10*	*0.03*	*0.08*	*0.01*	*0.14*	*0.02*	*0.02*	*0.01*	*0.04*	*0.10*			
Ni	0.33	0.18	-0.22	0.00	0.43	0.52	0.09	-0.33	0.15	0.07	0.80	0.18	0.99	0.91	0.30	0.95	-0.12	0.64		
	0.35	*0.61*	*0.54*	*0.99*	*0.22*	*0.12*	*0.80*	*0.59*	*0.67*	*0.84*	*0.01*	*0.62*	*0.00*	*0.00*	*0.41*	*0.00*	*0.75*	*0.05*		
Pb	0.70	0.21	0.40	0.31	0.45	0.52	0.66	0.88	0.73	0.68	0.39	0.65	0.33	0.45	0.79	0.40	0.73	0.80	0.24	
	0.03	*0.56*	*0.25*	*0.38*	*0.19*	*0.13*	*0.04*	*0.05*	*0.02*	*0.03*	*0.27*	*0.04*	*0.35*	*0.19*	*0.01*	*0.26*	*0.02*	*0.01*	*0.51*	
Zn	0.79	0.47	0.47	0.49	0.27	0.64	0.55	0.90	0.74	0.80	0.53	0.40	0.57	0.71	0.87	0.55	0.77	0.81	0.51	0.69
	0.01	*0.17*	*0.17*	*0.15*	*0.46*	*0.05*	*0.10*	*0.04*	*0.02*	*0.01*	*0.12*	*0.25*	*0.09*	*0.02*	*0.00*	*0.10*	*0.01*	*0.01*	*0.13*	*0.03*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.37 and Table 3.38 for PM mass and major species, respectively. PM_{10} mass and $PM_{2.5}$ mass shows similar C.V. For secondary ions, C.V. observed in PM_{10} was lesser than in $PM_{2.5}$.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.39 and Table 3.40 for PM mass and its major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other.

3.1.6 Site 6: Janakpuri

3.1.6.1 Summer Season

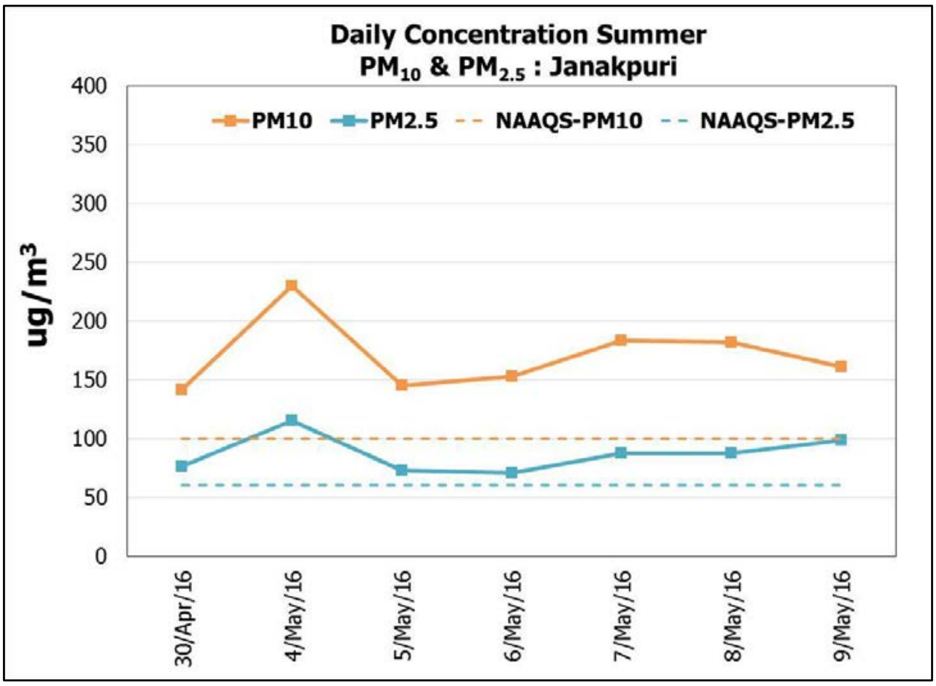


Figure 3.51: Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Janakpuri in Summer Season

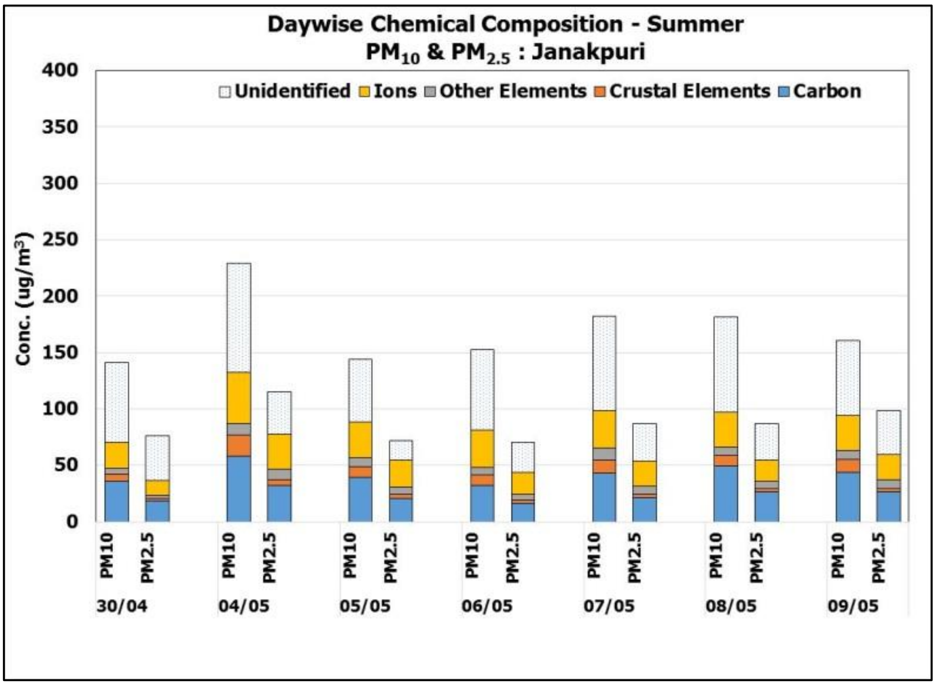


Figure 3.52: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Janakpuri in Summer Season

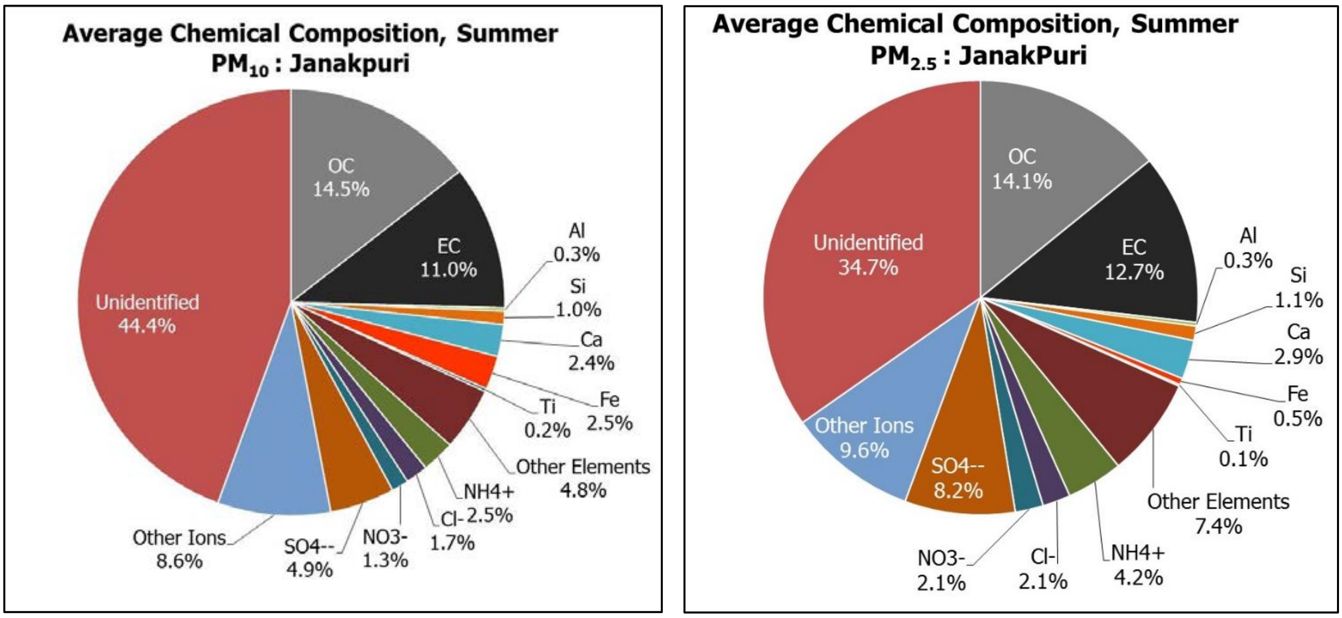


Figure 3.53 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Janakpuri in the Summer Season

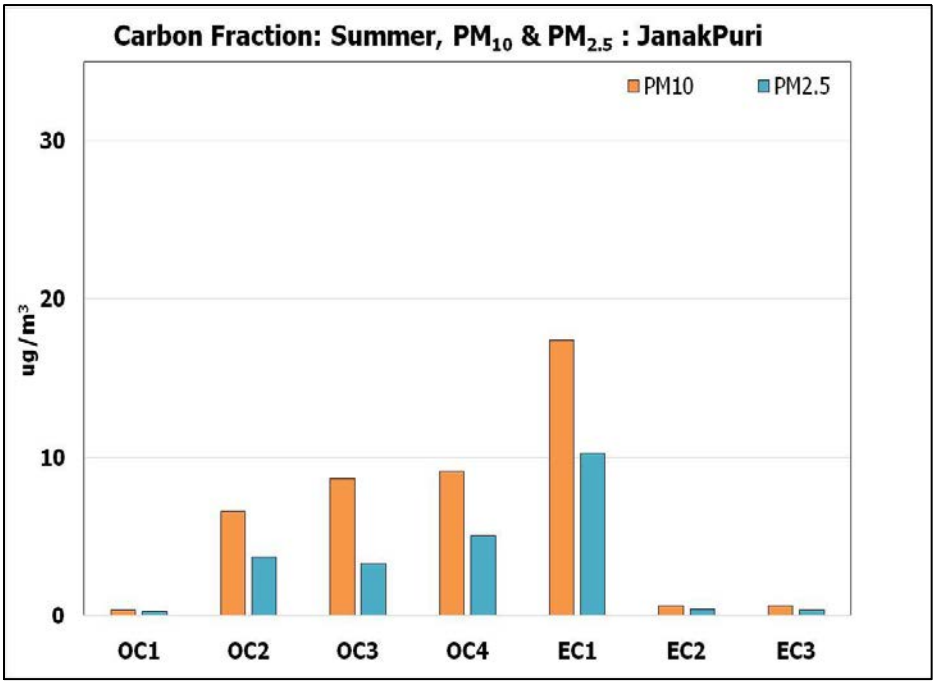


Figure 3.54 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Janakpuri in Summer Season

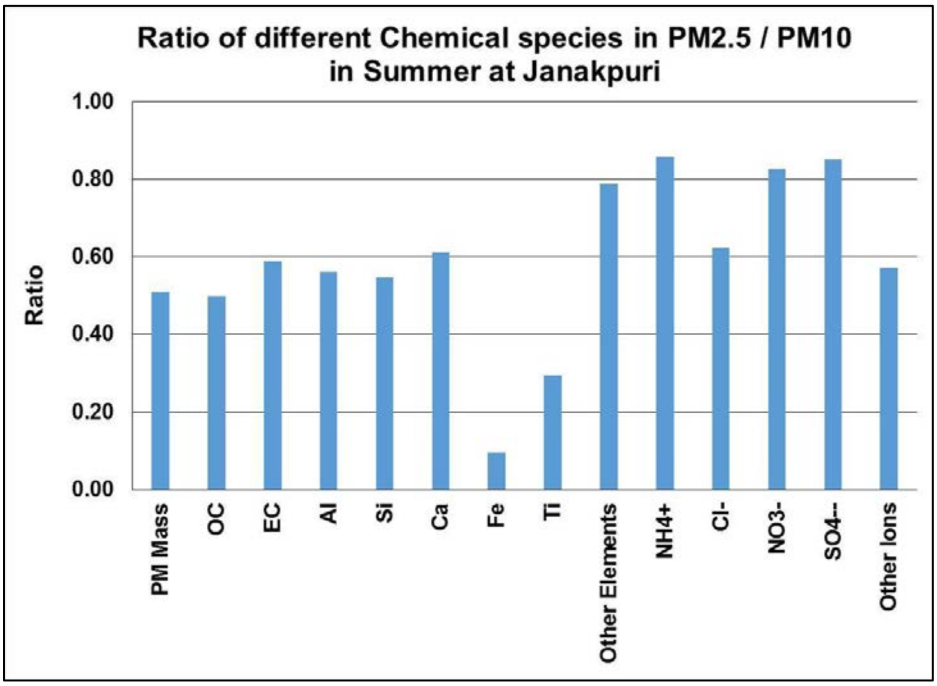


Figure 3.55: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Janakpuri in the Summer Season

At Janakpuri (JKP) site, observed average concentration of PM_{10} and $PM_{2.5}$ was 171±31 µg/m³ and 87±16 µg/m³, respectively, which is higher than NAAQS. In PM_{10}, daily concentration observed was from 142 to 230 µg/m³. Similarly, for $PM_{2.5}$, daily concentration was 71 to 115 µg/m³ (see Figure 3.51).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.52.

Carbon fraction contributes 26% (43 µg/m³) in PM_{10}, while its observed concentration in $PM_{2.5}$ is 27% (23 µg/m³). The total ion concentration in PM_{10} is 19% and it is 25% in $PM_{2.5}$. Concentration of crustal elements in PM_{10} is 6% and it is 4% in $PM_{2.5}$ (see Figure 3.53).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% in PM_{10} and 7% in $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 44% for PM_{10} and 37% for $PM_{2.5}$.

EC1 is the highest in both PM_{10} and $PM_{2.5}$, followed by OC4. In both PM_{10} and $PM_{2.5}$, the EC1 contribution is higher than the other fractions. EC1 for PM_{10} and $PM_{2.5}$ is 17 µg/m³ and 10 µg/m³, respectively, while OC4 for PM_{10} and $PM_{2.5}$ is 9 µg/m³ and 5 µg/m³, respectively (see Figure 3.54). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.55.

Table 3.41 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM_{10} at Janakpuri in Summer Season

µg/m3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	171	24.67	18.68	0.43	1.70	4.14	4.34	0.39	5.27	1.01	0.16	0.36	2.89	2.19	8.35	3.01	4.24	4.49	3.30
SD	31	5.11	3.86	0.22	0.49	1.43	1.51	0.14	1.60	0.32	0.07	0.11	0.65	0.48	1.55	1.41	0.64	1.52	1.04
Min	142	17.93	14.24	0.26	1.39	2.77	2.24	0.19	3.30	0.54	0.10	0.17	1.72	1.48	5.79	1.24	3.17	2.29	2.18
Max	230	32.21	26.10	0.92	2.75	7.13	7.25	0.63	7.75	1.47	0.31	0.53	3.50	2.96	10.41	5.42	5.08	6.66	5.31
C.V.	0.18	0.21	0.21	0.52	0.29	0.34	0.35	0.35	0.30	0.31	0.47	0.30	0.22	0.22	0.19	0.47	0.15	0.34	0.32
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	216	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	161	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	143	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.42 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at Janakpuri in Summer Season

µg/m3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	87	12.28	11.00	0.24	0.93	2.53	0.42	0.11	4.52	0.77	0.16	0.17	1.80	1.81	7.12	1.73	3.64	3.68	1.87
SD	16	2.58	3.15	0.08	0.11	0.79	0.27	0.02	1.55	0.21	0.07	0.11	0.40	0.43	1.40	0.87	0.62	1.49	0.73
Min	71	8.58	7.84	0.16	0.82	1.74	0.09	0.09	2.01	0.48	0.05	0.08	1.25	1.10	4.65	0.93	2.81	1.15	1.22
Max	115	15.95	16.26	0.38	1.08	3.98	0.79	0.15	6.46	1.08	0.25	0.38	2.51	2.37	8.93	3.10	4.69	5.90	3.12
C.V.	0.18	0.21	0.29	0.35	0.12	0.31	0.64	0.19	0.34	0.27	0.43	0.67	0.22	0.24	0.20	0.50	0.17	0.41	0.39
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	110	15.74	15.54	0.36	1.08	3.71	0.75	0.15	6.29	1.05	0.23	0.34	2.32	2.31	8.80	2.94	4.54	5.59	2.97
50 %ile	87	11.88	10.77	0.20	0.86	2.44	0.37	0.11	4.46	0.77	0.16	0.12	1.87	1.94	7.01	1.39	3.45	3.38	1.62
5 %ile	71	9.27	7.87	0.16	0.83	1.79	0.12	0.09	2.46	0.52	0.07	0.09	1.31	1.22	5.20	0.95	2.96	1.73	1.24

Table 3.43 Correlation Matrix for PM_{10} and Its major constituents at Janakpuri in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.83																			
	0.02																			
EC	0.95	0.93																		
	0.00	*0.00*																		
TC	0.90	0.99	0.98																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.39	0.42	0.37	0.41																
	0.39	*0.35*	*0.41*	*0.37*																
NO_3^-	0.66	0.56	0.68	0.62	0.81															
	0.11	*0.19*	*0.09*	*0.13*	*0.03*															
SO_4^{--}	0.87	0.89	0.85	0.89	0.62	0.70														
	0.01	*0.01*	*0.02*	*0.01*	*0.14*	*0.08*														
Na^+	0.44	0.03	0.38	0.19	0.13	0.51	0.04													
	0.32	*0.94*	*0.40*	*0.69*	*0.78*	*0.24*	*0.93*													
NH_4^+	0.62	0.72	0.67	0.71	0.77	0.80	0.89	-0.02												
	0.14	*0.07*	*0.10*	*0.07*	*0.05*	*0.03*	*0.01*	*0.97*												
K^+	0.64	0.29	0.52	0.39	0.32	0.60	0.58	0.47	0.59											
	0.12	*0.54*	*0.24*	*0.39*	*0.49*	*0.15*	*0.17*	*0.29*	*0.16*											
Ca^{++}	0.88	0.56	0.75	0.66	0.57	0.79	0.70	0.67	0.52	0.67										
	0.01	*0.19*	*0.05*	*0.11*	*0.19*	*0.04*	*0.08*	*0.10*	*0.23*	*0.10*										
Si	0.88	0.68	0.88	0.78	0.36	0.68	0.66	0.68	0.53	0.65	0.81									
	0.01	*0.10*	*0.01*	*0.04*	*0.43*	*0.10*	*0.11*	*0.09*	*0.23*	*0.12*	*0.03*									
Al	0.89	0.72	0.90	0.81	0.46	0.72	0.71	0.63	0.59	0.62	0.83	0.99								
	0.01	*0.07*	*0.01*	*0.03*	*0.30*	*0.07*	*0.07*	*0.13*	*0.16*	*0.13*	*0.02*	*0.00*								
Ca	0.84	0.64	0.83	0.73	0.54	0.78	0.69	0.66	0.63	0.69	0.82	0.97	0.98							
	0.02	*0.13*	*0.02*	*0.06*	*0.22*	*0.04*	*0.09*	*0.10*	*0.13*	*0.08*	*0.02*	*0.00*	*0.00*							
Fe	0.92	0.75	0.87	0.82	0.63	0.81	0.87	0.48	0.77	0.74	0.88	0.91	0.94	0.94						
	0.00	*0.05*	*0.01*	*0.03*	*0.13*	*0.03*	*0.01*	*0.28*	*0.04*	*0.06*	*0.01*	*0.01*	*0.00*	*0.00*						
Ti	0.88	0.80	0.86	0.84	0.69	0.78	0.90	0.34	0.83	0.65	0.80	0.86	0.91	0.91	0.98					
	0.01	*0.03*	*0.01*	*0.02*	*0.09*	*0.04*	*0.01*	*0.46*	*0.02*	*0.11*	*0.03*	*0.01*	*0.01*	*0.00*	*0.00*					
K	0.73	0.43	0.65	0.54	0.19	0.60	0.64	0.45	0.59	0.95	0.67	0.68	0.64	0.67	0.73	0.63				
	0.07	*0.33*	*0.11*	*0.21*	*0.68*	*0.16*	*0.13*	*0.31*	*0.17*	*0.00*	*0.10*	*0.10*	*0.12*	*0.10*	*0.07*	*0.13*				
S	0.54	0.61	0.55	0.60	0.41	0.36	0.76	-0.20	0.79	0.58	0.27	0.49	0.53	0.55	0.66	0.75	0.53			
	0.22	*0.14*	*0.20*	*0.16*	*0.36*	*0.43*	*0.05*	*0.66*	*0.04*	*0.17*	*0.55*	*0.26*	*0.22*	*0.20*	*0.10*	*0.05*	*0.23*			
Ni	0.87	0.64	0.79	0.72	0.66	0.81	0.82	0.51	0.76	0.80	0.88	0.88	0.91	0.94	0.99	0.96	0.74	0.66		
	0.01	*0.12*	*0.04*	*0.07*	*0.11*	*0.03*	*0.02*	*0.25*	*0.05*	*0.03*	*0.01*	*0.01*	*0.01*	*0.00*	*0.00*	*0.00*	*0.06*	*0.11*		
Pb	0.80	0.65	0.86	0.75	0.44	0.85	0.63	0.72	0.60	0.63	0.81	0.90	0.89	0.90	0.83	0.76	0.72	0.32	0.80	
	0.03	*0.12*	*0.01*	*0.05*	*0.32*	*0.02*	*0.13*	*0.07*	*0.16*	*0.13*	*0.03*	*0.01*	*0.01*	*0.01*	*0.02*	*0.05*	*0.07*	*0.49*	*0.03*	
Zn	0.70	0.55	0.70	0.62	0.71	0.96	0.73	0.51	0.83	0.78	0.77	0.73	0.76	0.83	0.85	0.81	0.77	0.51	0.87	0.87
	0.08	*0.21*	*0.08*	*0.13*	*0.07*	*0.00*	*0.06*	*0.24*	*0.02*	*0.04*	*0.04*	*0.06*	*0.05*	*0.02*	*0.02*	*0.03*	*0.04*	*0.24*	*0.01*	*0.01*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.44 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Janakpuri in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.76																			
	0.05																			
EC	0.98	0.78																		
	0.00	*0.04*																		
TC	0.93	0.93	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.50	0.15	0.60	0.42																
	0.26	*0.76*	*0.16*	*0.35*																
NO_3^-	0.66	0.30	0.69	0.55	0.66															
	0.11	*0.51*	*0.09*	*0.21*	*0.11*															
SO_4^{--}	0.70	0.42	0.80	0.66	0.76	0.82														
	0.08	*0.35*	*0.03*	*0.10*	*0.05*	*0.02*														
Na^+	0.51	0.41	0.54	0.51	0.05	0.53	0.64													
	0.24	*0.37*	*0.22*	*0.25*	*0.92*	*0.22*	*0.12*													
NH_4^+	0.82	0.68	0.89	0.85	0.66	0.81	0.88	0.64												
	0.03	*0.09*	*0.01*	*0.02*	*0.11*	*0.03*	*0.01*	*0.12*												
K^+	0.61	0.40	0.66	0.57	0.43	0.86	0.82	0.85	0.86											
	0.15	*0.38*	*0.11*	*0.18*	*0.34*	*0.01*	*0.03*	*0.02*	*0.01*											
Ca^{++}	0.46	0.46	0.45	0.49	-0.21	0.34	0.46	0.94	0.47	0.67										
	0.30	*0.30*	*0.31*	*0.27*	*0.65*	*0.46*	*0.30*	*0.00*	*0.29*	*0.10*										
Si	0.87	0.56	0.88	0.78	0.57	0.51	0.76	0.44	0.65	0.43	0.41									
	0.01	*0.20*	*0.01*	*0.04*	*0.18*	*0.25*	*0.05*	*0.33*	*0.11*	*0.33*	*0.36*									
Al	0.53	0.82	0.62	0.75	0.44	0.27	0.40	-0.02	0.59	0.17	-0.03	0.43								
	0.22	*0.03*	*0.14*	*0.05*	*0.33*	*0.57*	*0.37*	*0.97*	*0.17*	*0.72*	*0.96*	*0.34*								
Ca	0.57	0.47	0.63	0.59	0.22	0.62	0.79	0.80	0.63	0.71	0.81	0.66	0.25							
	0.18	*0.29*	*0.13*	*0.16*	*0.63*	*0.14*	*0.04*	*0.03*	*0.13*	*0.07*	*0.03*	*0.11*	*0.59*							
Fe	0.63	0.76	0.65	0.74	0.18	0.60	0.46	0.59	0.80	0.75	0.51	0.23	0.53	0.41						
	0.13	*0.05*	*0.12*	*0.06*	*0.71*	*0.15*	*0.30*	*0.16*	*0.03*	*0.05*	*0.25*	*0.62*	*0.22*	*0.36*						
Ti	0.63	0.92	0.69	0.84	0.13	0.41	0.49	0.43	0.66	0.45	0.51	0.48	0.81	0.65	0.72					
	0.13	*0.00*	*0.09*	*0.02*	*0.78*	*0.36*	*0.26*	*0.33*	*0.11*	*0.31*	*0.25*	*0.27*	*0.03*	*0.12*	*0.07*					
K	0.84	0.56	0.90	0.79	0.76	0.81	0.89	0.60	0.97	0.83	0.38	0.72	0.47	0.55	0.67	0.48				
	0.02	*0.19*	*0.01*	*0.03*	*0.05*	*0.03*	*0.01*	*0.16*	*0.00*	*0.02*	*0.40*	*0.07*	*0.29*	*0.20*	*0.10*	*0.28*				
S	0.79	0.62	0.81	0.77	0.45	0.77	0.72	0.74	0.93	0.90	0.57	0.51	0.36	0.52	0.88	0.53	0.91			
	0.04	*0.14*	*0.03*	*0.05*	*0.31*	*0.04*	*0.07*	*0.06*	*0.00*	*0.01*	*0.18*	*0.24*	*0.43*	*0.23*	*0.01*	*0.22*	*0.01*			
Ni	0.59	0.87	0.64	0.78	0.18	0.55	0.46	0.48	0.78	0.67	0.43	0.26	0.80	0.48	0.99	0.98	0.62	0.83		
	0.22	*0.02*	*0.17*	*0.07*	*0.73*	*0.26*	*0.36*	*0.33*	*0.07*	*0.14*	*0.39*	*0.62*	*0.06*	*0.33*	*0.00*	*0.00*	*0.19*	*0.04*		
Pb	0.76	0.81	0.87	0.89	0.61	0.64	0.83	0.52	0.92	0.68	0.41	0.67	0.81	0.66	0.72	0.83	0.84	0.75	0.81	
	0.05	*0.03*	*0.01*	*0.01*	*0.15*	*0.12*	*0.02*	*0.24*	*0.00*	*0.09*	*0.36*	*0.10*	*0.03*	*0.11*	*0.07*	*0.02*	*0.02*	*0.05*	*0.05*	
Zn	0.73	0.89	0.71	0.84	0.00	0.47	0.39	0.48	0.61	0.48	0.58	0.49	0.64	0.61	0.77	0.92	0.46	0.60	0.88	0.68
	0.06	*0.01*	*0.07*	*0.02*	*0.99*	*0.29*	*0.39*	*0.28*	*0.14*	*0.28*	*0.18*	*0.27*	*0.12*	*0.15*	*0.04*	*0.00*	*0.29*	*0.16*	*0.02*	*0.09*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.41 and Table 3.42 for PM mass and major species, respectively. PM_{10} mass and secondary ions (NH_4^+, NO_3-, and SO_4^{--}) has similar C.V. In $PM_{2.5}$.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.43 and Table 3.44 for PM mass and major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. Also, secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other in both $PM_{2.5}$ and PM_{10}.

3.1.6.2 Winter Season

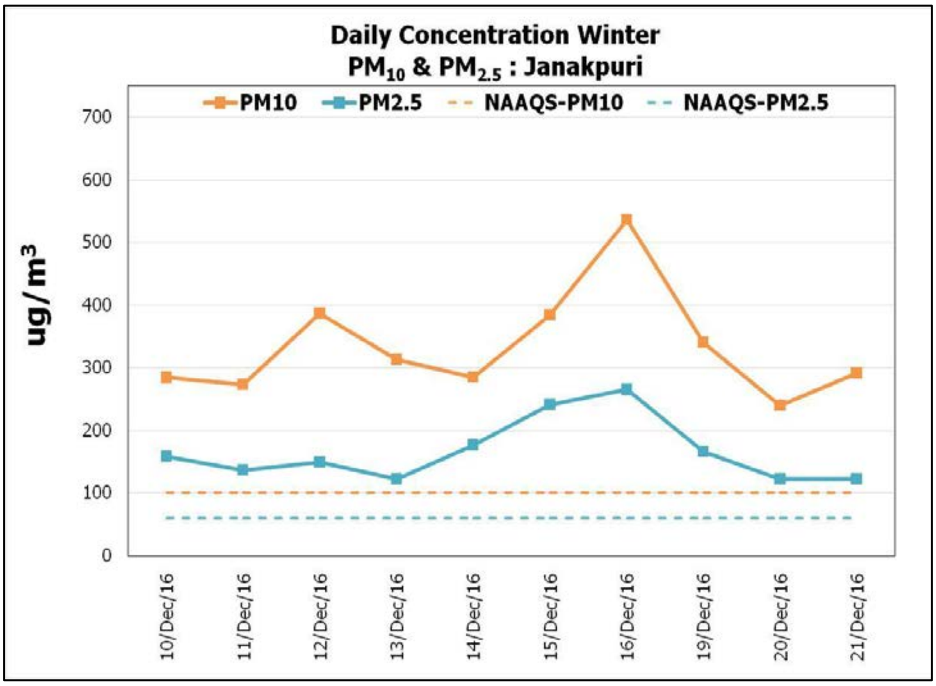


Figure 3.56 Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Janakpuri in Winter Season

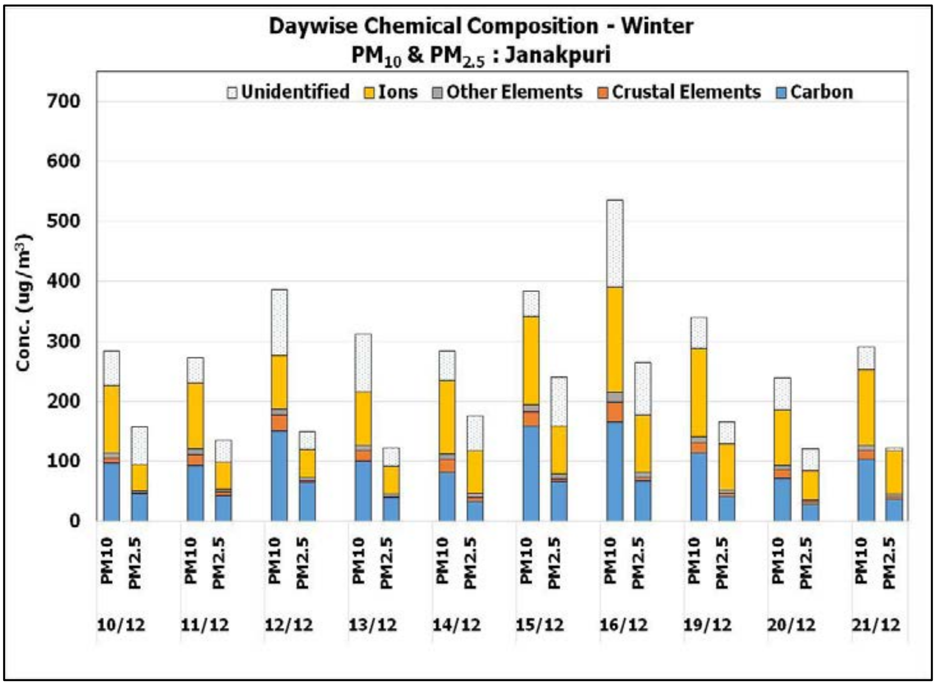


Figure 3.57: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Janakpuri in Winter Season

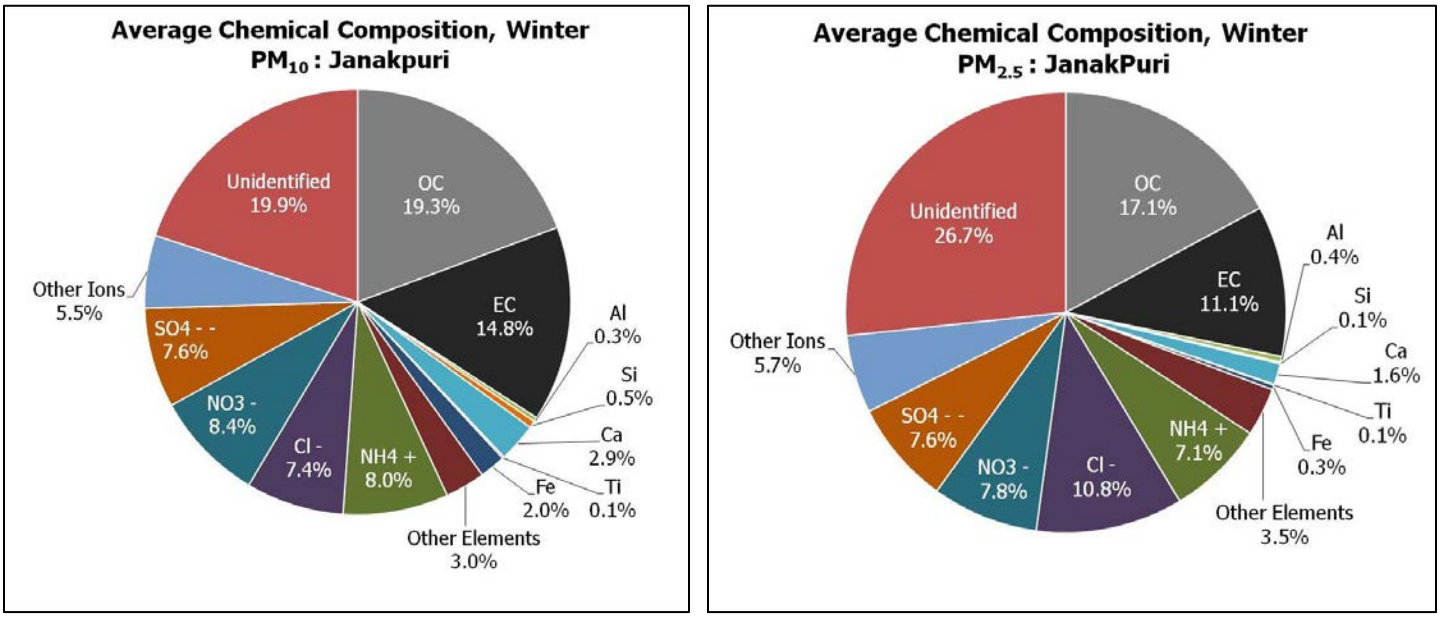


Figure 3.58: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Janakpuri in Winter Season

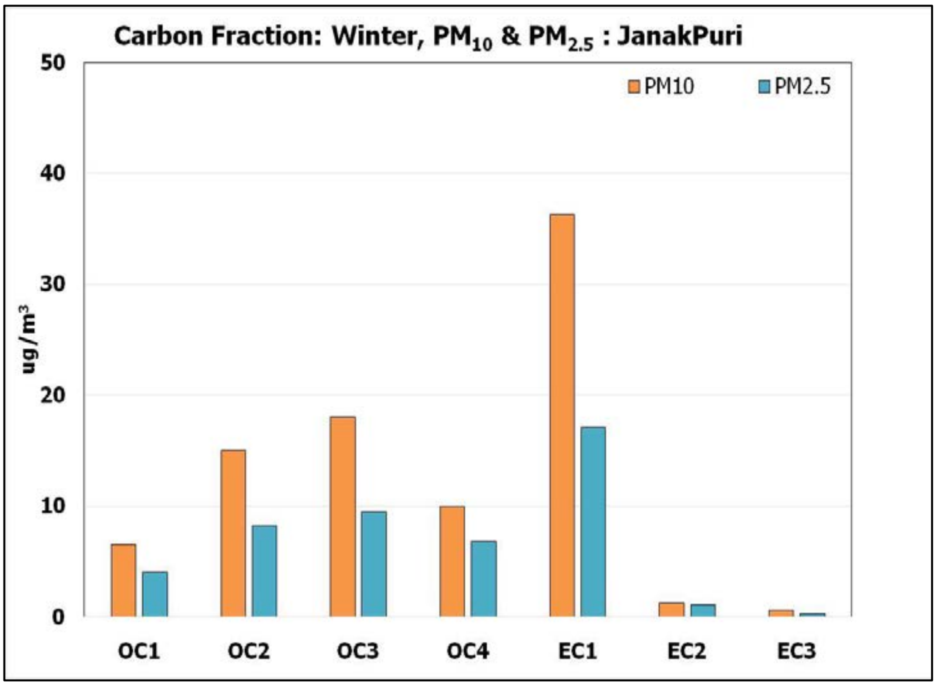


Figure 3.59 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Janakpuri in Winter Season

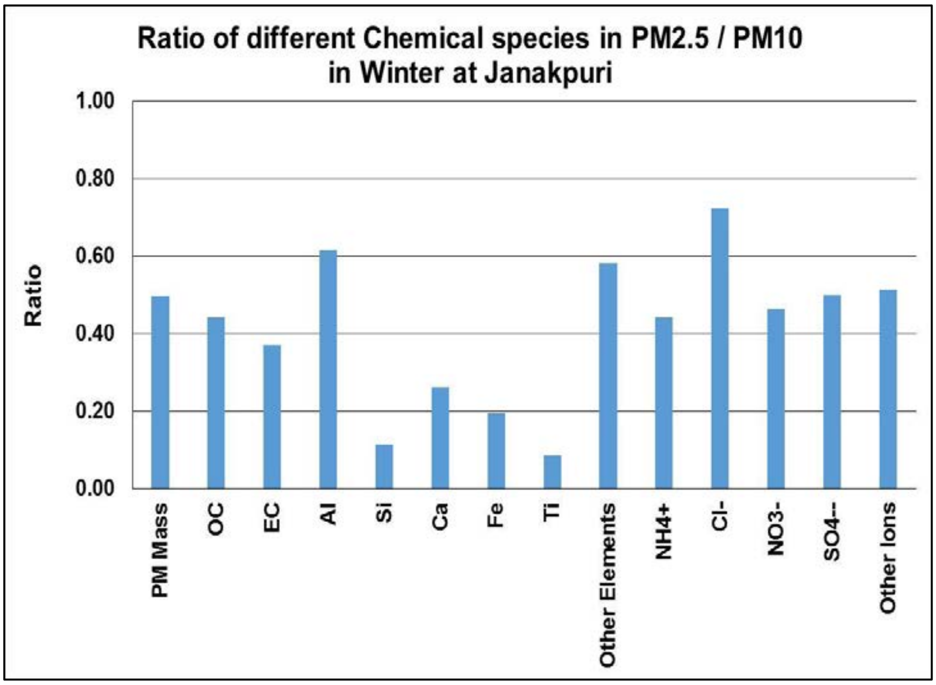


Figure 3.60 Ratio of Different Chemical Species in PM2.5/PM10 at Janakpuri in Winter Season

Average concentration of PM_{10} and $PM_{2.5}$ at Janakpuri was found to be 333±86 µg/m^3 and 166±50 µg/m^3, respectively. Average concentration of PM_{10} varied from 240 to 536 µg/m^3 and that of $PM_{2.5}$ varied from 122 to 265 µg/m^3 (see Figure 3.56).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.57.

Carbon fraction in PM_{10} was found to be 114 µg/m^3, while it was found to be 47 µg/m^3 in $PM_{2.5}$. The total ion concentration was found to be 37% for PM_{10} and 39% for $PM_{2.5}$. The crustal element was found to be 6% for PM_{10} and 3% for $PM_{2.5}$ (see Figure 3.58).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} and 4% in $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 27% in $PM_{2.5}$ and 20% in PM_{10}.

In PM_{10}, OC3 was found to be highest as compared to $PM_{2.5}$, followed by OC2, OC4, and OC1. Also, EC1 was found to be the highest in PM_{10} as compared to that in $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.59). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.60.

Table 3.45 Statistical evaluation of concentrat**ions ($\mu g/m^3$)** of mass and major species of PM$_{10}$ at Janakpuri in Winter Season

$\mu g/m^3$																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	333	64.36	49.44	1.11	1.80	9.83	6.57	0.48	4.25	3.30	0.47	0.94	24.83	27.99	25.30	1.14	26.67	3.79	10.10
SD	86	17.68	16.66	0.41	0.44	3.53	2.32	0.14	1.34	1.28	0.18	0.33	12.56	5.13	7.34	0.52	7.29	1.39	3.78
Min	240	42.82	29.21	0.57	1.29	3.29	3.45	0.24	2.20	2.11	0.16	0.39	9.90	18.20	16.26	0.54	14.79	1.51	6.10
Max	536	89.12	77.36	2.02	2.73	14.87	11.59	0.72	6.78	6.00	0.88	1.38	48.47	34.93	36.00	2.36	35.59	5.66	16.19
C.V.	0.26	0.27	0.34	0.37	0.24	0.36	0.35	0.29	0.31	0.39	0.39	0.35	0.51	0.18	0.29	0.46	0.27	0.37	0.37
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	469	88.62	75.14	1.75	2.52	14.28	10.55	0.68	6.34	5.39	0.75	1.38	44.85	33.66	35.90	1.93	34.76	5.61	15.45
50 %ile	313	60.62	49.13	1.05	1.72	9.71	6.31	0.45	3.78	2.77	0.46	0.94	23.84	27.99	24.12	1.14	26.85	3.79	9.34
5 %ile	170	31.51	23.56	0.50	0.90	3.43	2.94	0.19	1.81	1.74	0.17	0.36	11.36	12.32	12.24	0.53	11.42	1.45	5.06

Table 3.46 Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM$_{2.5}$ at Janakpuri in Winter Season

μg/m3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	166	28.43	18.36	0.69	0.21	2.58	0.57	0.09	2.12	2.24	0.28	0.52	17.92	12.97	12.65	0.39	11.80	2.03	1.00
SD	50	7.90	7.18	0.36	0.09	1.71	0.21	0.05	0.76	0.66	0.10	0.17	11.04	2.22	3.46	0.14	3.60	1.27	1.01
Min	122	18.93	10.10	0.19	0.05	0.22	0.31	0.02	1.27	1.24	0.12	0.25	3.25	9.79	8.67	0.20	8.92	0.23	0.11
Max	265	41.54	30.17	1.18	0.33	5.23	0.87	0.17	3.39	3.39	0.45	0.76	33.16	15.62	19.23	0.57	18.97	4.62	2.96
C.V.	0.30	0.28	0.39	0.52	0.45	0.66	0.38	0.53	0.36	0.29	0.35	0.34	0.62	0.17	0.27	0.36	0.31	0.63	1.01
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	254	40.11	30.13	1.10	0.32	5.10	0.84	0.16	3.23	3.21	0.41	0.76	32.35	15.49	18.08	0.57	18.43	3.84	2.70
50 %ile	154	27.73	15.53	0.76	0.23	2.77	0.50	0.10	1.86	2.23	0.27	0.48	15.29	13.42	11.61	0.34	10.25	1.91	0.51
5 %ile	122	19.57	11.15	0.22	0.08	0.34	0.31	0.02	1.36	1.36	0.16	0.28	4.50	9.95	8.95	0.22	8.97	0.49	0.14

Table 3.47 Correlation Matrix for PM_{10} and Its major constituents at Janakpuri in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.86																			
	0.00																			
EC	0.90	0.88																		
	0.00	*0.00*																		
TC	0.91	0.97	0.97																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.70	0.50	0.66	0.60																
	0.03	*0.14*	*0.04*	*0.07*																
NO_3^-	0.34	0.13	0.32	0.23	0.62															
	0.34	*0.72*	*0.37*	*0.53*	*0.06*															
SO_4^{--}	0.25	0.09	-0.12	-0.02	0.16	0.37														
	0.49	*0.82*	*0.74*	*0.97*	*0.66*	*0.29*														
Na^+	0.32	0.64	0.43	0.56	0.05	-0.50	-0.23													
	0.36	*0.05*	*0.21*	*0.09*	*0.90*	*0.14*	*0.53*													
NH_4^+	0.46	0.33	0.37	0.36	0.65	0.86	0.47	-0.34												
	0.18	*0.36*	*0.29*	*0.31*	*0.04*	*0.00*	*0.18*	*0.33*												
K^+	0.71	0.82	0.64	0.76	0.58	0.25	0.39	0.62	0.47											
	0.02	*0.00*	*0.05*	*0.01*	*0.08*	*0.48*	*0.26*	*0.06*	*0.17*											
Ca^{++}	0.64	0.83	0.70	0.79	0.45	0.04	-0.01	0.63	0.37	0.80										
	0.05	*0.00*	*0.03*	*0.01*	*0.19*	*0.92*	*0.98*	*0.05*	*0.30*	*0.01*										
Si	0.90	0.78	0.84	0.84	0.65	0.10	-0.04	0.40	0.20	0.53	0.57									
	0.00	*0.01*	*0.00*	*0.00*	*0.04*	*0.78*	*0.91*	*0.25*	*0.59*	*0.11*	*0.09*									
Al	0.75	0.56	0.55	0.57	0.79	0.43	0.33	0.06	0.56	0.57	0.43	0.78								
	0.01	*0.09*	*0.10*	*0.08*	*0.01*	*0.22*	*0.35*	*0.88*	*0.09*	*0.09*	*0.21*	*0.01*								
Ca	0.75	0.75	0.67	0.73	0.59	0.02	-0.04	0.38	0.29	0.53	0.63	0.86	0.81							
	0.01	*0.01*	*0.03*	*0.02*	*0.07*	*0.97*	*0.91*	*0.27*	*0.41*	*0.11*	*0.05*	*0.00*	*0.00*							
Fe	0.90	0.76	0.76	0.78	0.56	0.03	0.09	0.38	0.18	0.53	0.49	0.96	0.78	0.87						
	0.00	*0.01*	*0.01*	*0.01*	*0.10*	*0.93*	*0.80*	*0.28*	*0.62*	*0.11*	*0.15*	*0.00*	*0.01*	*0.00*						
Ti	0.80	0.69	0.72	0.73	0.65	0.00	-0.09	0.43	0.21	0.54	0.59	0.93	0.81	0.93	0.93					
	0.01	*0.03*	*0.02*	*0.02*	*0.04*	*1.00*	*0.81*	*0.22*	*0.56*	*0.11*	*0.07*	*0.00*	*0.01*	*0.00*	*0.00*					
K	0.80	0.67	0.71	0.71	0.80	0.32	0.04	0.18	0.50	0.54	0.58	0.88	0.94	0.93	0.84	0.91				
	0.01	*0.03*	*0.02*	*0.02*	*0.01*	*0.37*	*0.92*	*0.62*	*0.14*	*0.11*	*0.08*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.55	0.36	0.33	0.36	0.25	0.59	0.63	-0.31	0.51	0.25	0.04	0.34	0.46	0.17	0.38	0.11	0.31			
	0.10	*0.31*	*0.35*	*0.31*	*0.49*	*0.07*	*0.05*	*0.38*	*0.13*	*0.48*	*0.91*	*0.33*	*0.18*	*0.63*	*0.28*	*0.77*	*0.39*			
Ni	0.30	0.16	0.02	0.10	0.52	0.40	0.52	-0.21	0.58	0.34	0.08	0.29	0.79	0.54	0.38	0.43	0.62	0.32		
	0.40	*0.66*	*0.95*	*0.79*	*0.12*	*0.26*	*0.13*	*0.55*	*0.08*	*0.33*	*0.82*	*0.42*	*0.01*	*0.11*	*0.28*	*0.21*	*0.06*	*0.37*		
Pb	0.76	0.48	0.60	0.56	0.76	0.26	0.21	0.17	0.29	0.49	0.23	0.79	0.80	0.68	0.83	0.82	0.76	0.26	0.54	
	0.01	*0.16*	*0.07*	*0.10*	*0.01*	*0.47*	*0.57*	*0.63*	*0.41*	*0.15*	*0.53*	*0.01*	*0.01*	*0.03*	*0.00*	*0.00*	*0.01*	*0.47*	*0.11*	
Zn	0.69	0.58	0.54	0.58	0.55	0.20	0.32	0.16	0.51	0.56	0.44	0.54	0.57	0.68	0.67	0.64	0.61	0.21	0.53	0.68
	0.03	*0.08*	*0.11*	*0.08*	*0.10*	*0.58*	*0.37*	*0.66*	*0.13*	*0.09*	*0.21*	*0.11*	*0.09*	*0.03*	*0.04*	*0.05*	*0.06*	*0.55*	*0.11*	*0.03*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

Table 3.48 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Janakpuri in Winter Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.61																			
	0.06																			
EC	0.81	0.85																		
	0.01	*0.00*																		
TC	0.73	0.97	0.96																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.60	0.02	0.47	0.24																
	0.07	*0.96*	*0.18*	*0.50*																
NO_3^-	0.74	0.24	0.32	0.29	0.39															
	0.02	*0.51*	*0.37*	*0.42*	*0.27*															
SO_4^{--}	0.64	0.21	0.30	0.26	0.38	0.66														
	0.04	*0.56*	*0.40*	*0.47*	*0.28*	*0.04*														
Na^+	0.61	0.77	0.75	0.79	0.28	0.24	0.57													
	0.06	*0.01*	*0.01*	*0.01*	*0.44*	*0.50*	*0.09*													
NH_4^+	0.71	0.44	0.47	0.47	0.38	0.60	0.76	0.57												
	0.02	*0.21*	*0.17*	*0.17*	*0.28*	*0.07*	*0.01*	*0.08*												
K^+	0.49	0.35	0.40	0.39	0.54	0.30	0.27	0.36	0.55											
	0.15	*0.32*	*0.25*	*0.26*	*0.11*	*0.39*	*0.46*	*0.31*	*0.10*											
Ca^{++}	0.09	0.10	0.12	0.11	0.04	-0.04	0.02	0.26	-0.36	0.09										
	0.81	*0.79*	*0.75*	*0.76*	*0.91*	*0.92*	*0.95*	*0.48*	*0.31*	*0.81*										
Si	0.53	0.59	0.69	0.66	0.26	0.28	0.13	0.48	0.10	0.44	0.56									
	0.12	*0.07*	*0.03*	*0.04*	*0.48*	*0.43*	*0.71*	*0.16*	*0.78*	*0.21*	*0.09*									
Al	0.60	0.02	0.17	0.09	0.55	0.87	0.67	0.19	0.51	0.54	0.16	0.35								
	0.07	*0.96*	*0.64*	*0.80*	*0.10*	*0.00*	*0.04*	*0.61*	*0.13*	*0.11*	*0.67*	*0.32*								
Ca	0.17	-0.24	-0.22	-0.24	0.23	0.67	0.35	-0.17	0.19	0.40	0.14	0.23	0.87							
	0.64	*0.51*	*0.55*	*0.51*	*0.52*	*0.03*	*0.33*	*0.64*	*0.61*	*0.25*	*0.70*	*0.52*	*0.00*							
Fe	0.60	0.57	0.65	0.63	0.27	0.19	0.30	0.56	0.22	0.51	0.69	0.85	0.30	0.07						
	0.06	*0.08*	*0.04*	*0.05*	*0.45*	*0.60*	*0.39*	*0.09*	*0.54*	*0.13*	*0.03*	*0.00*	*0.40*	*0.85*						
Ti	0.37	-0.07	-0.01	-0.04	0.35	0.74	0.48	0.02	0.33	0.53	0.20	0.38	0.94	0.97	0.26					
	0.30	*0.86*	*0.97*	*0.91*	*0.32*	*0.01*	*0.16*	*0.96*	*0.36*	*0.11*	*0.58*	*0.28*	*0.00*	*0.00*	*0.47*					
K	0.88	0.51	0.68	0.61	0.50	0.70	0.62	0.57	0.45	0.44	0.51	0.72	0.68	0.35	0.81	0.53				
	0.00	*0.13*	*0.03*	*0.06*	*0.14*	*0.03*	*0.06*	*0.09*	*0.19*	*0.20*	*0.13*	*0.02*	*0.03*	*0.33*	*0.01*	*0.12*				
S	0.82	0.59	0.61	0.62	0.24	0.70	0.37	0.42	0.63	0.26	-0.07	0.28	0.38	0.06	0.32	0.17	0.64			
	0.00	*0.07*	*0.06*	*0.05*	*0.50*	*0.02*	*0.29*	*0.23*	*0.05*	*0.46*	*0.85*	*0.43*	*0.28*	*0.87*	*0.36*	*0.63*	*0.05*			
Ni	0.39	-0.15	-0.05	-0.10	0.46	0.79	0.56	0.01	0.42	0.51	0.05	0.20	0.97	0.95	0.11	0.97	0.48	0.22		
	0.26	*0.68*	*0.90*	*0.77*	*0.18*	*0.01*	*0.10*	*0.98*	*0.22*	*0.13*	*0.89*	*0.57*	*0.00*	*0.00*	*0.76*	*0.00*	*0.17*	*0.54*		
Pb	0.57	0.05	0.34	0.20	0.83	0.44	0.49	0.28	0.59	0.85	0.06	0.34	0.71	0.49	0.42	0.62	0.52	0.21	0.67	
	0.09	*0.89*	*0.34*	*0.59*	*0.00*	*0.21*	*0.15*	*0.43*	*0.07*	*0.00*	*0.88*	*0.34*	*0.02*	*0.15*	*0.23*	*0.06*	*0.12*	*0.55*	*0.04*	
Zn	0.61	0.46	0.55	0.52	0.39	0.58	0.65	0.60	0.78	0.54	-0.14	0.52	0.61	0.39	0.36	0.53	0.52	0.39	0.53	0.59
	0.06	*0.18*	*0.10*	*0.12*	*0.26*	*0.08*	*0.04*	*0.06*	*0.01*	*0.11*	*0.70*	*0.12*	*0.06*	*0.26*	*0.30*	*0.12*	*0.13*	*0.26*	*0.12*	*0.07*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.45 and Table 3.46 for PM mass and major species, respectively. PM_{10} mass shows lesser C.V. than $PM_{2.5}$ mass. For secondary ions, C.V. observed in PM_{10} and $PM_{2.5}$ was very less, which represents less variation in concentration during monitoring period.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.47 and Table 3.48 for PM mass and its major species. In PM_{10}, crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. In $PM_{2.5}$, OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass.

3.1.7 Site 7: Chandni Chowk

3.1.7.1 Summer Season

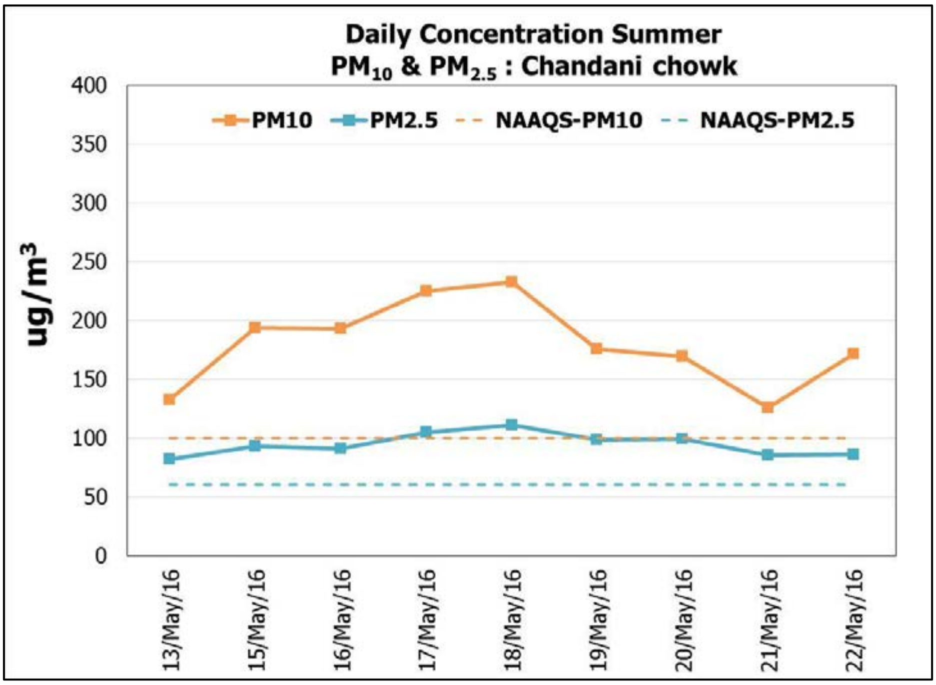


Figure 3.61 Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Chandni chowk in Summer Season

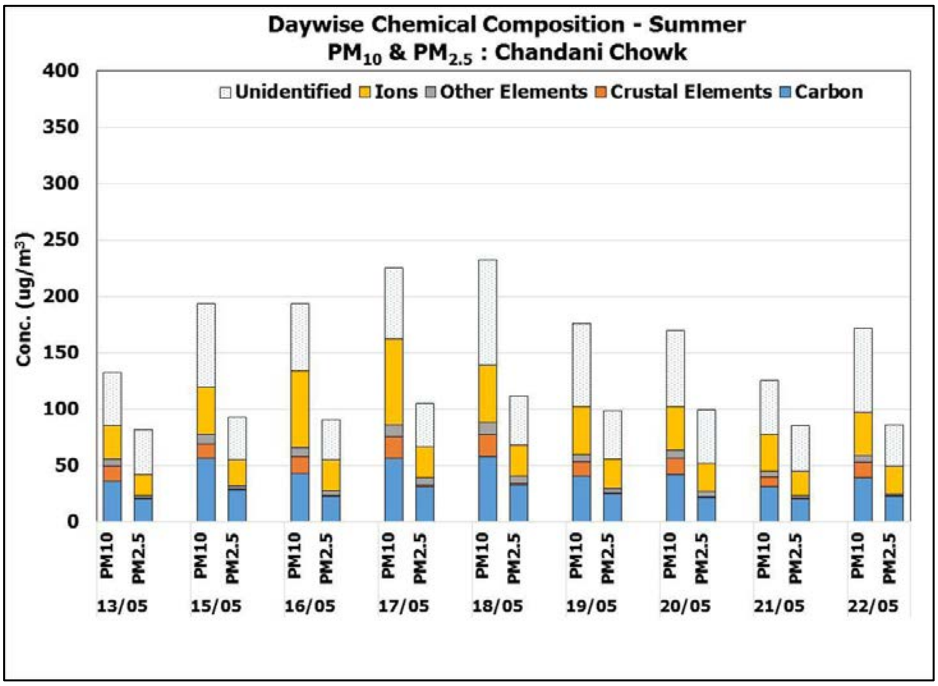


Figure 3.62 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Chandni Chowk in Summer Season

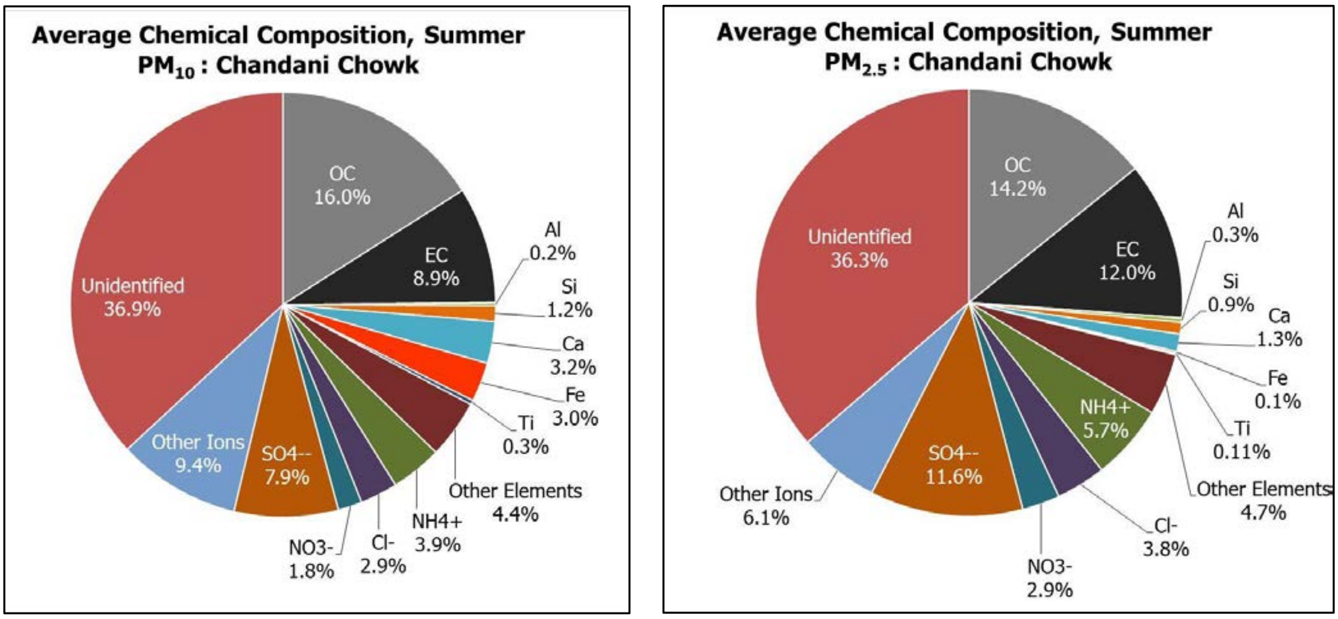


Figure 3.63: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Chandni Chowk in Summer Season

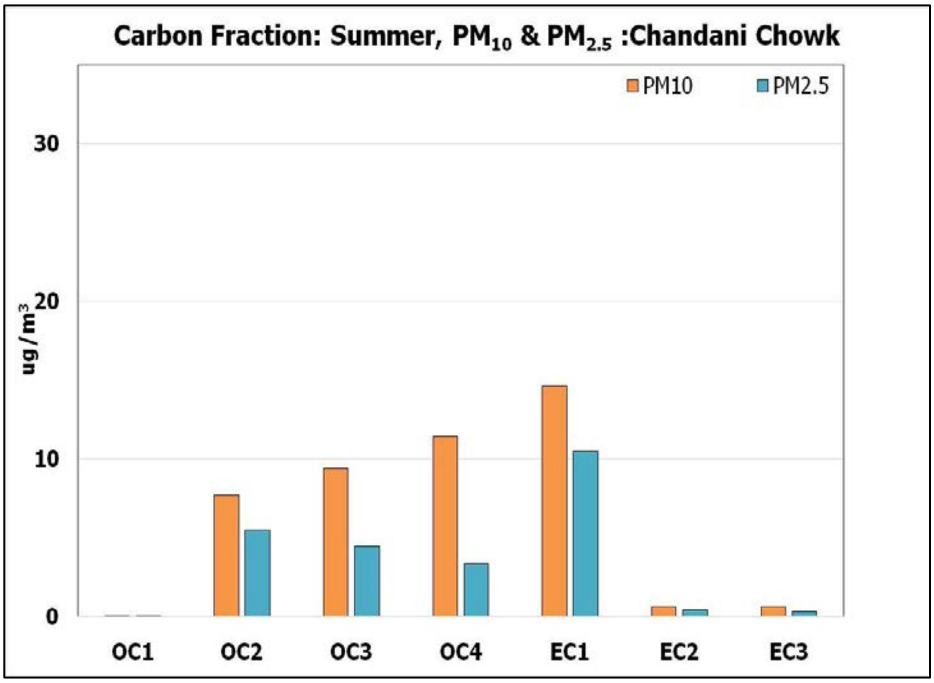


Figure 3.64: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Chandni Chowk in Summer Season

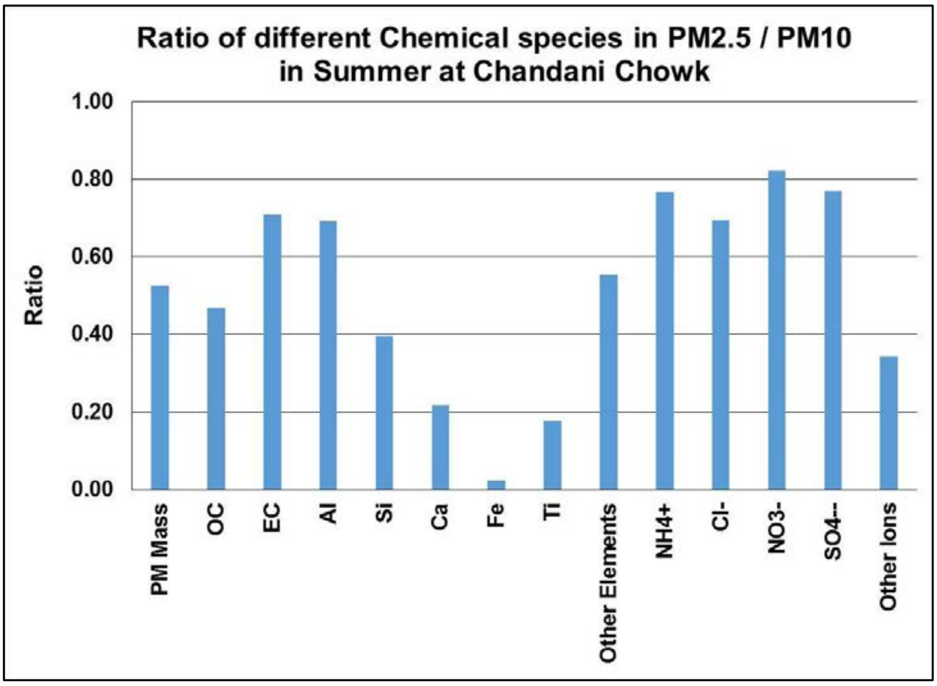


Figure 3.65: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Chandani Chowk in the Summer Season

Average concentration observed for PM_{10} and $PM_{2.5}$ at Chandni Chowk (CHN) was 180±36 $\mu g/m^3$ and 94 ±10 $\mu g/m^3$, respectively. The standard deviation observed in case of $PM_{2.5}$ was very less. For PM_{10}, observed daily concentration variation was from 125 to 233 $\mu g/m^3$. Similarly, for $PM_{2.5}$, daily concentration variation was from 82 to 111 $\mu g/m^3$ (see Figure 3.61).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.62.

The carbon fraction was 25% (45 $\mu g/m^3$) in PM_{10} and 26% (25 $\mu g/m^3$) in $PM_{2.5}$. The total Ion concentration is 26% in PM_{10} and 27% in $PM_{2.5}$. The crustal element concentration is 8% in PM_{10} and 1% in $PM_{2.5}$ (see Figure 3.63).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% in PM_{10} and 5% in $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 37% for PM_{10} and 36% for $PM_{2.5}$.

EC1 is highest in both PM_{10} and $PM_{2.5}$, followed by EC2 and EC3. In $PM_{2.5}$, OC2 was highest among organic carbon, followed by OC3 and OC4, whereas in PM_{10}, OC4 was highest, followed by OC3 and OC2. EC1 was found to be 15 $\mu g/m^3$ in PM_{10} and 11 $\mu g/m^3$ in $PM_{2.5}$, while OC4 was found to be 11 $\mu g/m^3$ in PM_{10} and 3 $\mu g/m^3$ in $PM_{2.5}$ (see Figure 3.64). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.65.

Table 3.49 Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM_{10} at Chandni Chowk in Summer Season

	$\mu g/m^3$																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	180	28.72	15.92	0.45	2.11	5.74	5.38	0.60	4.73	0.98	0.24	0.38	5.12	3.27	14.22	4.17	7.02	3.60	3.87
SD	36	6.02	4.88	0.14	0.54	2.04	1.34	0.17	1.52	0.37	0.17	0.10	6.50	0.43	3.11	1.57	1.45	1.23	2.25
Min	125	18.69	9.88	0.26	1.27	3.43	3.05	0.39	3.07	0.57	0.06	0.23	0.75	2.54	9.69	2.52	4.97	2.50	1.02
Max	233	35.45	22.14	0.70	2.91	8.88	7.41	0.85	7.22	1.51	0.52	0.54	17.46	3.86	18.51	7.45	9.35	5.82	7.16
C.V.	0.20	0.21	0.31	0.31	0.26	0.36	0.25	0.29	0.32	0.37	0.72	0.25	1.27	0.13	0.22	0.38	0.21	0.34	0.58
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	230	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	176	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	128	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.50 Statistical evaluation of co**ncentrations ($\mu g/m^3$)** of mass and major species of $PM_{2.5}$ at Chandni Chowk in Summer Season

	$\mu g/m^3$																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	94	13.40	11.28	0.31	0.84	1.25	0.14	0.11	2.32	0.82	0.14	0.16	3.55	2.69	10.93	2.09	5.38	2.01	0.86
SD	10	2.39	2.37	0.18	0.08	0.20	0.06	0.01	1.06	0.33	0.12	0.08	3.89	0.41	1.36	0.37	0.62	0.59	0.18
Min	82	10.44	8.90	0.22	0.77	1.04	0.02	0.08	1.09	0.49	0.03	0.09	0.65	2.02	8.44	1.39	4.06	1.02	0.57
Max	111	17.41	15.81	0.78	0.98	1.56	0.22	0.13	3.95	1.29	0.32	0.32	10.37	3.16	12.89	2.73	6.14	2.73	1.14
C.V.	0.10	0.18	0.21	0.57	0.09	0.16	0.46	0.14	0.46	0.40	0.85	0.50	1.09	0.15	0.12	0.18	0.12	0.30	0.21
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	109	17.00	15.02	0.59	0.96	1.54	0.20	0.12	3.75	1.28	0.32	0.30	10.33	3.14	12.55	2.54	6.11	2.69	1.11
50 %ile	93	12.55	10.37	0.25	0.81	1.16	0.15	0.11	2.05	0.79	0.09	0.12	1.94	2.69	10.95	2.11	5.49	1.97	0.84
5 %ile	83	10.81	8.97	0.22	0.77	1.06	0.04	0.08	1.10	0.50	0.04	0.10	0.86	2.14	8.96	1.52	4.44	1.16	0.62

Table 3.51 Correlation Matrix for PM_{10} and Its major constituents at Chandani Chowk in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.89																			
	0.00																			
EC	0.70	0.57																		
	0.04	*0.11*																		
TC	0.91	0.91	0.86																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.44	0.21	0.36	0.31																
	0.23	*0.59*	*0.34*	*0.41*																
NO_3^-	0.96	0.90	0.73	0.93	0.37															
	0.00	*0.00*	*0.03*	*0.00*	*0.33*															
SO_4^{--}	0.89	0.70	0.45	0.67	0.45	0.83														
	0.00	*0.03*	*0.22*	*0.05*	*0.22*	*0.01*														
Na^+	0.42	0.60	0.35	0.54	0.33	0.43	0.05													
	0.26	*0.09*	*0.36*	*0.13*	*0.39*	*0.25*	*0.91*													
NH_4^+	0.97	0.90	0.57	0.85	0.46	0.90	0.90	0.40												
	0.00	*0.00*	*0.11*	*0.00*	*0.22*	*0.00*	*0.00*	*0.29*												
K^+	0.76	0.50	0.84	0.73	0.47	0.74	0.69	0.05	0.68											
	0.02	*0.18*	*0.00*	*0.02*	*0.20*	*0.02*	*0.04*	*0.89*	*0.04*											
Ca^{++}	0.81	0.56	0.41	0.56	0.53	0.74	0.96	-0.05	0.83	0.76										
	0.01	*0.12*	*0.27*	*0.12*	*0.14*	*0.02*	*0.00*	*0.89*	*0.01*	*0.02*										
Si	0.84	0.60	0.85	0.81	0.50	0.76	0.62	0.38	0.74	0.88	0.63									
	0.01	*0.09*	*0.00*	*0.01*	*0.17*	*0.02*	*0.08*	*0.31*	*0.02*	*0.00*	*0.07*									
Al	0.81	0.56	0.46	0.58	0.36	0.69	0.78	0.10	0.79	0.75	0.83	0.81								
	0.01	*0.12*	*0.21*	*0.10*	*0.34*	*0.04*	*0.01*	*0.80*	*0.01*	*0.02*	*0.01*	*0.01*								
Ca	0.78	0.53	0.58	0.62	0.48	0.63	0.74	0.11	0.80	0.84	0.82	0.85	0.90							
	0.01	*0.14*	*0.10*	*0.07*	*0.20*	*0.07*	*0.02*	*0.78*	*0.01*	*0.01*	*0.01*	*0.00*	*0.00*							
Fe	0.64	0.64	0.42	0.61	0.14	0.67	0.63	0.04	0.61	0.40	0.49	0.38	0.47	0.30						
	0.06	*0.06*	*0.26*	*0.08*	*0.72*	*0.05*	*0.07*	*0.92*	*0.08*	*0.29*	*0.19*	*0.32*	*0.20*	*0.43*						
Ti	0.65	0.56	0.20	0.45	0.23	0.52	0.75	-0.03	0.78	0.56	0.81	0.46	0.73	0.82	0.29					
	0.06	*0.12*	*0.60*	*0.22*	*0.55*	*0.15*	*0.02*	*0.94*	*0.01*	*0.12*	*0.01*	*0.21*	*0.03*	*0.01*	*0.46*					
K	0.78	0.69	0.92	0.90	0.49	0.80	0.55	0.43	0.73	0.88	0.56	0.85	0.56	0.70	0.42	0.45				
	0.01	*0.04*	*0.00*	*0.00*	*0.18*	*0.01*	*0.12*	*0.25*	*0.03*	*0.00*	*0.12*	*0.00*	*0.12*	*0.04*	*0.26*	*0.22*				
S	0.77	0.65	0.60	0.71	0.18	0.77	0.78	0.13	0.69	0.55	0.63	0.55	0.44	0.46	0.48	0.37	0.50			
	0.02	*0.06*	*0.09*	*0.03*	*0.64*	*0.02*	*0.01*	*0.74*	*0.04*	*0.13*	*0.07*	*0.13*	*0.24*	*0.21*	*0.19*	*0.33*	*0.17*			
Ni	0.06	0.08	-0.58	-0.25	0.02	-0.12	0.19	0.00	0.23	-0.27	0.24	-0.13	0.36	0.25	-0.03	0.51	-0.36	-0.23		
	0.89	*0.85*	*0.10*	*0.52*	*0.97*	*0.76*	*0.62*	*1.00*	*0.55*	*0.48*	*0.53*	*0.75*	*0.34*	*0.52*	*0.94*	*0.16*	*0.34*	*0.55*		
Pb	0.76	0.51	0.86	0.75	0.47	0.70	0.65	0.12	0.71	0.97	0.71	0.91	0.74	0.89	0.34	0.60	0.89	0.55	-0.21	
	0.02	*0.16*	*0.00*	*0.02*	*0.20*	*0.04*	*0.06*	*0.76*	*0.03*	*0.00*	*0.03*	*0.00*	*0.02*	*0.00*	*0.37*	*0.09*	*0.00*	*0.13*	*0.58*	
Zn	0.69	0.57	0.74	0.73	0.47	0.54	0.43	0.52	0.67	0.65	0.41	0.85	0.56	0.77	0.17	0.44	0.76	0.48	-0.05	0.79
	0.04	*0.11*	*0.02*	*0.03*	*0.20*	*0.13*	*0.24*	*0.15*	*0.05*	*0.06*	*0.27*	*0.00*	*0.12*	*0.02*	*0.66*	*0.24*	*0.02*	*0.20*	*0.91*	*0.01*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.52 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Chandni Chowk in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.00																			
EC	0.77	0.90																		
	0.02	*0.00*																		
TC	0.83	0.98	0.98																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.55	-0.69	-0.95	-0.86																
	0.45	*0.31*	*0.05*	*0.14*																
NO_3^-	0.80	0.82	0.80	0.83	-0.62															
	0.01	*0.01*	*0.01*	*0.01*	*0.38*															
SO_4^{--}	0.81	0.70	0.66	0.69	0.37	0.88														
	0.01	*0.04*	*0.06*	*0.04*	*0.63*	*0.00*														
Na^+	0.26	0.14	0.00	0.07	0.69	0.47	0.70													
	0.50	*0.72*	*0.99*	*0.86*	*0.31*	*0.20*	*0.04*													
NH_4^+	0.87	0.79	0.86	0.84	0.17	0.81	0.82	0.30												
	0.00	*0.01*	*0.00*	*0.01*	*0.83*	*0.01*	*0.01*	*0.43*												
K^+	0.94	0.74	0.58	0.68	0.86	0.77	0.85	0.47	0.78											
	0.00	*0.02*	*0.10*	*0.04*	*0.14*	*0.02*	*0.00*	*0.20*	*0.01*											
Ca^{++}	0.40	0.36	0.34	0.36	0.23	0.64	0.56	0.62	0.59	0.41										
	0.28	*0.34*	*0.37*	*0.34*	*0.77*	*0.07*	*0.11*	*0.07*	*0.09*	*0.27*										
Si	0.61	0.53	0.77	0.67	-0.08	0.47	0.52	-0.07	0.73	0.39	0.16									
	0.11	*0.18*	*0.03*	*0.07*	*0.95*	*0.24*	*0.19*	*0.87*	*0.04*	*0.34*	*0.70*									
Al	0.18	0.20	0.25	0.23	0.07	0.11	0.39	0.31	0.44	0.26	0.10	0.67								
	0.64	*0.61*	*0.52*	*0.56*	*0.94*	*0.77*	*0.30*	*0.41*	*0.24*	*0.50*	*0.81*	*0.07*								
Ca	0.61	0.71	0.76	0.76	-0.93	0.79	0.66	0.34	0.75	0.49	0.76	0.65	0.15							
	0.08	*0.03*	*0.02*	*0.02*	*0.07*	*0.01*	*0.05*	*0.38*	*0.02*	*0.18*	*0.02*	*0.08*	*0.70*							
Fe	0.62	0.38	0.19	0.30	0.93	0.41	0.70	0.67	0.49	0.75	0.41	0.31	0.42	0.42						
	0.07	*0.31*	*0.62*	*0.44*	*0.07*	*0.27*	*0.04*	*0.05*	*0.18*	*0.02*	*0.27*	*0.45*	*0.27*	*0.26*						
Ti	0.49	0.30	0.30	0.31	0.73	0.50	0.71	0.75	0.67	0.54	0.80	0.42	0.49	0.65	0.76					
	0.18	*0.44*	*0.44*	*0.43*	*0.27*	*0.17*	*0.03*	*0.02*	*0.05*	*0.13*	*0.01*	*0.31*	*0.18*	*0.06*	*0.02*					
K	0.88	0.74	0.53	0.65	0.54	0.66	0.58	0.21	0.62	0.84	0.45	0.39	-0.15	0.57	0.63	0.40				
	0.00	*0.02*	*0.14*	*0.06*	*0.46*	*0.06*	*0.10*	*0.58*	*0.07*	*0.01*	*0.23*	*0.34*	*0.70*	*0.11*	*0.07*	*0.29*				
S	0.82	0.78	0.79	0.80	-0.18	0.77	0.76	0.19	0.67	0.72	0.13	0.69	0.01	0.54	0.40	0.22	0.64			
	0.01	*0.01*	*0.01*	*0.01*	*0.82*	*0.02*	*0.02*	*0.63*	*0.05*	*0.03*	*0.75*	*0.06*	*0.98*	*0.13*	*0.29*	*0.56*	*0.06*			
Ni	0.76	0.65	0.63	0.66	0.90	0.75	0.84	0.59	0.83	0.73	0.75	0.63	0.37	0.86	0.79	0.88	0.68	0.57		
	0.02	*0.06*	*0.07*	*0.06*	*0.10*	*0.02*	*0.01*	*0.10*	*0.01*	*0.03*	*0.02*	*0.10*	*0.32*	*0.00*	*0.01*	*0.00*	*0.05*	*0.11*		
Pb	0.64	0.71	0.78	0.76	-0.61	0.72	0.64	0.25	0.77	0.51	0.61	0.76	0.69	0.96	0.49	0.64	0.62	0.55	0.86	
	0.09	*0.05*	*0.02*	*0.03*	*0.59*	*0.04*	*0.09*	*0.54*	*0.03*	*0.20*	*0.11*	*0.03*	*0.06*	*0.00*	*0.22*	*0.09*	*0.10*	*0.16*	*0.01*	
Zn	0.71	0.69	0.79	0.76	0.22	0.73	0.70	0.28	0.84	0.57	0.65	0.83	0.27	0.95	0.54	0.70	0.60	0.62	0.92	0.97
	0.03	*0.04*	*0.01*	*0.02*	*0.78*	*0.03*	*0.04*	*0.47*	*0.01*	*0.11*	*0.06*	*0.01*	*0.49*	*0.00*	*0.14*	*0.03*	*0.09*	*0.07*	*0.00*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.49 and Table 3.50 for PM mass and major species, respectively. Both PM_{10} and $PM_{2.5}$ mass has similar C.V. The secondary ions (NH_4^+, NO_3-, and SO_4^{--}) have less C.V. in $PM_{2.5}$ than in PM_{10}.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.51 and Table 3.52 for PM mass and major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass. OC, EC, and TC show better correlation with PM_{10} and $PM_{2.5}$ mass. Also, secondary ions (NH_4^+, NO_3-, and SO_4^{--}) show better correlation with each other in both $PM_{2.5}$ and PM_{10}.

3.1.7.2 Winter Season

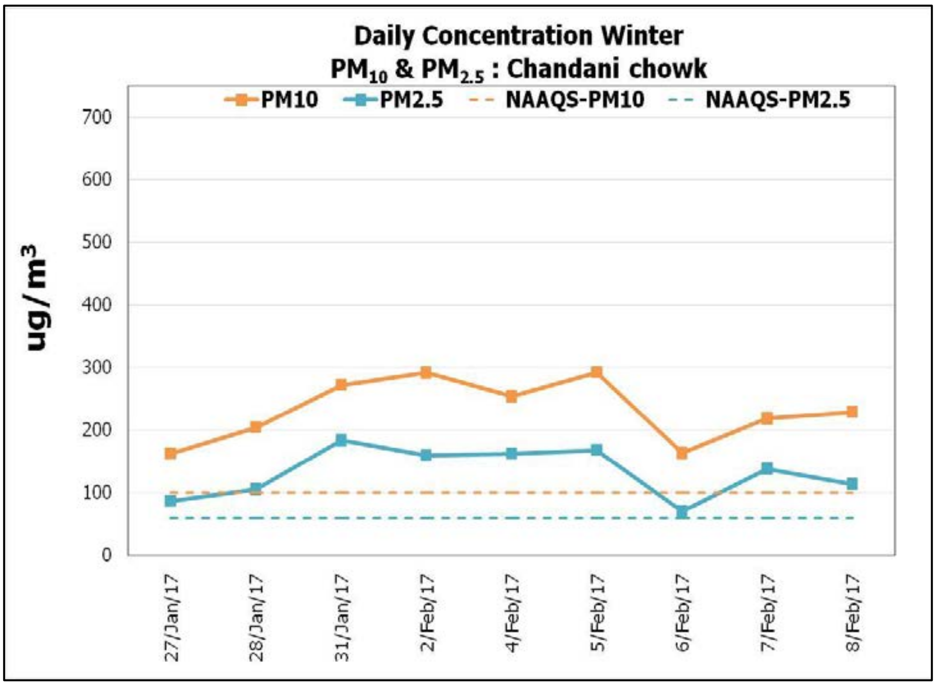


Figure 3.66: Variation in 24 Hourly Concentration of PM_{10} and $PM_{2.5}$ at Chandni chowk in Winter Season

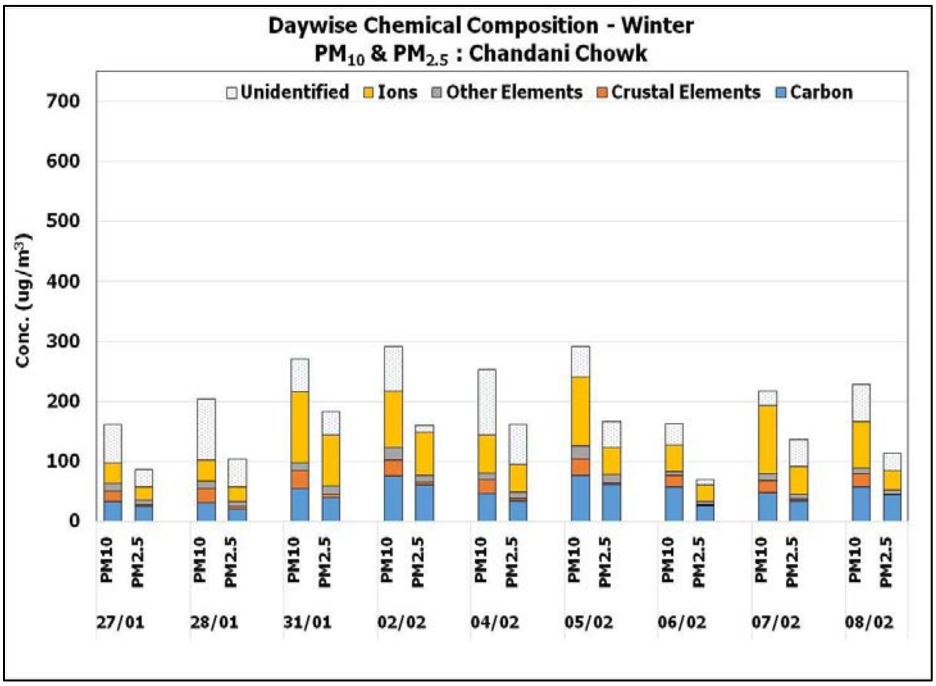


Figure 3.67: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Chandni chowk in Winter Season

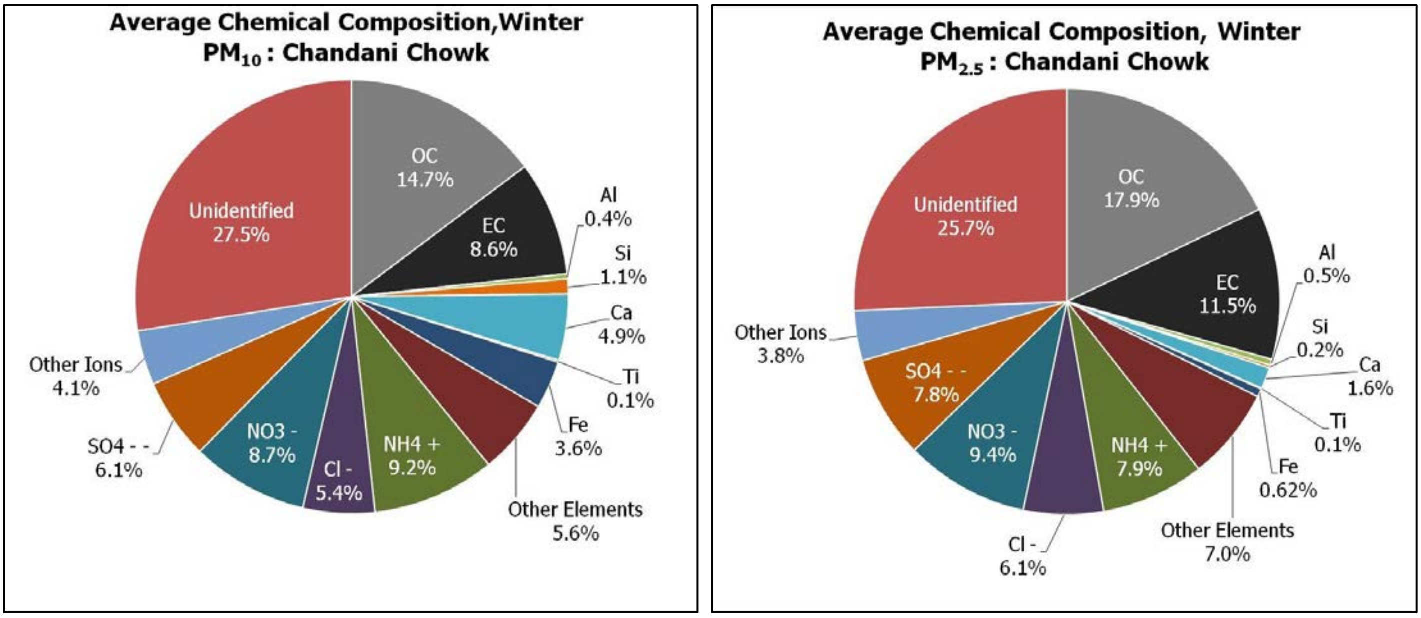


Figure 3.68 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Chandni chowk in Winter Season

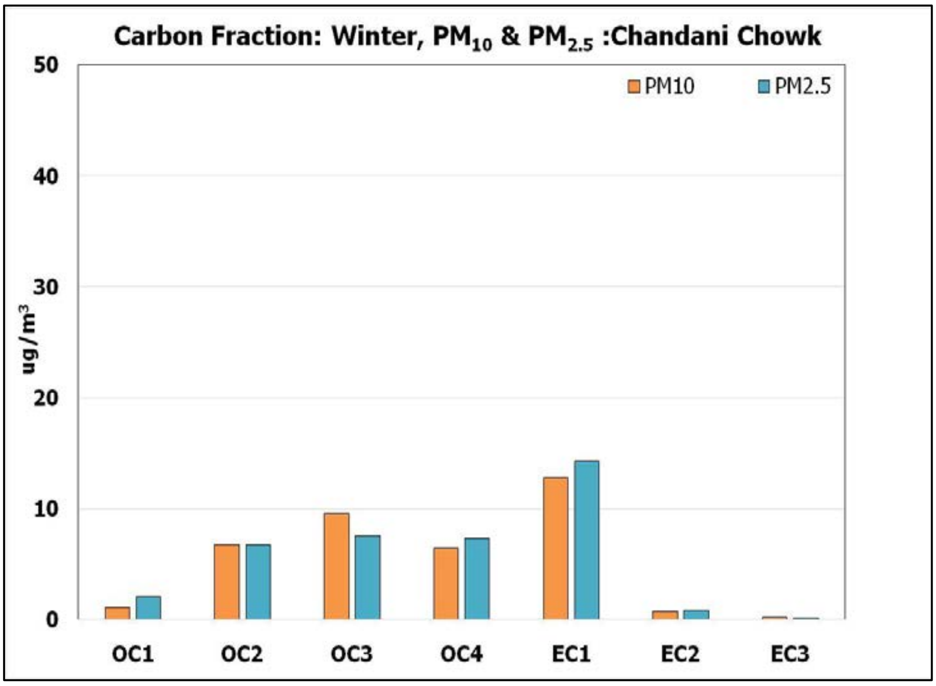


Figure 3.69: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Chandni chowk in Winter Season

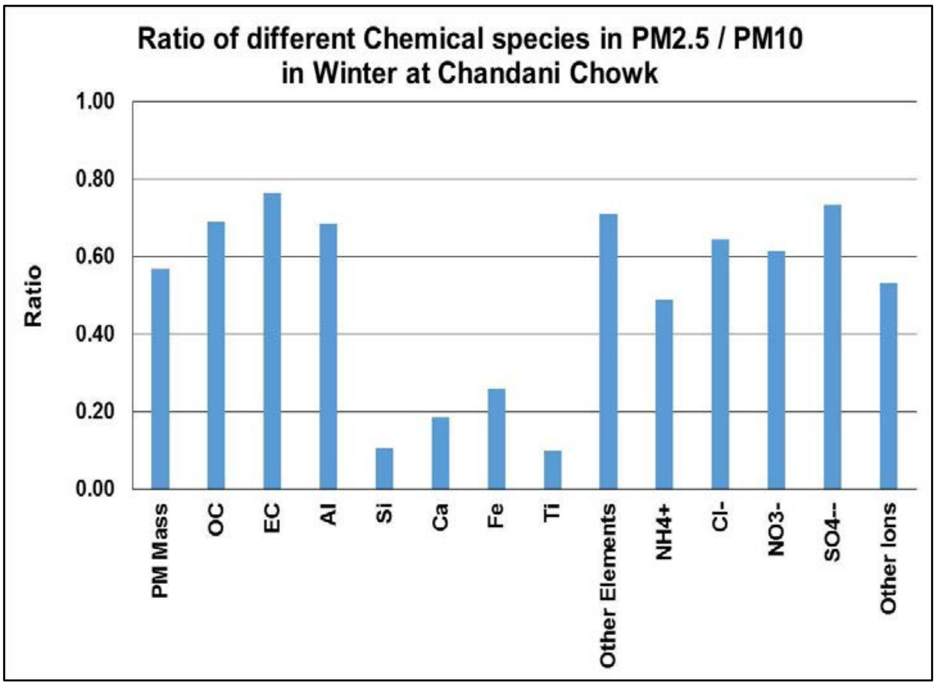


Figure 3.70 Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Chandni Chowk in Winter Season

At Chandni Chowk, the average concentration of PM_{10} and $PM_{2.5}$ was found to be 232±50 $\mu g/m^3$ and 132±40 $\mu g/m^3$, respectively. Average concentration of PM_{10} and $PM_{2.5}$ varied from 162 to 292$\mu g/m^3$ and 71 to 183 $\mu g/m^3$, respectively (see Figure 3.66).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.67.

The carbon fraction was found to be 54 $\mu g/m^3$ for PM_{10} and 39 $\mu g/m^3$ for $PM_{2.5}$. The percentage mass distribution showed that the organic carbon and elemental carbon of $PM_{2.5}$ was higher as compared to that of PM_{10}. The total ion concentration was found to be 34% for PM_{10} and 35% for $PM_{2.5}$. The crustal element was found to be 10% for PM_{10} and 3% for $PM_{2.5}$ (see Figure 3.68).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 6 % in PM_{10} and 7 % in $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 28% for PM_{10} and 26% for $PM_{2.5}$.

In PM_{10}, OC3 was found to be higher, followed by OC2, OC4, and OC1, and In case of $PM_{2.5}$, OC3 was found to be higher followed by OC4, OC2, and OC1. EC1 in $PM_{2.5}$ was found to be higher as compared to that in PM_{10} followed by EC2 and EC3 (see Figure 3.69). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.70.

Table 3.53 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Chandni Chowk in Winter Season

µg/m^3																			
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	232	34.18	19.84	0.88	2.58	11.43	8.28	0.33	3.83	3.46	1.05	3.24	12.41	20.24	14.05	0.65	21.27	2.11	5.52
SD	50	10.84	5.17	0.21	0.63	2.41	1.23	0.10	1.37	1.15	0.57	2.55	8.65	9.30	7.71	0.44	18.15	1.39	3.09
Min	162	19.42	12.87	0.63	1.75	8.27	6.50	0.25	2.46	1.62	0.34	0.95	4.79	9.47	3.33	0.10	1.49	0.25	1.78
Max	292	50.98	29.75	1.28	3.57	15.00	10.41	0.54	6.47	5.56	1.65	7.73	30.55	32.46	27.61	1.63	59.41	4.60	10.12
C.V.	0.21	0.32	0.26	0.24	0.24	0.21	0.15	0.30	0.36	0.33	0.54	0.79	0.70	0.46	0.55	0.68	0.85	0.66	0.56
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	292	49.39	27.68	1.18	3.41	14.68	9.91	0.50	6.15	5.17	1.64	7.60	27.26	32.27	24.84	1.37	49.81	4.00	9.86
50 %ile	230	35.08	19.52	0.88	2.62	11.11	8.40	0.31	3.55	3.43	1.20	2.63	10.62	20.55	13.79	0.57	20.15	2.19	5.79
5 %ile	106	15.13	9.02	0.42	1.19	5.34	3.86	0.17	1.92	1.38	0.36	0.99	5.16	9.38	5.28	0.18	4.22	0.49	2.02

Table 3.54 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM2.5 at Chandni Chowk in Winter Season

µg/m^3																			
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	132	23.59	15.16	0.60	0.27	2.14	0.82	0.09	2.08	3.16	0.59	2.52	8.01	12.42	10.30	0.66	10.36	1.09	2.13
SD	40	9.50	5.21	0.23	0.10	1.09	0.61	0.04	0.87	1.16	0.16	0.85	5.36	6.49	4.82	0.97	5.15	1.11	0.43
Min	71	12.87	8.74	0.28	0.13	0.38	0.21	0.03	1.03	1.42	0.32	0.97	1.71	5.01	4.81	0.19	5.51	0.06	1.69
Max	183	39.87	24.23	0.97	0.46	3.63	1.74	0.13	3.69	5.07	0.82	3.80	16.89	23.66	17.91	2.39	21.01	3.25	2.61
C.V.	0.30	0.40	0.34	0.38	0.35	0.51	0.75	0.42	0.42	0.37	0.28	0.34	0.67	0.52	0.47	1.46	0.50	1.02	0.20
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	177	38.84	22.81	0.94	0.42	3.43	1.70	0.13	3.29	4.90	0.79	3.64	16.35	21.80	17.41	1.96	19.04	2.72	2.60
50 %ile	138	20.79	14.98	0.53	0.28	2.05	0.59	0.10	1.79	2.68	0.60	2.44	6.23	11.64	9.83	0.24	8.96	1.11	1.98
5 %ile	77	13.56	9.12	0.33	0.15	0.64	0.25	0.04	1.08	1.79	0.34	1.37	2.11	5.01	4.89	0.20	5.70	0.07	1.71

Table 3.55 Correlation Matrix for PM_{10} and Its major constituents at Chandani Chowk in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.67																			
	0.05																			
EC	0.69	0.92																		
	0.04	*0.00*																		
TC	0.68	0.99	0.96																	
	0.04	*0.00*	*0.00*																	
Cl^-	0.16	0.17	0.06	0.13																
	0.69	*0.67*	*0.88*	*0.73*																
NO_3^-	0.66	0.42	0.62	0.49	0.07															
	0.05	*0.26*	*0.08*	*0.18*	*0.85*															
SO_4^{--}	0.71	0.42	0.64	0.50	0.18	0.90														
	0.03	*0.26*	*0.06*	*0.17*	*0.64*	*0.00*														
Na^+	0.47	0.45	0.66	0.52	0.22	0.39	0.69													
	0.20	*0.23*	*0.05*	*0.15*	*0.56*	*0.30*	*0.04*													
NH_4^+	0.64	0.52	0.42	0.50	0.55	0.06	0.18	0.40												
	0.07	*0.15*	*0.26*	*0.17*	*0.13*	*0.88*	*0.64*	*0.29*												
K^+	0.54	0.73	0.85	0.78	0.34	0.47	0.60	0.85	0.55											
	0.13	*0.03*	*0.00*	*0.01*	*0.38*	*0.20*	*0.09*	*0.00*	*0.13*											
Ca^{++}	0.29	0.48	0.58	0.53	0.69	0.36	0.47	0.71	0.50	0.85										
	0.46	*0.19*	*0.10*	*0.15*	*0.04*	*0.35*	*0.20*	*0.03*	*0.17*	*0.00*										
Si	0.90	0.47	0.44	0.47	0.19	0.34	0.44	0.35	0.77	0.36	0.17									
	0.00	*0.20*	*0.24*	*0.20*	*0.63*	*0.38*	*0.24*	*0.36*	*0.02*	*0.34*	*0.66*									
Al	0.77	0.40	0.32	0.38	0.26	0.12	0.25	0.26	0.79	0.25	0.15	0.96								
	0.02	*0.29*	*0.41*	*0.32*	*0.51*	*0.77*	*0.53*	*0.51*	*0.01*	*0.52*	*0.70*	*0.00*								
Ca	0.95	0.62	0.60	0.62	0.24	0.44	0.53	0.46	0.82	0.54	0.33	0.98	0.91							
	0.00	*0.08*	*0.09*	*0.07*	*0.54*	*0.24*	*0.15*	*0.21*	*0.01*	*0.14*	*0.39*	*0.00*	*0.00*							
Fe	0.84	0.41	0.35	0.40	0.27	0.27	0.36	0.24	0.75	0.27	0.17	0.98	0.98	0.93						
	0.01	*0.27*	*0.35*	*0.29*	*0.48*	*0.48*	*0.35*	*0.53*	*0.02*	*0.49*	*0.66*	*0.00*	*0.00*	*0.00*						
Ti	0.77	0.62	0.41	0.56	0.20	0.17	0.21	0.10	0.71	0.26	0.00	0.78	0.74	0.78	0.73					
	0.02	*0.07*	*0.28*	*0.12*	*0.61*	*0.67*	*0.59*	*0.80*	*0.03*	*0.50*	*1.00*	*0.01*	*0.02*	*0.01*	*0.03*					
K	0.57	0.79	0.85	0.82	-0.28	0.40	0.51	0.57	0.22	0.57	0.19	0.37	0.27	0.48	0.26	0.41				
	0.11	*0.01*	*0.00*	*0.01*	*0.47*	*0.29*	*0.17*	*0.11*	*0.58*	*0.11*	*0.62*	*0.33*	*0.48*	*0.20*	*0.50*	*0.27*				
S	0.91	0.63	0.76	0.69	0.01	0.66	0.79	0.72	0.56	0.69	0.36	0.76	0.60	0.84	0.63	0.59	0.71			
	0.00	*0.07*	*0.02*	*0.04*	*0.97*	*0.05*	*0.01*	*0.03*	*0.12*	*0.04*	*0.34*	*0.02*	*0.09*	*0.00*	*0.07*	*0.09*	*0.03*			
Ni	0.56	0.37	0.33	0.37	-0.29	0.03	0.27	0.39	0.27	0.20	-0.22	0.57	0.50	0.53	0.45	0.64	0.62	0.62		
	0.12	*0.32*	*0.39*	*0.33*	*0.45*	*0.93*	*0.49*	*0.30*	*0.48*	*0.60*	*0.58*	*0.11*	*0.17*	*0.15*	*0.22*	*0.06*	*0.07*	*0.08*		
Pb	0.43	0.15	0.13	0.14	-0.07	-0.23	0.09	0.42	0.55	0.14	-0.10	0.63	0.67	0.57	0.56	0.54	0.40	0.52	0.79	
	0.25	*0.71*	*0.74*	*0.71*	*0.85*	*0.56*	*0.82*	*0.26*	*0.13*	*0.72*	*0.80*	*0.07*	*0.05*	*0.11*	*0.12*	*0.13*	*0.29*	*0.15*	*0.01*	
Zn	0.72	0.66	0.68	0.68	0.01	0.34	0.60	0.71	0.42	0.58	0.24	0.61	0.52	0.66	0.50	0.61	0.82	0.81	0.86	0.67
	0.03	*0.05*	*0.04*	*0.05*	*0.99*	*0.38*	*0.09*	*0.03*	*0.27*	*0.11*	*0.54*	*0.08*	*0.15*	*0.06*	*0.17*	*0.08*	*0.01*	*0.01*	*0.00*	*0.05*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents *‘P-value’*

Table 3.56 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Chandni Chowk in Winter Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.63																			
	0.07																			
EC	0.72	0.95																		
	0.03	*0.00*																		
TC	0.67	0.99	0.98																	
	0.05	*0.00*	*0.00*																	
Cl^-	0.46	0.15	0.19	0.17																
	0.21	*0.71*	*0.62*	*0.67*																
NO_3^-	0.91	0.70	0.74	0.72	0.62															
	0.00	*0.04*	*0.02*	*0.03*	*0.08*															
SO_4^{--}	0.88	0.74	0.75	0.75	0.66	0.98														
	0.00	*0.02*	*0.02*	*0.02*	*0.06*	*0.00*														
Na^+	0.26	0.91	0.77	0.87	0.18	0.37	0.50													
	0.67	*0.03*	*0.13*	*0.06*	*0.77*	*0.54*	*0.39*													
NH_4^+	0.84	0.54	0.54	0.55	0.65	0.95	0.95	0.34												
	0.01	*0.13*	*0.14*	*0.13*	*0.06*	*0.00*	*0.00*	*0.58*												
K^+	0.46	0.31	0.13	0.25	0.12	0.48	0.51	0.89	0.62											
	0.21	*0.41*	*0.74*	*0.52*	*0.77*	*0.19*	*0.16*	*0.04*	*0.08*											
Ca^{++}	0.84	0.86	0.93	0.88	0.89	0.94	0.99	0.62	0.95	0.84										
	0.07	*0.07*	*0.02*	*0.05*	*0.05*	*0.02*	*0.00*	*0.27*	*0.01*	*0.08*										
Si	0.74	0.36	0.42	0.38	0.16	0.71	0.66	-0.12	0.78	0.52	0.68									
	0.02	*0.35*	*0.26*	*0.31*	*0.68*	*0.03*	*0.06*	*0.84*	*0.01*	*0.15*	*0.21*									
Al	0.32	-0.38	-0.36	-0.38	0.19	0.26	0.17	-0.69	0.42	0.56	0.08	0.51								
	0.41	*0.32*	*0.35*	*0.32*	*0.63*	*0.50*	*0.66*	*0.20*	*0.26*	*0.12*	*0.90*	*0.16*								
Ca	0.71	0.53	0.45	0.51	0.12	0.62	0.65	0.75	0.69	0.74	0.95	0.77	0.29							
	0.03	*0.14*	*0.22*	*0.16*	*0.77*	*0.07*	*0.06*	*0.14*	*0.04*	*0.02*	*0.02*	*0.02*	*0.44*							
Fe	0.74	0.51	0.46	0.50	0.37	0.75	0.77	0.47	0.87	0.81	0.89	0.86	0.58	0.83						
	0.04	*0.20*	*0.25*	*0.21*	*0.37*	*0.03*	*0.03*	*0.43*	*0.01*	*0.01*	*0.04*	*0.01*	*0.13*	*0.01*						
Ti	0.79	0.45	0.44	0.45	0.00	0.64	0.60	0.22	0.67	0.69	0.70	0.85	0.51	0.89	0.82					
	0.01	*0.22*	*0.24*	*0.22*	*1.00*	*0.06*	*0.09*	*0.72*	*0.05*	*0.04*	*0.19*	*0.00*	*0.17*	*0.00*	*0.01*					
K	0.90	0.50	0.54	0.52	0.43	0.90	0.84	0.09	0.90	0.53	0.80	0.86	0.51	0.71	0.84	0.85				
	0.00	*0.17*	*0.13*	*0.15*	*0.25*	*0.00*	*0.01*	*0.89*	*0.00*	*0.14*	*0.10*	*0.00*	*0.16*	*0.03*	*0.01*	*0.00*				
S	0.89	0.57	0.68	0.61	0.20	0.77	0.72	-0.03	0.71	0.33	0.74	0.87	0.24	0.77	0.80	0.84	0.85			
	0.00	*0.11*	*0.04*	*0.08*	*0.61*	*0.02*	*0.03*	*0.96*	*0.03*	*0.39*	*0.15*	*0.00*	*0.54*	*0.02*	*0.02*	*0.00*	*0.00*			
Ni	0.28	0.03	-0.12	-0.02	0.14	0.33	0.35	0.86	0.51	0.92	0.91	0.41	0.70	0.47	0.83	0.48	0.38	0.10		
	0.47	*0.94*	*0.76*	*0.95*	*0.71*	*0.38*	*0.36*	*0.07*	*0.16*	*0.00*	*0.03*	*0.28*	*0.04*	*0.20*	*0.01*	*0.19*	*0.32*	*0.80*		
Pb	0.63	0.74	0.84	0.79	-0.13	0.58	0.53	0.48	0.36	0.18	0.53	0.45	-0.12	0.38	0.23	0.49	0.46	0.65	0.03	
	0.07	*0.02*	*0.00*	*0.01*	*0.74*	*0.10*	*0.15*	*0.42*	*0.34*	*0.64*	*0.36*	*0.23*	*0.77*	*0.32*	*0.59*	*0.18*	*0.21*	*0.06*	*0.94*	
Zn	0.49	0.53	0.58	0.55	-0.26	0.34	0.36	0.48	0.28	0.35	0.02	0.57	-0.07	0.68	0.39	0.59	0.31	0.68	0.16	0.71
	0.18	*0.14*	*0.11*	*0.12*	*0.49*	*0.38*	*0.35*	*0.41*	*0.47*	*0.36*	*0.97*	*0.11*	*0.85*	*0.04*	*0.35*	*0.10*	*0.42*	*0.05*	*0.68*	*0.03*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.53 **and Table 3.54** for PM mass and major species, respectively. PM_{10} mass shows lesser C.V. than $PM_{2.5}$ mass. For elements, C.V. observed in PM_{10} was very less than that in $PM_{2.5}$. Ions like sodium and potassium have highest C.V. due to much variation in their concentration during monitoring period.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.55 and Table 3.56 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than they show with $PM_{2.5}$. OC, EC, and TC show better correlation with PM_{10} mass than they do with $PM_{2.5}$ mass.

3.1.8 Site 8: Panipat

3.1.8.1 Summer Season

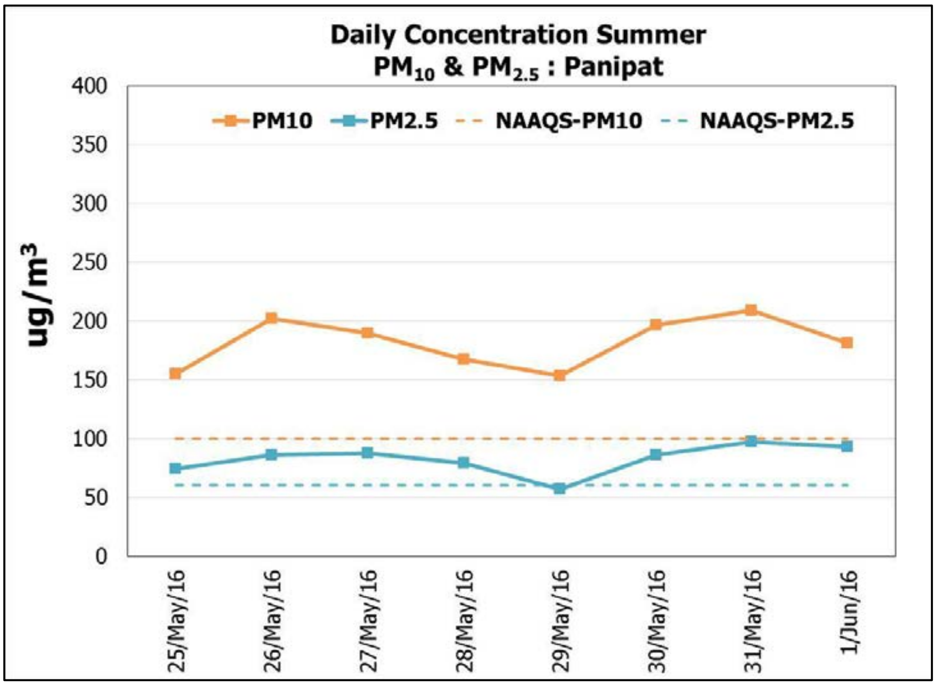


Figure 3.71 Variation in Hourly Concentration of PM_{10} and $PM_{2.5}$ at Panipat in Summer Season

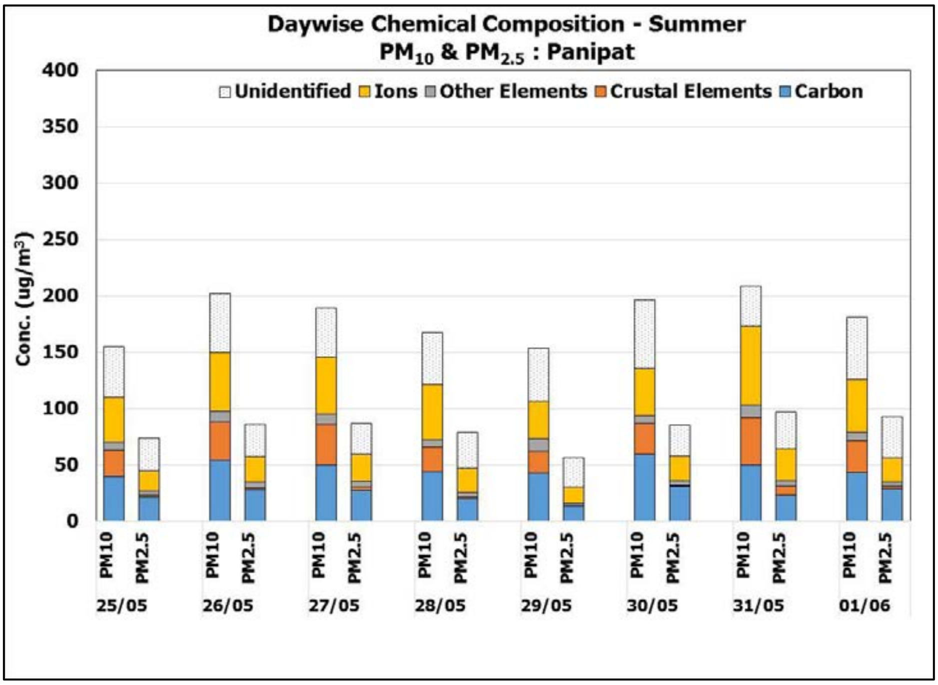


Figure 3.72: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Panipat in Summer Season

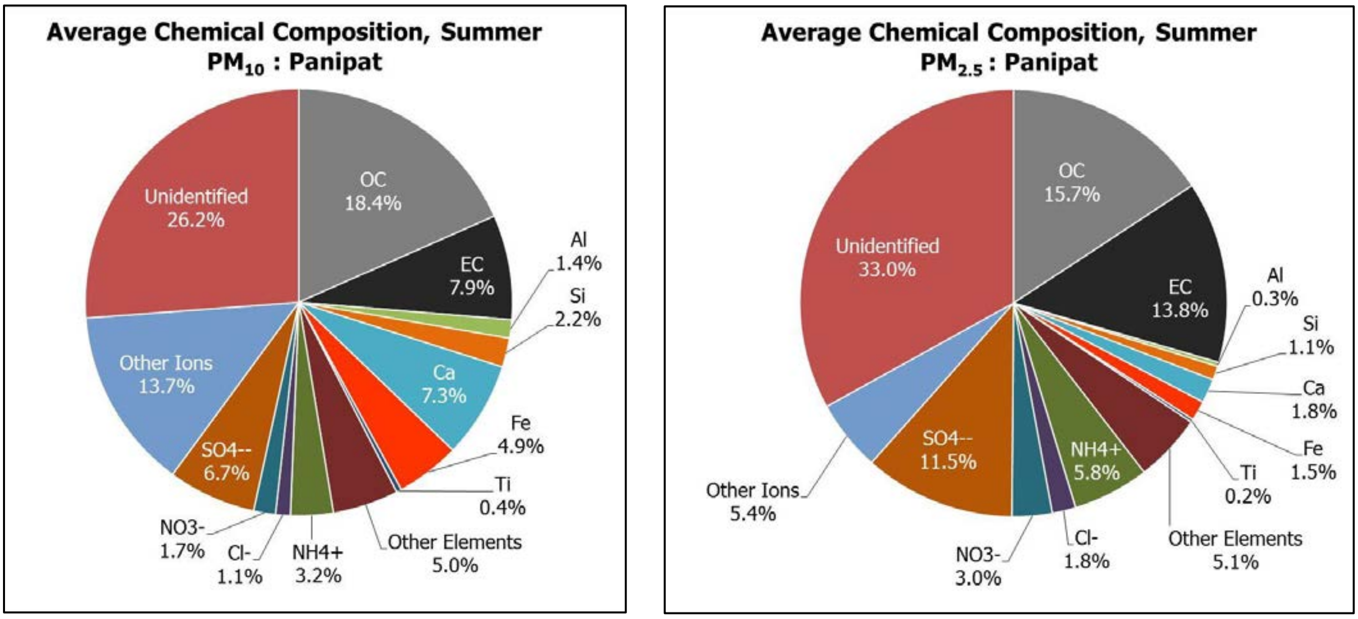


Figure 3.73: Average Chemical Composition of PM_{10} and PM2.5 at Panipat in Summer Season

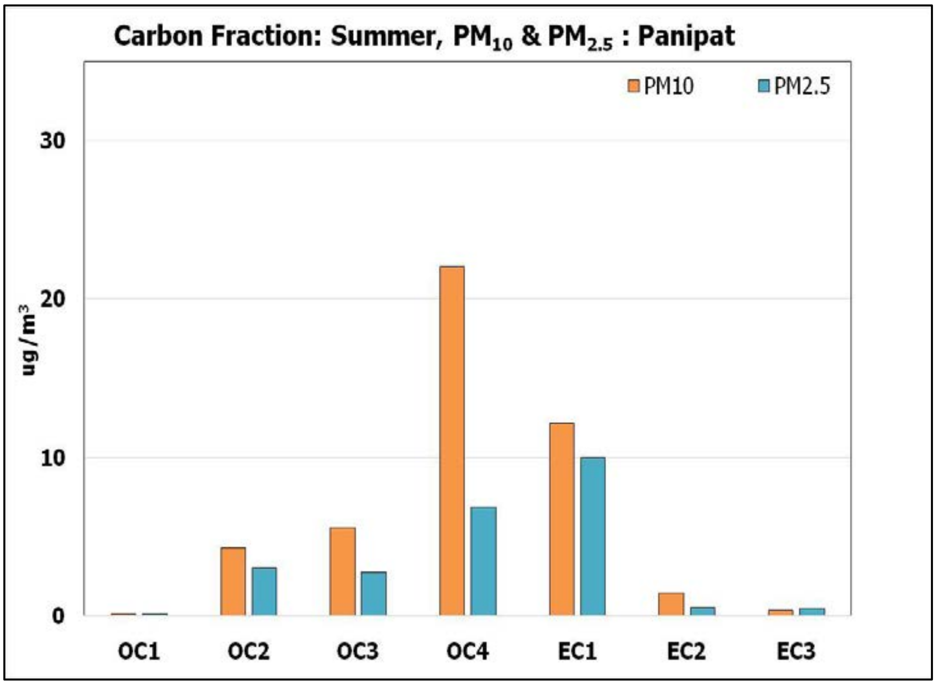


Figure 3.74 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Panipat in Summer Season

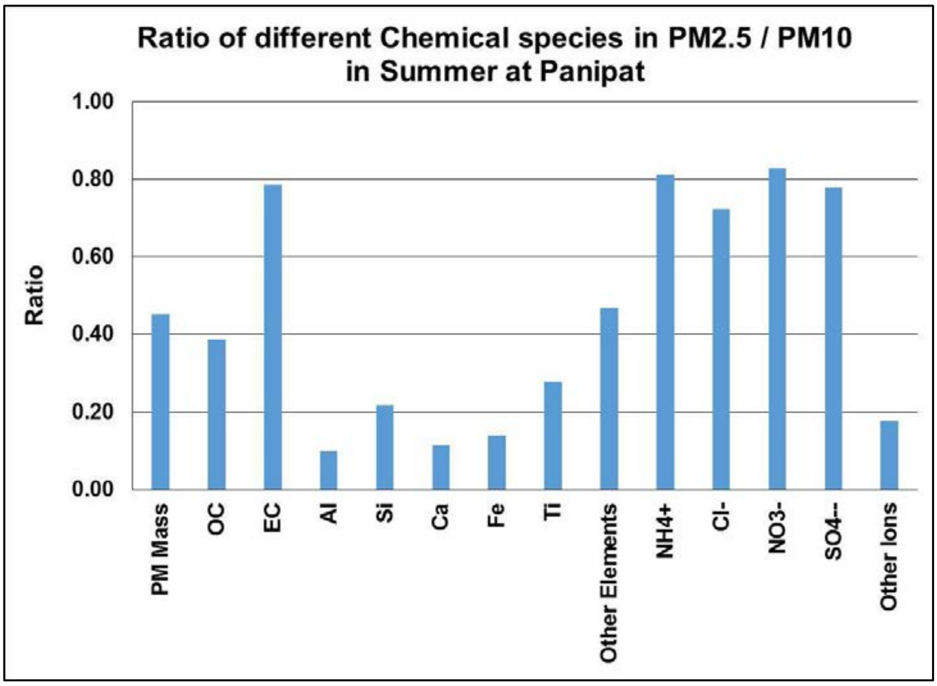


Figure 3.75: Ratio of Different Chemical Species in $PM_{2.5}$ /PM_{10} at Panipat in Summer Season

Average concentration observed at Panipat (PNP) was 181±21 µg/m³ for PM_{10} and 82±13 µg/m³ for $PM_{2.5}$. For PM_{10}, observed daily concentration variation was from 153 to 209 µg/m³. Similarly, for $PM_{2.5}$, daily concentration variation is 57 to 97 µg/m³ (see Figure 3.71).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.72.

The carbon fraction was found to be the highest, with 26% (48 µg/m³) in PM_{10} and 30% (24 µg/m³) in $PM_{2.5}$. concentration of Ions is 26% in both PM_{10} and $PM_{2.5}$. The crustal element concentration is 16% in PM_{10} and 3% in $PM_{2.5}$ (see Figure 3.73).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% in both PM_{10} and $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 26% for PM_{10} and 37% for $PM_{2.5}$.

OC4 was found to be highest in PM_{10}, followed by EC1, OC3, OC2, EC2, and EC3. On the other hand, EC1 is higher in $PM_{2.5}$, followed by OC4, OC2, OC3, EC2, and EC3. EC1 was found to be 12µg/m³ in PM_{10} and 10 µg/m³ in $PM_{2.5}$, while OC4 was found to be 22 µg/m³ in PM_{10} and 7 µg/m³ in $PM_{2.5}$ (see Figure 3.74). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.75.

Table 3.57 Statistical **evaluation of concentrations (µg/m³)** of mass and major species of PM_{10} at Panipat in Summer Season

µg/m³																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	181	33.33	14.39	2.53	4.00	13.21	8.81	0.70	4.23	1.44	0.18	0.30	2.03	3.01	12.10	5.93	5.85	3.43	11.58
SD	21	5.63	3.10	1.01	1.56	3.69	3.05	0.20	1.71	0.45	0.09	0.08	1.26	0.34	2.20	3.34	0.86	1.50	3.64
Min	153	26.87	10.19	1.30	2.04	8.62	4.37	0.37	1.29	0.91	0.07	0.22	0.69	2.45	9.06	2.17	4.65	0.87	7.29
Max	209	43.58	18.94	4.14	6.21	21.25	12.52	0.97	7.29	2.07	0.32	0.46	4.27	3.55	14.81	12.78	7.14	5.83	18.14
C.V.	0.12	0.17	0.22	0.40	0.39	0.28	0.35	0.28	0.40	0.31	0.51	0.25	0.62	0.11	0.18	0.56	0.15	0.44	0.31
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	206	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	185	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	154	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3,58 Statistical **evaluation of concentrations (µg/m³)** of mass and major species of $PM_{2.5}$ at Panipat in Summer Season

µg/m³																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	82	12.93	11.32	0.25	0.87	1.50	1.23	0.19	2.21	1.10	0.11	0.15	1.47	2.49	9.42	1.31	4.75	1.79	0.29
SD	13	3.64	3.07	0.09	0.05	0.33	1.99	0.17	0.68	0.27	0.07	0.08	1.04	0.43	1.53	0.61	0.60	0.67	0.24
Min	57	7.56	5.86	0.18	0.77	1.26	0.03	0.09	0.98	0.80	0.01	0.00	0.47	1.79	6.29	0.51	3.57	0.79	0.13
Max	97	19.94	15.43	0.44	0.93	2.27	6.10	0.60	3.03	1.55	0.21	0.23	3.47	3.01	10.74	1.97	5.50	2.61	0.85
C.V.	0.15	0.28	0.27	0.35	0.06	0.22	1.62	0.85	0.31	0.24	0.66	0.50	0.71	0.17	0.16	0.47	0.13	0.38	0.85
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	96	18.31	14.92	0.39	0.93	2.00	4.36	0.46	2.95	1.45	0.21	0.23	3.15	2.95	10.74	1.97	5.40	2.58	0.68
50 %ile	86	12.56	10.91	0.23	0.87	1.45	0.54	0.13	2.34	1.10	0.10	0.16	1.28	2.55	9.89	1.28	4.88	1.90	0.18
5 %ile	63	8.66	6.93	0.18	0.79	1.28	0.16	0.10	1.19	0.82	0.02	0.04	0.47	1.84	7.05	0.59	3.83	0.93	0.14

Table 3.59 Correlation Matrix for PM_{10} and Its major constituents at Panipat in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.63																			
	0.10																			
EC	0.58	0.07																		
	0.13	*0.88*																		
TC	0.81	0.88	0.53																	
	0.02	*0.00*	*0.18*																	
Cl^-	-0.31	-0.03	-0.36	-0.20																
	0.46	*0.94*	*0.39*	*0.64*																
NO_3^-	0.93	0.77	0.47	0.88	-0.49															
	0.00	*0.02*	*0.24*	*0.00*	*0.22*															
SO_4^{--}	0.75	0.35	0.32	0.45	-0.59	0.75														
	0.03	*0.39*	*0.43*	*0.26*	*0.12*	*0.03*														
Na^+	0.59	0.24	0.07	0.23	0.05	0.44	0.24													
	0.13	*0.57*	*0.87*	*0.58*	*0.92*	*0.28*	*0.57*													
NH_4^+	0.76	0.29	0.47	0.47	-0.69	0.75	0.93	0.29												
	0.03	*0.49*	*0.24*	*0.24*	*0.06*	*0.03*	*0.00*	*0.48*												
K^+	0.62	0.08	0.19	0.16	0.17	0.35	0.48	0.71	0.34											
	0.10	*0.85*	*0.65*	*0.71*	*0.69*	*0.40*	*0.23*	*0.05*	*0.41*											
Ca^{++}	0.68	0.15	0.25	0.25	-0.18	0.53	0.47	0.88	0.55	0.68										
	0.07	*0.72*	*0.55*	*0.55*	*0.68*	*0.18*	*0.24*	*0.00*	*0.16*	*0.06*										
Si	0.74	0.04	0.80	0.41	-0.32	0.55	0.45	0.55	0.51	0.64	0.68									
	0.04	*0.93*	*0.02*	*0.32*	*0.45*	*0.16*	*0.26*	*0.16*	*0.20*	*0.09*	*0.06*									
Al	0.71	0.00	0.76	0.36	-0.36	0.53	0.41	0.65	0.54	0.59	0.75	0.97								
	0.05	*1.00*	*0.03*	*0.39*	*0.39*	*0.17*	*0.32*	*0.08*	*0.17*	*0.12*	*0.03*	*0.00*								
Ca	0.70	0.32	0.00	0.28	-0.26	0.62	0.67	0.82	0.67	0.68	0.90	0.45	0.52							
	0.06	*0.44*	*0.99*	*0.51*	*0.54*	*0.10*	*0.07*	*0.01*	*0.07*	*0.07*	*0.00*	*0.26*	*0.19*							
Fe	0.76	0.33	0.75	0.63	-0.20	0.64	0.36	0.46	0.34	0.57	0.45	0.89	0.81	0.28						
	0.03	*0.43*	*0.03*	*0.10*	*0.64*	*0.09*	*0.39*	*0.25*	*0.42*	*0.14*	*0.27*	*0.00*	*0.01*	*0.50*						
Ti	0.67	0.04	0.76	0.39	-0.39	0.53	0.36	0.57	0.45	0.55	0.59	0.95	0.96	0.38	0.90					
	0.07	*0.93*	*0.03*	*0.34*	*0.35*	*0.18*	*0.38*	*0.14*	*0.27*	*0.16*	*0.13*	*0.00*	*0.00*	*0.35*	*0.00*					
K	0.73	0.20	0.23	0.28	0.05	0.50	0.59	0.76	0.48	0.98	0.73	0.66	0.63	0.77	0.60	0.59				
	0.04	*0.63*	*0.59*	*0.51*	*0.91*	*0.21*	*0.13*	*0.03*	*0.23*	*0.00*	*0.04*	*0.08*	*0.10*	*0.03*	*0.12*	*0.13*				
S	0.74	0.02	0.68	0.34	-0.50	0.59	0.80	0.30	0.77	0.64	0.57	0.84	0.77	0.52	0.68	0.73	0.67			
	0.04	*0.96*	*0.06*	*0.42*	*0.20*	*0.12*	*0.02*	*0.47*	*0.03*	*0.09*	*0.14*	*0.01*	*0.03*	*0.19*	*0.07*	*0.04*	*0.07*			
Ni	0.48	0.37	0.32	0.47	0.13	0.42	-0.06	0.60	-0.12	0.48	0.41	0.61	0.57	0.23	0.81	0.67	0.46	0.23		
	0.22	*0.37*	*0.44*	*0.25*	*0.76*	*0.31*	*0.89*	*0.12*	*0.78*	*0.23*	*0.31*	*0.11*	*0.14*	*0.58*	*0.01*	*0.07*	*0.25*	*0.58*		
Pb	0.64	0.07	0.27	0.18	-0.29	0.47	0.80	0.39	0.65	0.81	0.45	0.57	0.50	0.60	0.50	0.52	0.85	0.82	0.16	
	0.09	*0.88*	*0.51*	*0.66*	*0.49*	*0.24*	*0.02*	*0.35*	*0.08*	*0.01*	*0.26*	*0.14*	*0.20*	*0.12*	*0.21*	*0.19*	*0.01*	*0.01*	*0.71*	
Zn	0.77	0.36	0.64	0.61	-0.18	0.65	0.70	0.12	0.56	0.57	0.34	0.68	0.52	0.32	0.71	0.51	0.58	0.83	0.33	0.67
	0.03	*0.38*	*0.09*	*0.11*	*0.67*	*0.08*	*0.05*	*0.78*	*0.15*	*0.14*	*0.41*	*0.07*	*0.19*	*0.44*	*0.05*	*0.20*	*0.13*	*0.01*	*0.42*	*0.07*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.60 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Panipat in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.63																			
	0.09																			
EC	0.73	0.51																		
	0.04	*0.20*																		
TC	0.78	0.89	0.84																	
	0.02	*0.00*	*0.01*																	
Cl^-	0.24	-0.15	-0.21	-0.21																
	0.57	*0.72*	*0.61*	*0.62*																
NO_3^-	0.90	0.53	0.59	0.64	0.15															
	0.00	*0.18*	*0.13*	*0.09*	*0.73*															
SO_4^{--}	0.97	0.63	0.85	0.84	0.07	0.88														
	0.00	*0.10*	*0.01*	*0.01*	*0.87*	*0.00*														
Na^+	0.44	0.50	0.04	0.34	0.21	0.57	0.33													
	0.27	*0.20*	*0.92*	*0.42*	*0.63*	*0.14*	*0.43*													
NH_4^+	0.80	0.37	0.35	0.42	0.15	0.91	0.73	0.43												
	0.02	*0.36*	*0.40*	*0.31*	*0.72*	*0.00*	*0.04*	*0.29*												
K^+	0.70	0.44	0.54	0.56	-0.20	0.80	0.72	0.66	0.69											
	0.05	*0.28*	*0.17*	*0.15*	*0.64*	*0.02*	*0.05*	*0.08*	*0.06*											
Ca^{++}	0.38	0.11	0.43	0.30	-0.16	0.39	0.36	0.39	0.33	0.59										
	0.35	*0.79*	*0.28*	*0.47*	*0.71*	*0.34*	*0.38*	*0.33*	*0.43*	*0.13*										
Si	0.40	0.29	-0.18	0.09	0.71	0.27	0.17	0.47	0.36	0.01	0.19									
	0.32	*0.49*	*0.68*	*0.84*	*0.05*	*0.52*	*0.68*	*0.24*	*0.38*	*0.97*	*0.65*									
Al	0.66	0.38	0.39	0.44	0.43	0.47	0.56	0.05	0.53	0.06	0.33	0.69								
	0.08	*0.36*	*0.33*	*0.27*	*0.29*	*0.24*	*0.15*	*0.90*	*0.18*	*0.88*	*0.42*	*0.06*								
Ca	0.42	0.20	0.47	0.37	-0.11	0.41	0.39	0.49	0.29	0.60	0.98	0.23	0.32							
	0.31	*0.64*	*0.24*	*0.37*	*0.80*	*0.31*	*0.34*	*0.22*	*0.49*	*0.11*	*0.00*	*0.59*	*0.44*							
Fe	0.56	-0.02	0.04	0.01	0.37	0.52	0.44	0.27	0.71	0.52	0.24	0.45	0.34	0.18						
	0.15	*0.95*	*0.93*	*0.99*	*0.37*	*0.19*	*0.28*	*0.52*	*0.05*	*0.19*	*0.56*	*0.27*	*0.41*	*0.68*						
Ti	0.58	-0.01	0.06	0.03	0.36	0.53	0.45	0.28	0.72	0.53	0.28	0.46	0.36	0.21	1.00					
	0.13	*0.98*	*0.88*	*0.95*	*0.38*	*0.18*	*0.26*	*0.51*	*0.05*	*0.17*	*0.51*	*0.26*	*0.38*	*0.62*	*0.00*					
K	0.65	0.26	0.52	0.44	0.05	0.74	0.66	0.69	0.54	0.91	0.57	0.03	0.00	0.62	0.45	0.47				
	0.08	*0.53*	*0.19*	*0.28*	*0.90*	*0.04*	*0.08*	*0.06*	*0.17*	*0.00*	*0.15*	*0.94*	*0.99*	*0.10*	*0.26*	*0.25*				
S	0.70	0.27	0.85	0.62	-0.27	0.69	0.82	-0.09	0.62	0.60	0.39	-0.26	0.38	0.35	0.31	0.32	0.49			
	0.05	*0.51*	*0.01*	*0.10*	*0.52*	*0.06*	*0.01*	*0.83*	*0.10*	*0.12*	*0.34*	*0.54*	*0.35*	*0.40*	*0.46*	*0.44*	*0.22*			
Ni	0.66	-0.20	-0.17	-0.25	0.30	0.48	0.45	0.13	0.68	0.47	0.18	0.40	0.30	0.08	1.00	1.00	0.38	0.25		
	0.11	*0.66*	*0.71*	*0.59*	*0.51*	*0.28*	*0.31*	*0.78*	*0.09*	*0.29*	*0.70*	*0.37*	*0.52*	*0.87*	*0.00*	*0.00*	*0.40*	*0.60*		
Pb	0.76	0.27	0.49	0.42	0.54	0.48	0.70	-0.06	0.50	0.18	0.00	0.45	0.71	-0.01	0.60	0.61	0.20	0.49	0.61	
	0.03	*0.52*	*0.22*	*0.30*	*0.17*	*0.23*	*0.05*	*0.88*	*0.21*	*0.67*	*1.00*	*0.26*	*0.05*	*0.99*	*0.12*	*0.11*	*0.64*	*0.22*	*0.15*	
Zn	0.92	0.59	0.80	0.79	0.14	0.73	0.95	0.16	0.62	0.57	0.17	0.18	0.54	0.19	0.49	0.50	0.51	0.75	0.54	0.84
	0.00	*0.13*	*0.02*	*0.02*	*0.74*	*0.04*	*0.00*	*0.70*	*0.10*	*0.14*	*0.69*	*0.67*	*0.17*	*0.65*	*0.22*	*0.21*	*0.19*	*0.03*	*0.21*	*0.01*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.57 and Table 3.58 for PM mass and major species, respectively. PM_{10} mass shows lesser C.V. than PM2.5 mass. For crustal elements, C.V. changes variably in $PM_{2.5}$ than in PM_{10}.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.59 and Table 3.60 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. OC, EC, and TC show better correlation with PM_{10} mass than with $PM_{2.5}$ mass.

3.1.8.2 Winter Season

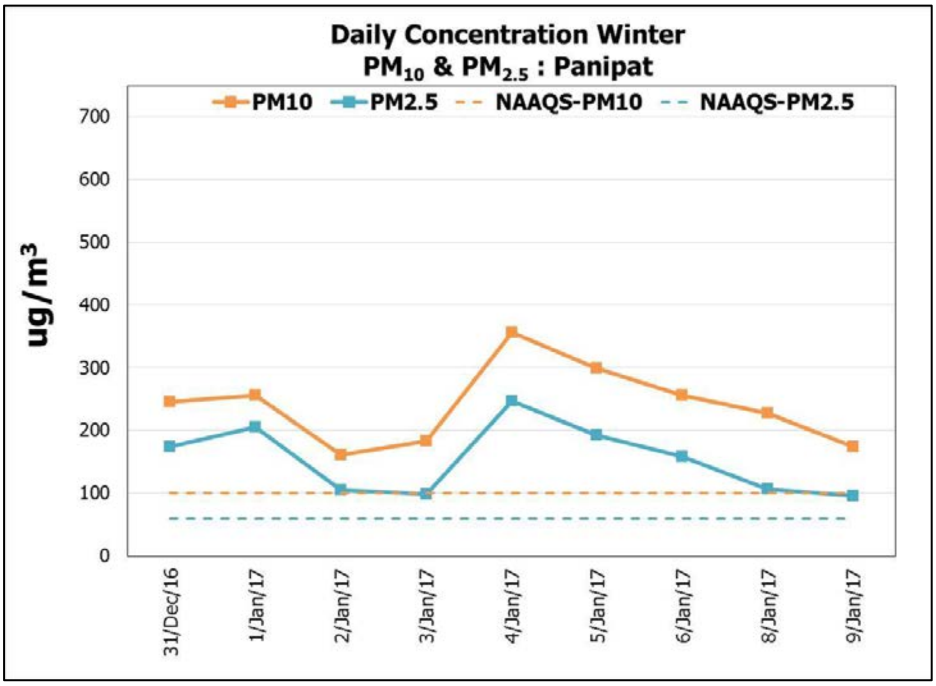


Figure 3.76: Variation in 24 t Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Panipat in Winter Season

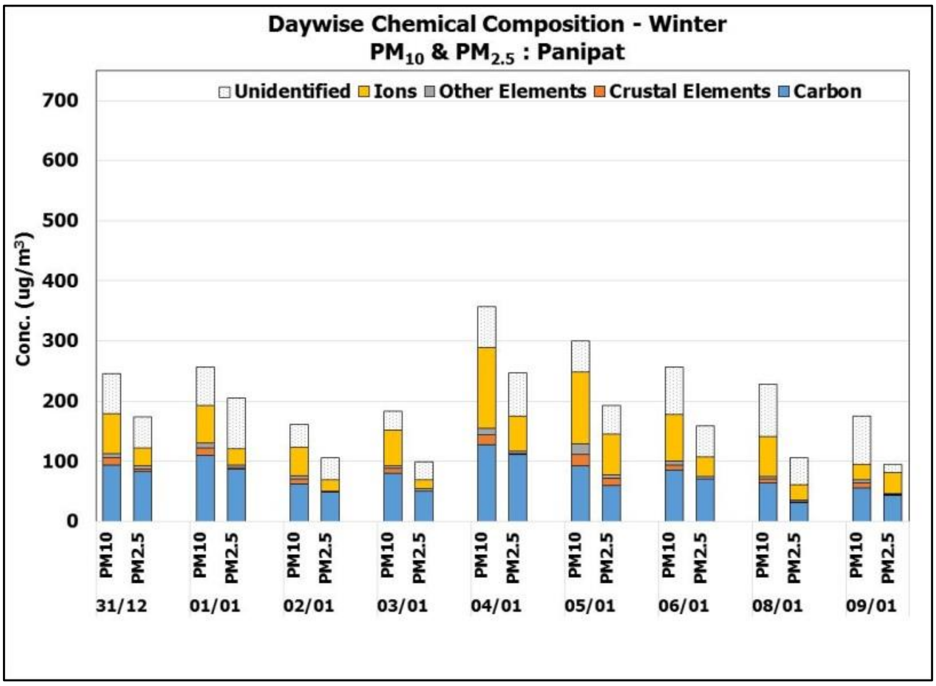


Figure 3.77: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Panipat in Winter Season

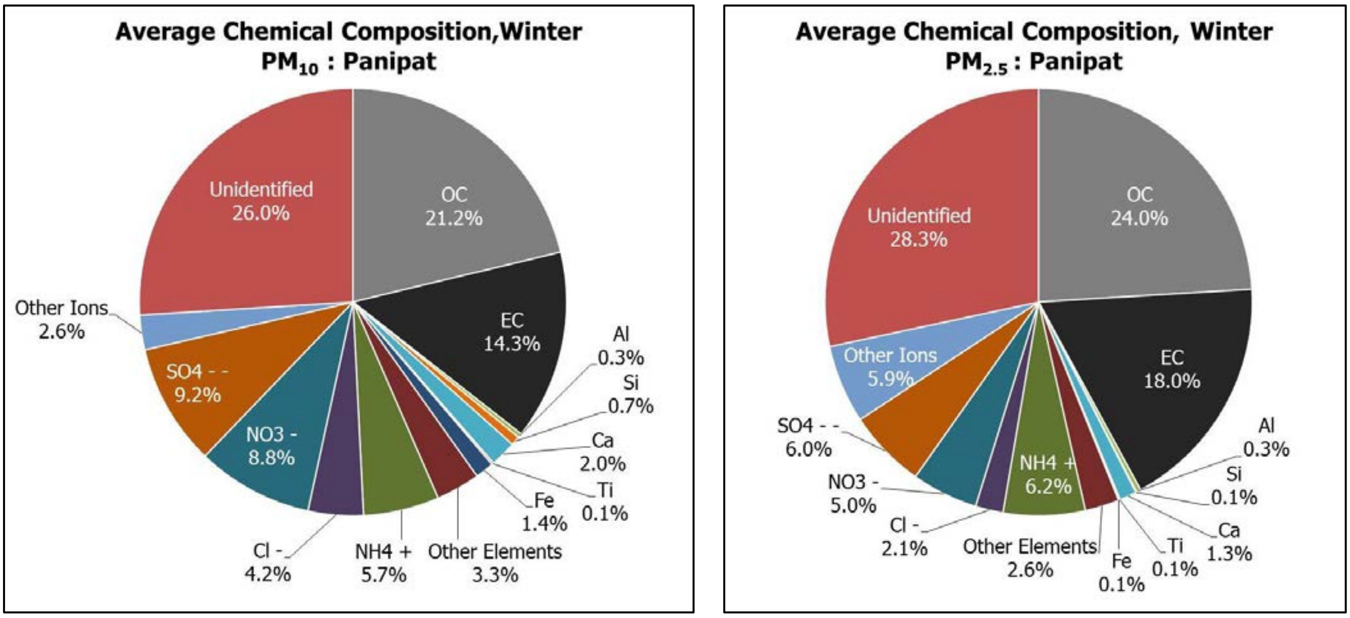


Figure 3.78: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Panipat in Winter Season

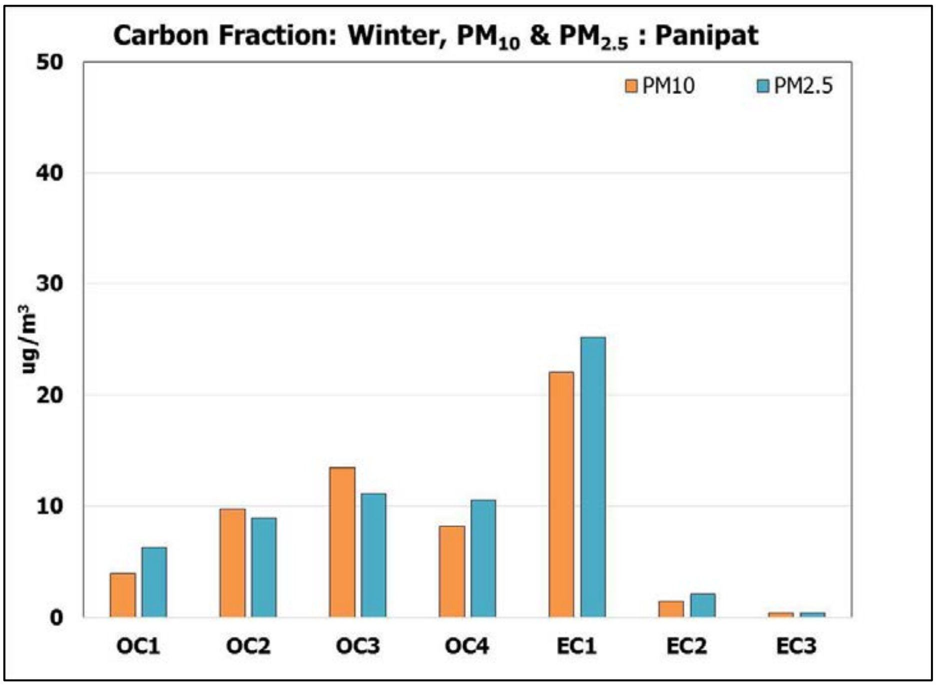


Figure 3.79: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Panipat in Winter Season

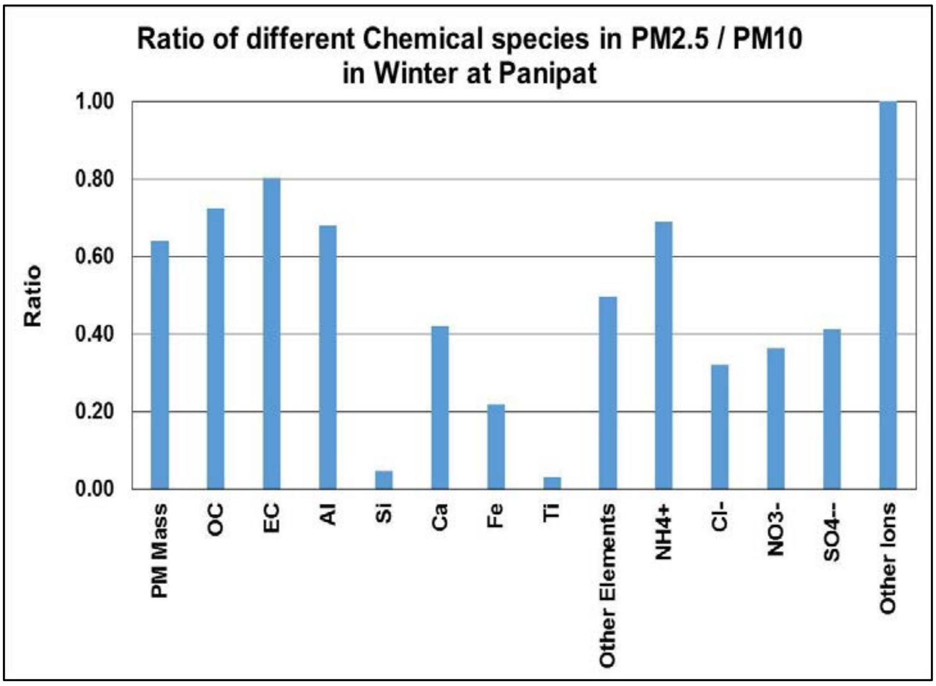


Figure 3.80: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Panipat in Winter Season

Average concentration of PM_{10} and $PM_{2.5}$ at Panipat was found to be 240±63 µg/m³ and 154±55 µg/m³, respectively. Average concentration of PM_{10} varied from 161 to 357 µg/m³, and in case of $PM_{2.5}$, it varied from 95 to 247 µg/m³ (see Figure 3.76).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.77.

The carbon fraction was found to be a major potion followed by total ions and crustal element. The carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 85µg/m³ and 65µg/m³, respectively. The percentage mass distribution showed that the organic carbon and elemental carbon of $PM_{2.5}$ is higher as compared to that of PM_{10}. The crustal element of PM_{10} and $PM_{2.5}$ was found to be 5% and 2%, respectively. The total ion concentration of PM_{10} is 31% and that of PM2.5 is 25% (see Figure 3.78).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3 % in both PM_{10} and $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 26% in PM_{10} and 28% in $PM_{2.5}$.

The carbon fraction showed that OC3 was higher in PM_{10}, followed by OC2, OC4, and OC1, and in case of $PM_{2.5}$, OC3 was higher, followed by OC4, OC2, and OC1. EC1, followed by EC2, were found to be higher in $PM_{2.5}$ as compared to those in PM_{10}, while EC3 was found to be similar in both PM_{10} and $PM_{2.5}$ (see Figure 3.79). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.80.

Table 5 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Panipat in Winter Season

	µg/m3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	240	50.97	34.45	0.78	1.69	4.74	3.39	0.36	2.91	2.82	0.12	0.72	10.03	21.13	22.12	0.67	13.77	2.32	2.08
SD	63	13.14	11.27	0.29	0.76	2.50	1.61	0.23	1.63	1.92	0.07	0.22	7.46	9.38	12.16	0.30	7.44	1.14	1.52
Min	161	34.09	21.21	0.40	0.64	1.60	0.83	0.16	1.21	1.21	0.06	0.19	3.03	10.57	2.85	0.31	5.93	0.94	0.28
Max	357	73.34	53.77	1.23	2.70	8.57	6.51	0.94	6.76	6.99	0.27	0.90	22.97	39.78	39.02	1.23	29.83	4.31	4.63
C.V.	0.26	0.26	0.33	0.38	0.45	0.53	0.47	0.64	0.56	0.68	0.57	0.30	0.74	0.44	0.55	0.45	0.54	0.49	0.73
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	334	68.13	51.91	1.15	2.68	8.48	5.75	0.72	5.64	6.16	0.24	0.90	21.12	36.93	37.82	1.12	25.39	3.93	4.15
50 %ile	243	52.48	32.66	0.84	1.77	4.37	3.19	0.32	2.46	2.40	0.11	0.77	8.22	18.25	22.66	0.62	13.18	2.11	2.22
5 %ile	112	23.61	16.24	0.34	0.70	2.05	1.22	0.19	1.42	1.24	0.06	0.21	3.14	9.98	6.57	0.31	6.39	1.04	0.32

Table 3.62 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Panipat in Winter Season

	µg/m3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	154	36.93	27.68	0.53	0.08	1.99	0.11	0.08	1.10	1.79	0.08	0.29	3.22	7.71	9.14	1.25	9.51	1.37	4.72
SD	55	15.00	10.96	0.57	0.05	3.28	0.05	0.08	0.39	0.48	0.06	0.22	3.20	3.37	3.58	1.49	6.73	0.93	7.05
Min	95	19.10	12.27	0.13	0.03	0.03	0.04	0.00	0.52	1.08	0.02	0.11	0.25	4.58	3.92	0.09	3.76	0.77	0.54
Max	247	67.20	44.09	1.96	0.22	9.49	0.23	0.26	1.72	2.34	0.18	0.74	10.13	15.37	14.13	4.13	24.69	3.68	12.85
C.V.	0.36	0.41	0.40	1.08	0.68	1.64	0.48	1.09	0.36	0.27	0.71	0.76	1.00	0.44	0.39	1.19	0.71	0.68	1.49
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	230	59.18	42.22	1.45	0.17	7.36	0.19	0.21	1.61	2.34	0.16	0.66	8.46	12.96	13.36	3.70	21.10	2.92	11.64
50 %ile	159	28.13	27.16	0.38	0.07	0.26	0.11	0.07	1.15	1.96	0.06	0.18	2.26	7.43	9.60	0.59	8.01	0.91	0.75
5 %ile	97	22.23	13.71	0.14	0.03	0.05	0.05	0.00	0.57	1.13	0.03	0.11	0.53	4.65	3.99	0.10	3.89	0.79	0.56

Table 3.63 Correlation Matrix for PM_{10} and Its major constituents at Panipat in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.00																			
EC	0.78	0.81																		
	0.01	*0.01*																		
TC	0.86	0.96	0.94																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.85	0.81	0.87	0.88																
	0.00	*0.01*	*0.00*	*0.00*																
NO_3^-	0.79	0.59	0.41	0.53	0.71															
	0.01	*0.09*	*0.28*	*0.14*	*0.03*															
SO_4^{--}	0.74	0.75	0.36	0.60	0.52	0.79														
	0.02	*0.02*	*0.34*	*0.09*	*0.15*	*0.01*														
Na^+	0.67	0.70	0.67	0.72	0.55	0.25	0.55													
	0.05	*0.04*	*0.05*	*0.03*	*0.13*	*0.52*	*0.13*													
NH_4^+	0.90	0.67	0.61	0.67	0.70	0.81	0.76	0.61												
	0.00	*0.05*	*0.08*	*0.05*	*0.04*	*0.01*	*0.02*	*0.08*												
K^+	0.78	0.80	0.85	0.86	0.95	0.61	0.51	0.59	0.64											
	0.01	*0.01*	*0.00*	*0.00*	*0.00*	*0.08*	*0.16*	*0.09*	*0.07*											
Ca^{++}	0.33	0.31	0.49	0.41	0.11	-0.13	0.10	0.44	0.23	0.24										
	0.39	*0.42*	*0.18*	*0.27*	*0.77*	*0.75*	*0.81*	*0.24*	*0.56*	*0.54*										
Si	0.88	0.52	0.48	0.53	0.62	0.81	0.64	0.44	0.87	0.57	0.31									
	0.00	*0.15*	*0.19*	*0.15*	*0.07*	*0.01*	*0.06*	*0.23*	*0.00*	*0.11*	*0.42*									
Al	0.81	0.59	0.78	0.71	0.76	0.47	0.37	0.71	0.69	0.79	0.55	0.77								
	0.01	*0.10*	*0.01*	*0.03*	*0.02*	*0.20*	*0.33*	*0.03*	*0.04*	*0.01*	*0.12*	*0.02*								
Ca	0.77	0.68	0.70	0.73	0.93	0.73	0.42	0.27	0.61	0.87	-0.03	0.62	0.63							
	0.02	*0.04*	*0.04*	*0.03*	*0.00*	*0.02*	*0.26*	*0.48*	*0.08*	*0.00*	*0.93*	*0.08*	*0.07*							
Fe	0.54	0.65	0.46	0.59	0.75	0.63	0.43	0.14	0.28	0.67	-0.31	0.31	0.28	0.82						
	0.14	*0.06*	*0.22*	*0.09*	*0.02*	*0.07*	*0.24*	*0.72*	*0.47*	*0.05*	*0.42*	*0.41*	*0.46*	*0.01*						
Ti	0.48	0.33	0.14	0.26	0.54	0.71	0.40	-0.05	0.28	0.47	-0.29	0.55	0.33	0.69	0.81					
	0.20	*0.38*	*0.71*	*0.50*	*0.13*	*0.03*	*0.29*	*0.90*	*0.47*	*0.20*	*0.44*	*0.13*	*0.39*	*0.04*	*0.01*					
K	0.64	0.57	0.36	0.50	0.74	0.85	0.57	0.09	0.49	0.64	-0.33	0.58	0.36	0.85	0.92	0.92				
	0.06	*0.11*	*0.34*	*0.17*	*0.02*	*0.00*	*0.11*	*0.82*	*0.18*	*0.06*	*0.39*	*0.10*	*0.35*	*0.00*	*0.00*	*0.00*				
S	0.80	0.58	0.40	0.52	0.74	0.96	0.69	0.22	0.74	0.66	-0.12	0.84	0.54	0.83	0.72	0.84	0.92			
	0.01	*0.10*	*0.29*	*0.15*	*0.02*	*0.00*	*0.04*	*0.57*	*0.02*	*0.06*	*0.75*	*0.01*	*0.13*	*0.01*	*0.03*	*0.00*	*0.00*			
Ni	0.39	0.16	0.05	0.12	0.45	0.61	0.22	-0.14	0.24	0.41	-0.30	0.55	0.34	0.67	0.68	0.95	0.82	0.79		
	0.30	*0.68*	*0.90*	*0.77*	*0.22*	*0.08*	*0.58*	*0.72*	*0.54*	*0.28*	*0.44*	*0.12*	*0.37*	*0.05*	*0.05*	*0.00*	*0.01*	*0.01*		
Pb	0.82	0.61	0.40	0.54	0.72	0.97	0.74	0.25	0.77	0.63	-0.10	0.85	0.52	0.79	0.70	0.81	0.90	0.99	0.74	
	0.01	*0.08*	*0.28*	*0.13*	*0.03*	*0.00*	*0.02*	*0.52*	*0.02*	*0.07*	*0.80*	*0.00*	*0.15*	*0.01*	*0.04*	*0.01*	*0.00*	*0.00*	*0.02*	
Zn	0.42	0.62	0.56	0.62	0.63	0.44	0.27	-0.03	0.27	0.52	-0.14	0.10	0.06	0.69	0.73	0.32	0.60	0.43	0.20	0.43
	0.26	*0.07*	*0.12*	*0.07*	*0.07*	*0.24*	*0.48*	*0.95*	*0.48*	*0.16*	*0.72*	*0.80*	*0.88*	*0.04*	*0.03*	*0.41*	*0.09*	*0.25*	*0.61*	*0.24*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.64 Correlation Matrix for PM$_{2.5}$ and Its major constituents at Panipat in Winter Season

	PM$_{2.5}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.00																			
EC	0.93	0.90																		
	0.00	*0.00*																		
TC	0.91	0.98	0.97																	
	0.00	*0.00*	*0.00*																	
Cl$^-$	0.81	0.82	0.74	0.81																
	0.05	*0.05*	*0.09*	*0.05*																
NO$_3^-$	0.68	0.81	0.56	0.72	0.71															
	0.14	*0.05*	*0.25*	*0.10*	*0.11*															
SO$_4^{--}$	0.77	0.86	0.68	0.80	0.47	0.84														
	0.07	*0.03*	*0.14*	*0.06*	*0.34*	*0.04*														
Na$^+$	-0.15	-0.54	-0.43	-0.51	0.19	-0.20	0.09													
	0.73	*0.17*	*0.29*	*0.20*	*0.73*	*0.71*	*0.87*													
NH$_4^+$	0.67	0.26	0.47	0.35	0.82	0.92	0.88	0.27												
	0.07	*0.54*	*0.24*	*0.39*	*0.05*	*0.01*	*0.02*	*0.52*												
K$^+$	0.55	0.07	0.39	0.20	0.87	0.60	0.55	0.36	0.95											
	0.16	*0.87*	*0.34*	*0.63*	*0.02*	*0.21*	*0.26*	*0.38*	*0.00*											
Ca^{++}	1.00	1.00	1.00	1.00	*	*	*	-1.00	1.00	1.00										
	*	*	*	*	*	*	*	*	*	*										
Si	0.35	-0.15	0.19	-0.01	0.21	-0.08	0.27	0.59	0.82	0.92	1.00									
	0.35	*0.69*	*0.62*	*0.98*	*0.70*	*0.88*	*0.60*	*0.12*	*0.01*	*0.00*	*									
Al	0.37	-0.09	0.23	0.05	0.49	0.01	0.26	0.39	0.88	0.97	1.00	0.95								
	0.32	*0.83*	*0.55*	*0.90*	*0.32*	*0.98*	*0.62*	*0.35*	*0.00*	*0.00*	*	*0.00*								
Ca	0.34	-0.15	0.27	0.03	-0.28	-0.45	-0.07	0.39	0.78	0.90	1.00	0.95	0.91							
	0.41	*0.72*	*0.53*	*0.95*	*0.65*	*0.45*	*0.92*	*0.39*	*0.04*	*0.01*	*	*0.00*	*0.00*							
Fe	0.63	0.15	0.48	0.30	0.70	0.39	0.49	0.50	0.90	0.97	1.00	0.84	0.78	0.88						
	0.07	*0.69*	*0.19*	*0.43*	*0.12*	*0.45*	*0.32*	*0.21*	*0.00*	*0.00*	*	*0.01*	*0.01*	*0.00*						
Ti	0.08	-0.37	-0.01	-0.22	-0.19	-0.38	-0.02	0.57	0.74	0.88	1.00	0.96	0.92	0.90	0.67					
	0.84	*0.37*	*0.98*	*0.60*	*0.76*	*0.53*	*0.98*	*0.18*	*0.06*	*0.01*	*	*0.00*	*0.00*	*0.00*	*0.07*					
K	0.76	0.40	0.64	0.52	0.51	0.58	0.78	0.43	0.84	0.80	1.00	0.68	0.55	0.70	0.88	0.49				
	0.02	*0.28*	*0.07*	*0.16*	*0.31*	*0.23*	*0.07*	*0.29*	*0.01*	*0.02*	*	*0.04*	*0.13*	*0.05*	*0.00*	*0.22*				
S	0.73	0.62	0.77	0.70	0.33	0.64	0.75	-0.29	0.70	0.59	1.00	0.41	0.43	0.55	0.54	0.33	0.71			
	0.03	*0.08*	*0.02*	*0.04*	*0.52*	*0.17*	*0.09*	*0.49*	*0.05*	*0.12*	*	*0.27*	*0.25*	*0.16*	*0.14*	*0.43*	*0.03*			
Ni	0.15	-0.29	0.06	-0.14	-0.20	-0.32	0.08	0.46	0.80	0.92	1.00	0.95	0.95	0.92	0.68	0.99	0.49	0.41		
	0.73	*0.49*	*0.89*	*0.73*	*0.75*	*0.60*	*0.90*	*0.30*	*0.03*	*0.00*	*	*0.00*	*0.00*	*0.00*	*0.07*	*0.00*	*0.22*	*0.31*		
Pb	0.88	0.79	0.93	0.88	0.75	0.51	0.51	-0.20	0.52	0.49	1.00	0.30	0.29	0.35	0.56	0.13	0.72	0.72	0.17	
	0.00	*0.01*	*0.00*	*0.00*	*0.09*	*0.31*	*0.31*	*0.64*	*0.19*	*0.22*	*	*0.44*	*0.46*	*0.40*	*0.11*	*0.75*	*0.03*	*0.03*	*0.69*	
Zn	0.53	0.16	0.51	0.32	0.07	0.09	0.33	0.24	0.78	0.86	1.00	0.81	0.77	0.92	0.87	0.76	0.82	0.66	0.78	0.60
	0.14	*0.69*	*0.16*	*0.41*	*0.89*	*0.86*	*0.52*	*0.57*	*0.02*	*0.01*	*	*0.01*	*0.02*	*0.00*	*0.00*	*0.03*	*0.01*	*0.05*	*0.02*	*0.09*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.61 and Table 3.62 for PM mass and the major species, respectively. PM_{10} mass shows lesser C.V. than $PM_{2.5}$ mass. For elements, C.V. observed in PM10 was lesser than that in PM2.5..

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.63 and Table 3.64 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. OC, EC, and TC show better correlation with $PM_{2.5}$ mass than in PM_{10} mass.

3.1.9 Site 9: Nariana

3.1.9.1 Summer Season

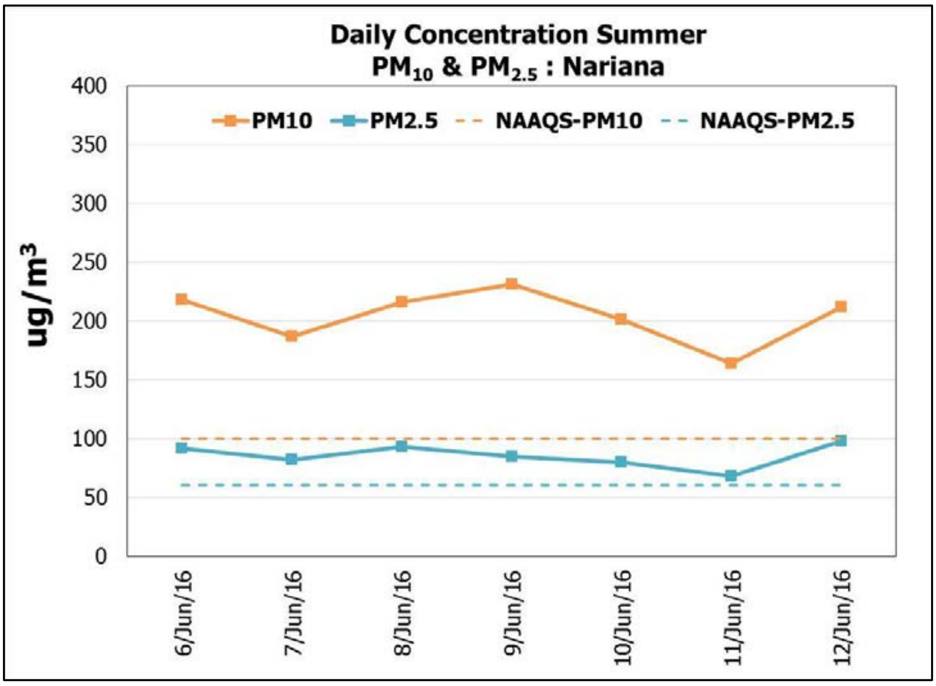


Figure 3.81 Variation in 24 the Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Naraina in the Summer Season

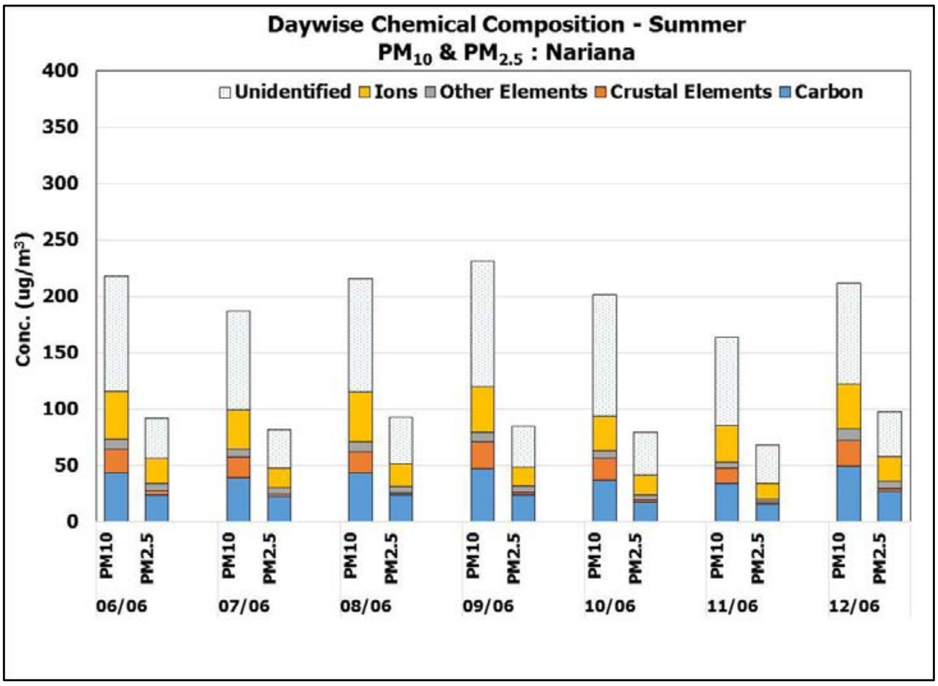


Figure 3.82 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Naraina in Summer Season

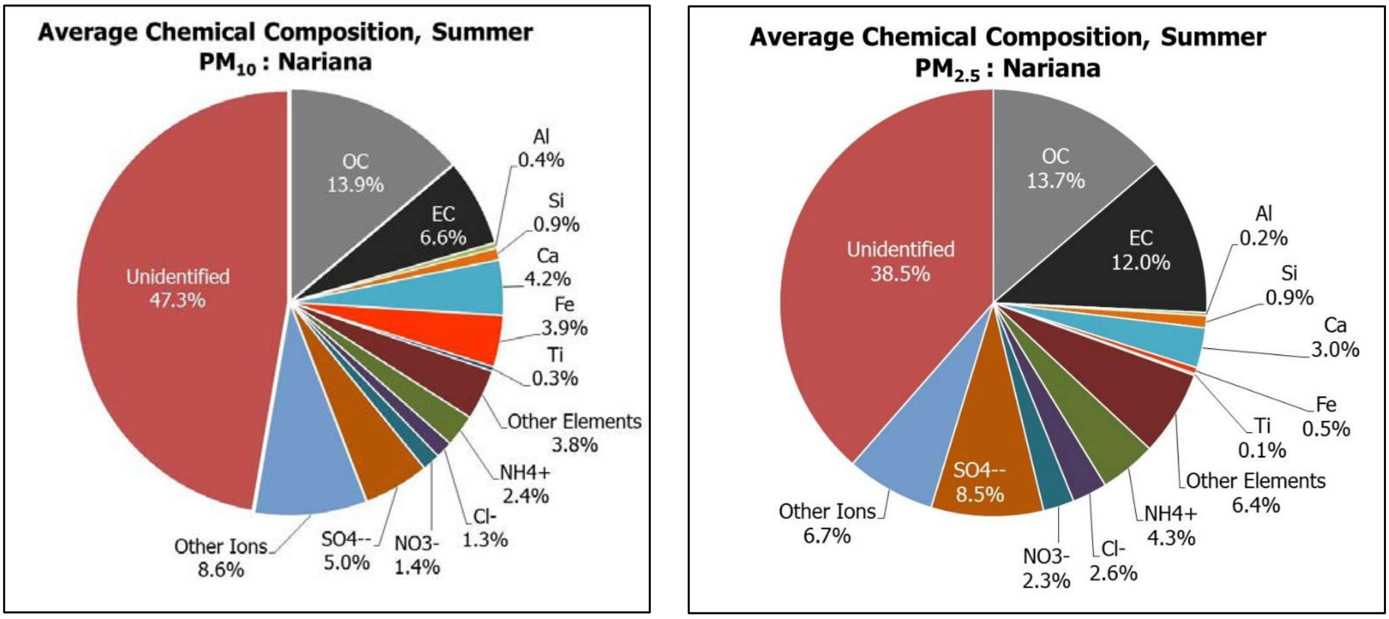


Figure 3.83: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Naraina in Summer Season

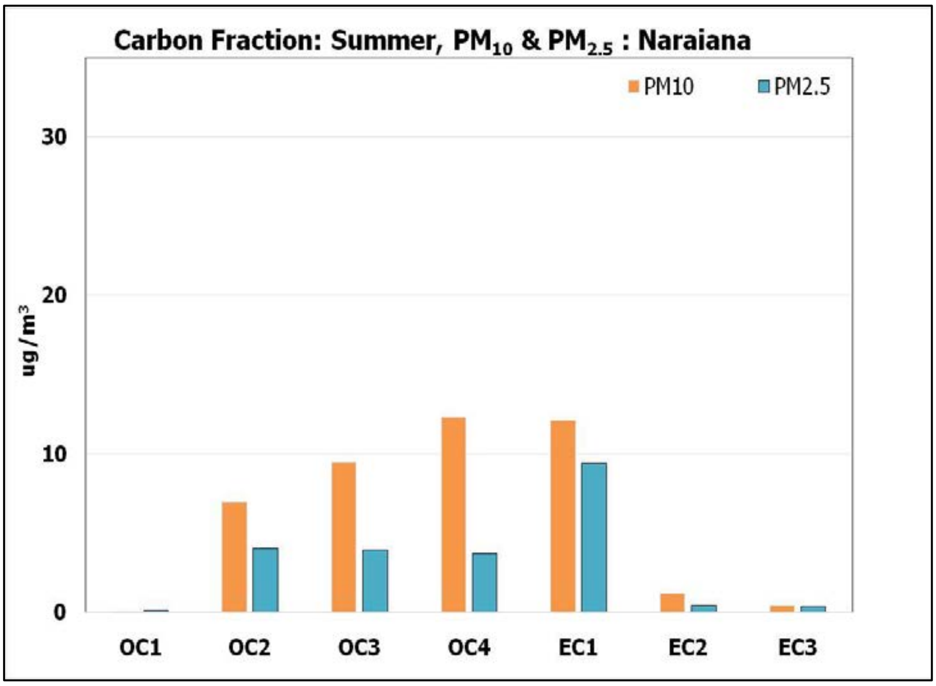


Figure 3.84 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Naraina in Summer Season

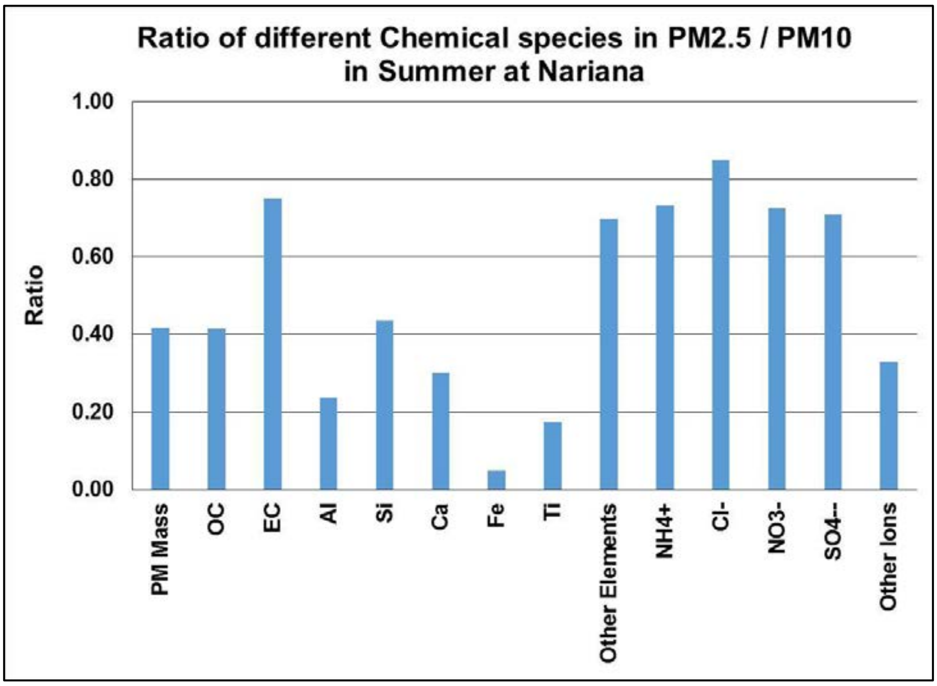


Figure 3.85 Ratio of Different Chemical Species in $PM_{2.5}$/PM_{10} at Naraina in the Summer Season

Average concentration observed at Naraina (NYR) in summer season was 204±23 µg/m³ for PM_{10} and 85±10 µg/m³ for $PM_{2.5}$. During monitoring period, spread of PM_{10} and $PM_{2.5}$ was very less in terms of daily concentration. Still average concentration of PM_{10} was 2 times NAAQS. For PM_{10}, observed daily concentration variation was from 163 to 231 µg/m³. Similarly, for $PM_{2.5}$, daily concentration variation was from 68 to 98 µg/m³ (see Figure 3.81).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in (see Figure 3.82).

The ionic portion was found to be highest: 27% in PM_{10} & 34% in $PM_{2.5}$. The carbon fraction was 42 µg/m³ (21%) in PM_{10} and 22 µg/m³ (26%) in $PM_{2.5}$. Concentration of crustal elements is 10% in PM_{10} and 3% in $PM_{2.5}$ (see Figure 3.83).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% in PM10 and 6% in PM2.5.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 47% for PM_{10} and 43% for $PM_{2.5}$.

OC4 in PM_{10} was found to be higher as compared to that in $PM_{2.5}$, followed by OC3 and OC2. EC1 in PM_{10} was found to be higher as compared to that in PM2.5, followed by EC2 and EC3. EC1 was found to be 12 µg/m³ in PM_{10} and 9 µg/m³ in $PM_{2.5}$, whereas OC4 in PM_{10} and $PM_{2.5}$ was found to be 12 µg/m³ and 3 µg/m³, respectively (see Figure 3.84). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.85.

Table 3.65 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Naraina in Summer Season

µg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	204	28.24	13.54	0.83	1.80	8.56	7.99	0.66	4.44	1.22	0.14	0.29	2.64	2.76	10.17	3.88	4.98	2.70	7.16
SD	23	3.17	3.40	0.32	0.66	1.18	1.84	0.12	1.46	0.13	0.05	0.07	1.03	0.18	1.89	0.68	1.02	1.07	1.28
Min	163	23.82	8.65	0.52	1.07	6.33	5.89	0.49	1.89	1.06	0.10	0.18	1.06	2.50	7.96	2.69	3.81	1.42	4.53
Max	231	32.86	16.23	1.32	2.96	10.16	10.46	0.79	6.53	1.35	0.23	0.39	3.88	2.94	12.81	4.80	6.38	3.92	8.38
C.V.	0.11	0.11	0.25	0.39	0.36	0.14	0.23	0.18	0.33	0.11	0.34	0.25	0.39	0.07	0.19	0.18	0.21	0.40	0.18
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	227	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	211	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	170	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.66 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Naraina in Summer Season

µg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	85	11.68	10.18	0.20	0.78	2.58	0.40	0.11	3.54	0.91	0.07	0.15	2.25	2.00	7.22	1.67	3.64	1.81	1.17
SD	10	2.02	2.02	0.04	0.07	0.60	0.12	0.01	1.20	0.23	0.01	0.04	0.90	0.29	1.20	0.50	0.69	0.59	0.54
Min	68	8.61	7.21	0.17	0.68	1.70	0.22	0.10	1.09	0.46	0.04	0.10	1.00	1.55	5.01	1.10	2.45	1.21	0.37
Max	98	14.65	12.31	0.29	0.89	3.49	0.53	0.13	4.49	1.12	0.08	0.21	3.57	2.47	8.60	2.31	4.41	2.82	1.89
C.V.	0.12	0.17	0.20	0.21	0.08	0.23	0.30	0.10	0.34	0.26	0.22	0.25	0.40	0.14	0.17	0.30	0.19	0.32	0.46
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	96	14.09	12.15	0.26	0.87	3.39	0.52	0.13	4.40	1.12	0.08	0.20	3.49	2.39	8.48	2.28	4.40	2.63	1.85
50 %ile	84	12.04	10.87	0.19	0.78	2.48	0.45	0.11	4.06	0.99	0.07	0.16	2.05	1.96	7.09	1.47	3.48	1.85	1.25
5 %ile	71	8.99	7.29	0.17	0.70	1.86	0.24	0.10	1.62	0.55	0.04	0.10	1.23	1.65	5.52	1.15	2.70	1.21	0.49

Table 3.67 Correlation Matrix for PM_{10} and Its major constituents at Naraina in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.75																			
	0.05																			
EC	0.66	0.38																		
	0.11	*0.40*																		
TC	0.85	0.82	0.84																	
	0.02	*0.02*	*0.02*																	
Cl^-	0.43	0.65	0.37	0.61																
	0.34	*0.12*	*0.42*	*0.15*																
NO_3^-	0.69	0.62	0.53	0.69	0.75															
	0.09	*0.14*	*0.22*	*0.09*	*0.06*															
SO_4^{--}	0.67	0.52	0.52	0.62	0.60	0.98														
	0.10	*0.23*	*0.23*	*0.14*	*0.16*	*0.00*														
Na^+	0.24	0.38	0.73	0.67	0.46	0.32	0.24													
	0.61	*0.41*	*0.06*	*0.10*	*0.30*	*0.49*	*0.61*													
NH_4^+	0.63	0.60	0.56	0.70	0.20	0.66	0.71	0.47												
	0.13	*0.15*	*0.19*	*0.08*	*0.67*	*0.11*	*0.07*	*0.29*												
K^+	0.32	-0.19	0.63	0.29	-0.19	0.30	0.44	0.11	0.40											
	0.48	*0.69*	*0.13*	*0.54*	*0.68*	*0.51*	*0.32*	*0.82*	*0.37*											
Ca^{++}	0.90	0.57	0.77	0.81	0.33	0.46	0.43	0.28	0.37	0.43										
	0.01	*0.18*	*0.05*	*0.03*	*0.47*	*0.29*	*0.33*	*0.55*	*0.41*	*0.34*										
Si	0.76	0.68	0.78	0.88	0.48	0.58	0.52	0.75	0.69	0.14	0.67									
	0.05	*0.10*	*0.04*	*0.01*	*0.27*	*0.17*	*0.23*	*0.05*	*0.09*	*0.77*	*0.10*									
Al	0.75	0.82	0.69	0.90	0.54	0.62	0.54	0.73	0.76	0.03	0.60	0.97								
	0.05	*0.02*	*0.09*	*0.01*	*0.21*	*0.14*	*0.21*	*0.06*	*0.05*	*0.95*	*0.15*	*0.00*								
Ca	0.75	0.41	0.72	0.69	-0.04	0.46	0.56	0.24	0.76	0.76	0.72	0.52	0.52							
	0.05	*0.36*	*0.07*	*0.09*	*0.94*	*0.30*	*0.20*	*0.61*	*0.05*	*0.05*	*0.07*	*0.23*	*0.24*							
Fe	0.71	0.93	0.32	0.74	0.51	0.36	0.23	0.34	0.41	-0.34	0.60	0.67	0.78	0.30						
	0.08	*0.00*	*0.49*	*0.06*	*0.25*	*0.44*	*0.61*	*0.45*	*0.36*	*0.46*	*0.15*	*0.10*	*0.04*	*0.52*						
Ti	0.74	0.94	0.20	0.67	0.49	0.44	0.34	0.19	0.46	-0.35	0.55	0.62	0.74	0.30	0.97					
	0.06	*0.00*	*0.66*	*0.10*	*0.27*	*0.32*	*0.45*	*0.68*	*0.30*	*0.45*	*0.21*	*0.14*	*0.06*	*0.51*	*0.00*					
K	0.72	0.67	0.86	0.92	0.44	0.52	0.49	0.61	0.60	0.47	0.79	0.67	0.70	0.76	0.59	0.48				
	0.07	*0.10*	*0.01*	*0.00*	*0.32*	*0.23*	*0.27*	*0.15*	*0.15*	*0.29*	*0.04*	*0.10*	*0.08*	*0.05*	*0.17*	*0.28*				
S	0.86	0.62	0.76	0.83	0.61	0.93	0.92	0.43	0.72	0.47	0.71	0.77	0.74	0.68	0.44	0.48	0.68			
	0.01	*0.14*	*0.05*	*0.02*	*0.14*	*0.00*	*0.00*	*0.34*	*0.07*	*0.29*	*0.07*	*0.04*	*0.06*	*0.10*	*0.33*	*0.28*	*0.09*			
Ni	0.72	0.93	0.40	0.78	0.51	0.35	0.23	0.40	0.40	-0.27	0.66	0.69	0.78	0.34	0.99	0.94	0.67	0.45		
	0.07	*0.00*	*0.38*	*0.04*	*0.24*	*0.45*	*0.63*	*0.38*	*0.37*	*0.56*	*0.11*	*0.09*	*0.04*	*0.45*	*0.00*	*0.00*	*0.10*	*0.31*		
Pb	0.50	0.81	0.48	0.77	0.47	0.25	0.13	0.71	0.47	-0.27	0.46	0.76	0.85	0.27	0.88	0.76	0.67	0.36	0.90	
	0.25	*0.03*	*0.27*	*0.04*	*0.29*	*0.59*	*0.79*	*0.07*	*0.28*	*0.56*	*0.30*	*0.05*	*0.02*	*0.56*	*0.01*	*0.05*	*0.10*	*0.43*	*0.01*	
Zn	0.57	0.07	0.21	0.17	-0.07	0.54	0.65	-0.29	0.46	0.51	0.37	0.25	0.17	0.54	-0.05	0.12	0.03	0.61	-0.10	-0.32
	0.18	*0.88*	*0.65*	*0.71*	*0.89*	*0.21*	*0.11*	*0.53*	*0.30*	*0.24*	*0.42*	*0.59*	*0.71*	*0.21*	*0.91*	*0.79*	*0.95*	*0.15*	*0.84*	*0.49*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents *'P-value'*

Table 3.68 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Naraina in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.95																			
	0.00																			
EC	0.78	0.79																		
	0.04	*0.04*																		
TC	0.91	0.95	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.56	0.67	0.40	0.57																
	0.19	*0.10*	*0.37*	*0.18*																
NO_3^-	0.83	0.86	0.59	0.76	0.46															
	0.02	*0.01*	*0.17*	*0.05*	*0.30*															
SO_4^{--}	0.95	0.86	0.72	0.84	0.29	0.78														
	0.00	*0.01*	*0.07*	*0.02*	*0.53*	*0.04*														
Na^+	0.28	0.12	-0.25	-0.07	0.25	0.02	0.27													
	0.54	*0.81*	*0.59*	*0.88*	*0.59*	*0.96*	*0.57*													
NH_4^+	0.76	0.62	0.65	0.67	0.26	0.69	0.75	-0.02												
	0.05	*0.14*	*0.12*	*0.10*	*0.57*	*0.09*	*0.05*	*0.97*												
K^+	0.57	0.62	0.41	0.54	0.07	0.70	0.66	-0.22	0.58											
	0.18	*0.14*	*0.37*	*0.21*	*0.88*	*0.08*	*0.11*	*0.64*	*0.17*											
Ca^{++}	0.17	0.33	0.15	0.25	0.50	0.50	0.00	-0.44	0.38	0.43										
	0.72	*0.47*	*0.75*	*0.58*	*0.26*	*0.25*	*0.99*	*0.33*	*0.40*	*0.34*										
Si	0.44	0.23	0.41	0.34	-0.36	0.46	0.61	-0.06	0.75	0.40	-0.06									
	0.32	*0.62*	*0.37*	*0.46*	*0.43*	*0.30*	*0.15*	*0.89*	*0.05*	*0.37*	*0.89*									
Al	0.47	0.53	0.26	0.42	0.96	0.38	0.19	0.39	0.24	-0.13	0.42	-0.32								
	0.28	*0.22*	*0.58*	*0.35*	*0.00*	*0.40*	*0.68*	*0.38*	*0.61*	*0.78*	*0.34*	*0.49*								
Ca	0.25	0.38	0.25	0.33	0.44	0.59	0.10	-0.47	0.50	0.48	0.98	0.11	0.37							
	0.60	*0.40*	*0.60*	*0.47*	*0.32*	*0.16*	*0.83*	*0.29*	*0.25*	*0.27*	*0.00*	*0.82*	*0.41*							
Fe	0.58	0.43	0.39	0.43	0.30	0.65	0.52	0.19	0.78	0.15	0.34	0.67	0.43	0.45						
	0.17	*0.33*	*0.39*	*0.33*	*0.51*	*0.11*	*0.24*	*0.68*	*0.04*	*0.75*	*0.46*	*0.10*	*0.34*	*0.31*						
Ti	0.23	0.02	-0.10	-0.04	0.08	0.33	0.20	0.37	0.56	-0.05	0.22	0.55	0.29	0.30	0.86					
	0.63	*0.97*	*0.83*	*0.93*	*0.87*	*0.48*	*0.67*	*0.41*	*0.19*	*0.92*	*0.63*	*0.20*	*0.52*	*0.51*	*0.01*					
K	0.89	0.87	0.90	0.93	0.36	0.80	0.87	-0.02	0.67	0.47	0.09	0.55	0.27	0.21	0.56	0.10				
	0.01	*0.01*	*0.01*	*0.00*	*0.43*	*0.03*	*0.01*	*0.97*	*0.10*	*0.29*	*0.85*	*0.20*	*0.57*	*0.65*	*0.19*	*0.83*				
S	0.95	0.89	0.88	0.93	0.38	0.75	0.96	0.15	0.71	0.53	-0.01	0.54	0.27	0.10	0.50	0.09	0.96			
	0.00	*0.01*	*0.01*	*0.00*	*0.40*	*0.05*	*0.00*	*0.75*	*0.08*	*0.22*	*0.99*	*0.22*	*0.55*	*0.83*	*0.25*	*0.85*	*0.00*			
Ni	0.78	0.67	0.48	0.61	0.72	0.61	0.62	0.49	0.70	0.12	0.28	0.29	0.80	0.32	0.80	0.63	0.58	0.63		
	0.04	*0.10*	*0.28*	*0.15*	*0.07*	*0.14*	*0.14*	*0.26*	*0.08*	*0.79*	*0.55*	*0.53*	*0.03*	*0.48*	*0.03*	*0.13*	*0.18*	*0.13*		
Pb	0.70	0.72	0.52	0.66	0.50	0.91	0.60	0.04	0.62	0.35	0.50	0.44	0.52	0.59	0.82	0.51	0.75	0.63	0.70	
	0.08	*0.07*	*0.23*	*0.11*	*0.25*	*0.01*	*0.16*	*0.94*	*0.14*	*0.44*	*0.25*	*0.33*	*0.24*	*0.16*	*0.03*	*0.24*	*0.05*	*0.13*	*0.08*	
Zn	0.80	0.83	0.70	0.81	0.31	0.90	0.80	-0.22	0.81	0.87	0.53	0.56	0.16	0.63	0.52	0.18	0.78	0.77	0.47	0.71
	0.03	*0.02*	*0.08*	*0.03*	*0.49*	*0.01*	*0.03*	*0.63*	*0.03*	*0.01*	*0.22*	*0.19*	*0.74*	*0.13*	*0.23*	*0.71*	*0.04*	*0.05*	*0.29*	*0.08*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.65 and Table 3.66 for PM mass and major species, respectively. In PM_{10} mass, there is variation in percentile with respect to statistical parameter due to distribution of PM mass, whereas in $PM_{2.5,}$ observed Mass and Percentile are similar. For crustal Elements, C.V. for $PM_{2.5}$ and PM_{10} are similar.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.67 and Table 3.68 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. OC, EC, and TC show better correlation with $PM_{2.5}$ mass than with PM_{10} mass. The secondary ions show better correlation with each other in both PM_{10} and $PM_{2.5}$.

3.1.9.2 Winter Season

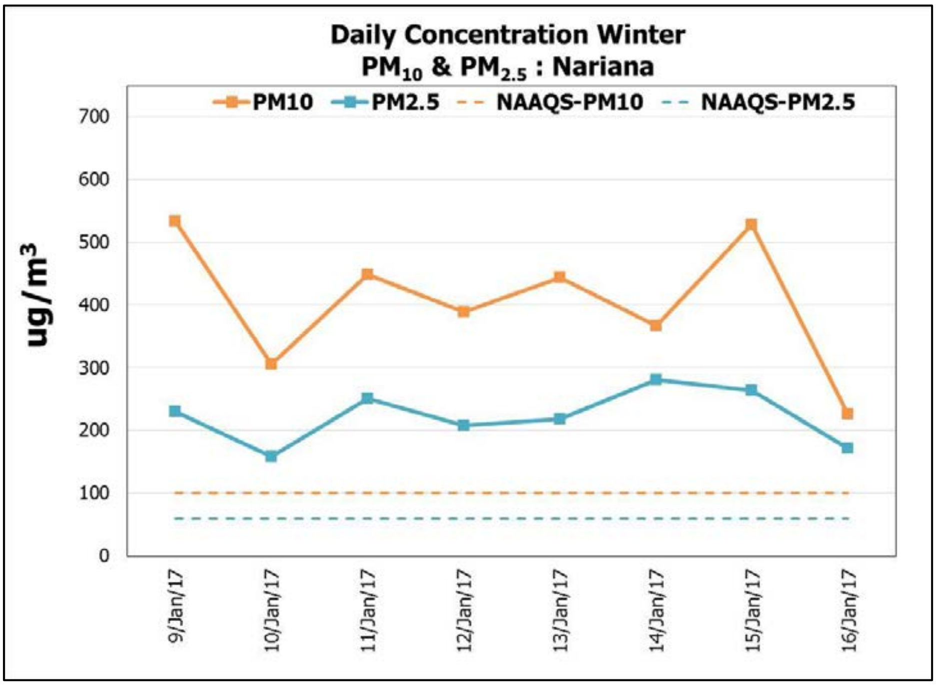


Figure 3.86: Variation in 24 the Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Naraina in Winter Season

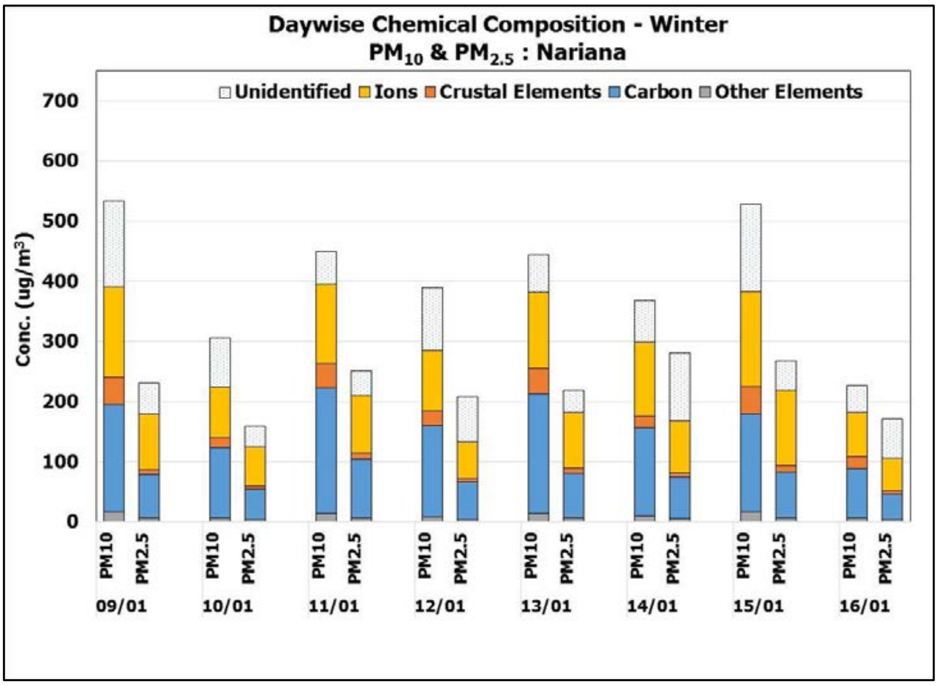


Figure 3.87 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Naraina in Winter Season

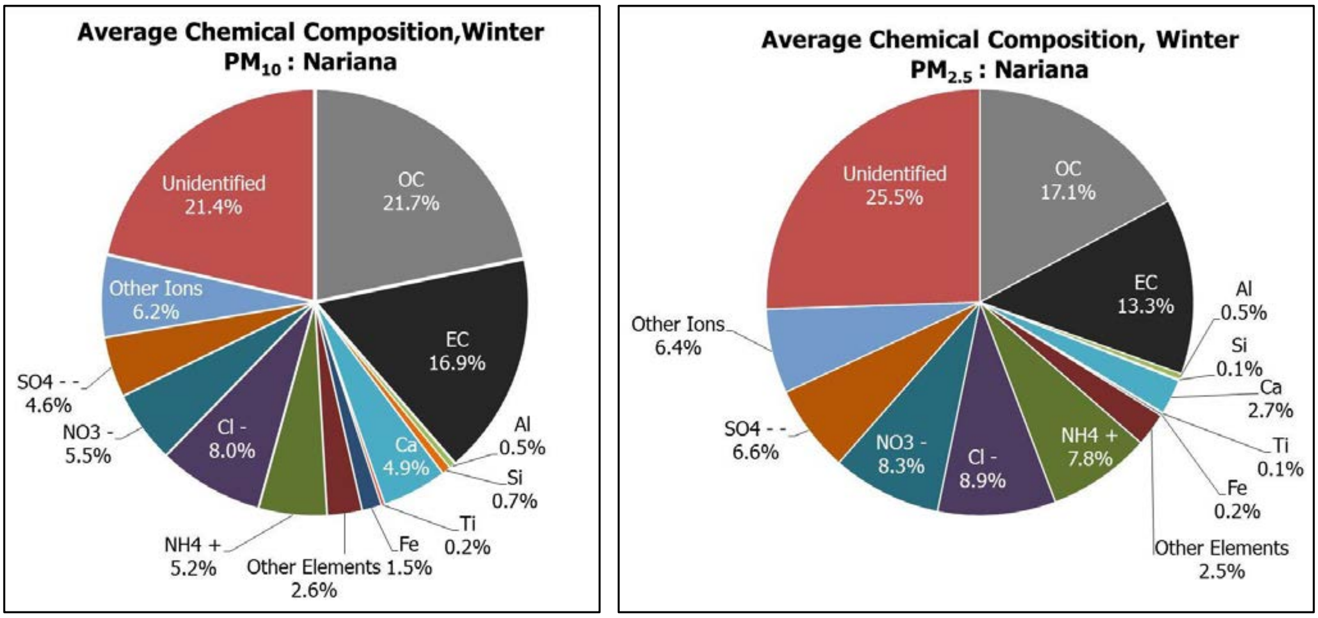


Figure 3.88: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Naraina in Winter Season

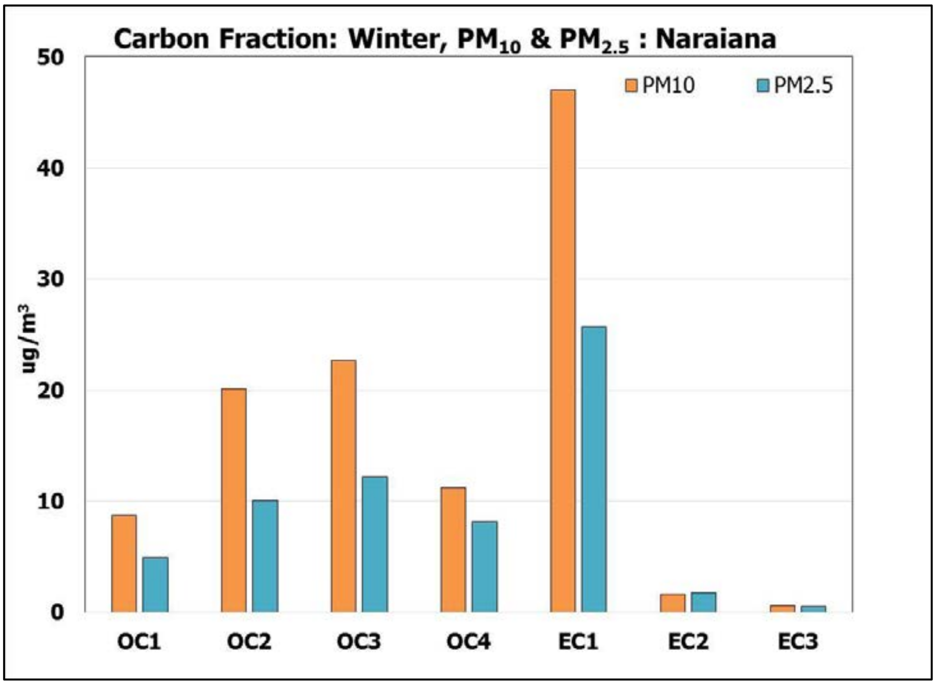


Figure 3.89 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Naraina in Winter Season

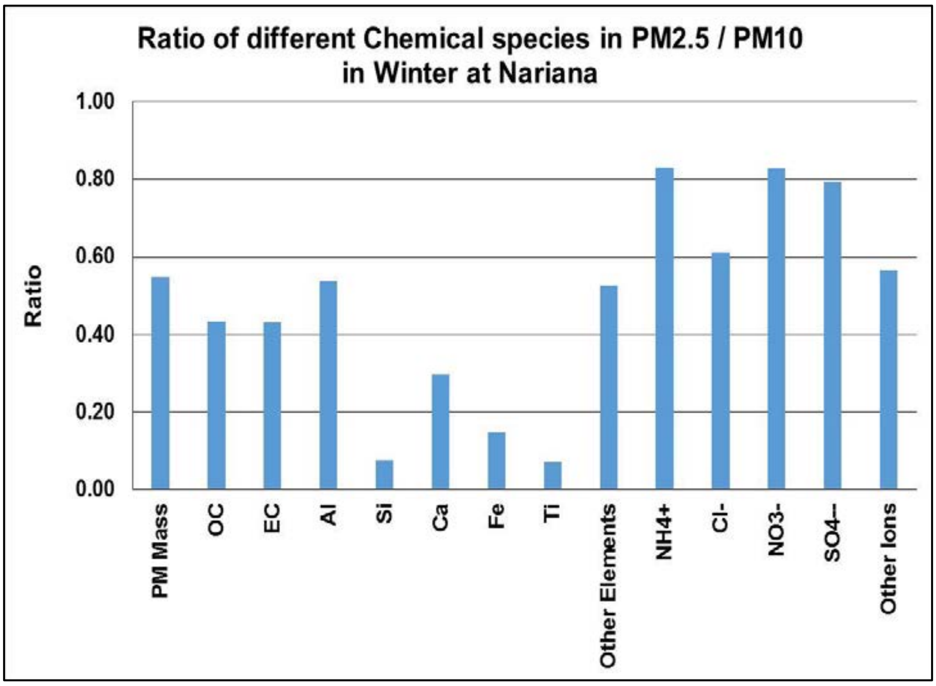


Figure 3.90: Ratio of Different Chemical Species in $PM_{2.5}$/PM_{10} at Naraina in Winter Season

At Naraina, the average concentrations of PM_{10} and $PM_{2.5}$ were found to be 405±106 µg/m^3 and 223±43 µg/m^3, respectively. Average concentration of PM_{10} varied from 226 to 533 µg/m^3, and in case of $PM_{2.5}$, it varied from 158 to 280 µg/m^3 (see Figure 3.86).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.87.

The carbon fraction was found to be 157 µg/m^3 for PM_{10} and 68 µg/m^3 for $PM_{2.5}$. The total ion concentration was found to be 30% for PM_{10} and, a little higher for $PM_{2.5}$ (38%). The crustal element was found to be 3% for PM_{10} and 4% for $PM_{2.5}$ (see Figure 3.88).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% for both PM_{10} and $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 26% in $PM_{2.5}$ and 21% in PM_{10}.

In PM_{10} and $PM_{2.5}$, OC3 was found to be higher, followed by OC2, OC4 and OC1. The EC1 in PM_{10} was higher as compared to that in $PM_{2.5}$, followed by EC3, but EC2 in $PM_{2.5}$ was found to be little higher as compared to that in PM_{10} (see Figure 3.89). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.90.

Table 3.69 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM_{10} at Naraina in Winter Season

	µg/m3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	405	87.98	68.61	1.91	2.70	20.04	5.99	0.98	4.44	2.73	0.49	1.47	32.49	22.24	18.59	0.95	20.97	2.47	16.06
SD	106	25.96	17.42	0.94	1.13	8.33	2.46	0.44	1.80	1.22	0.18	0.47	8.42	6.34	6.50	0.92	6.70	1.60	6.47
Min	226	45.33	36.11	0.85	1.52	10.17	2.46	0.41	2.32	1.16	0.31	0.90	14.52	15.05	10.38	0.06	12.13	0.22	8.14
Max	533	120.30	89.32	3.00	3.97	30.41	9.04	1.51	6.66	4.73	0.85	2.27	43.02	34.76	28.13	2.59	32.07	4.13	24.24
C.V.	0.26	0.30	0.25	0.49	0.42	0.42	0.41	0.45	0.41	0.45	0.36	0.32	0.26	0.29	0.35	0.97	0.32	0.65	0.40
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	531	119.21	87.06	2.97	3.97	29.37	8.82	1.50	6.64	4.36	0.78	2.15	41.70	31.18	27.87	2.31	29.45	4.13	23.54
50 %ile	405	86.60	70.98	1.91	2.70	20.04	5.99	0.98	4.44	2.73	0.44	1.47	33.24	22.24	18.18	0.95	22.06	3.01	16.06
5 %ile	160	34.67	25.83	0.89	1.31	9.16	2.46	0.43	2.04	1.19	0.24	0.66	11.16	10.26	8.25	0.07	9.14	0.22	7.22

Table 3.70 Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at Naraina in Winter Season

	µg/m3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	223	38.11	29.62	1.03	0.21	5.93	0.43	0.14	1.98	1.82	0.35	0.79	19.88	18.43	14.74	0.74	17.40	1.31	4.30
SD	43	11.32	5.87	0.54	0.09	1.70	0.10	0.10	0.48	0.60	0.15	0.34	4.50	6.35	6.17	0.88	5.79	1.17	1.71
Min	158	18.51	23.27	0.35	0.07	3.63	0.35	0.03	1.27	0.92	0.16	0.35	12.83	12.56	8.24	0.05	10.64	0.08	2.32
Max	280	55.02	42.07	1.58	0.31	7.87	0.60	0.25	2.51	2.64	0.56	1.23	27.44	32.40	24.86	2.85	28.00	2.95	6.98
C.V.	0.19	0.30	0.20	0.52	0.46	0.29	0.23	0.67	0.24	0.33	0.43	0.43	0.23	0.34	0.42	1.19	0.33	0.89	0.40
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	275	51.86	38.38	1.57	0.30	7.84	0.58	0.25	2.50	2.55	0.53	1.19	25.80	28.50	23.49	2.13	25.33	2.84	6.62
50 %ile	224	41.06	29.05	1.16	0.23	5.99	0.39	0.16	2.09	1.96	0.35	0.77	20.08	16.53	14.62	0.46	18.44	1.26	3.71
5 %ile	163	21.55	23.31	0.37	0.08	3.78	0.35	0.03	1.32	1.05	0.16	0.40	13.77	12.85	8.37	0.13	10.68	0.10	2.51

Table 3.71 Correlation Matrix for PM$_{10}$ and Its major constituents at Naraina in Winter Season

	PM$_{10}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.00																			
EC	0.86	0.93																		
	0.00	*0.00*																		
TC	0.87	0.99	0.98																	
	0.00	*0.00*	*0.00*																	
Cl$^-$	0.76	0.70	0.69	0.71																
	0.03	*0.06*	*0.06*	*0.05*																
NO$_3^-$	0.84	0.53	0.68	0.60	0.50															
	0.01	*0.18*	*0.06*	*0.11*	*0.21*															
SO$_4^{--}$	0.91	0.52	0.59	0.56	0.67	0.87														
	0.00	*0.18*	*0.12*	*0.15*	*0.07*	*0.01*														
Na$^+$	0.36	0.28	0.17	0.24	0.50	-0.05	0.41													
	0.38	*0.50*	*0.69*	*0.57*	*0.21*	*0.90*	*0.31*													
NH$_4^+$	0.84	0.56	0.70	0.63	0.60	0.97	0.90	0.09												
	0.01	*0.15*	*0.05*	*0.09*	*0.12*	*0.00*	*0.00*	*0.83*												
K$^+$	-0.19	-0.13	-0.16	-0.15	0.32	-0.50	-0.17	0.68	-0.37											
	0.65	*0.76*	*0.70*	*0.73*	*0.44*	*0.21*	*0.70*	*0.06*	*0.36*											
Ca^{++}	0.82	0.68	0.60	0.66	0.33	0.78	0.75	0.15	0.72	-0.53										
	0.01	*0.06*	*0.12*	*0.07*	*0.43*	*0.02*	*0.03*	*0.73*	*0.04*	*0.18*										
Si	0.82	0.90	0.76	0.86	0.57	0.65	0.64	0.22	0.66	-0.34	0.88									
	0.00	*0.00*	*0.01*	*0.00*	*0.14*	*0.08*	*0.09*	*0.61*	*0.08*	*0.40*	*0.00*									
Al	0.77	0.71	0.62	0.69	0.43	0.78	0.76	0.12	0.76	-0.54	0.97	0.93								
	0.01	*0.02*	*0.06*	*0.03*	*0.29*	*0.02*	*0.03*	*0.77*	*0.03*	*0.17*	*0.00*	*0.00*								
Ca	0.76	0.70	0.64	0.68	0.34	0.79	0.72	0.09	0.72	-0.56	1.00	0.90	0.97							
	0.01	*0.02*	*0.05*	*0.03*	*0.41*	*0.02*	*0.04*	*0.84*	*0.04*	*0.15*	*0.00*	*0.00*	*0.00*							
Fe	0.94	0.83	0.82	0.84	0.62	0.81	0.89	0.35	0.83	-0.33	0.88	0.87	0.88	0.85						
	0.00	*0.00*	*0.00*	*0.00*	*0.10*	*0.01*	*0.00*	*0.39*	*0.01*	*0.43*	*0.00*	*0.00*	*0.00*	*0.00*						
Ti	0.81	0.85	0.77	0.83	0.55	0.66	0.71	0.32	0.67	-0.34	0.89	0.94	0.92	0.90	0.92					
	0.00	*0.00*	*0.01*	*0.00*	*0.16*	*0.08*	*0.05*	*0.44*	*0.07*	*0.41*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.95	0.83	0.80	0.83	0.62	0.87	0.89	0.22	0.87	-0.41	0.93	0.91	0.92	0.89	0.97	0.89				
	0.00	*0.00*	*0.01*	*0.00*	*0.10*	*0.01*	*0.00*	*0.61*	*0.01*	*0.31*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.86	0.74	0.64	0.71	0.63	0.72	0.87	0.48	0.78	-0.16	0.86	0.88	0.88	0.83	0.90	0.83	0.92			
	0.00	*0.02*	*0.05*	*0.02*	*0.09*	*0.04*	*0.01*	*0.23*	*0.02*	*0.71*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*			
Ni	0.51	0.53	0.42	0.49	0.19	0.70	0.59	-0.06	0.66	-0.68	0.94	0.82	0.92	0.93	0.69	0.81	0.73	0.70		
	0.13	*0.12*	*0.23*	*0.15*	*0.65*	*0.05*	*0.13*	*0.89*	*0.08*	*0.07*	*0.00*	*0.00*	*0.00*	*0.00*	*0.03*	*0.01*	*0.02*	*0.02*		
Pb	0.48	0.48	0.58	0.53	0.04	0.56	0.33	-0.40	0.54	-0.78	0.45	0.46	0.54	0.50	0.60	0.55	0.56	0.30	0.51	
	0.16	*0.16*	*0.08*	*0.12*	*0.92*	*0.15*	*0.42*	*0.33*	*0.17*	*0.02*	*0.27*	*0.18*	*0.11*	*0.14*	*0.07*	*0.10*	*0.09*	*0.41*	*0.13*	
Zn	0.80	0.65	0.64	0.66	0.49	0.88	0.72	-0.10	0.82	-0.45	0.82	0.78	0.81	0.82	0.74	0.65	0.86	0.79	0.70	0.37
	0.01	*0.04*	*0.04*	*0.04*	*0.22*	*0.00*	*0.04*	*0.82*	*0.01*	*0.26*	*0.01*	*0.01*	*0.01*	*0.00*	*0.02*	*0.04*	*0.00*	*0.01*	*0.02*	*0.29*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents *'P-value'*

Table 3.72 Correlation Matrix for PM$_{2.5}$ and Its major constituents at Naraina in Winter Season

	PM$_{2.5}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.27																			
	0.46																			
EC	0.13	0.96																		
	0.72	*0.00*																		
TC	0.21	0.99	0.99																	
	0.56	*0.00*	*0.00*																	
Cl$^-$	0.46	0.48	0.37	0.44																
	0.25	*0.23*	*0.37*	*0.28*																
NO$_3^-$	0.64	-0.22	-0.35	-0.27	-0.01															
	0.09	*0.61*	*0.40*	*0.51*	*0.98*															
SO$_4^{--}$	0.79	-0.04	-0.23	-0.12	0.04	0.89														
	0.02	*0.93*	*0.59*	*0.78*	*0.93*	*0.00*														
Na$^+$	0.65	0.47	0.34	0.42	0.32	-0.05	0.25													
	0.04	*0.18*	*0.34*	*0.23*	*0.44*	*0.91*	*0.55*													
NH$_4^+$	0.79	-0.02	-0.17	-0.08	0.28	0.93	0.93	0.41												
	0.01	*0.95*	*0.65*	*0.82*	*0.51*	*0.00*	*0.00*	*0.24*												
K$^+$	0.54	0.05	-0.07	0.00	0.36	0.71	0.65	-0.06	0.76											
	0.11	*0.88*	*0.85*	*1.00*	*0.38*	*0.05*	*0.08*	*0.88*	*0.01*											
Ca^{++}	0.52	0.02	-0.02	0.00	0.51	0.60	0.56	-0.15	0.43	0.78										
	0.12	*0.97*	*0.96*	*1.00*	*0.20*	*0.12*	*0.15*	*0.68*	*0.22*	*0.01*										
Si	0.18	-0.09	-0.07	-0.08	0.00	0.48	0.45	-0.48	0.24	0.71	0.82									
	0.61	*0.80*	*0.84*	*0.82*	*0.99*	*0.23*	*0.27*	*0.16*	*0.51*	*0.02*	*0.00*									
Al	0.34	-0.20	-0.24	-0.22	0.09	0.63	0.62	-0.33	0.37	0.76	0.85	0.94								
	0.33	*0.58*	*0.50*	*0.54*	*0.83*	*0.09*	*0.10*	*0.35*	*0.29*	*0.01*	*0.00*	*0.00*								
Ca	0.68	-0.03	-0.15	-0.08	0.50	0.67	0.73	0.09	0.60	0.82	0.93	0.69	0.82							
	0.03	*0.94*	*0.67*	*0.82*	*0.21*	*0.07*	*0.04*	*0.81*	*0.07*	*0.00*	*0.00*	*0.03*	*0.00*							
Fe	0.35	0.59	0.62	0.61	0.07	0.30	0.37	-0.07	0.12	0.40	0.48	0.61	0.44	0.32						
	0.33	*0.07*	*0.06*	*0.06*	*0.87*	*0.47*	*0.37*	*0.86*	*0.75*	*0.26*	*0.16*	*0.06*	*0.21*	*0.36*						
Ti	0.29	-0.17	-0.19	-0.18	0.14	0.58	0.55	-0.41	0.27	0.70	0.85	0.94	0.99	0.78	0.48					
	0.42	*0.64*	*0.59*	*0.62*	*0.74*	*0.13*	*0.16*	*0.24*	*0.46*	*0.02*	*0.00*	*0.00*	*0.00*	*0.01*	*0.16*					
K	0.71	0.14	0.05	0.10	0.34	0.62	0.76	0.07	0.51	0.66	0.80	0.68	0.70	0.82	0.65	0.70				
	0.02	*0.70*	*0.90*	*0.78*	*0.40*	*0.10*	*0.03*	*0.86*	*0.13*	*0.04*	*0.01*	*0.03*	*0.03*	*0.00*	*0.04*	*0.02*				
S	0.67	0.07	-0.05	0.02	0.12	0.56	0.78	0.12	0.47	0.58	0.68	0.68	0.75	0.77	0.58	0.73	0.93			
	0.03	*0.86*	*0.89*	*0.96*	*0.78*	*0.15*	*0.02*	*0.73*	*0.17*	*0.08*	*0.03*	*0.03*	*0.01*	*0.01*	*0.08*	*0.02*	*0.00*			
Ni	0.15	-0.28	-0.30	-0.29	0.08	0.61	0.53	-0.50	0.24	0.73	0.83	0.93	0.96	0.76	0.35	0.95	0.57	0.58		
	0.69	*0.43*	*0.40*	*0.41*	*0.86*	*0.11*	*0.18*	*0.14*	*0.51*	*0.02*	*0.00*	*0.00*	*0.00*	*0.01*	*0.33*	*0.00*	*0.09*	*0.08*		
Pb	0.67	0.16	0.03	0.11	0.81	0.26	0.39	0.42	0.63	0.66	0.71	0.30	0.44	0.82	0.04	0.39	0.55	0.45	0.37	
	0.03	*0.66*	*0.94*	*0.77*	*0.02*	*0.53*	*0.35*	*0.23*	*0.05*	*0.04*	*0.02*	*0.40*	*0.20*	*0.00*	*0.91*	*0.27*	*0.10*	*0.19*	*0.29*	
Zn	0.57	0.13	0.02	0.08	0.33	0.57	0.65	-0.07	0.53	0.84	0.84	0.84	0.89	0.86	0.59	0.89	0.85	0.86	0.78	0.58
	0.08	*0.73*	*0.97*	*0.82*	*0.42*	*0.14*	*0.08*	*0.84*	*0.11*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.07*	*0.00*	*0.00*	*0.00*	*0.01*	*0.08*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.69 and Table 3.70 for PM mass and major species, respectively. $PM_{2.5}$ mass shows lesser C.V. than PM_{10} mass. For elements, C.V. observed in PM_{10} was lesser than that in $PM_{2.5}$..

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.71 and Table 3.72 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. OC, EC, and TC show better correlation with PM_{10} mass than with $PM_{2.5}$ mass.

3.1.10 Site 10: Wazirpur

3.1.10.1 Summer Season

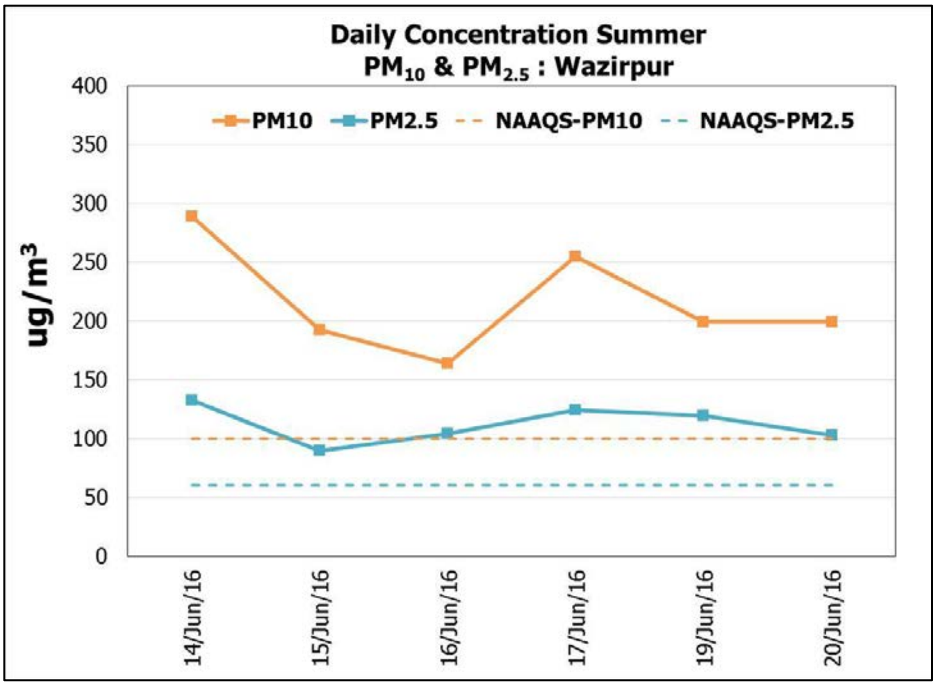


Figure 3.91 Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Wazirpur in Summer Season

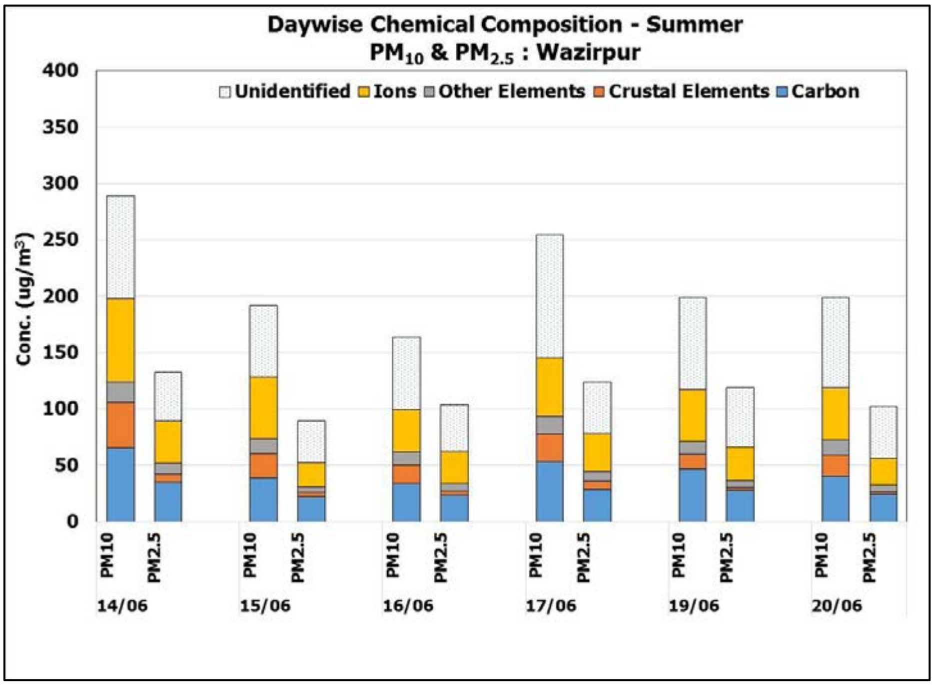


Figure 3.92 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Wazirpur in Summer Season

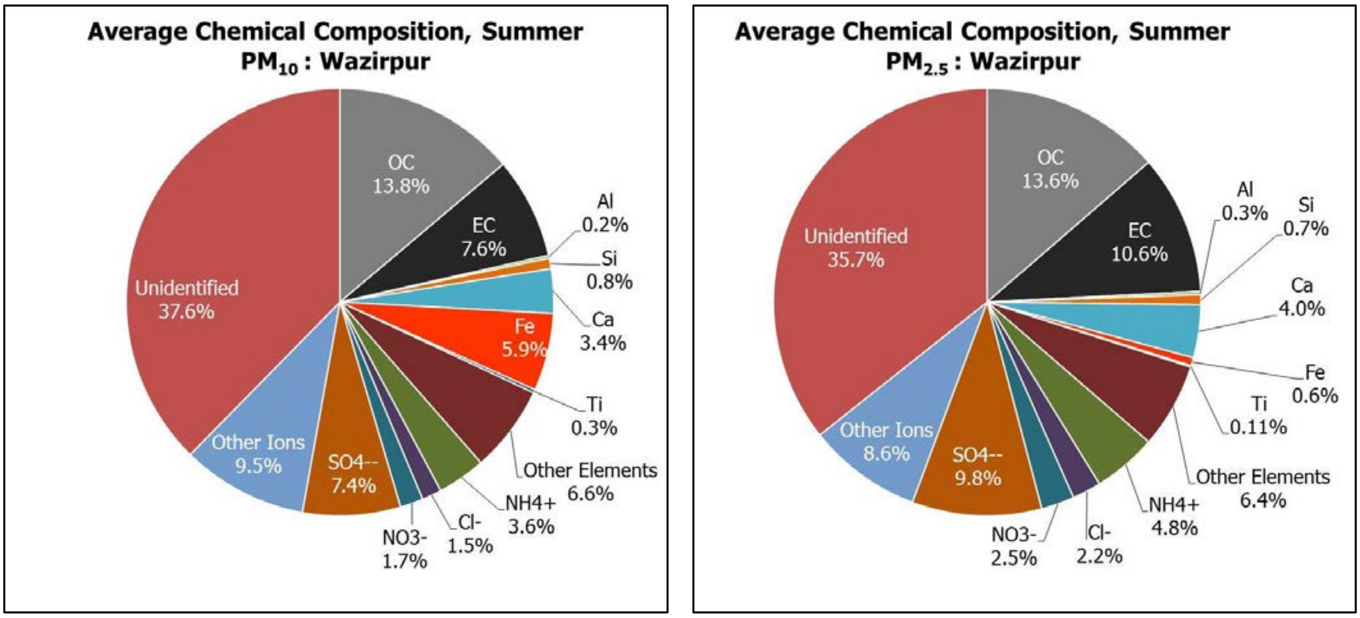


Figure 3.93: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Wazirpur in Summer Season

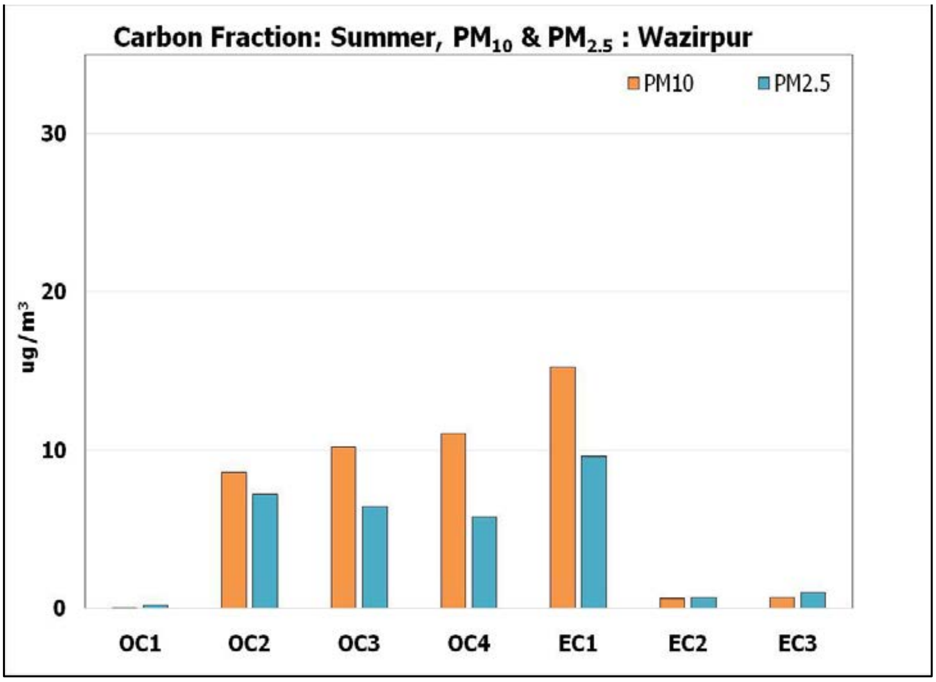


Figure 3.94: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Wazirpur in Summer Season

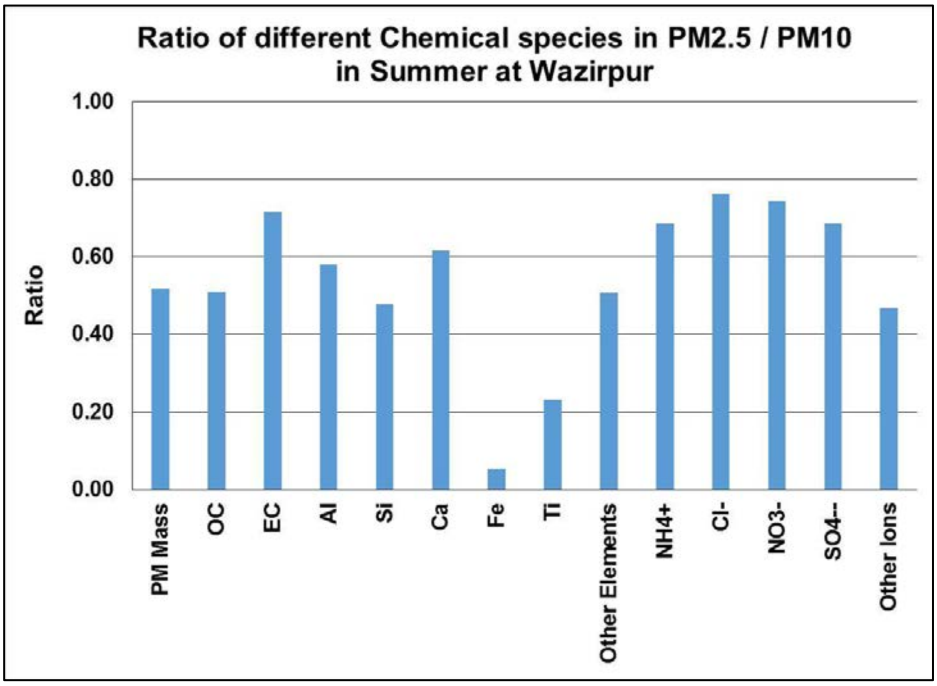


Figure 3.95: Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Wazirpur in Summer Season

Average concentration observed at Wazirpur (WZP) in summer season was 216±46 $\mu g/m^3$ for PM_{10} and 112±16 $\mu g/m^3$ for $PM_{2.5}$. The spread of PM_{10} and $PM_{2.5}$ is very less in terms of daily concentration. But the average concentrations of PM_{10} and $PM_{2.5}$ were found to be 2 times and 1.2 times the NAAQS, respectively. The observed daily concentration variation for PM_{10} was from 164 to 289 $\mu g/m^3$. Similarly, daily concentration variation for $PM_{2.5}$ was from 89 to 133 $\mu g/m^3$ (see Figure 3.91).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.92.

The ionic portion was found to be highest: 24% in PM_{10} and 26% in $PM_{2.5}$. The concentrations of carbon fraction observed are 47 $\mu g/m^3$ and 27 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$, respectively. Concentration of crustal elements is 11% in PM_{10} and 4% in $PM_{2.5}$ (see Figure 3.93).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 7% in PM_{10} and 6% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 38% for PM_{10} and 39% for $PM_{2.5}$.

EC1 was found to be highest in PM_{10}, followed by OC4, OC3, OC2, EC2, and EC3, whereas EC1 is higher in $PM_{2.5}$, followed by OC2, OC3, OC4, EC3, and EC2. EC1 is 15 $\mu g/m^3$ in PM_{10} and 10 $\mu g/m^3$ in $PM_{2.5}$, while OC4 was found to be 11 $\mu g/m^3$ in PM_{10} and OC2 was found to be 7 $\mu g/m^3$ in $PM_{2.5}$ (see Figure 3.94). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.95.

Table 3.73 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Wazirpur in Summer Season

μg/m^3																			
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	216	29.91	16.54	0.48	1.72	7.27	12.71	0.55	4.75	1.91	0.24	0.86	3.22	3.77	16.00	6.97	7.89	3.62	6.40
SD	46	7.69	4.12	0.23	1.12	3.42	5.03	0.27	1.33	0.38	0.11	0.11	0.90	0.87	3.47	5.26	1.54	1.32	2.85
Min	164	21.67	11.62	0.31	0.66	3.92	8.10	0.31	2.58	1.49	0.13	0.72	1.96	2.34	10.80	2.10	5.54	2.46	3.04
Max	289	43.11	22.20	0.93	3.62	13.65	21.69	1.03	6.25	2.47	0.42	0.99	4.16	4.69	20.22	16.50	9.45	5.93	10.47
C.V.	0.21	0.26	0.25	0.48	0.65	0.47	0.40	0.49	0.28	0.20	0.44	0.13	0.28	0.23	0.22	0.75	0.20	0.36	0.45
N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
95 %ile	280	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	199	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	171	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.74 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Wazirpur in Summer Season

μg/m^3																			
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	112	15.24	11.82	0.28	0.82	4.48	0.68	0.13	3.87	1.55	0.15	0.48	2.44	2.80	10.95	2.84	5.41	2.66	2.82
SD	16	1.59	3.39	0.08	0.12	1.69	0.45	0.04	1.21	0.35	0.09	0.18	0.69	0.63	1.31	1.26	0.53	0.91	1.66
Min	89	13.50	8.37	0.17	0.65	2.99	0.14	0.09	2.28	1.14	0.04	0.19	1.59	2.10	9.00	1.62	4.52	1.53	1.02
Max	133	17.53	17.93	0.38	1.03	6.88	1.33	0.19	5.54	2.06	0.30	0.74	3.16	3.75	12.71	4.70	5.93	4.15	5.33
C.V.	0.14	0.10	0.29	0.30	0.15	0.38	0.66	0.28	0.31	0.23	0.60	0.37	0.28	0.23	0.12	0.44	0.10	0.34	0.59
N	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
95 %ile	130	17.29	16.55	0.37	0.99	6.73	1.27	0.18	5.37	2.01	0.27	0.68	3.13	3.64	12.48	4.54	5.91	3.89	5.06
50 %ile	111	14.98	11.46	0.27	0.82	3.82	0.58	0.13	3.72	1.47	0.14	0.48	2.58	2.70	11.06	2.44	5.50	2.46	2.44
5 %ile	92	13.60	8.60	0.18	0.68	3.01	0.20	0.09	2.48	1.18	0.06	0.26	1.62	2.15	9.29	1.66	4.69	1.70	1.13

Table 3.75 Correlation Matrix for PM_{10} and Its major constituents at Wazirpur in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.98																			
	0.00																			
EC	0.85	0.83																		
	0.03	*0.04*																		
TC	0.98	0.98	0.93																	
	0.00	*0.00*	*0.01*																	
Cl-	0.76	0.81	0.55	0.74																
	0.08	*0.05*	*0.26*	*0.09*																
NO3-	0.56	0.52	0.76	0.63	0.33															
	0.25	*0.29*	*0.08*	*0.18*	*0.52*															
SO4- -	0.72	0.68	0.78	0.74	0.40	0.94														
	0.11	*0.14*	*0.07*	*0.09*	*0.43*	*0.01*														
Na+	0.71	0.80	0.43	0.70	0.69	0.08	0.31													
	0.12	*0.06*	*0.40*	*0.12*	*0.13*	*0.88*	*0.56*													
NH4+	0.43	0.39	0.69	0.52	0.12	0.97	0.91	0.00												
	0.39	*0.44*	*0.13*	*0.30*	*0.82*	*0.00*	*0.01*	*0.99*												
K+	0.50	0.63	0.27	0.52	0.52	-0.02	0.19	0.96	-0.05											
	0.31	*0.18*	*0.61*	*0.29*	*0.29*	*0.97*	*0.72*	*0.00*	*0.93*											
Ca++	0.41	0.49	-0.07	0.31	0.67	-0.21	0.02	0.77	-0.34	0.72										
	0.42	*0.33*	*0.90*	*0.56*	*0.14*	*0.70*	*0.97*	*0.07*	*0.51*	*0.11*										
Si	0.61	0.71	0.28	0.58	0.64	-0.01	0.24	0.98	-0.09	0.96	0.85									
	0.20	*0.11*	*0.59*	*0.22*	*0.18*	*0.98*	*0.65*	*0.00*	*0.87*	*0.00*	*0.03*									
Al	0.89	0.93	0.65	0.86	0.68	0.34	0.58	0.93	0.26	0.82	0.64	0.89								
	0.02	*0.01*	*0.17*	*0.03*	*0.14*	*0.52*	*0.23*	*0.01*	*0.63*	*0.04*	*0.18*	*0.02*								
Ca	0.81	0.87	0.52	0.77	0.64	0.16	0.43	0.97	0.09	0.88	0.71	0.94	0.98							
	0.05	*0.03*	*0.30*	*0.07*	*0.17*	*0.76*	*0.40*	*0.00*	*0.87*	*0.02*	*0.11*	*0.01*	*0.00*							
Fe	0.93	0.93	0.67	0.87	0.64	0.42	0.68	0.83	0.34	0.69	0.58	0.79	0.97	0.93						
	0.01	*0.01*	*0.14*	*0.02*	*0.17*	*0.40*	*0.14*	*0.04*	*0.51*	*0.13*	*0.23*	*0.06*	*0.00*	*0.01*						
Ti	0.79	0.86	0.48	0.76	0.72	0.13	0.38	0.99	0.04	0.90	0.78	0.97	0.97	0.99	0.90					
	0.06	*0.03*	*0.34*	*0.08*	*0.11*	*0.80*	*0.45*	*0.00*	*0.95*	*0.02*	*0.07*	*0.00*	*0.00*	*0.00*	*0.01*					
K	0.50	0.60	0.19	0.47	0.71	-0.31	-0.14	0.85	-0.44	0.78	0.79	0.83	0.68	0.76	0.54	0.82				
	0.31	*0.21*	*0.72*	*0.34*	*0.12*	*0.56*	*0.79*	*0.03*	*0.38*	*0.07*	*0.06*	*0.04*	*0.14*	*0.08*	*0.27*	*0.05*				
S	0.82	0.83	0.50	0.75	0.64	-0.01	0.24	0.83	-0.13	0.67	0.64	0.79	0.87	0.90	0.86	0.89	0.81			
	0.05	*0.04*	*0.31*	*0.09*	*0.17*	*0.98*	*0.64*	*0.04*	*0.81*	*0.15*	*0.17*	*0.06*	*0.02*	*0.01*	*0.03*	*0.02*	*0.05*			
Ni	0.94	0.94	0.70	0.89	0.63	0.46	0.70	0.81	0.38	0.66	0.54	0.76	0.97	0.92	1.00	0.88	0.51	0.85		
	0.01	*0.01*	*0.12*	*0.02*	*0.18*	*0.36*	*0.12*	*0.05*	*0.46*	*0.16*	*0.27*	*0.08*	*0.00*	*0.01*	*0.00*	*0.02*	*0.30*	*0.03*		
Pb	0.83	0.91	0.66	0.86	0.89	0.35	0.47	0.91	0.21	0.81	0.65	0.84	0.89	0.86	0.80	0.90	0.78	0.76	0.79	
	0.04	*0.01*	*0.15*	*0.03*	*0.02*	*0.50*	*0.34*	*0.01*	*0.69*	*0.05*	*0.17*	*0.04*	*0.02*	*0.03*	*0.05*	*0.01*	*0.07*	*0.08*	*0.06*	
Zn	0.75	0.75	0.74	0.77	0.86	0.43	0.39	0.40	0.23	0.19	0.24	0.28	0.49	0.40	0.47	0.45	0.50	0.54	0.49	0.72
	0.09	*0.09*	*0.09*	*0.07*	*0.03*	*0.40*	*0.44*	*0.43*	*0.66*	*0.72*	*0.65*	*0.59*	*0.33*	*0.43*	*0.34*	*0.37*	*0.31*	*0.27*	*0.32*	*0.11*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.76 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Wazirpur in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.93																			
	0.01																			
EC	0.90	0.86																		
	0.02	*0.03*																		
TC	0.94	0.94	0.99																	
	0.01	*0.01*	*0.00*																	
Cl^-	0.60	0.69	0.83	0.81																
	0.21	*0.13*	*0.04*	*0.05*																
NO_3^-	0.85	0.71	0.82	0.81	0.53															
	0.03	*0.11*	*0.05*	*0.05*	*0.29*															
SO_4^{--}	0.90	0.78	0.68	0.73	0.22	0.69														
	0.01	*0.07*	*0.14*	*0.10*	*0.68*	*0.13*														
Na^+	0.39	0.52	0.49	0.52	0.80	0.13	0.08													
	0.45	*0.29*	*0.32*	*0.30*	*0.05*	*0.80*	*0.88*													
NH_4^+	0.72	0.60	0.86	0.81	0.60	0.61	0.65	0.27												
	0.10	*0.21*	*0.03*	*0.05*	*0.20*	*0.20*	*0.17*	*0.61*												
K^+	0.59	0.69	0.69	0.71	0.90	0.51	0.21	0.88	0.32											
	0.22	*0.13*	*0.13*	*0.12*	*0.01*	*0.30*	*0.69*	*0.02*	*0.54*											
Ca^{++}	0.87	0.89	0.66	0.75	0.38	0.49	0.89	0.39	0.53	0.42										
	0.03	*0.02*	*0.16*	*0.08*	*0.46*	*0.32*	*0.02*	*0.44*	*0.28*	*0.41*										
Si	0.59	0.68	0.59	0.64	0.72	0.20	0.39	0.92	0.44	0.77	0.68									
	0.22	*0.14*	*0.22*	*0.17*	*0.11*	*0.71*	*0.44*	*0.01*	*0.38*	*0.07*	*0.14*									
Al	0.89	0.89	0.73	0.80	0.42	0.54	0.92	0.36	0.65	0.39	0.99	0.65								
	0.02	*0.02*	*0.10*	*0.05*	*0.41*	*0.27*	*0.01*	*0.49*	*0.16*	*0.45*	*0.00*	*0.16*								
Ca	0.58	0.76	0.50	0.60	0.41	0.11	0.58	0.47	0.41	0.37	0.85	0.70	0.84							
	0.23	*0.08*	*0.32*	*0.21*	*0.42*	*0.83*	*0.23*	*0.34*	*0.42*	*0.48*	*0.03*	*0.12*	*0.04*							
Fe	0.83	0.78	0.84	0.85	0.61	0.52	0.78	0.47	0.90	0.44	0.81	0.72	0.88	0.71						
	0.04	*0.07*	*0.04*	*0.03*	*0.20*	*0.29*	*0.07*	*0.35*	*0.01*	*0.39*	*0.05*	*0.11*	*0.02*	*0.11*						
Ti	0.82	0.87	0.91	0.92	0.82	0.53	0.64	0.66	0.83	0.67	0.77	0.81	0.83	0.76	0.94					
	0.05	*0.03*	*0.01*	*0.01*	*0.05*	*0.28*	*0.17*	*0.15*	*0.04*	*0.14*	*0.07*	*0.05*	*0.04*	*0.08*	*0.01*					
K	0.75	0.89	0.68	0.77	0.70	0.39	0.58	0.80	0.41	0.78	0.85	0.91	0.81	0.84	0.72	0.84				
	0.09	*0.02*	*0.14*	*0.07*	*0.12*	*0.45*	*0.23*	*0.06*	*0.41*	*0.07*	*0.03*	*0.01*	*0.05*	*0.04*	*0.11*	*0.04*				
S	0.81	0.83	0.77	0.81	0.67	0.43	0.70	0.72	0.69	0.65	0.87	0.92	0.88	0.79	0.92	0.93	0.91			
	0.05	*0.04*	*0.08*	*0.05*	*0.14*	*0.40*	*0.12*	*0.10*	*0.13*	*0.17*	*0.03*	*0.01*	*0.02*	*0.06*	*0.01*	*0.01*	*0.01*			
Ni	0.90	0.82	0.91	0.91	0.66	0.66	0.82	0.49	0.91	0.52	0.81	0.71	0.87	0.63	0.98	0.94	0.72	0.91		
	0.01	*0.04*	*0.01*	*0.01*	*0.16*	*0.16*	*0.05*	*0.33*	*0.01*	*0.29*	*0.05*	*0.12*	*0.02*	*0.18*	*0.00*	*0.01*	*0.10*	*0.01*		
Pb	0.97	0.96	0.96	0.99	0.77	0.81	0.78	0.55	0.76	0.73	0.82	0.69	0.85	0.62	0.85	0.91	0.82	0.85	0.92	
	0.00	*0.00*	*0.00*	*0.00*	*0.07*	*0.05*	*0.07*	*0.26*	*0.08*	*0.10*	*0.05*	*0.13*	*0.03*	*0.19*	*0.03*	*0.01*	*0.05*	*0.03*	*0.01*	
Zn	0.72	0.56	0.40	0.47	-0.02	0.42	0.91	0.07	0.45	0.06	0.83	0.41	0.82	0.50	0.67	0.46	0.49	0.66	0.68	0.56
	0.11	*0.25*	*0.43*	*0.35*	*0.97*	*0.40*	*0.01*	*0.89*	*0.37*	*0.92*	*0.04*	*0.42*	*0.05*	*0.31*	*0.14*	*0.36*	*0.32*	*0.16*	*0.14*	*0.24*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.73 and Table 3.74 for PM mass and major species, respectively. In PM_{10} mass, there is variation in percentile with respect to statistical parameter due to distribution of PM mass, whereas in $PM_{2.5}$, they are similar. For crustal elements, C.V. for PM_{10} is lesser than that for $PM_{2.5}$. The secondary ions show less C.V. in $PM_{2.5}$ than in PM_{10}.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.75 and Table 3.76 for PM mass and its major species. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. OC, EC, and TC show better correlation with both $PM_{2.5}$ mass and PM_{10} mass. The secondary ions show better correlation with each other in PM_{10}.

3.1.10.2 Winter Season

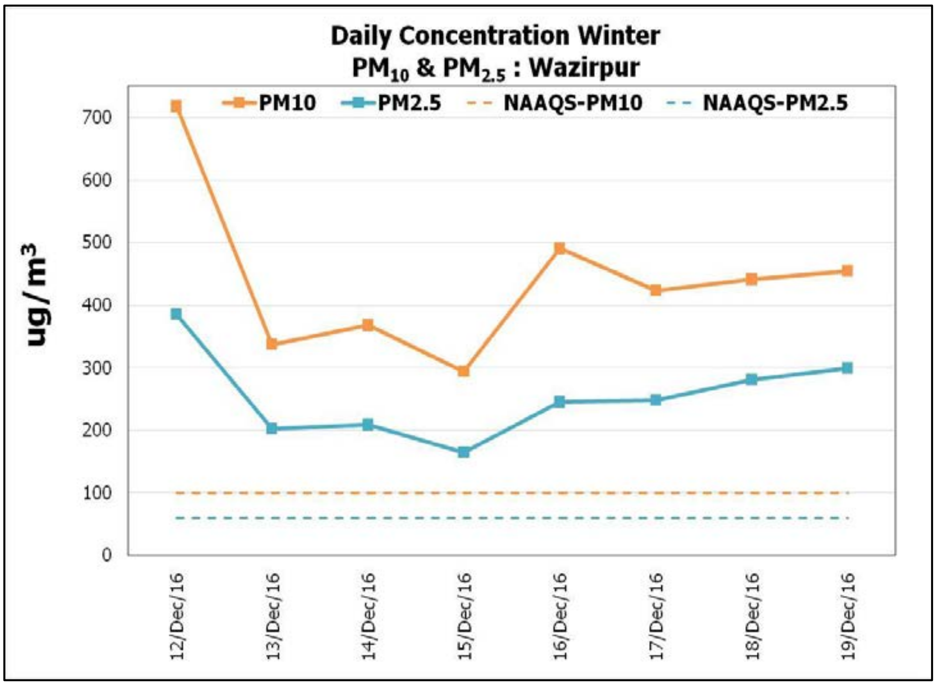


Figure 3.96 Variation in 24 the Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Wazirpur in Winter Season

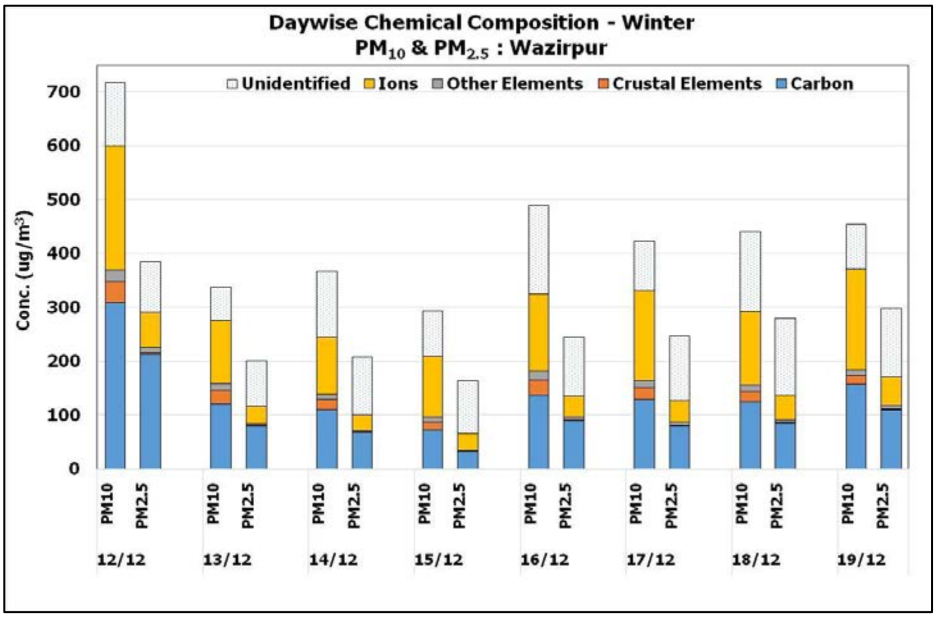


Figure 3.97 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Wazirpur in Winter Season

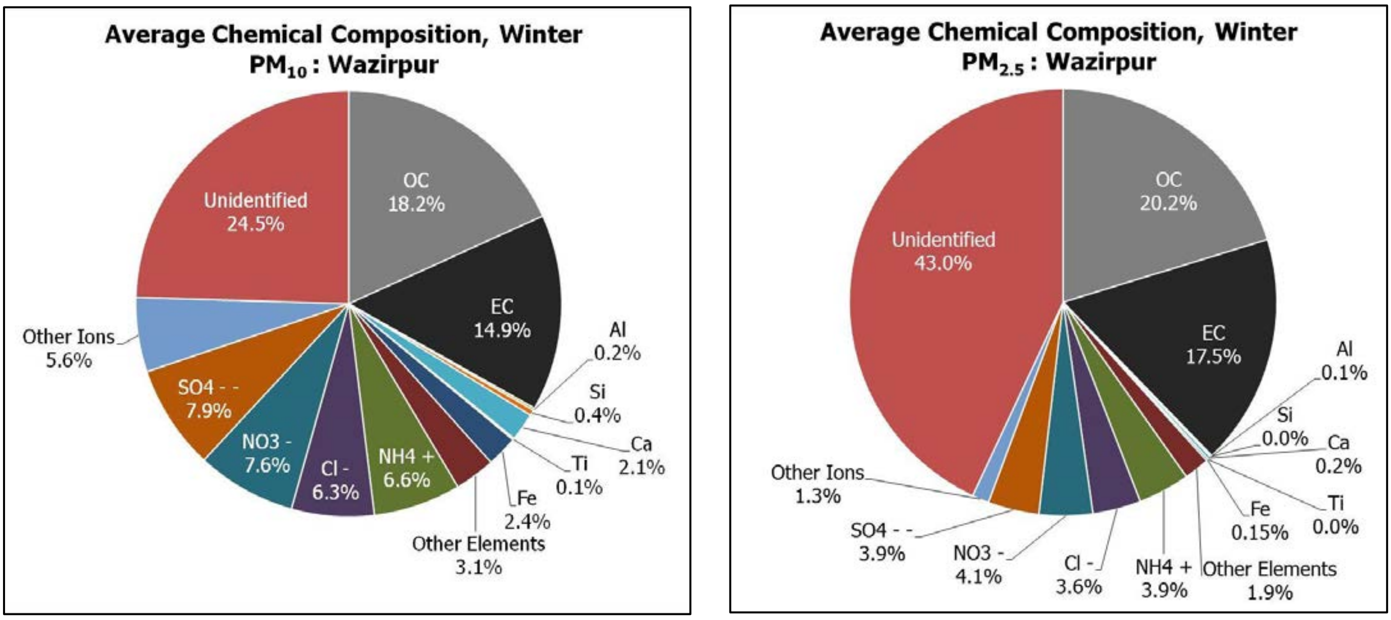


Figure 3.98: Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Wazirpur in Winter Season

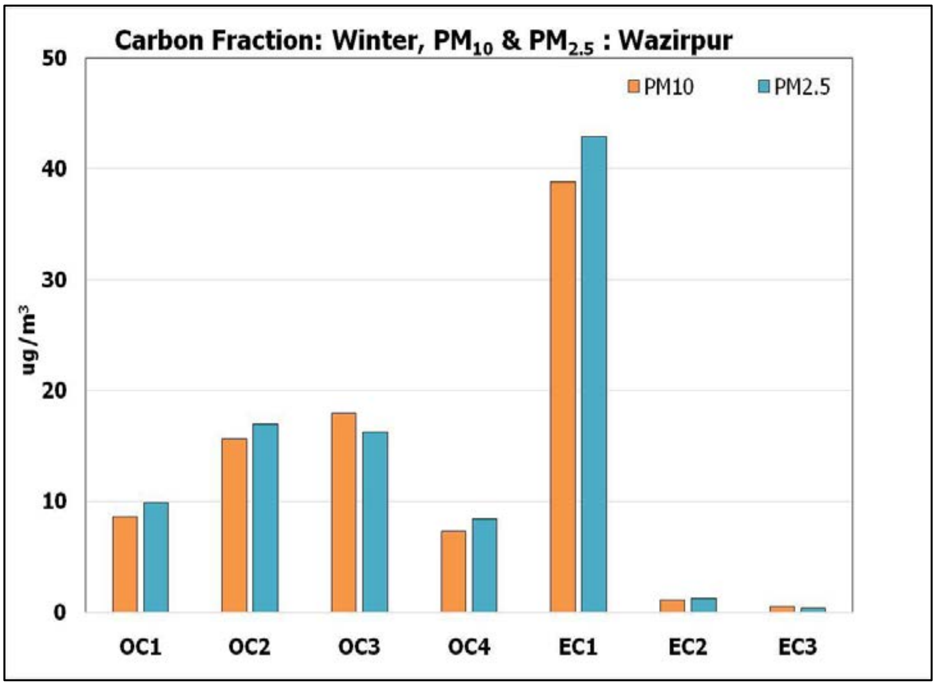


Figure 3.99 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Wazirpur in Winter Season

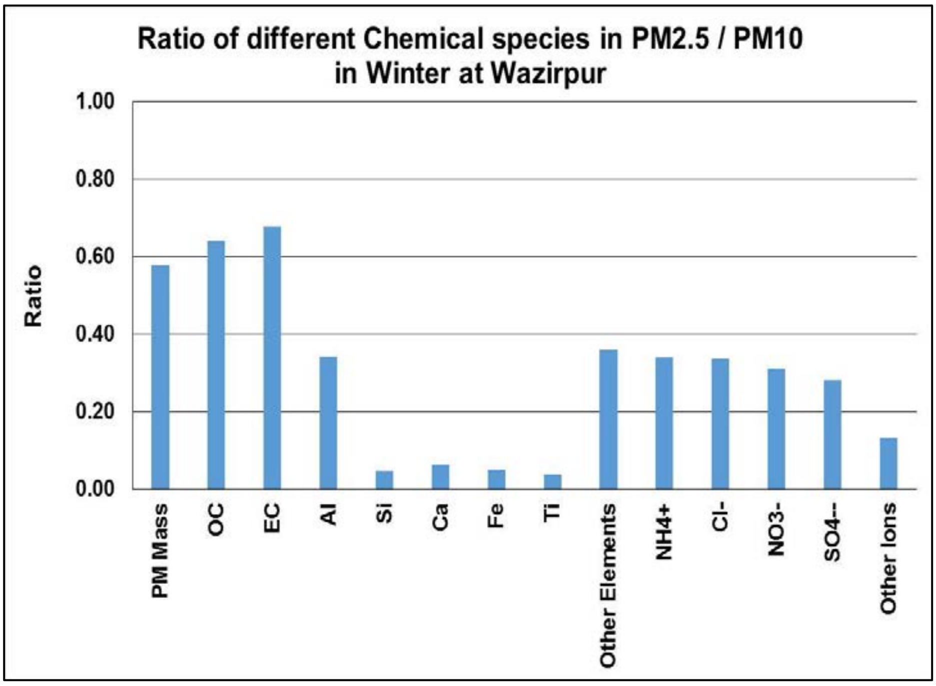


Figure 3.100: Ratio of Different Chemical Species in $PM_{2.5}$/PM_{10} at Wazirpur in Winter Season

At Wazirpur, the average concentration of PM_{10} was found to be 441±129 µg/m^3, which is 4.4 times than the NAAQS, while the average concentration of $PM_{2.5}$ was found to be 254±69 µg/m^3. Average concentration of PM_{10} varied from 294 to 718 µg/m^3, while $PM_{2.5}$ varied from 165 to 386 µg/m^3 (see Figure 3.96).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.97.

The carbon fraction was found to be 146 µg/m^3 for PM_{10} and 96 µg/m^3 for $PM_{2.5}$. The percentage mass distribution showed that the organic carbon and elemental carbon for $PM_{2.5}$ was higher as compared to that for PM_{10}. The total ion concentration was found to be 34% for PM_{10} and 17% for $PM_{2.5}$. The concentration for crustal elements was found to be 5% for PM_{10} and was very less for $PM_{2.5}$ (1%) (see Figure 3.98).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} and 2 % in $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 43% in $PM_{2.5}$ and 25% in PM_{10}.

In PM_{10}, OC3 was found to be higher, followed by OC2, OC1, and OC4, and In case of $PM_{2.5}$, OC2 was found to be higher, followed by OC3, OC1, and OC4. EC1, followed by EC2, were found to be higher in $PM_{2.5}$ than in PM_{10}, while EC3 in PM_{10} was a little higher as compared to that in $PM_{2.5}$ (see Figure 3.99). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.100.

Table 3.77 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Wazirpur in Winter Season

µg/m3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	441	80.36	65.72	0.85	1.82	9.38	10.40	0.56	4.43	3.46	0.71	2.11	27.64	33.30	34.99	1.69	29.26	5.15	14.89
SD	129	40.18	30.65	0.24	0.51	3.23	4.35	0.16	0.86	1.04	0.33	1.04	10.70	12.46	11.33	0.64	8.27	1.14	7.49
Min	294	40.95	33.40	0.57	1.37	5.93	5.62	0.35	3.43	2.60	0.38	0.90	14.83	18.60	24.81	0.91	21.32	3.73	8.83
Max	718	175.58	134.03	1.22	2.95	15.70	18.94	0.86	5.67	5.83	1.34	3.86	49.18	55.07	55.40	2.81	46.01	6.93	32.10
C.V.	0.29	0.50	0.47	0.29	0.28	0.34	0.42	0.29	0.20	0.30	0.46	0.49	0.39	0.37	0.32	0.38	0.28	0.22	0.50
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	638	142.12	114.57	1.17	2.64	14.20	17.07	0.79	5.63	5.06	1.21	3.58	44.23	50.49	51.52	2.63	42.49	6.76	26.62
50 %ile	441	69.88	61.67	0.81	1.74	9.38	9.36	0.55	4.43	3.27	0.71	2.06	27.64	33.30	30.08	1.69	29.26	5.15	13.99
5 %ile	203	40.53	31.88	0.39	0.90	4.44	4.92	0.24	2.02	1.74	0.35	0.96	12.56	15.22	17.40	0.76	14.15	2.31	8.09

Table 3.78 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Wazirpur in Winter Season

µg/m3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	254	51.48	44.54	0.29	0.09	0.59	0.39	0.03	1.49	1.78	0.22	0.92	9.26	10.30	9.83	0.40	9.95	0.77	0.93
SD	69	28.47	24.17	0.14	0.05	0.56	0.27	0.01	0.66	1.04	0.12	0.75	4.93	3.57	2.57	0.67	4.10	0.73	0.54
Min	165	19.71	14.10	0.10	0.03	0.11	0.19	0.01	0.69	0.71	0.09	0.26	3.74	5.76	7.53	0.02	6.26	0.07	0.13
Max	386	116.91	97.14	0.49	0.18	1.34	1.00	0.05	2.49	3.88	0.44	2.64	18.18	16.79	15.50	1.98	18.70	1.79	1.91
C.V.	0.27	0.55	0.54	0.50	0.54	0.95	0.68	0.44	0.44	0.59	0.56	0.82	0.53	0.35	0.26	1.70	0.41	0.95	0.58
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	355	95.68	82.38	0.47	0.16	1.32	0.81	0.04	2.45	3.47	0.42	2.14	17.11	15.47	14.00	1.52	16.38	1.76	1.67
50 %ile	247	45.44	39.45	0.28	0.09	0.24	0.32	0.03	1.33	1.48	0.17	0.72	7.52	10.04	9.11	0.11	8.35	0.61	0.91
5 %ile	178	26.32	19.98	0.12	0.04	0.13	0.19	0.01	0.74	0.82	0.11	0.30	4.41	6.25	7.73	0.03	6.54	0.08	0.29

Table 3.79 Correlation Matrix for PM_{10} and Its major constituents at Wazirpur in Winter Season

	PM10	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.86																			
	0.01																			
EC	0.89	0.97																		
	0.00	*0.00*																		
TC	0.88	1.00	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.32	0.07	0.27	0.16																
	0.44	*0.86*	*0.51*	*0.70*																
NO_3^-	0.76	0.66	0.74	0.70	0.35															
	0.03	*0.08*	*0.03*	*0.05*	*0.39*															
SO_4^{--}	0.77	0.73	0.84	0.78	0.46	0.88														
	0.03	*0.04*	*0.01*	*0.02*	*0.25*	*0.00*														
Na^+	0.68	0.65	0.71	0.68	0.19	0.55	0.83													
	0.07	*0.08*	*0.05*	*0.06*	*0.66*	*0.16*	*0.01*													
NH_4^+	0.91	0.83	0.92	0.88	0.54	0.78	0.91	0.79												
	0.00	*0.01*	*0.00*	*0.00*	*0.17*	*0.02*	*0.00*	*0.02*												
K^+	0.82	0.58	0.65	0.61	0.41	0.50	0.61	0.71	0.79											
	0.01	*0.14*	*0.08*	*0.11*	*0.32*	*0.21*	*0.11*	*0.05*	*0.02*											
Ca^{++}	0.84	0.90	0.84	0.88	-0.09	0.46	0.56	0.69	0.74	0.72										
	0.01	*0.00*	*0.01*	*0.00*	*0.83*	*0.25*	*0.15*	*0.06*	*0.04*	*0.04*										
Si	0.87	0.81	0.76	0.79	-0.06	0.50	0.57	0.74	0.74	0.80	0.96									
	0.01	*0.02*	*0.03*	*0.02*	*0.89*	*0.21*	*0.14*	*0.04*	*0.04*	*0.02*	*0.00*									
Al	0.63	0.24	0.29	0.26	0.22	0.34	0.35	0.52	0.48	0.88	0.49	0.67								
	0.10	*0.57*	*0.49*	*0.53*	*0.60*	*0.41*	*0.40*	*0.19*	*0.23*	*0.00*	*0.22*	*0.07*								
Ca	0.79	0.71	0.69	0.71	-0.01	0.41	0.56	0.80	0.70	0.88	0.91	0.95	0.76							
	0.02	*0.05*	*0.06*	*0.05*	*0.98*	*0.31*	*0.15*	*0.02*	*0.05*	*0.00*	*0.00*	*0.00*	*0.03*							
Fe	0.81	0.74	0.72	0.74	-0.01	0.38	0.50	0.72	0.70	0.88	0.93	0.95	0.73	0.99						
	0.02	*0.03*	*0.05*	*0.04*	*0.98*	*0.35*	*0.21*	*0.05*	*0.06*	*0.00*	*0.00*	*0.00*	*0.04*	*0.00*						
Ti	0.76	0.72	0.68	0.71	-0.11	0.32	0.49	0.76	0.64	0.82	0.92	0.94	0.69	0.98	0.98					
	0.03	*0.04*	*0.06*	*0.05*	*0.80*	*0.43*	*0.22*	*0.03*	*0.09*	*0.01*	*0.00*	*0.00*	*0.06*	*0.00*	*0.00*					
K	0.75	0.49	0.54	0.52	0.26	0.40	0.49	0.66	0.67	0.98	0.71	0.81	0.93	0.91	0.90	0.85				
	0.03	*0.22*	*0.17*	*0.19*	*0.53*	*0.33*	*0.22*	*0.07*	*0.07*	*0.00*	*0.05*	*0.02*	*0.00*	*0.00*	*0.00*	*0.01*				
S	0.91	0.84	0.82	0.83	0.09	0.79	0.67	0.56	0.78	0.71	0.85	0.87	0.55	0.76	0.77	0.70	0.68			
	0.00	*0.01*	*0.01*	*0.01*	*0.84*	*0.02*	*0.07*	*0.15*	*0.02*	*0.05*	*0.01*	*0.01*	*0.16*	*0.03*	*0.02*	*0.06*	*0.07*			
Ni	0.75	0.56	0.56	0.56	0.03	0.37	0.42	0.63	0.61	0.92	0.81	0.89	0.89	0.95	0.95	0.92	0.97	0.75		
	0.03	*0.15*	*0.15*	*0.15*	*0.94*	*0.36*	*0.30*	*0.09*	*0.11*	*0.00*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.03*		
Pb	0.97	0.77	0.79	0.78	0.37	0.72	0.64	0.51	0.84	0.82	0.77	0.81	0.67	0.72	0.76	0.67	0.76	0.91	0.75	
	0.00	*0.03*	*0.02*	*0.02*	*0.36*	*0.05*	*0.09*	*0.20*	*0.01*	*0.01*	*0.03*	*0.02*	*0.07*	*0.05*	*0.03*	*0.07*	*0.03*	*0.00*	*0.03*	
Zn	0.77	0.54	0.51	0.53	-0.10	0.59	0.54	0.67	0.58	0.70	0.70	0.85	0.79	0.80	0.75	0.76	0.74	0.77	0.80	0.72
	0.03	*0.16*	*0.20*	*0.17*	*0.82*	*0.13*	*0.16*	*0.07*	*0.13*	*0.05*	*0.05*	*0.01*	*0.02*	*0.02*	*0.03*	*0.03*	*0.04*	*0.02*	*0.02*	*0.04*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

Table 3.80 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Wazirpur in Winter Season

	PM2.5	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.89																			
	0.00																			
EC	0.92	0.99																		
	0.00	*0.00*																		
TC	0.91	1.00	1.00																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.35	0.10	0.21	0.15																
	0.39	*0.81*	*0.62*	*0.72*																
NO_3^-	0.82	0.78	0.76	0.77	-0.09															
	0.01	*0.02*	*0.03*	*0.03*	*0.84*															
SO_4^{--}	0.87	0.94	0.91	0.93	-0.05	0.92														
	0.01	*0.00*	*0.00*	*0.00*	*0.90*	*0.00*														
Na^+	0.23	0.03	0.05	0.04	-0.07	0.38	0.15													
	0.59	*0.95*	*0.91*	*0.93*	*0.87*	*0.35*	*0.72*													
NH_4^+	0.96	0.94	0.93	0.94	0.16	0.90	0.96	0.18												
	0.00	*0.00*	*0.00*	*0.00*	*0.70*	*0.00*	*0.00*	*0.67*												
K^+	0.75	0.77	0.81	0.79	0.18	0.70	0.75	-0.13	0.75											
	0.03	*0.03*	*0.02*	*0.02*	*0.67*	*0.05*	*0.03*	*0.76*	*0.03*											
Ca^{++}	0.47	0.41	0.44	0.43	-0.01	0.50	0.36	0.26	0.44	0.60										
	0.24	*0.31*	*0.27*	*0.29*	*0.98*	*0.20*	*0.38*	*0.54*	*0.28*	*0.12*										
Si	0.77	0.87	0.90	0.89	0.34	0.43	0.66	-0.10	0.73	0.65	0.42									
	0.02	*0.01*	*0.00*	*0.00*	*0.41*	*0.29*	*0.08*	*0.82*	*0.04*	*0.08*	*0.30*									
Al	0.75	0.53	0.60	0.57	0.66	0.48	0.49	0.50	0.63	0.31	0.10	0.53								
	0.03	*0.17*	*0.12*	*0.15*	*0.08*	*0.23*	*0.21*	*0.21*	*0.09*	*0.45*	*0.82*	*0.18*								
Ca	0.51	0.38	0.41	0.40	0.38	0.30	0.34	0.64	0.43	-0.06	-0.11	0.41	0.87							
	0.20	*0.35*	*0.31*	*0.33*	*0.35*	*0.48*	*0.41*	*0.09*	*0.29*	*0.89*	*0.80*	*0.32*	*0.00*							
Fe	0.77	0.97	0.95	0.96	0.01	0.67	0.87	-0.03	0.83	0.73	0.42	0.89	0.42	0.32						
	0.03	*0.00*	*0.00*	*0.00*	*0.98*	*0.07*	*0.01*	*0.95*	*0.01*	*0.04*	*0.31*	*0.00*	*0.30*	*0.44*						
Ti	0.70	0.58	0.64	0.61	0.41	0.38	0.48	0.50	0.58	0.26	0.09	0.65	0.88	0.90	0.53					
	0.05	*0.13*	*0.09*	*0.11*	*0.31*	*0.35*	*0.23*	*0.21*	*0.13*	*0.54*	*0.84*	*0.08*	*0.00*	*0.00*	*0.18*					
K	0.81	0.75	0.84	0.79	0.51	0.58	0.65	0.05	0.72	0.89	0.57	0.79	0.63	0.28	0.72	0.56				
	0.02	*0.03*	*0.01*	*0.02*	*0.20*	*0.13*	*0.08*	*0.90*	*0.04*	*0.00*	*0.14*	*0.02*	*0.10*	*0.50*	*0.05*	*0.15*				
S	0.97	0.93	0.96	0.94	0.37	0.80	0.87	0.15	0.95	0.81	0.54	0.84	0.71	0.45	0.84	0.64	0.88			
	0.00	*0.00*	*0.00*	*0.00*	*0.36*	*0.02*	*0.01*	*0.72*	*0.00*	*0.02*	*0.17*	*0.01*	*0.05*	*0.27*	*0.01*	*0.09*	*0.00*			
Ni	0.19	-0.07	-0.01	-0.04	0.30	0.06	-0.04	0.81	0.06	-0.33	-0.15	-0.03	0.69	0.86	-0.14	0.71	0.01	0.08		
	0.65	*0.88*	*0.97*	*0.92*	*0.47*	*0.88*	*0.93*	*0.01*	*0.89*	*0.43*	*0.72*	*0.95*	*0.06*	*0.01*	*0.74*	*0.05*	*0.98*	*0.86*		
Pb	0.86	0.73	0.78	0.75	0.40	0.72	0.68	0.06	0.80	0.87	0.75	0.67	0.50	0.12	0.62	0.37	0.87	0.89	-0.10	
	0.01	*0.04*	*0.02*	*0.03*	*0.33*	*0.05*	*0.06*	*0.88*	*0.02*	*0.01*	*0.03*	*0.07*	*0.21*	*0.78*	*0.10*	*0.37*	*0.01*	*0.00*	*0.81*	
Zn	0.91	0.94	0.94	0.94	0.21	0.76	0.86	0.27	0.91	0.62	0.50	0.86	0.68	0.58	0.90	0.70	0.72	0.93	0.18	0.72
	0.00	*0.00*	*0.00*	*0.00*	*0.62*	*0.03*	*0.01*	*0.52*	*0.00*	*0.10*	*0.21*	*0.01*	*0.06*	*0.13*	*0.00*	*0.05*	*0.04*	*0.00*	*0.67*	*0.04*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For the winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.77 and Table 3.78 for PM mass and the major species, respectively. $PM_{2.5}$ mass shows similar C.V. than PM_{10} mass. The percentile statistics show that statistical results corresponding to mean, max, and min have larger differences. This is due to a large variation in PM mass. For elements, the C.V. observed in PM_{10} was lesser than $PM_{2.5}$.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.79 and Table 3.80 for PM mass and its major species, respectively. OC, EC, and TC show similar correlation with both PM_{10} mass and $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$.

3.1.11 Site 11: Rohini

3.1.11.1 Summer Season

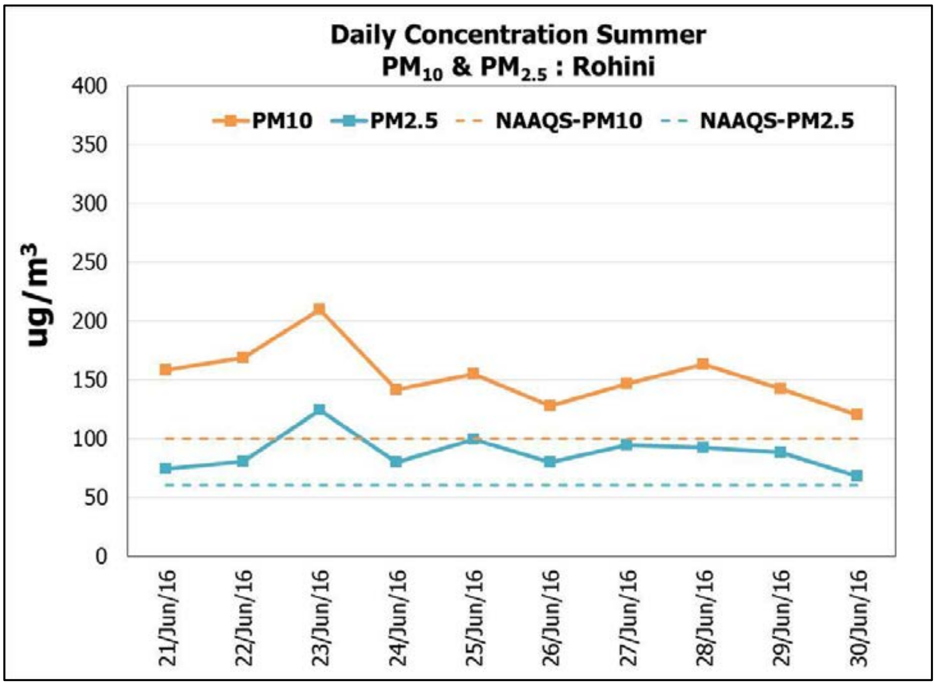


Figure 3.101 Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Rohini in Summer Season

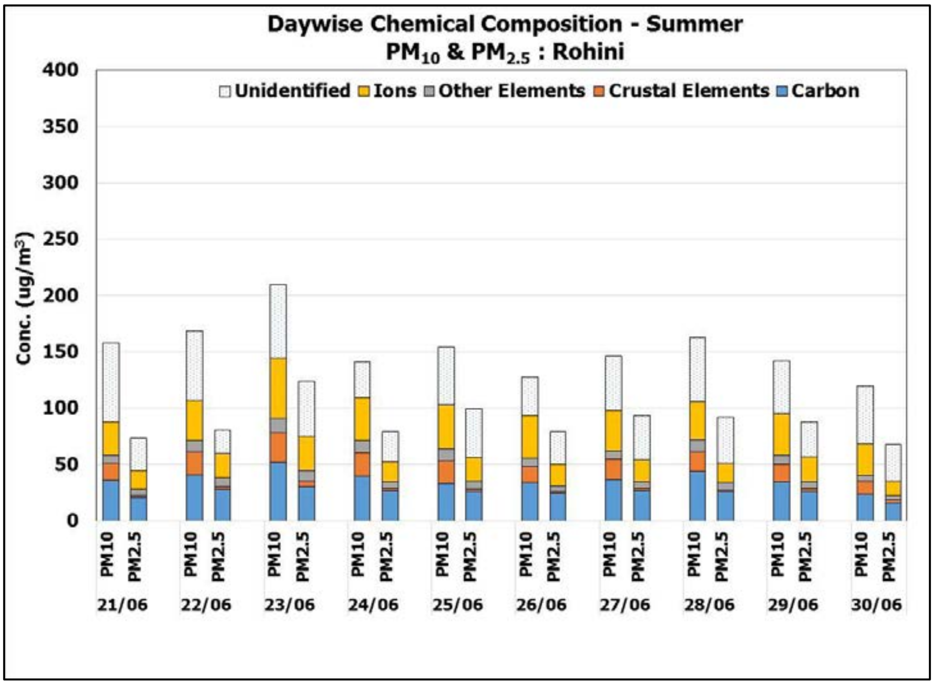


Figure 3.102: Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Rohini in Summer Season

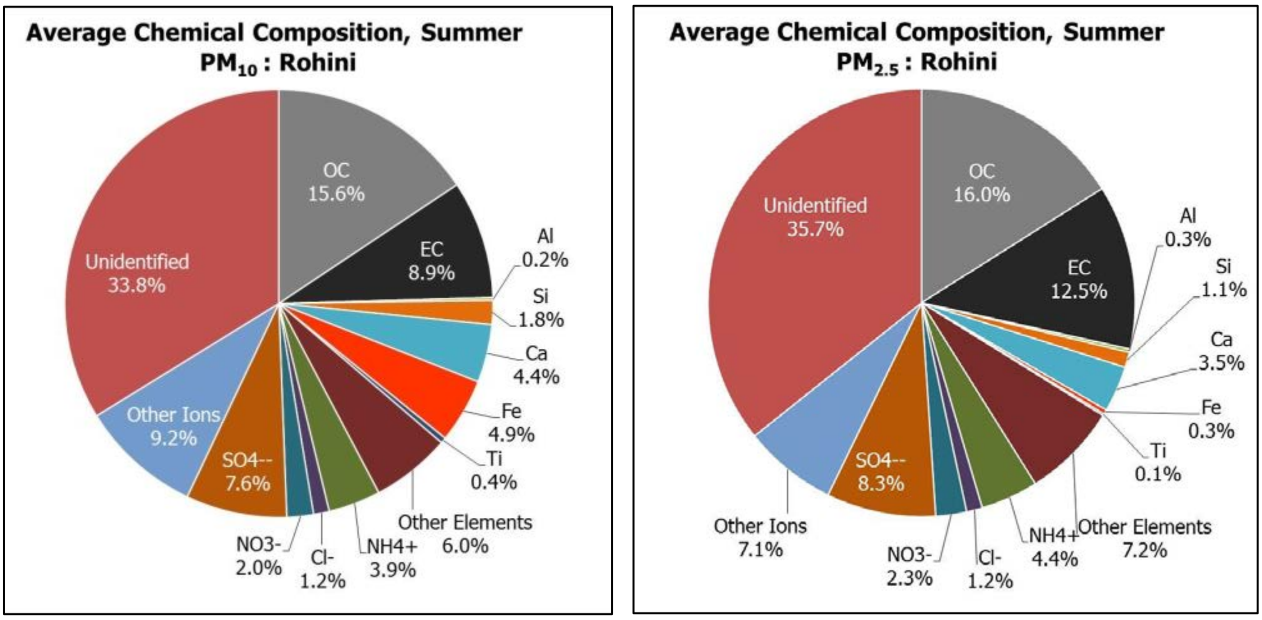


Figure 3.103 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Rohini in Summer Season

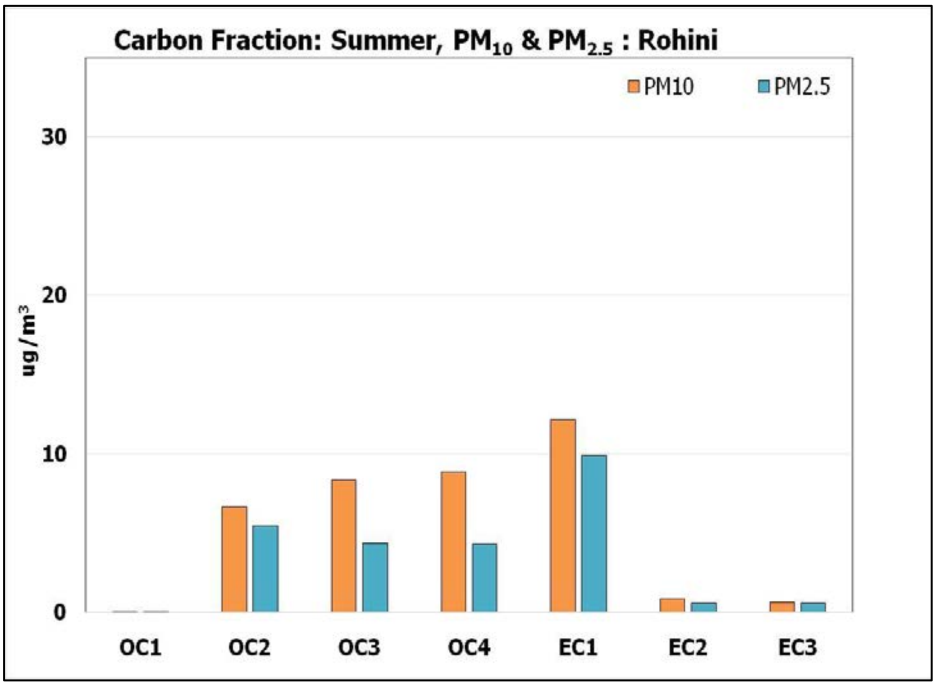


Figure 3.104: Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Rohini in Summer Season

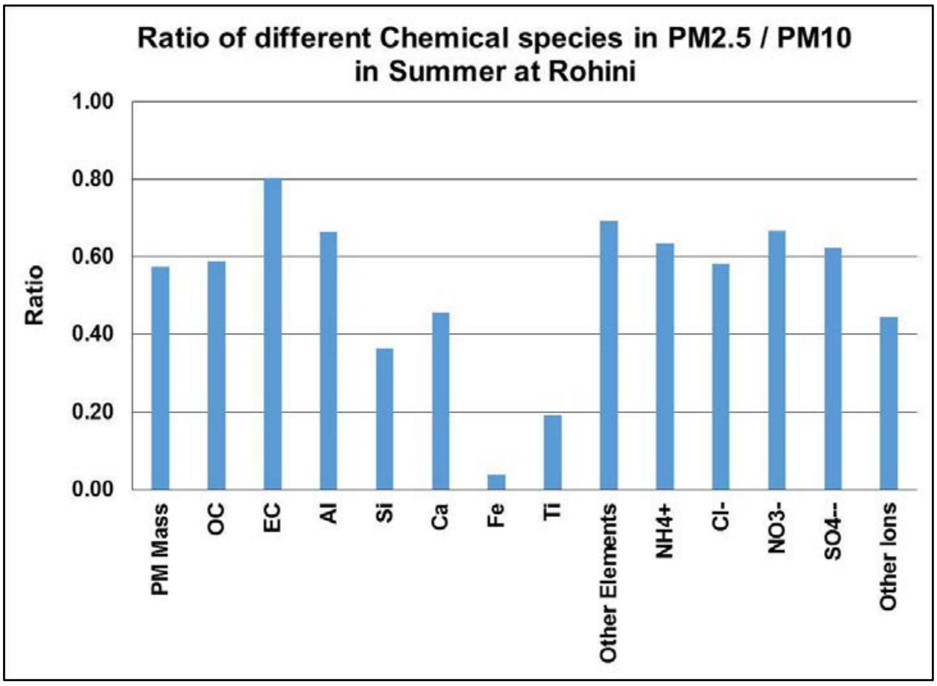


Figure 3.105 Ratio of Different Chemical Species in $PM_{2.5}/PM_{10}$ at Rohini in Summer Season

Average concentrations observed at Rohini (RHN) were 153±25 µg/m^3 for PM_{10} and 88±16 µg/m^3 for $PM_{2.5}$. Average concentration of PM_{10} and $PM_{2.5}$ was almost 1.5 times NAAQS. The observed daily concentration variation in PM_{10} was from 120 to 210 µg/m^3. Similarly, Daily concentration variation for $PM_{2.5}$ is from 68 to 124 µg/m^3 (see Figure 3.101).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.102.

The carbon fraction concentration observed is 38 µg/m^3 in PM_{10} and 25 µg/m^3 in $PM_{2.5}$. The ionic portion was found to be 24% in PM_{10} and 23% in $PM_{2.5}$. Concentration of crustal elements is 12% in PM_{10} and 3% in $PM_{2.5}$ (see Figure 3.103).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 6% in PM_{10} and 7% in $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 34% for PM_{10} and 38% for $PM_{2.5}$, respectively.

EC1 was found to be highest in PM_{10}, followed by OC4, OC3, OC2, EC2, and EC3. However, EC1 is the highest in $PM_{2.5}$, followed by OC2, OC3, and OC4, while EC2 and EC3 were found to be similar. EC1 was found to be 12 µg/m^3 in PM_{10} and 10 µg/m^3 in $PM_{2.5}$, whereas OC4 was found to be 9 µg/m^3 in PM_{10} and OC2 was found to be 5 µg/m^3 in $PM_{2.5}$ (see Figure 3.104). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.105.

Table 3.81 Statistical evalua**tion of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Rohini in Summer Season

µg/m^3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	153	23.94	13.65	0.33	2.77	6.71	7.47	0.67	4.58	1.76	0.30	0.49	1.81	3.08	11.69	2.19	6.04	2.96	5.51
SD	25	5.69	2.26	0.17	0.78	2.01	2.09	0.15	1.57	0.42	0.12	0.17	0.73	0.80	1.33	1.74	0.77	1.29	1.49
Min	120	15.12	9.02	0.13	1.93	3.88	3.98	0.39	2.18	1.24	0.17	0.25	0.91	2.11	10.15	0.19	5.09	1.25	3.12
Max	210	36.99	17.04	0.73	4.65	10.79	9.70	0.91	6.55	2.45	0.49	0.86	3.04	4.86	14.83	5.38	7.70	5.05	8.17
C.V.	0.16	0.24	0.17	0.52	0.28	0.30	0.28	0.22	0.34	0.24	0.38	0.34	0.40	0.26	0.11	0.79	0.13	0.44	0.27
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	191	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	150	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	123	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3,82 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Rohini in Summer Season

µg/m^3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	88	14.09	10.95	0.22	1.01	3.06	0.29	0.13	3.47	1.49	0.15	0.25	1.05	2.05	7.28	0.84	3.84	2.49	1.47
SD	16	2.26	2.01	0.04	0.15	0.74	0.28	0.02	1.25	0.45	0.05	0.11	0.27	0.45	1.35	0.76	0.63	1.15	0.42
Min	68	8.82	7.08	0.19	0.82	2.39	0.02	0.11	1.75	1.02	0.05	0.11	0.75	1.62	5.01	0.09	2.65	1.02	1.06
Max	124	16.78	13.84	0.32	1.29	4.90	0.83	0.18	5.75	2.24	0.21	0.42	1.48	3.21	9.69	2.20	4.60	4.29	2.17
C.V.	0.18	0.16	0.18	0.16	0.15	0.24	0.97	0.16	0.36	0.30	0.34	0.44	0.26	0.22	0.18	0.90	0.16	0.46	0.29
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	113	16.39	13.29	0.28	1.23	4.25	0.79	0.16	5.35	2.14	0.21	0.42	1.47	2.76	9.31	2.17	4.54	3.92	2.03
50 %ile	84	14.75	11.14	0.21	1.02	2.98	0.20	0.12	3.41	1.38	0.14	0.23	0.98	1.93	7.41	0.69	4.13	2.74	1.37
5 %ile	71	10.55	7.66	0.19	0.82	2.41	0.04	0.11	1.95	1.02	0.08	0.12	0.78	1.69	5.54	0.12	2.92	1.12	1.07

Table 3.83 Correlation Matrix for PM_{10} and Its major constituents at Rohini in Summer Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.57	0.67																		
	0.08	*0.04*																		
TC	0.89	0.97	0.82																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.40	0.48	0.16	0.42																
	0.26	*0.17*	*0.66*	*0.23*																
NO_3^-	0.72	0.65	0.18	0.56	0.42															
	0.02	*0.04*	*0.61*	*0.10*	*0.23*															
SO_4^{--}	0.65	0.74	0.45	0.71	0.39	0.76														
	0.04	*0.02*	*0.19*	*0.02*	*0.27*	*0.01*														
Na^+	0.42	0.50	0.06	0.40	0.25	0.15	0.26													
	0.22	*0.15*	*0.88*	*0.25*	*0.49*	*0.68*	*0.48*													
NH_4^+	0.71	0.62	0.05	0.49	0.61	0.90	0.70	0.30												
	0.02	*0.06*	*0.89*	*0.15*	*0.06*	*0.00*	*0.03*	*0.40*												
K^+	0.59	0.76	0.38	0.70	0.30	0.50	0.49	0.72	0.45											
	0.07	*0.01*	*0.28*	*0.02*	*0.40*	*0.15*	*0.15*	*0.02*	*0.19*											
Ca^{++}	0.61	0.68	0.35	0.63	0.71	0.46	0.55	0.31	0.46	0.31										
	0.06	*0.03*	*0.33*	*0.05*	*0.02*	*0.19*	*0.10*	*0.39*	*0.18*	*0.39*										
Si	0.73	0.75	0.09	0.60	0.69	0.67	0.55	0.51	0.81	0.57	0.70									
	0.02	*0.01*	*0.80*	*0.07*	*0.03*	*0.03*	*0.10*	*0.14*	*0.00*	*0.09*	*0.03*									
Al	0.79	0.82	0.51	0.79	0.40	0.69	0.78	0.66	0.70	0.79	0.43	0.59								
	0.01	*0.00*	*0.14*	*0.01*	*0.25*	*0.03*	*0.01*	*0.04*	*0.03*	*0.01*	*0.21*	*0.08*								
Ca	0.69	0.78	0.33	0.70	0.75	0.54	0.55	0.41	0.57	0.50	0.96	0.83	0.51							
	0.03	*0.01*	*0.36*	*0.02*	*0.01*	*0.11*	*0.10*	*0.24*	*0.09*	*0.14*	*0.00*	*0.00*	*0.13*							
Fe	0.72	0.75	0.64	0.78	-0.03	0.51	0.48	0.40	0.30	0.69	0.35	0.42	0.65	0.43						
	0.02	*0.01*	*0.05*	*0.01*	*0.94*	*0.14*	*0.16*	*0.26*	*0.40*	*0.03*	*0.32*	*0.23*	*0.04*	*0.21*						
Ti	0.75	0.85	0.78	0.90	0.30	0.52	0.72	0.52	0.40	0.74	0.55	0.46	0.86	0.58	0.85					
	0.01	*0.00*	*0.01*	*0.00*	*0.41*	*0.12*	*0.02*	*0.12*	*0.25*	*0.01*	*0.10*	*0.19*	*0.00*	*0.08*	*0.00*					
K	0.64	0.74	0.36	0.68	0.29	0.51	0.36	0.63	0.37	0.87	0.52	0.60	0.64	0.66	0.80	0.73				
	0.05	*0.01*	*0.30*	*0.03*	*0.41*	*0.14*	*0.31*	*0.05*	*0.29*	*0.00*	*0.12*	*0.07*	*0.05*	*0.04*	*0.01*	*0.02*				
S	0.71	0.57	0.35	0.54	0.46	0.80	0.61	0.08	0.75	0.23	0.57	0.60	0.58	0.55	0.54	0.58	0.38			
	0.02	*0.09*	*0.32*	*0.11*	*0.18*	*0.01*	*0.06*	*0.82*	*0.01*	*0.53*	*0.09*	*0.07*	*0.08*	*0.10*	*0.11*	*0.08*	*0.27*			
Ni	0.59	0.76	0.48	0.73	0.19	0.49	0.82	0.42	0.35	0.57	0.66	0.45	0.66	0.65	0.61	0.77	0.57	0.34		
	0.07	*0.01*	*0.16*	*0.02*	*0.60*	*0.15*	*0.00*	*0.22*	*0.32*	*0.09*	*0.04*	*0.19*	*0.04*	*0.04*	*0.06*	*0.01*	*0.08*	*0.33*		
Pb	0.47	0.51	0.53	0.55	-0.15	0.32	0.64	-0.12	0.16	0.05	0.38	0.21	0.26	0.31	0.53	0.49	0.11	0.38	0.69	
	0.17	*0.14*	*0.12*	*0.10*	*0.68*	*0.36*	*0.05*	*0.74*	*0.66*	*0.89*	*0.28*	*0.56*	*0.46*	*0.39*	*0.12*	*0.15*	*0.77*	*0.27*	*0.03*	
Zn	0.76	0.81	0.45	0.76	0.57	0.63	0.74	0.24	0.58	0.39	0.89	0.66	0.58	0.88	0.41	0.61	0.49	0.55	0.79	0.55
	0.01	*0.01*	*0.19*	*0.01*	*0.08*	*0.05*	*0.01*	*0.50*	*0.08*	*0.27*	*0.00*	*0.04*	*0.08*	*0.00*	*0.24*	*0.06*	*0.15*	*0.10*	*0.01*	*0.10*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.84 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Rohini in Summer Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.68																			
	0.03																			
EC	0.74	0.79																		
	0.01	*0.01*																		
TC	0.75	0.95	0.94																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.47	0.48	0.66	0.60																
	0.17	*0.16*	*0.04*	*0.07*																
NO_3^-	0.76	0.25	0.51	0.40	0.65															
	0.01	*0.49*	*0.13*	*0.26*	*0.04*															
SO_4^{--}	0.79	0.61	0.84	0.76	0.54	0.60														
	0.01	*0.06*	*0.00*	*0.01*	*0.11*	*0.07*														
Na^+	0.53	0.60	0.40	0.54	0.43	0.42	0.55													
	0.11	*0.07*	*0.25*	*0.11*	*0.22*	*0.23*	*0.10*													
NH_4^+	0.80	0.35	0.46	0.42	0.23	0.76	0.64	0.45												
	0.01	*0.33*	*0.18*	*0.22*	*0.53*	*0.01*	*0.05*	*0.20*												
K^+	0.61	0.79	0.56	0.72	0.49	0.43	0.32	0.70	0.32											
	0.06	*0.01*	*0.09*	*0.02*	*0.15*	*0.22*	*0.36*	*0.02*	*0.37*											
Ca^{++}	0.71	0.58	0.67	0.66	0.56	0.58	0.77	0.67	0.33	0.58										
	0.02	*0.08*	*0.03*	*0.04*	*0.09*	*0.08*	*0.01*	*0.03*	*0.35*	*0.08*										
Si	0.23	0.35	0.05	0.22	0.05	0.02	0.37	0.79	0.30	0.23	0.31									
	0.52	*0.32*	*0.90*	*0.54*	*0.89*	*0.97*	*0.29*	*0.01*	*0.41*	*0.52*	*0.38*									
Al	0.28	0.21	0.01	0.12	-0.36	0.01	-0.18	-0.01	0.23	0.43	-0.11	-0.15								
	0.44	*0.56*	*0.98*	*0.74*	*0.30*	*0.98*	*0.62*	*0.97*	*0.53*	*0.22*	*0.77*	*0.69*								
Ca	0.79	0.47	0.58	0.55	0.63	0.87	0.68	0.70	0.61	0.64	0.87	0.25	-0.03							
	0.01	*0.17*	*0.08*	*0.10*	*0.05*	*0.00*	*0.03*	*0.02*	*0.06*	*0.05*	*0.00*	*0.48*	*0.93*							
Fe	0.33	-0.13	0.09	-0.03	0.36	0.75	0.15	0.28	0.39	0.29	0.43	-0.16	-0.10	0.73						
	0.35	*0.72*	*0.80*	*0.94*	*0.30*	*0.01*	*0.68*	*0.43*	*0.27*	*0.41*	*0.22*	*0.65*	*0.78*	*0.02*						
Ti	0.78	0.65	0.66	0.69	0.80	0.84	0.61	0.69	0.61	0.78	0.70	0.22	0.01	0.90	0.58					
	0.01	*0.04*	*0.04*	*0.03*	*0.01*	*0.00*	*0.06*	*0.03*	*0.06*	*0.01*	*0.02*	*0.55*	*0.97*	*0.00*	*0.08*					
K	0.74	0.77	0.69	0.77	0.75	0.62	0.52	0.60	0.37	0.87	0.68	0.16	0.26	0.73	0.27	0.88				
	0.02	*0.01*	*0.03*	*0.01*	*0.01*	*0.05*	*0.13*	*0.07*	*0.29*	*0.00*	*0.03*	*0.66*	*0.47*	*0.02*	*0.46*	*0.00*				
S	0.76	0.54	0.76	0.68	0.56	0.65	0.69	0.14	0.43	0.38	0.71	-0.23	-0.03	0.69	0.37	0.65	0.61			
	0.01	*0.11*	*0.01*	*0.03*	*0.09*	*0.04*	*0.03*	*0.70*	*0.22*	*0.28*	*0.02*	*0.52*	*0.94*	*0.03*	*0.29*	*0.04*	*0.06*			
Ni	0.63	0.83	0.62	0.81	0.71	0.71	0.36	0.56	0.31	0.88	0.68	-0.06	0.17	0.82	0.84	0.91	0.96	0.61		
	0.07	*0.01*	*0.08*	*0.01*	*0.03*	*0.03*	*0.35*	*0.12*	*0.42*	*0.00*	*0.05*	*0.88*	*0.66*	*0.01*	*0.00*	*0.00*	*0.00*	*0.08*		
Pb	0.84	0.45	0.65	0.58	0.31	0.58	0.60	0.28	0.56	0.46	0.58	-0.02	0.38	0.57	0.28	0.49	0.55	0.62	0.41	
	0.00	*0.19*	*0.04*	*0.08*	*0.39*	*0.08*	*0.07*	*0.44*	*0.09*	*0.19*	*0.08*	*0.96*	*0.28*	*0.08*	*0.44*	*0.15*	*0.10*	*0.05*	*0.27*	
Zn	0.70	0.34	0.75	0.57	0.29	0.61	0.67	0.02	0.69	0.21	0.36	-0.28	0.22	0.44	0.27	0.42	0.32	0.69	0.25	0.73
	0.02	*0.33*	*0.01*	*0.09*	*0.42*	*0.06*	*0.03*	*0.96*	*0.03*	*0.56*	*0.31*	*0.44*	*0.54*	*0.21*	*0.45*	*0.23*	*0.37*	*0.03*	*0.52*	*0.02*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.81 and Table 3.82 for PM mass and the major species, respectively. In PM_{10}, there is variation in percentile with respect to statistical parameter due to distribution of PM mass, whereas in PM2.5, they are similar. For crustal elements, C.V. for PM_{10} is lesser than for $PM_{2.5}$. The secondary ions show less C.V. in $PM_{2.5}$ than in PM_{10}.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.83 and Table 3.84 for PM mass and its major species. OC, EC, and TC show better correlation with both $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than with $PM_{2.5}$. The secondary ions show better correlation with each other in PM_{10}.

3.1.11.2 Winter Season

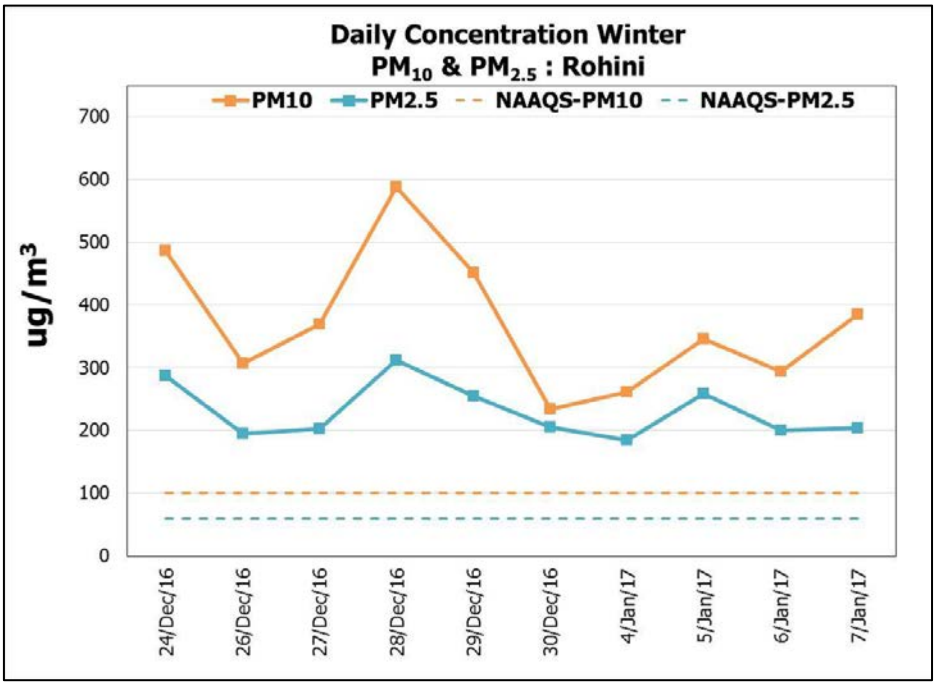


Figure 3.106: Variation in 24 Hourly Concentrations of PM_{10} and $PM_{2.5}$ at Rohini in Winter Season

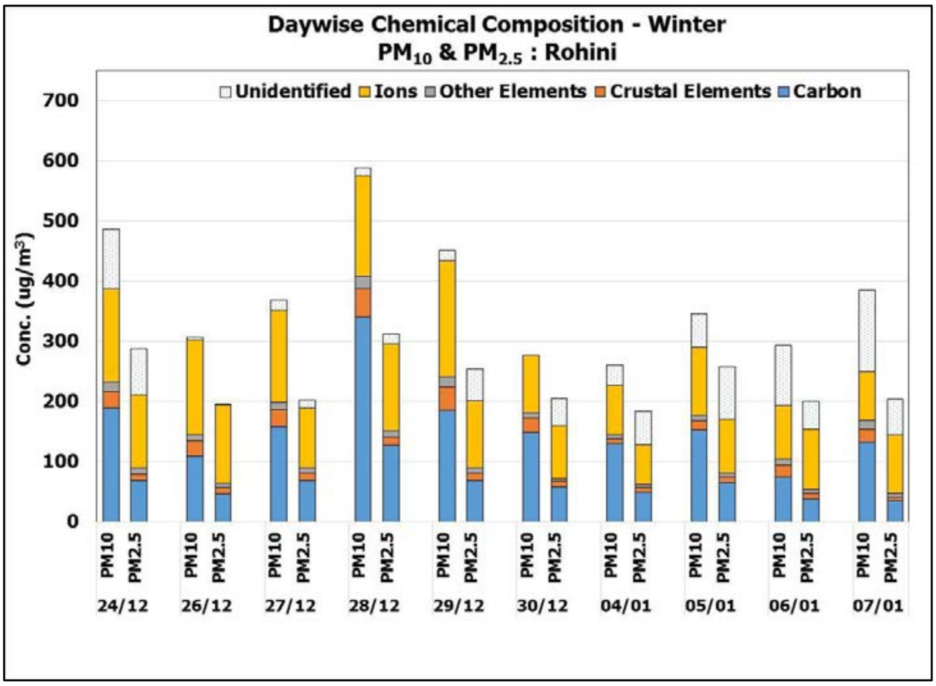


Figure 3.107 Variation in Chemical Composition of PM_{10} and $PM_{2.5}$ at Rohini in Winter Season

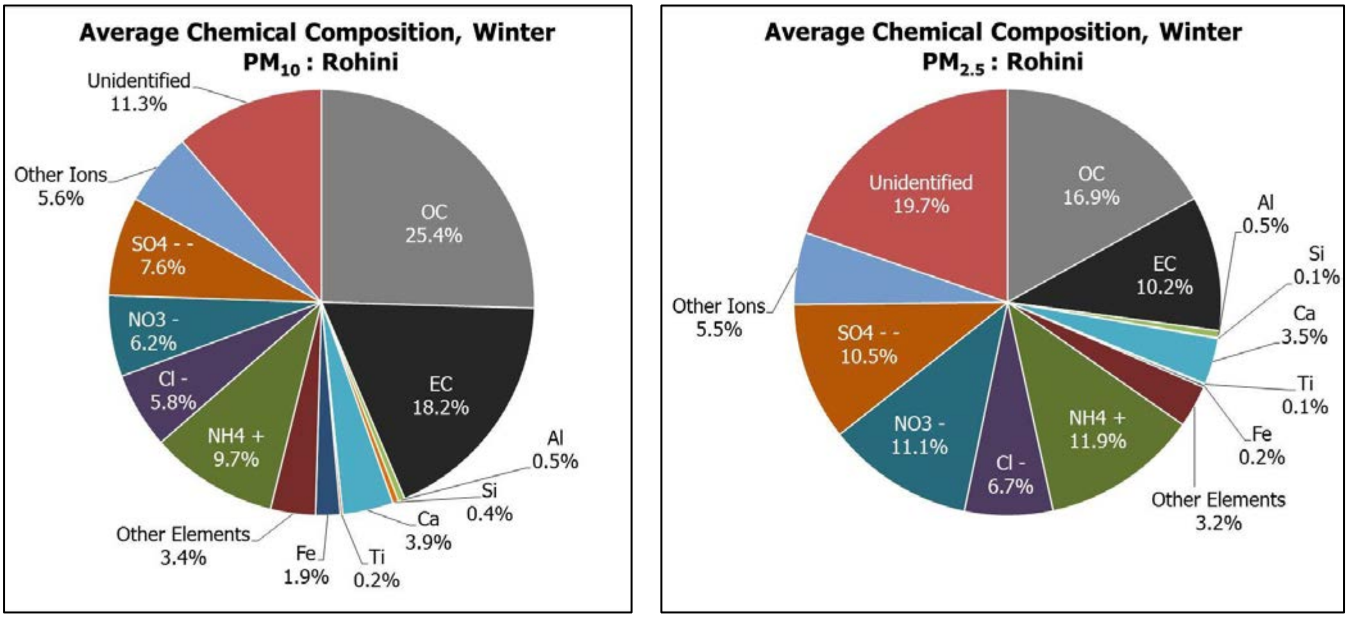


Figure 3.108 Average Chemical Composition of PM_{10} and $PM_{2.5}$ at Rohini in Winter Season

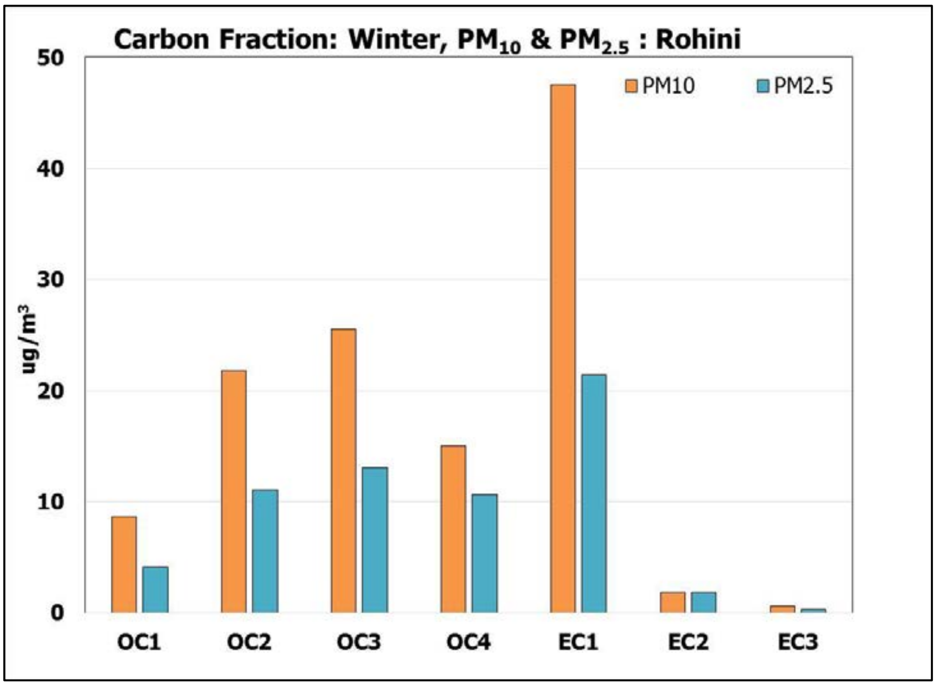


Figure 3.109 Average Concentration of Carbon Fractions of PM_{10} and $PM_{2.5}$ at Rohini in Winter Season

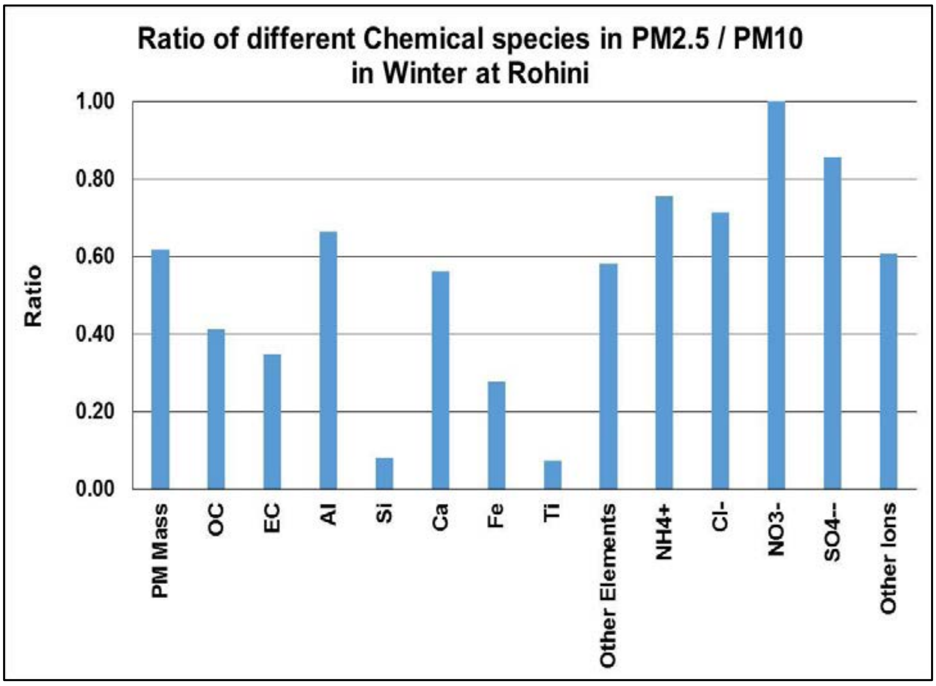


Figure 3.110: Ratio of Different Chemical Species in $PM_{2.5}$/PM_{10} at Rohini in Winter Season

231±44 $\mu g/m^3$, respectively. PM_{10} was found to be 3.7 times higher than the NAAQS. Concentration of PM_{10} varied from 233 to 588 $\mu g/m^3$, and In case of $PM_{2.5}$, it varied from 184 to 312 $\mu g/m^3$ (see Figure 3.106).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.107.

The carbon fraction was observed to the major portion: 162 $\mu g/m^3$ for PM_{10} and 63 $\mu g/m^3$ for $PM_{2.5}$. The total ion concentration was found to be 35% in PM_{10} and was higher in $PM_{2.5}$ (46%). Concentration of crustal elements was found to be 7% for PM_{10} and 4% for $PM_{2.5}$ (see Figure 3.108).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in both PM_{10} and $PM_{2.5}$. The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be was found to be 11% for PM_{10} and 20% in case of $PM_{2.5}$.

In case of carbon fraction, OC3 was found to be higher in PM_{10} as compared to that in $PM_{2.5}$, followed by OC2, OC4, and OC1. EC1 was found to be higher in PM_{10} as compared to that in $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.109). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.110.

Table 3.85 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Rohini in Winter Season

µg/m3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	372	94.67	67.62	1.84	1.67	14.35	6.90	0.66	4.86	4.49	0.30	1.50	21.52	22.90	28.12	1.34	36.20	4.23	11.42
SD	110	39.76	32.79	0.85	0.71	6.76	2.77	0.31	1.91	1.60	0.12	0.60	16.66	15.73	11.83	0.60	9.16	2.07	3.53
Min	233	48.21	25.95	0.50	0.69	3.49	3.46	0.20	2.60	2.50	0.10	0.66	1.82	8.38	10.03	0.53	21.54	0.32	7.41
Max	588	192.54	148.48	3.56	3.23	25.43	13.21	1.34	8.24	7.90	0.57	2.64	51.15	51.18	45.62	2.43	54.10	7.52	17.76
C.V.	0.30	0.42	0.48	0.46	0.42	0.47	0.40	0.47	0.39	0.36	0.41	0.40	0.77	0.69	0.42	0.45	0.25	0.49	0.31
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	543	155.23	118.59	3.06	2.86	24.69	11.49	1.14	7.61	6.99	0.50	2.50	50.23	48.80	45.53	2.23	50.66	7.01	16.64
50 %ile	369	92.55	60.28	1.84	1.53	14.35	6.31	0.66	4.86	4.09	0.29	1.36	16.72	19.60	28.78	1.34	36.20	4.23	11.42
5 %ile	178	44.41	29.71	0.69	0.70	5.13	3.15	0.26	2.29	2.09	0.11	0.63	5.07	8.93	11.02	0.57	15.97	1.26	5.67

Table 3.86 Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Rohini in Winter Season

µg/m3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	231	38.97	23.59	1.22	0.14	8.06	0.50	0.18	2.27	3.28	0.16	0.80	15.38	25.65	24.12	0.80	27.35	2.22	6.17
SD	44	14.83	11.61	0.58	0.05	1.79	0.20	0.10	0.69	0.88	0.06	0.25	7.56	4.30	5.19	0.49	5.26	1.52	1.22
Min	184	22.70	11.99	0.28	0.05	4.64	0.34	0.02	1.50	2.21	0.06	0.34	4.93	19.16	15.50	0.00	18.39	0.24	3.46
Max	312	75.56	51.02	2.09	0.22	11.14	1.00	0.31	3.74	5.33	0.26	1.27	27.92	32.52	34.90	1.58	38.21	5.10	7.99
C.V.	0.19	0.38	0.49	0.48	0.39	0.22	0.41	0.54	0.30	0.27	0.39	0.31	0.49	0.17	0.22	0.62	0.19	0.68	0.20
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	301	61.75	42.83	1.90	0.21	10.48	0.86	0.29	3.44	4.69	0.24	1.14	25.67	31.62	31.69	1.45	35.43	4.81	7.65
50 %ile	205	38.07	21.63	1.34	0.15	8.21	0.42	0.21	2.08	3.22	0.15	0.77	15.89	25.04	22.58	0.78	26.47	1.68	6.37
5 %ile	189	24.09	12.28	0.29	0.06	5.55	0.35	0.02	1.56	2.25	0.07	0.45	6.39	20.48	18.18	0.12	21.02	0.67	4.40

Table 3.87 Correlation Matrix for PM_{10} and Its major constituents at Rohini in Winter Season

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.75																			
	0.01																			
EC	0.79	0.95																		
	0.01	*0.00*																		
TC	0.77	0.99	0.99																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.31	0.42	0.57	0.50																
	0.51	*0.35*	*0.19*	*0.26*																
NO_3^-	0.39	-0.04	0.05	0.00	-0.28															
	0.39	*0.93*	*0.92*	*1.00*	*0.54*															
SO_4^{--}	0.48	0.07	0.09	0.08	-0.35	0.97														
	0.28	*0.88*	*0.85*	*0.86*	*0.44*	*0.00*														
Na^+	0.68	0.34	0.40	0.37	0.13	0.70	0.68													
	0.04	*0.38*	*0.29*	*0.33*	*0.78*	*0.08*	*0.10*													
NH_4^+	0.59	0.48	0.38	0.44	0.05	0.62	0.68	0.78												
	0.10	*0.20*	*0.32*	*0.24*	*0.92*	*0.14*	*0.09*	*0.01*												
K^+	0.33	0.38	0.33	0.36	0.61	-0.01	-0.03	0.59	0.66											
	0.38	*0.31*	*0.39*	*0.34*	*0.15*	*0.98*	*0.95*	*0.10*	*0.05*											
Ca^{++}	-0.35	-0.24	-0.22	-0.23	-0.46	0.69	0.58	-0.14	0.17	-0.20										
	0.36	*0.54*	*0.57*	*0.55*	*0.30*	*0.09*	*0.17*	*0.72*	*0.67*	*0.60*										
Si	0.79	0.82	0.77	0.81	0.53	0.18	0.25	0.59	0.77	0.74	-0.18									
	0.01	*0.00*	*0.01*	*0.01*	*0.23*	*0.69*	*0.59*	*0.09*	*0.02*	*0.02*	*0.65*									
Al	0.77	0.64	0.75	0.70	0.65	0.42	0.40	0.69	0.66	0.61	-0.07	0.82								
	0.01	*0.05*	*0.01*	*0.03*	*0.11*	*0.35*	*0.38*	*0.04*	*0.06*	*0.08*	*0.86*	*0.00*								
Ca	0.71	0.61	0.69	0.65	0.49	0.59	0.55	0.74	0.78	0.61	0.13	0.81	0.95							
	0.02	*0.06*	*0.03*	*0.04*	*0.27*	*0.17*	*0.20*	*0.02*	*0.01*	*0.08*	*0.75*	*0.01*	*0.00*							
Fe	0.90	0.82	0.84	0.84	0.44	0.35	0.40	0.65	0.72	0.53	-0.10	0.91	0.89	0.87						
	0.00	*0.00*	*0.00*	*0.00*	*0.32*	*0.44*	*0.37*	*0.06*	*0.03*	*0.15*	*0.80*	*0.00*	*0.00*	*0.00*						
Ti	0.88	0.73	0.81	0.77	0.58	0.40	0.41	0.69	0.68	0.56	-0.13	0.88	0.97	0.93	0.97					
	0.00	*0.02*	*0.01*	*0.01*	*0.17*	*0.38*	*0.36*	*0.04*	*0.04*	*0.12*	*0.73*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.98	0.69	0.76	0.74	0.30	0.54	0.59	0.74	0.65	0.34	-0.22	0.79	0.83	0.80	0.92	0.92				
	0.00	*0.03*	*0.01*	*0.02*	*0.51*	*0.21*	*0.16*	*0.02*	*0.06*	*0.37*	*0.58*	*0.01*	*0.00*	*0.01*	*0.00*	*0.00*				
S	0.96	0.71	0.74	0.73	0.37	0.29	0.39	0.63	0.61	0.38	-0.33	0.80	0.78	0.69	0.93	0.90	0.94			
	0.00	*0.02*	*0.02*	*0.02*	*0.42*	*0.53*	*0.38*	*0.07*	*0.08*	*0.32*	*0.39*	*0.01*	*0.01*	*0.03*	*0.00*	*0.00*	*0.00*			
Ni	0.62	0.46	0.61	0.53	0.57	0.59	0.53	0.67	0.61	0.48	0.10	0.64	0.95	0.94	0.76	0.88	0.73	0.63		
	0.05	*0.18*	*0.06*	*0.11*	*0.19*	*0.16*	*0.22*	*0.05*	*0.08*	*0.20*	*0.81*	*0.05*	*0.00*	*0.00*	*0.01*	*0.00*	*0.02*	*0.05*		
Pb	0.88	0.83	0.82	0.84	0.44	0.35	0.44	0.58	0.75	0.53	-0.13	0.94	0.87	0.86	0.97	0.94	0.89	0.90	0.74	
	0.00	*0.00*	*0.00*	*0.00*	*0.32*	*0.44*	*0.32*	*0.10*	*0.02*	*0.14*	*0.75*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.02*	
Zn	0.86	0.68	0.69	0.69	0.40	0.43	0.47	0.76	0.84	0.66	-0.08	0.93	0.85	0.87	0.95	0.92	0.89	0.88	0.71	0.93
	0.00	*0.03*	*0.03*	*0.03*	*0.38*	*0.34*	*0.29*	*0.02*	*0.01*	*0.05*	*0.83*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.02*	*0.00*

Note: Bold values represent 'Correlation Coefficient' and *Italic* represents '*P-value*'

Table 3.88 Correlation Matrix for $PM_{2.5}$ and Its major constituents at Rohini in Winter Season

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.84																			
	0.00																			
EC	0.75	0.93																		
	0.01	*0.00*																		
TC	0.81	0.99	0.98																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.26	0.20	0.26	0.23																
	0.46	*0.59*	*0.47*	*0.52*																
NO_3^-	0.76	0.57	0.48	0.54	0.41															
	0.01	*0.09*	*0.16*	*0.11*	*0.23*															
SO_4^{--}	0.80	0.81	0.73	0.78	0.61	0.81														
	0.01	*0.01*	*0.02*	*0.01*	*0.06*	*0.00*														
Na^+	0.66	0.55	0.57	0.57	0.51	0.85	0.78													
	0.04	*0.10*	*0.09*	*0.09*	*0.14*	*0.00*	*0.01*													
NH_4^+	0.89	0.82	0.70	0.78	0.50	0.86	0.96	0.73												
	0.00	*0.00*	*0.03*	*0.01*	*0.14*	*0.00*	*0.00*	*0.02*												
K^+	0.43	0.69	0.69	0.70	0.08	0.41	0.66	0.54	0.55											
	0.22	*0.03*	*0.03*	*0.02*	*0.83*	*0.24*	*0.04*	*0.11*	*0.10*											
Ca^{++}	0.16	0.34	0.31	0.33	0.03	-0.04	0.29	0.26	0.09	0.41										
	0.66	*0.33*	*0.39*	*0.35*	*0.94*	*0.92*	*0.42*	*0.47*	*0.81*	*0.25*										
Si	0.66	0.64	0.65	0.66	0.59	0.74	0.91	0.82	0.78	0.70	0.44									
	0.04	*0.05*	*0.04*	*0.04*	*0.07*	*0.02*	*0.00*	*0.00*	*0.01*	*0.02*	*0.21*									
Al	0.46	0.57	0.57	0.58	0.62	0.71	0.86	0.72	0.73	0.60	0.33	0.85								
	0.18	*0.09*	*0.09*	*0.08*	*0.05*	*0.02*	*0.00*	*0.02*	*0.02*	*0.07*	*0.35*	*0.00*								
Ca	0.51	0.76	0.83	0.81	0.19	0.20	0.58	0.45	0.43	0.72	0.73	0.67	0.48							
	0.13	*0.01*	*0.00*	*0.01*	*0.60*	*0.57*	*0.08*	*0.19*	*0.22*	*0.02*	*0.02*	*0.04*	*0.16*							
Fe	0.78	0.47	0.44	0.47	0.44	0.67	0.54	0.61	0.64	-0.12	0.01	0.43	0.33	0.20						
	0.01	*0.17*	*0.20*	*0.17*	*0.20*	*0.04*	*0.11*	*0.06*	*0.05*	*0.75*	*0.97*	*0.22*	*0.35*	*0.59*						
Ti	0.37	0.49	0.51	0.51	0.63	0.65	0.81	0.66	0.66	0.58	0.32	0.83	0.99	0.45	0.24					
	0.30	*0.15*	*0.13*	*0.13*	*0.05*	*0.04*	*0.01*	*0.04*	*0.04*	*0.08*	*0.37*	*0.00*	*0.00*	*0.19*	*0.50*					
K	0.82	0.78	0.70	0.76	0.34	0.82	0.89	0.84	0.90	0.75	0.17	0.80	0.65	0.50	0.47	0.58				
	0.00	*0.01*	*0.02*	*0.01*	*0.34*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.64*	*0.01*	*0.04*	*0.14*	*0.17*	*0.08*				
S	0.76	0.43	0.43	0.44	0.59	0.72	0.66	0.71	0.69	0.02	0.16	0.66	0.52	0.29	0.92	0.46	0.53			
	0.01	*0.22*	*0.22*	*0.21*	*0.07*	*0.02*	*0.04*	*0.02*	*0.03*	*0.95*	*0.66*	*0.04*	*0.12*	*0.42*	*0.00*	*0.18*	*0.11*			
Ni	0.43	0.58	0.54	0.57	0.57	0.63	0.82	0.71	0.69	0.59	0.44	0.76	0.96	0.48	0.30	0.93	0.64	0.45		
	0.22	*0.08*	*0.11*	*0.09*	*0.09*	*0.05*	*0.00*	*0.02*	*0.03*	*0.08*	*0.21*	*0.01*	*0.00*	*0.16*	*0.41*	*0.00*	*0.05*	*0.20*		
Pb	0.72	0.57	0.68	0.63	0.61	0.56	0.67	0.54	0.70	0.32	-0.16	0.64	0.41	0.43	0.62	0.37	0.61	0.68	0.25	
	0.02	*0.09*	*0.03*	*0.05*	*0.06*	*0.09*	*0.04*	*0.10*	*0.03*	*0.37*	*0.67*	*0.05*	*0.24*	*0.22*	*0.06*	*0.29*	*0.06*	*0.03*	*0.48*	
Zn	0.65	0.38	0.43	0.41	0.59	0.69	0.68	0.66	0.67	0.16	0.17	0.75	0.66	0.31	0.73	0.64	0.51	0.92	0.54	0.66
	0.04	*0.28*	*0.21*	*0.24*	*0.07*	*0.03*	*0.03*	*0.04*	*0.04*	*0.66*	*0.63*	*0.01*	*0.04*	*0.39*	*0.02*	*0.05*	*0.13*	*0.00*	*0.11*	*0.04*

Note: Bold values represent ‘Correlation Coefficient’ and *Italic* represents ‘*P-value*’

For the winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.85 and Table 3.86 for PM mass and the major species, respectively. $PM_{2.5}$ mass shows lesser C.V. than PM_{10} mass. The secondary ions show variation in PM_{10} whereas variation is less in $PM_{2.5}$.

Correlation Matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.87 and Table 3.88 for PM mass and its major species. OC, EC, and TC show a similar correlation with both PM_{10} mass and $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$.

3.1.12 Site 12: Sonipat

3.1.12.1 Summer season

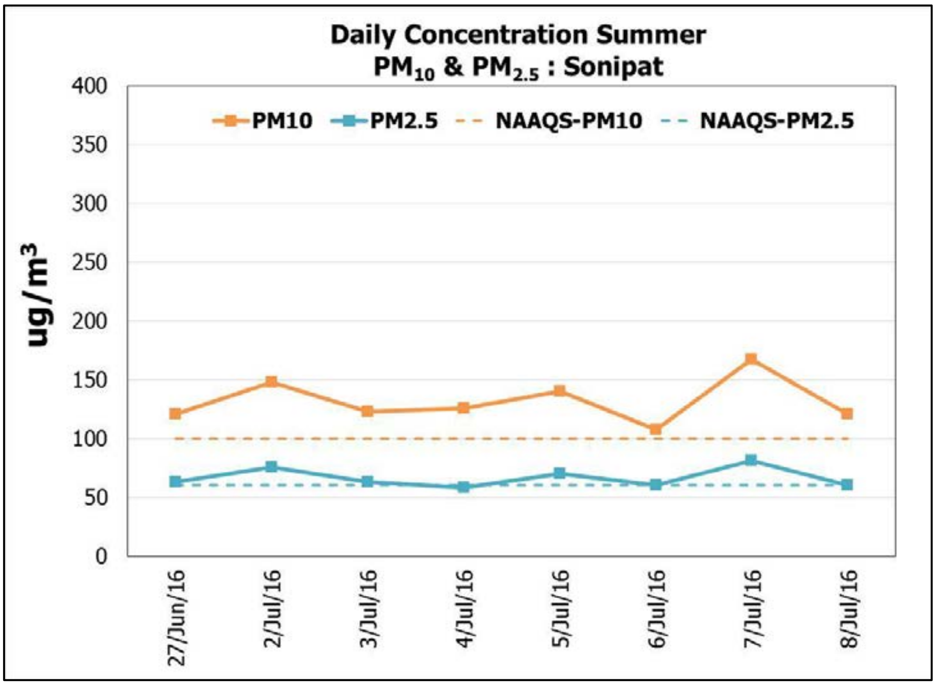


Figure 3.111: Variation in 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Sonipat in the summer season

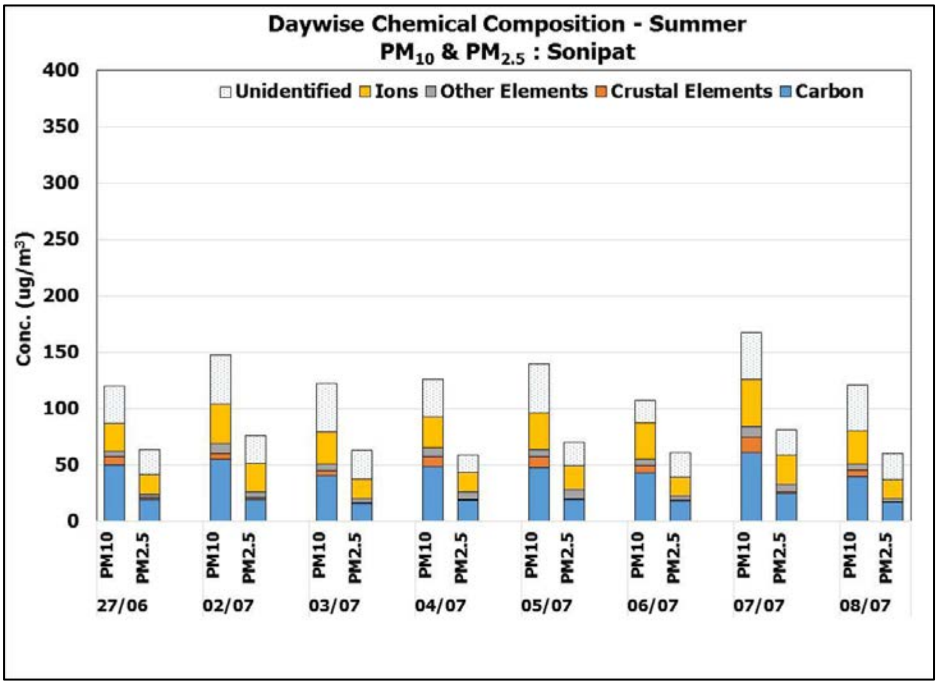


Figure 3.112: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Sonipat in the summer season

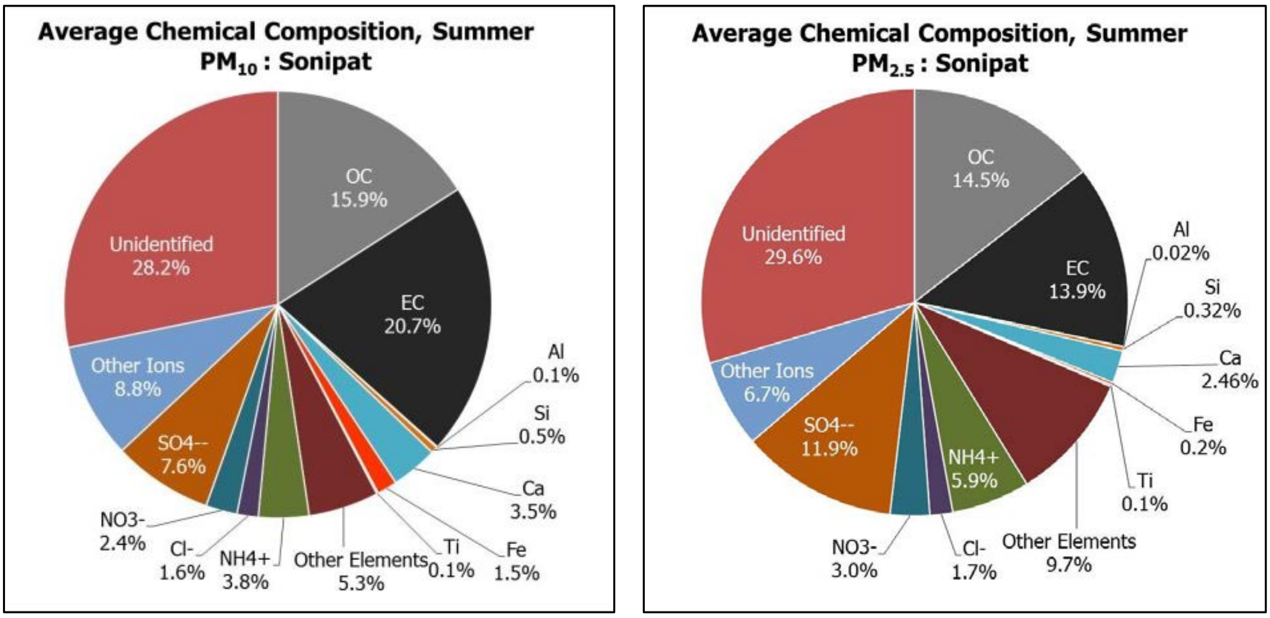


Figure 3.113: Average chemical composition of PM_{10} and $PM_{2.5}$ at Sonipat in the summer season

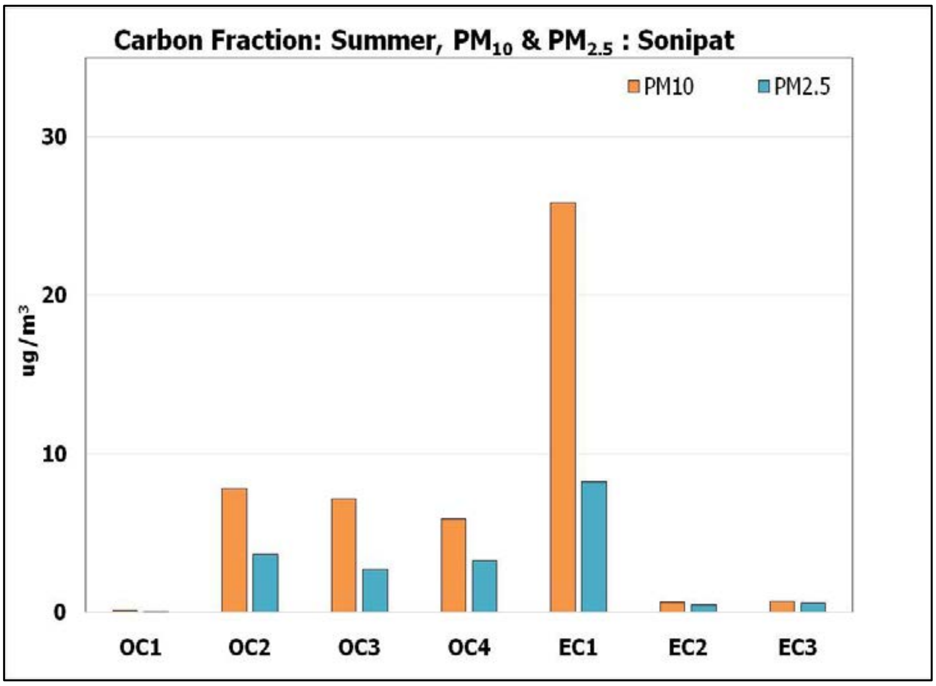


Figure 3.114: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Sonipat in the summer season

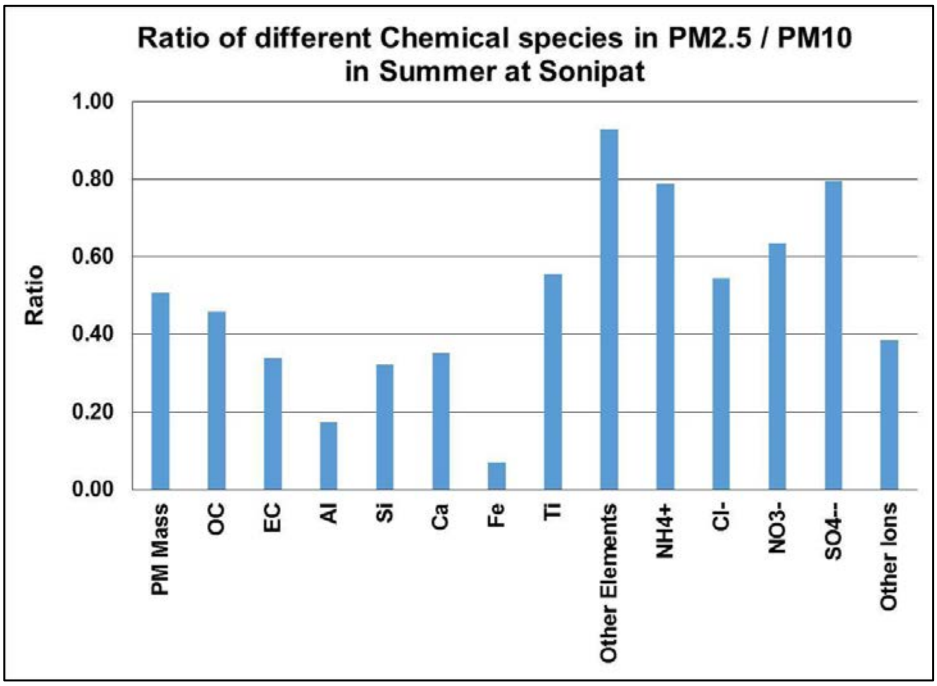


Figure 3.115: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in the summer season at Sonipat

Average concentration observed at Sonipat (SNP) was 131±19 µg/m^3 and 66±8 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. Although, the monitoring period was nearer to monsoons (in the month of July), the average concentration observed in PM_{10} was 1.3 times of the NAAQS. However, concentration of $PM_{2.5}$ was closer to the NAAQS. The observed daily concentration variation in PM_{10} was from 107 to 167 µg/m^3. Similarly, for $PM_{2.5}$, Daily concentration variation was 58 to 81 µg/m^3 (see Figure 3.111).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.112.

The average value of carbon fraction was 48 µg/m^3 and 19 µg/m^3 in PM_{10} & $PM_{2.5}$, respectively. The % mass distribution showed that organic carbon and elemental carbon was higher in PM_{10} than in $PM_{2.5}$. The total ions in PM_{10} was 24% and for $PM_{2.5}$ it was 29%. The crustal elements were 6% in PM10 and 2% in $PM_{2.5}$ (see Figure 3.113)

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, Pb) was found to be 5% and 10% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 28% for PM_{10} and 31% for $PM_{2.5}$.

EC1 was the highest in PM_{10}, followed by OC2, OC3, OC4, EC3, and EC2. EC1 was the highest in PM2.5. Concentration of OC2, OC3, and OC4 was similar in $PM_{2.5}$ (see Figure 114). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.115.

Table 3.89 : Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM_{10} at Sonipat for the Summer Season

$\mu g/m^3$																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	131	20.92	27.15	0.10	0.66	4.64	1.99	0.16	3.36	1.79	0.23	0.39	2.11	3.12	9.93	2.77	5.00	2.77	3.13
SD	19	4.52	4.56	0.09	0.29	1.43	1.12	0.09	1.07	0.49	0.12	0.17	0.54	0.26	2.20	1.00	1.11	1.07	0.60
Min	107	15.34	20.76	0.02	0.42	3.18	0.65	0.06	1.85	1.16	0.06	0.14	1.18	2.67	7.77	1.66	3.80	1.24	2.36
Max	167	28.10	32.98	0.29	1.23	7.62	4.16	0.32	4.91	2.61	0.46	0.69	2.98	3.52	13.52	4.10	6.85	3.99	4.44
C.V.	0.14	0.22	0.17	0.96	0.43	0.31	0.56	0.52	0.32	0.28	0.53	0.45	0.26	0.08	0.22	0.36	0.22	0.39	0.19
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	160	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	124	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	112	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.90 : Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of $PM_{2.5}$ at Sonipat for the Summer Season

$\mu g/m^3$																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	66	9.62	9.21	0.02	0.21	1.63	0.14	0.09	1.49	1.46	0.09	0.15	1.15	1.99	7.89	1.84	3.94	1.08	0.64
SD	8	1.51	1.08	0.03	0.16	0.13	0.06	0.01	0.30	0.33	0.08	0.05	0.15	0.25	2.32	0.78	0.90	0.31	0.11
Min	58	7.63	8.17	0.00	0.00	1.52	0.04	0.08	0.98	1.02	0.02	0.07	1.02	1.67	5.83	1.23	3.04	0.72	0.51
Max	81	12.61	11.53	0.07	0.49	1.87	0.24	0.11	1.89	2.06	0.26	0.21	1.46	2.51	11.68	3.59	5.48	1.53	0.85
C.V.	0.13	0.16	0.12	1.61	0.76	0.08	0.46	0.12	0.20	0.22	0.97	0.34	0.13	0.13	0.29	0.42	0.23	0.28	0.17
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95 %ile	79	11.79	10.92	0.06	0.44	1.83	0.23	0.11	1.86	1.89	0.22	0.21	1.39	2.35	11.58	3.04	5.37	1.51	0.82
50 %ile	63	9.56	9.06	0.00	0.21	1.58	0.14	0.09	1.48	1.50	0.05	0.16	1.08	1.98	7.05	1.66	3.56	1.04	0.60
5 %ile	59	7.79	8.20	0.00	0.03	1.52	0.06	0.08	1.08	1.04	0.02	0.08	1.02	1.70	5.95	1.23	3.13	0.74	0.54

Table 3.91 : Correlation matrix for PM_{10} and its composition for the Summer Season at Sonipat

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.80																			
	0.02																			
EC	0.54	0.28																		
	0.17	*0.51*																		
TC	0.84	0.80	0.80																	
	0.01	*0.02*	*0.02*																	
Cl^-	0.70	0.72	0.28	0.63																
	0.05	*0.04*	*0.50*	*0.10*																
NO_3^-	0.41	0.61	-0.26	0.22	0.09															
	0.31	*0.11*	*0.53*	*0.61*	*0.84*															
SO_4^{--}	0.58	0.37	0.53	0.57	0.48	0.24														
	0.13	*0.37*	*0.18*	*0.14*	*0.23*	*0.57*														
Na^+	0.36	0.71	-0.24	0.29	0.50	0.71	0.25													
	0.38	*0.05*	*0.57*	*0.48*	*0.21*	*0.05*	*0.54*													
NH_4^+	0.60	0.44	0.39	0.52	0.41	0.47	0.97	0.37												
	0.12	*0.28*	*0.34*	*0.19*	*0.31*	*0.25*	*0.00*	*0.37*												
K^+	0.72	0.61	0.08	0.43	0.15	0.76	0.20	0.31	0.37											
	0.05	*0.11*	*0.85*	*0.29*	*0.73*	*0.03*	*0.64*	*0.46*	*0.37*											
Ca^{++}	0.51	0.59	0.23	0.51	0.51	0.23	0.06	0.61	0.05	0.20										
	0.20	*0.13*	*0.58*	*0.19*	*0.20*	*0.58*	*0.89*	*0.11*	*0.91*	*0.63*										
Si	0.77	0.84	0.18	0.64	0.50	0.66	0.21	0.72	0.31	0.70	0.83									
	0.03	*0.01*	*0.66*	*0.09*	*0.21*	*0.07*	*0.63*	*0.05*	*0.46*	*0.06*	*0.01*									
Al	0.67	0.69	0.08	0.48	0.63	0.46	0.25	0.77	0.29	0.44	0.88	0.89								
	0.07	*0.06*	*0.85*	*0.23*	*0.10*	*0.26*	*0.54*	*0.03*	*0.48*	*0.28*	*0.00*	*0.00*								
Ca	0.65	0.83	0.18	0.63	0.61	0.50	0.15	0.78	0.20	0.43	0.93	0.94	0.90							
	0.08	*0.01*	*0.67*	*0.09*	*0.11*	*0.21*	*0.72*	*0.02*	*0.64*	*0.29*	*0.00*	*0.00*	*0.00*							
Fe	0.69	0.90	0.22	0.70	0.62	0.52	0.14	0.75	0.19	0.49	0.87	0.94	0.85	0.99						
	0.06	*0.00*	*0.60*	*0.06*	*0.10*	*0.19*	*0.75*	*0.03*	*0.65*	*0.22*	*0.01*	*0.00*	*0.01*	*0.00*						
Ti	0.68	0.93	0.19	0.70	0.68	0.50	0.14	0.76	0.19	0.47	0.82	0.90	0.81	0.96	0.99					
	0.06	*0.00*	*0.65*	*0.06*	*0.06*	*0.20*	*0.75*	*0.03*	*0.66*	*0.24*	*0.01*	*0.00*	*0.01*	*0.00*	*0.00*					
K	0.87	0.55	0.67	0.76	0.28	0.38	0.55	0.06	0.58	0.77	0.30	0.61	0.41	0.40	0.44	0.40				
	0.01	*0.16*	*0.07*	*0.03*	*0.50*	*0.36*	*0.16*	*0.89*	*0.13*	*0.03*	*0.47*	*0.11*	*0.32*	*0.33*	*0.27*	*0.33*				
S	0.69	0.69	0.49	0.74	0.31	0.67	0.71	0.56	0.79	0.57	0.44	0.69	0.51	0.60	0.60	0.56	0.73			
	0.06	*0.06*	*0.22*	*0.04*	*0.45*	*0.07*	*0.05*	*0.15*	*0.02*	*0.14*	*0.28*	*0.06*	*0.19*	*0.12*	*0.11*	*0.15*	*0.04*			
Ni	0.68	0.65	0.21	0.54	0.45	0.52	0.21	0.54	0.29	0.53	0.82	0.87	0.76	0.85	0.80	0.75	0.55	0.63		
	0.06	*0.08*	*0.62*	*0.17*	*0.26*	*0.19*	*0.62*	*0.17*	*0.48*	*0.18*	*0.01*	*0.01*	*0.03*	*0.01*	*0.02*	*0.03*	*0.16*	*0.10*		
Pb	0.60	0.50	0.43	0.59	0.19	0.57	0.60	0.52	0.67	0.48	0.60	0.72	0.63	0.63	0.57	0.49	0.68	0.91	0.72	
	0.12	*0.21*	*0.28*	*0.13*	*0.65*	*0.14*	*0.12*	*0.19*	*0.07*	*0.23*	*0.12*	*0.05*	*0.10*	*0.10*	*0.14*	*0.22*	*0.07*	*0.00*	*0.05*	
Zn	0.41	0.46	0.23	0.44	0.16	0.61	0.54	0.69	0.62	0.33	0.59	0.66	0.65	0.62	0.56	0.48	0.43	0.85	0.59	0.94
	0.31	*0.25*	*0.58*	*0.28*	*0.70*	*0.11*	*0.16*	*0.06*	*0.10*	*0.43*	*0.12*	*0.08*	*0.08*	*0.10*	*0.15*	*0.23*	*0.29*	*0.01*	*0.13*	*0.00*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.92 : Correlation matrix for PM$_{2.5}$ and its composition for the Summer Season at Sonipat

	PM$_{2.5}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO4- -	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.81																			
	0.01																			
EC	0.77	0.93																		
	0.03	*0.00*																		
TC	0.81	0.99	0.98																	
	0.02	*0.00*	*0.00*																	
Cl$^-$	0.44	-0.03	-0.16	-0.09																
	0.27	*0.94*	*0.70*	*0.83*																
NO$_3^-$	0.90	0.88	0.82	0.87	0.22															
	0.00	*0.00*	*0.01*	*0.01*	*0.60*															
SO4- -	0.92	0.69	0.62	0.67	0.58	0.85														
	0.00	*0.06*	*0.10*	*0.07*	*0.13*	*0.01*														
Na$^+$	0.39	0.40	0.24	0.34	0.25	0.34	0.14													
	0.33	*0.33*	*0.57*	*0.42*	*0.55*	*0.42*	*0.75*													
NH$_4^+$	0.78	0.51	0.53	0.53	0.41	0.76	0.85	-0.04												
	0.02	*0.20*	*0.18*	*0.18*	*0.31*	*0.03*	*0.01*	*0.92*												
K$^+$	0.70	0.61	0.54	0.59	0.22	0.64	0.44	0.76	0.22											
	0.05	*0.11*	*0.17*	*0.13*	*0.59*	*0.09*	*0.28*	*0.03*	*0.60*											
Ca^{++}	0.36	0.63	0.82	0.72	-0.61	0.48	0.18	-0.07	0.33	0.21										
	0.38	*0.10*	*0.01*	*0.04*	*0.11*	*0.23*	*0.67*	*0.88*	*0.42*	*0.61*										
Si	0.49	0.60	0.52	0.58	-0.09	0.38	0.23	0.65	0.25	0.49	0.41									
	0.22	*0.11*	*0.19*	*0.13*	*0.83*	*0.36*	*0.59*	*0.08*	*0.55*	*0.22*	*0.31*									
Al	0.35	0.41	0.49	0.45	-0.32	0.52	0.24	-0.05	0.20	0.53	0.52	-0.10								
	0.40	*0.32*	*0.22*	*0.26*	*0.44*	*0.19*	*0.58*	*0.91*	*0.64*	*0.18*	*0.19*	*0.81*								
Ca	0.77	0.83	0.93	0.89	-0.02	0.72	0.71	-0.02	0.60	0.34	0.72	0.37	0.36							
	0.03	*0.01*	*0.00*	*0.00*	*0.97*	*0.04*	*0.05*	*0.97*	*0.11*	*0.41*	*0.04*	*0.36*	*0.38*							
Fe	0.46	0.81	0.73	0.79	-0.43	0.60	0.22	0.55	0.14	0.61	0.64	0.73	0.45	0.47						
	0.25	*0.02*	*0.04*	*0.02*	*0.29*	*0.11*	*0.61*	*0.16*	*0.75*	*0.11*	*0.09*	*0.04*	*0.26*	*0.24*						
Ti	0.54	0.76	0.66	0.73	-0.23	0.71	0.31	0.66	0.31	0.66	0.53	0.70	0.41	0.36	0.93					
	0.17	*0.03*	*0.08*	*0.04*	*0.59*	*0.05*	*0.45*	*0.08*	*0.45*	*0.08*	*0.18*	*0.05*	*0.32*	*0.39*	*0.00*					
K	0.89	0.53	0.53	0.54	0.60	0.60	0.78	0.37	0.67	0.63	0.16	0.48	0.12	0.62	0.18	0.23				
	0.00	*0.17*	*0.18*	*0.17*	*0.12*	*0.11*	*0.02*	*0.37*	*0.07*	*0.09*	*0.70*	*0.23*	*0.77*	*0.11*	*0.67*	*0.58*				
S	0.70	0.82	0.68	0.77	0.10	0.89	0.72	0.29	0.69	0.36	0.39	0.43	0.28	0.56	0.64	0.76	0.33			
	0.05	*0.01*	*0.07*	*0.03*	*0.82*	*0.00*	*0.04*	*0.49*	*0.06*	*0.38*	*0.33*	*0.28*	*0.51*	*0.15*	*0.09*	*0.03*	*0.42*			
Ni	0.70	0.85	0.87	0.88	-0.22	0.89	0.56	0.25	0.56	0.59	0.75	0.40	0.71	0.69	0.78	0.82	0.34	0.80		
	0.06	*0.01*	*0.01*	*0.00*	*0.60*	*0.00*	*0.15*	*0.55*	*0.15*	*0.13*	*0.03*	*0.33*	*0.05*	*0.06*	*0.02*	*0.01*	*0.41*	*0.02*		
Pb	0.82	0.62	0.68	0.65	0.33	0.87	0.88	-0.07	0.88	0.40	0.43	0.03	0.54	0.73	0.21	0.32	0.63	0.66	0.73	
	0.01	*0.10*	*0.07*	*0.08*	*0.43*	*0.01*	*0.00*	*0.87*	*0.00*	*0.33*	*0.29*	*0.95*	*0.17*	*0.04*	*0.63*	*0.44*	*0.10*	*0.07*	*0.04*	
Zn	0.69	0.73	0.52	0.65	0.42	0.79	0.75	0.46	0.59	0.38	0.08	0.39	-0.02	0.45	0.45	0.61	0.41	0.90	0.56	0.54
	0.06	*0.04*	*0.18*	*0.08*	*0.30*	*0.02*	*0.03*	*0.26*	*0.12*	*0.36*	*0.86*	*0.33*	*0.97*	*0.27*	*0.26*	*0.11*	*0.31*	*0.00*	*0.15*	*0.16*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.89 and Table 3.90 for the PM mass and major species, respectively. In PM_{10}, there is a variation with the percentile respective to the statistical parameter due to the distribution of PM mass, whereas in $PM_{2.5}$, they are similar. For crustal elements, C.V. for PM_{10} is lesser than $PM_{2.5}$. The secondary particulates (NO_3^-, SO_4^{--} and NH_4^+) show less C.V. in $PM_{2.5}$ than in PM_{10}.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.91 and Table 3.92 for PM mass and its major species. OC, EC, and TC show better correlation with $PM_{2.5}$ mass than PM_{10} mass. The crustal elements (Al, Si, Ca, Fe and Ti) show better correlation with PM_{10} mass as compared to $PM_{2.5}$. The secondary particulates showed better correlation with each other in PM_{10}.

3.1.13 Site 13: Ghaziabad-1

3.1.13.1 Summer Season:

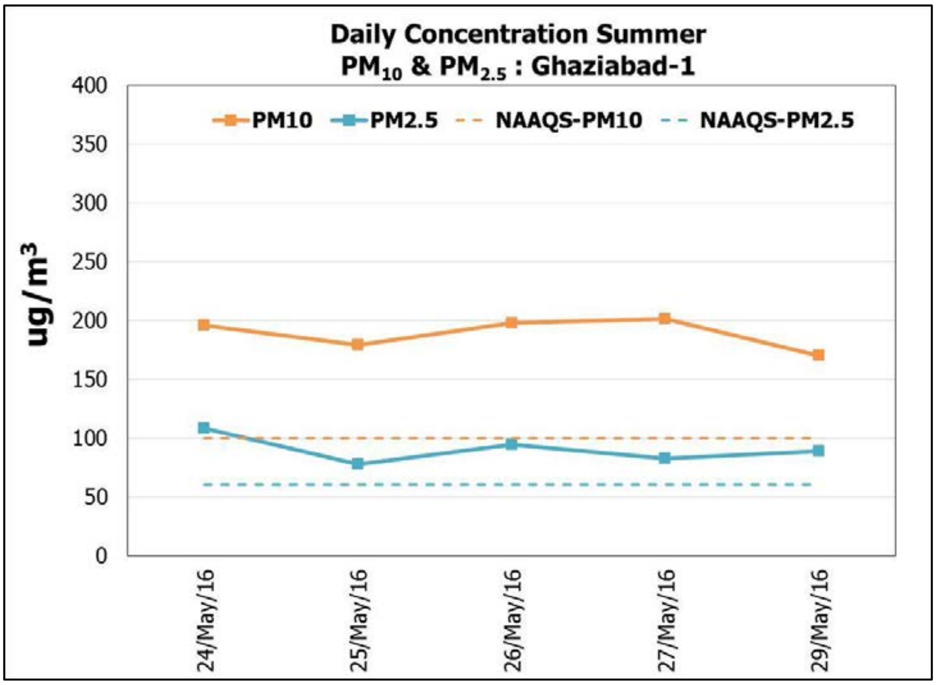


Figure 3.116: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in summer season

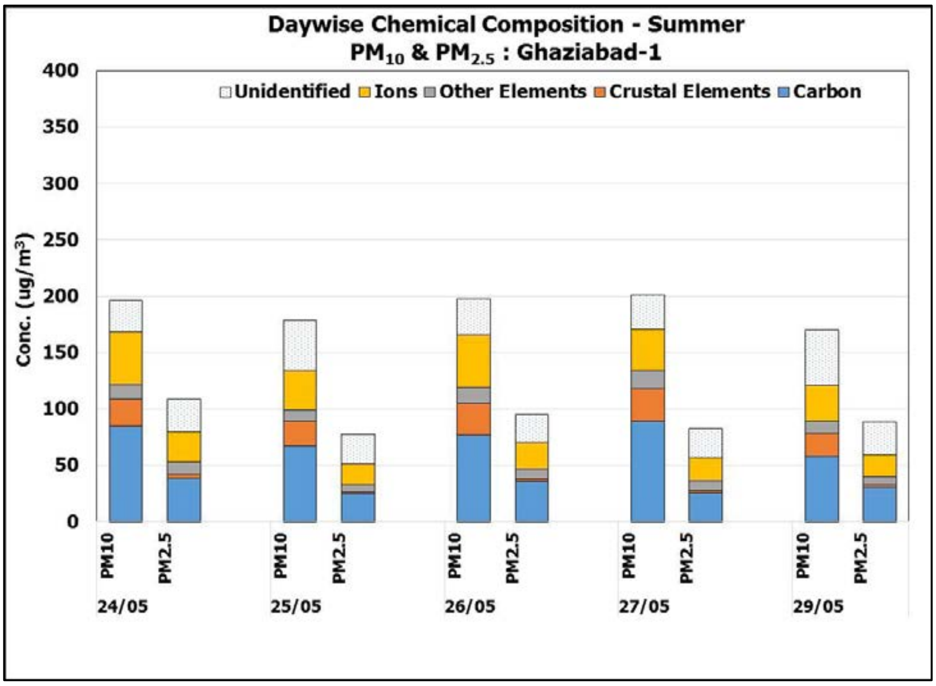


Figure 3.117: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in summer season

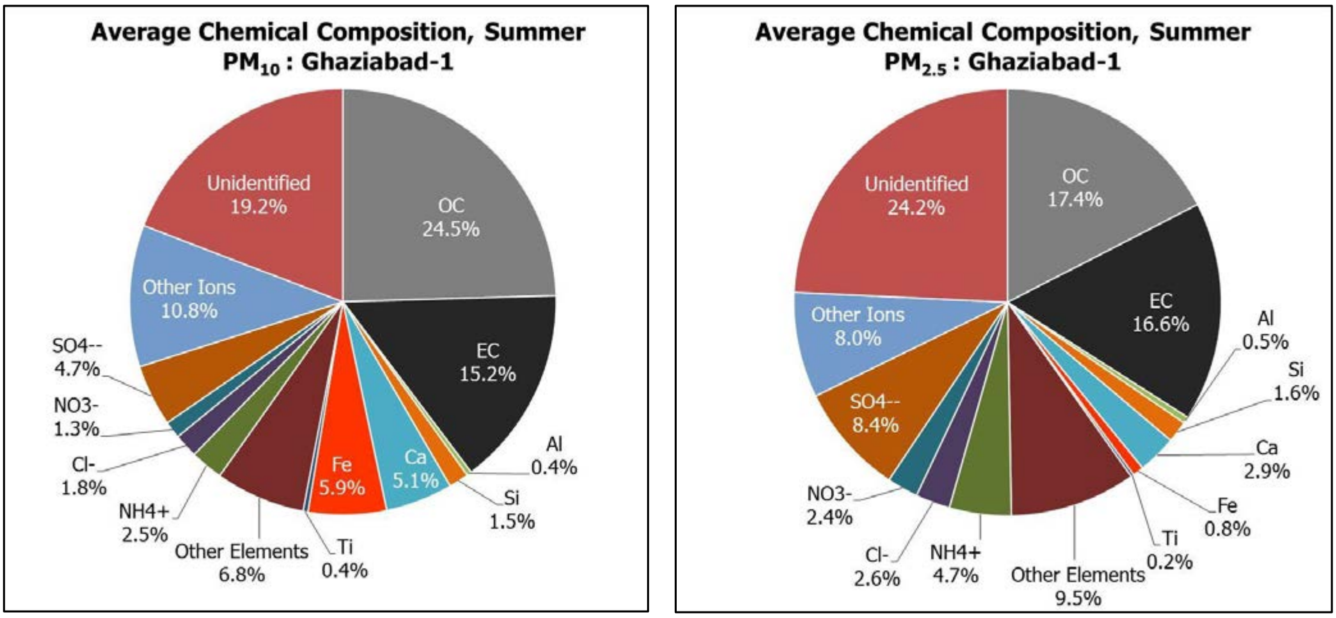


Figure 3.118: Average chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in summer season

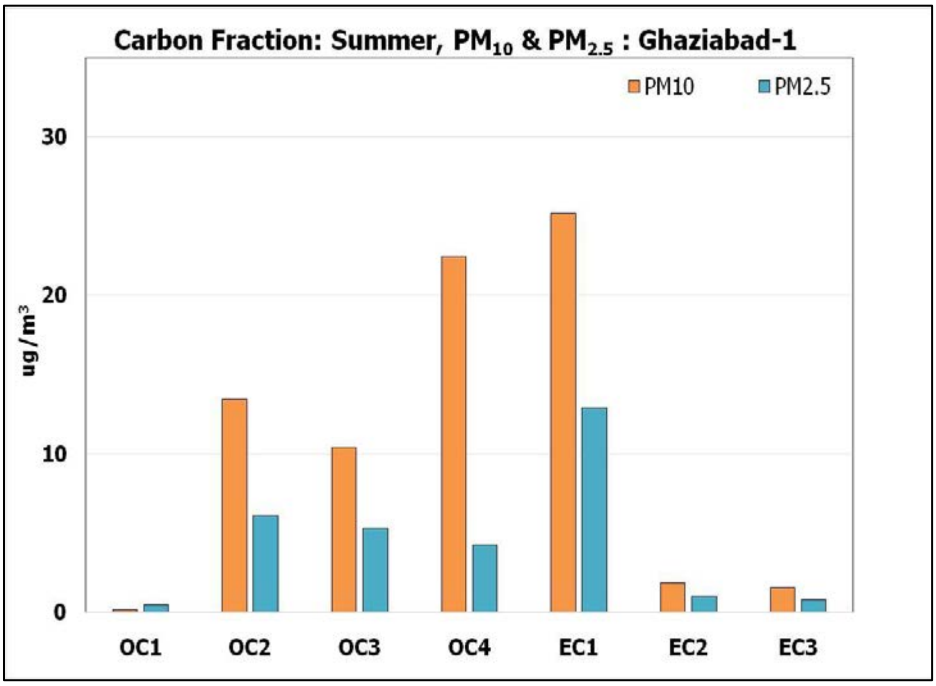


Figure 3.119: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in summer season

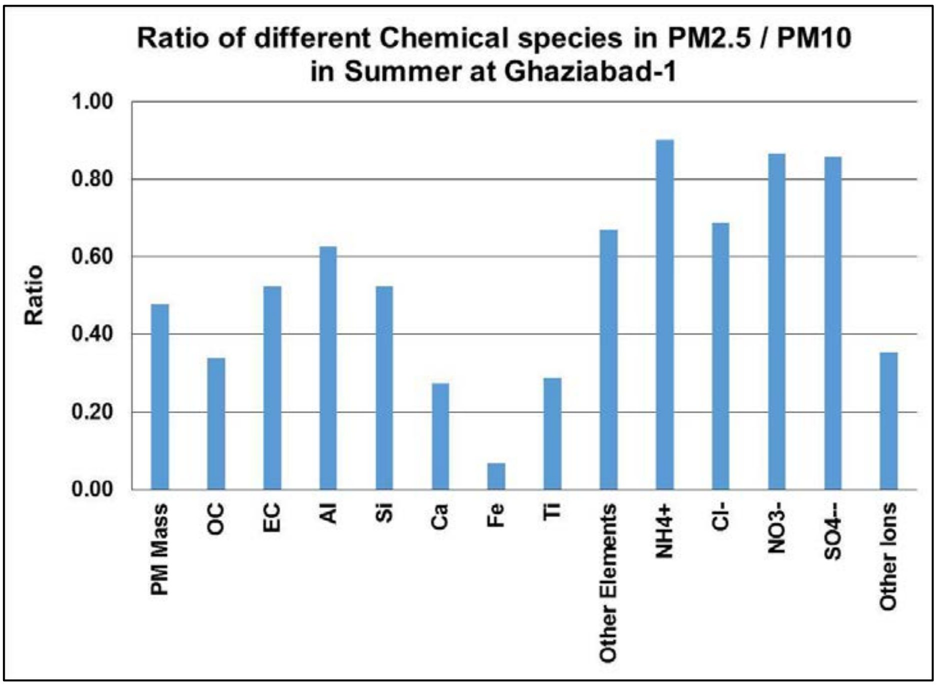


Figure 3.120: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in summer season at Ghaziabad-1

Average concentration observed at Ghaziabad-1 (GHZ1) was 189±14 µg/m^3 and 90±12 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. Average concentration of PM_{10} was 1.9 times of the NAAQS, whereas $PM_{2.5}$ was 1.5 times of the NAAQS. Daily concentration variation was observed in PM_{10} was from 170 to 201 µg/m^3. Similarly, for $PM_{2.5}$, daily concentration variation was 77 to 108 µg/m^3 (see Figure 3.116).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.117.

Carbon fractions were found to be highest in both PM_{10} and $PM_{2.5}$. The average value of carbon fraction was 75 µg/m^3 & 31 µg/m^3 in PM_{10} and $PM_{2.5}$, respectively. The total portion of ion in PM_{10} is 21% and for $PM_{2.5}$ is 25%. The crustal elements is 13% in PM_{10} and 3% in $PM_{2.5}$ (see Figure 3.118).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, Pb) was found to be 7% and 10% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 19% in PM_{10} and 29% in $PM_{2.5}$.

EC1 was found to be the highest in PM_{10}, followed by OC4, OC2, OC3, EC2, and EC3. EC1 was the highest in $PM_{2.5}$, followed by OC2, OC3, OC4, EC2, and EC3 (see Figure 3.119). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.120.

Table 3.93: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Ghaziabad-1 for Summer Season

µg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	189	46.30	28.64	0.72	2.83	9.62	11.17	0.70	6.34	1.44	1.41	1.29	3.42	2.45	8.82	4.71	4.68	4.86	7.04
SD	14	10.70	5.73	0.19	0.62	0.83	2.64	0.33	0.84	0.25	1.18	0.34	1.36	0.35	1.15	1.82	0.84	0.45	1.21
Min	170	31.68	24.18	0.52	1.99	8.27	8.04	0.38	5.54	1.10	0.30	0.74	2.35	1.93	7.35	2.97	3.75	4.18	5.37
Max	201	60.91	38.59	1.01	3.52	10.41	14.03	1.10	7.63	1.81	3.40	1.63	5.66	2.89	10.11	7.21	5.78	5.29	8.37
C.V.	0.07	0.23	0.20	0.26	0.22	0.09	0.24	0.47	0.13	0.17	0.84	0.26	0.40	0.14	0.13	0.39	0.18	0.09	0.17
N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
95 %ile	200	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	196	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	172	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.94: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Ghaziabad-1 for Summer Season

µg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	90	15.69	15.00	0.45	1.48	2.64	0.75	0.20	5.01	1.13	0.56	0.74	2.35	2.13	7.57	0.54	4.22	4.24	0.50
SD	12	4.54	2.18	0.31	0.84	1.05	0.11	0.10	0.90	0.14	0.27	0.26	0.76	0.44	0.92	0.30	1.01	0.53	0.09
Min	77	11.25	11.66	0.26	0.81	1.78	0.63	0.11	4.28	0.89	0.17	0.40	1.57	1.66	6.68	0.26	3.30	3.69	0.35
Max	108	21.91	16.68	0.99	2.93	4.35	0.87	0.36	6.48	1.24	0.82	0.99	3.33	2.70	8.87	1.05	5.90	4.96	0.58
C.V.	0.13	0.29	0.15	0.69	0.56	0.40	0.14	0.48	0.18	0.13	0.47	0.34	0.32	0.21	0.12	0.56	0.24	0.12	0.18
N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
95 %ile	105	21.31	16.65	0.87	2.62	4.05	0.87	0.33	6.21	1.24	0.82	0.99	3.25	2.62	8.73	0.94	5.59	4.89	0.57
50 %ile	88	13.83	16.22	0.32	1.23	2.45	0.71	0.20	4.85	1.20	0.52	0.79	2.16	2.25	7.19	0.46	3.91	4.01	0.53
5 %ile	78	11.50	12.11	0.26	0.86	1.78	0.64	0.12	4.29	0.94	0.23	0.43	1.61	1.67	6.73	0.30	3.37	3.74	0.37

Table 3.95: Correlation matrix for PM_{10} and its composition for Summer Season at Ghaziabad-1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.90																			
	0.04																			
EC	0.41	0.10																		
	0.50	*0.88*																		
TC	0.95	0.89	0.54																	
	0.01	*0.04*	*0.35*																	
Cl^-	0.67	0.56	-0.15	0.41																
	0.22	*0.33*	*0.81*	*0.50*																
NO_3^-	0.60	0.27	0.79	0.59	0.24															
	0.29	*0.66*	*0.11*	*0.30*	*0.70*															
SO_4^{--}	0.45	0.19	0.49	0.38	0.30	0.91														
	0.45	*0.77*	*0.41*	*0.53*	*0.62*	*0.03*														
Na^+	0.41	0.12	0.19	0.19	0.65	0.70	0.85													
	0.49	*0.84*	*0.76*	*0.76*	*0.23*	*0.19*	*0.07*													
NH_4^+	0.50	0.17	0.87	0.54	0.08	0.98	0.85	0.60												
	0.39	*0.79*	*0.06*	*0.35*	*0.90*	*0.00*	*0.07*	*0.29*												
K^+	0.78	0.51	0.67	0.73	0.54	0.59	0.29	0.34	0.57											
	0.12	*0.39*	*0.22*	*0.16*	*0.35*	*0.29*	*0.64*	*0.58*	*0.32*											
Ca^{++}	0.61	0.61	-0.04	0.50	0.70	-0.11	-0.30	-0.01	-0.19	0.68										
	0.27	*0.28*	*0.94*	*0.40*	*0.19*	*0.86*	*0.62*	*0.99*	*0.76*	*0.21*										
Si	0.78	0.57	0.77	0.84	0.29	0.58	0.22	0.11	0.59	0.94	0.57									
	0.12	*0.31*	*0.12*	*0.08*	*0.63*	*0.30*	*0.72*	*0.87*	*0.30*	*0.02*	*0.31*									
Al	0.65	0.45	0.55	0.63	0.45	0.32	-0.04	0.07	0.31	0.95	0.80	0.90								
	0.24	*0.45*	*0.34*	*0.26*	*0.45*	*0.61*	*0.96*	*0.91*	*0.61*	*0.02*	*0.10*	*0.04*								
Ca	0.95	0.95	0.21	0.90	0.63	0.51	0.48	0.40	0.40	0.54	0.47	0.57	0.39							
	0.01	*0.01*	*0.74*	*0.04*	*0.25*	*0.38*	*0.42*	*0.50*	*0.51*	*0.35*	*0.43*	*0.32*	*0.52*							
Fe	0.82	0.89	-0.19	0.67	0.85	0.14	0.17	0.34	-0.02	0.45	0.72	0.36	0.39	0.87						
	0.09	*0.04*	*0.76*	*0.22*	*0.07*	*0.82*	*0.79*	*0.57*	*0.98*	*0.45*	*0.17*	*0.55*	*0.52*	*0.06*						
Ti	0.85	0.80	0.01	0.69	0.90	0.23	0.15	0.38	0.10	0.71	0.87	0.58	0.68	0.79	0.93					
	0.07	*0.10*	*0.98*	*0.20*	*0.04*	*0.71*	*0.82*	*0.53*	*0.88*	*0.18*	*0.05*	*0.31*	*0.21*	*0.12*	*0.02*					
K	0.70	0.75	0.45	0.84	0.12	0.18	-0.15	-0.33	0.19	0.65	0.61	0.83	0.72	0.60	0.46	0.53				
	0.19	*0.15*	*0.45*	*0.08*	*0.85*	*0.77*	*0.81*	*0.59*	*0.76*	*0.24*	*0.28*	*0.08*	*0.17*	*0.28*	*0.44*	*0.36*				
S	0.61	0.64	0.26	0.67	0.29	-0.04	-0.37	-0.35	-0.05	0.69	0.84	0.77	0.84	0.45	0.50	0.65	0.91			
	0.28	*0.24*	*0.67*	*0.22*	*0.64*	*0.95*	*0.54*	*0.57*	*0.94*	*0.19*	*0.07*	*0.13*	*0.07*	*0.45*	*0.39*	*0.24*	*0.03*			
Ni	0.71	0.84	-0.35	0.56	0.81	0.05	0.16	0.33	-0.11	0.26	0.61	0.18	0.20	0.83	0.98	0.85	0.33	0.36		
	0.18	*0.08*	*0.57*	*0.33*	*0.10*	*0.94*	*0.80*	*0.58*	*0.86*	*0.67*	*0.28*	*0.78*	*0.75*	*0.09*	*0.00*	*0.07*	*0.59*	*0.56*		
Pb	0.43	0.18	-0.01	0.15	0.89	0.29	0.32	0.73	0.17	0.57	0.58	0.25	0.48	0.30	0.52	0.70	-0.11	0.13	0.46	
	0.47	*0.77*	*0.98*	*0.82*	*0.04*	*0.64*	*0.60*	*0.16*	*0.78*	*0.32*	*0.31*	*0.68*	*0.41*	*0.63*	*0.37*	*0.19*	*0.86*	*0.84*	*0.44*	
Zn	0.36	0.31	0.21	0.36	0.29	-0.17	-0.50	-0.32	-0.16	0.68	0.86	0.66	0.88	0.12	0.29	0.55	0.67	0.90	0.13	0.31
	0.55	*0.61*	*0.74*	*0.56*	*0.64*	*0.79*	*0.39*	*0.60*	*0.80*	*0.20*	*0.06*	*0.22*	*0.05*	*0.85*	*0.64*	*0.34*	*0.21*	*0.04*	*0.83*	*0.62*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.96: Correlation matrix for $PM_{2.5}$ and its composition for Summer Season at Ghaziabad-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.94																			
	0.02																			
EC	0.81	0.68																		
	0.10	*0.20*																		
TC	0.97	0.97	0.85																	
	0.01	*0.01*	*0.07*																	
Cl^-	-0.36	-0.62	-0.08	-0.48																
	0.55	*0.27*	*0.90*	*0.42*																
NO_3^-	0.75	0.85	0.25	0.71	-0.69															
	0.14	*0.07*	*0.69*	*0.18*	*0.20*															
SO_4^{--}	0.85	0.94	0.44	0.84	-0.59	0.94														
	0.07	*0.02*	*0.46*	*0.08*	*0.30*	*0.02*														
Na^+	0.35	0.46	0.54	0.53	-0.17	0.06	0.37													
	0.56	*0.43*	*0.35*	*0.36*	*0.79*	*0.93*	*0.55*													
NH_4^+	0.82	0.84	0.34	0.73	-0.52	0.97	0.92	-0.01												
	0.09	*0.07*	*0.58*	*0.16*	*0.37*	*0.01*	*0.03*	*0.99*												
K^+	0.89	0.99	0.56	0.91	-0.70	0.91	0.97	0.41	0.88											
	0.04	*0.00*	*0.33*	*0.03*	*0.19*	*0.03*	*0.01*	*0.49*	*0.05*											
Ca^{++}	0.82	0.74	0.97	0.88	-0.10	0.30	0.54	0.69	0.37	0.63										
	0.09	*0.15*	*0.01*	*0.05*	*0.87*	*0.63*	*0.35*	*0.20*	*0.55*	*0.26*										
Si	0.91	0.77	0.82	0.85	-0.27	0.59	0.61	0.07	0.70	0.70	0.73									
	0.03	*0.13*	*0.09*	*0.07*	*0.67*	*0.29*	*0.28*	*0.92*	*0.19*	*0.19*	*0.16*									
Al	0.87	0.78	0.48	0.74	-0.27	0.85	0.82	-0.08	0.95	0.77	0.47	0.83								
	0.05	*0.12*	*0.42*	*0.16*	*0.66*	*0.07*	*0.09*	*0.90*	*0.01*	*0.13*	*0.43*	*0.09*								
Ca	0.44	0.68	0.19	0.57	-0.62	0.61	0.76	0.72	0.47	0.73	0.38	0.07	0.25							
	0.46	*0.20*	*0.76*	*0.32*	*0.27*	*0.28*	*0.14*	*0.17*	*0.42*	*0.16*	*0.53*	*0.91*	*0.69*							
Fe	0.31	0.17	-0.07	0.10	0.35	0.40	0.41	-0.23	0.54	0.18	-0.01	0.18	0.62	0.04						
	0.61	*0.78*	*0.91*	*0.87*	*0.56*	*0.51*	*0.49*	*0.71*	*0.35*	*0.77*	*0.99*	*0.77*	*0.26*	*0.95*						
Ti	0.38	0.50	-0.19	0.30	-0.36	0.79	0.77	0.04	0.76	0.60	-0.05	0.09	0.60	0.64	0.69					
	0.53	*0.39*	*0.77*	*0.62*	*0.55*	*0.11*	*0.13*	*0.95*	*0.14*	*0.29*	*0.94*	*0.89*	*0.28*	*0.25*	*0.20*					
K	0.90	0.85	0.52	0.80	-0.25	0.85	0.91	0.19	0.93	0.83	0.58	0.73	0.95	0.48	0.66	0.70				
	0.04	*0.07*	*0.37*	*0.11*	*0.68*	*0.07*	*0.03*	*0.76*	*0.02*	*0.08*	*0.31*	*0.16*	*0.01*	*0.42*	*0.22*	*0.19*				
S	0.81	0.67	0.98	0.83	0.05	0.24	0.47	0.58	0.35	0.54	0.98	0.77	0.51	0.23	0.10	-0.09	0.59			
	0.10	*0.22*	*0.00*	*0.09*	*0.93*	*0.70*	*0.43*	*0.30*	*0.57*	*0.35*	*0.00*	*0.13*	*0.39*	*0.71*	*0.88*	*0.89*	*0.30*			
Ni	0.43	0.45	0.10	0.36	0.07	0.49	0.66	0.41	0.52	0.46	0.29	0.08	0.48	0.63	0.76	0.80	0.70	0.28		
	0.48	*0.45*	*0.87*	*0.55*	*0.91*	*0.41*	*0.23*	*0.50*	*0.37*	*0.43*	*0.64*	*0.91*	*0.41*	*0.26*	*0.13*	*0.10*	*0.19*	*0.65*		
Pb	0.87	0.81	0.86	0.89	-0.09	0.47	0.71	0.69	0.54	0.72	0.94	0.69	0.61	0.53	0.28	0.27	0.77	0.92	0.59	
	0.05	*0.10*	*0.06*	*0.04*	*0.89*	*0.43*	*0.18*	*0.20*	*0.35*	*0.17*	*0.02*	*0.20*	*0.27*	*0.35*	*0.64*	*0.66*	*0.13*	*0.03*	*0.30*	
Zn	0.56	0.39	0.45	0.45	0.43	0.27	0.47	0.31	0.43	0.32	0.54	0.38	0.58	0.21	0.79	0.43	0.72	0.63	0.81	0.74
	0.32	*0.51*	*0.44*	*0.45*	*0.47*	*0.66*	*0.42*	*0.62*	*0.47*	*0.60*	*0.34*	*0.52*	*0.31*	*0.73*	*0.11*	*0.47*	*0.17*	*0.26*	*0.10*	*0.15*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.93 and Table 3.94 for the PM mass and major species, respectively. PM_{10} mass and $PM_{2.5}$ mass both show less C.V. The secondary particulates in PM_{10} and $PM_{2.5}$ both have a similar C.V. The crustal elements show better C.V. in PM_{10} as compared to $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.95 and Table 3.96 for PM mass and its major species. OC, EC, and TC show better correlation with $PM_{2.5}$ mass than PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass and $PM_{2.5}$. The secondary particulates showed better correlation with each other in both PM_{10} and $PM_{2.5}$.

3.1.13.2 Winter Season

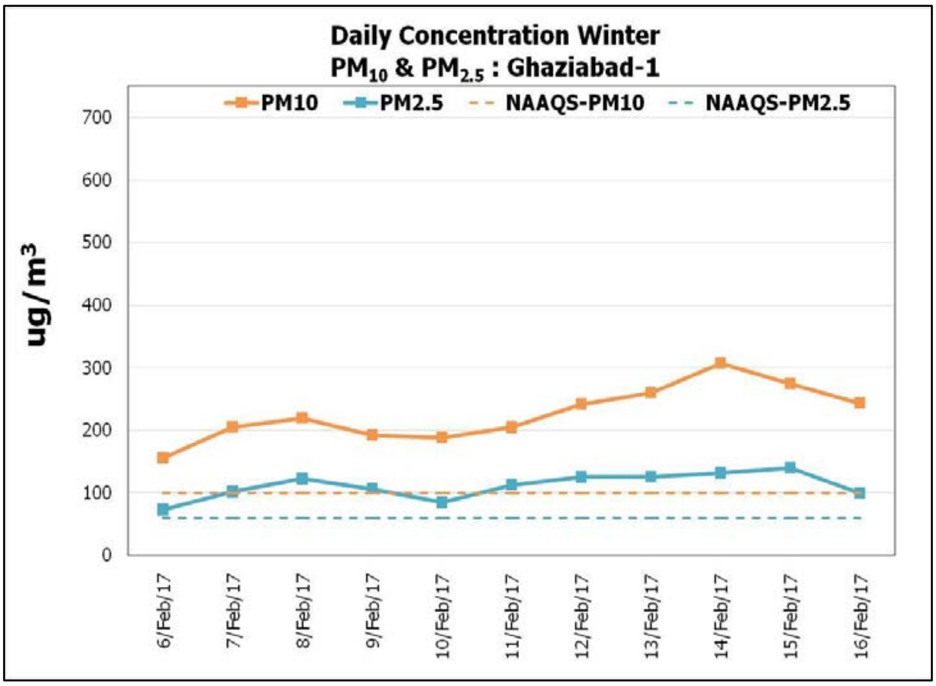


Figure 3.121: Variation in 24hourly concentration of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in winter season

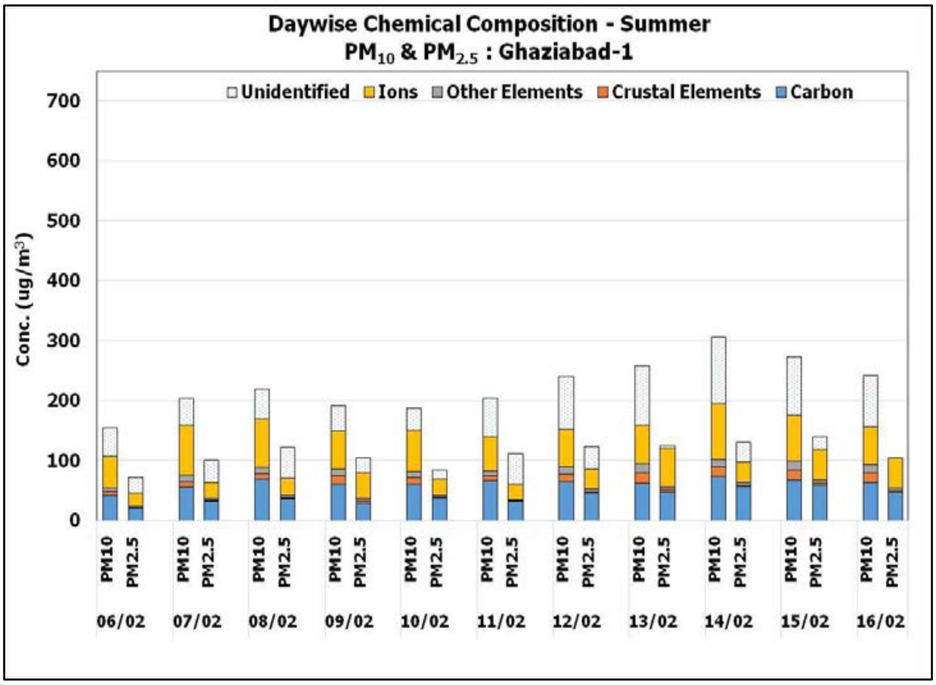


Figure 3.122: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in winter season

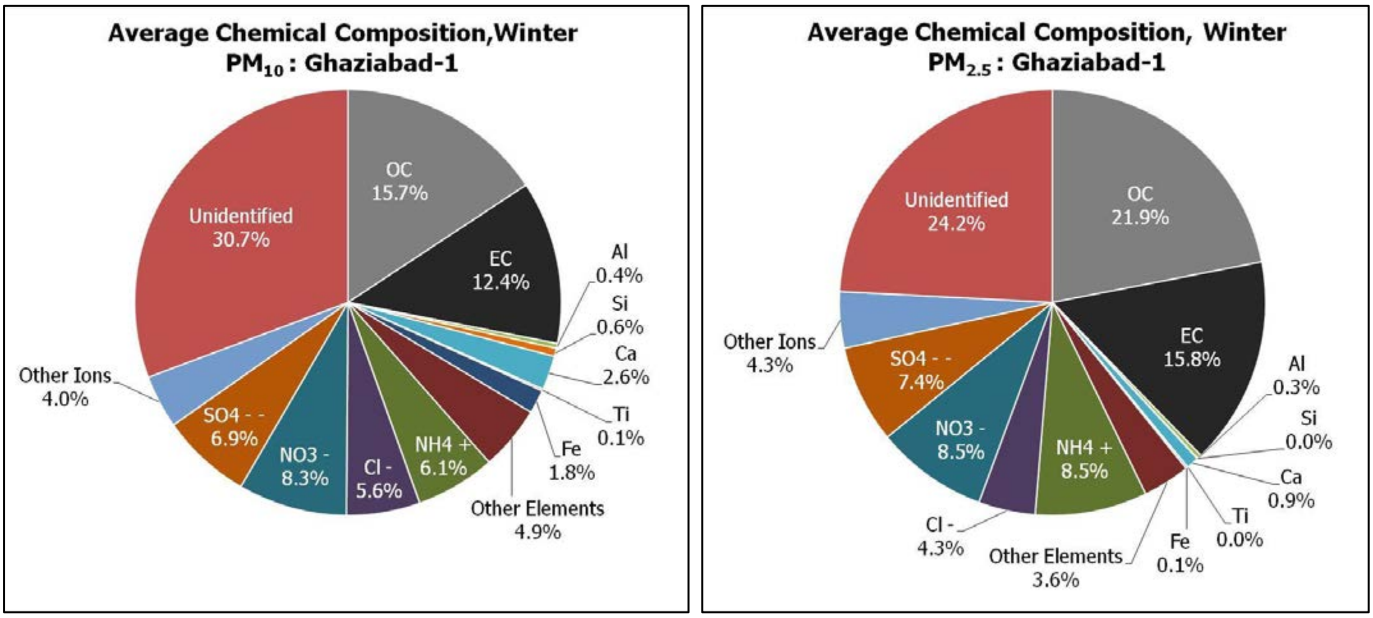


Figure 3.123: Average chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in winter season

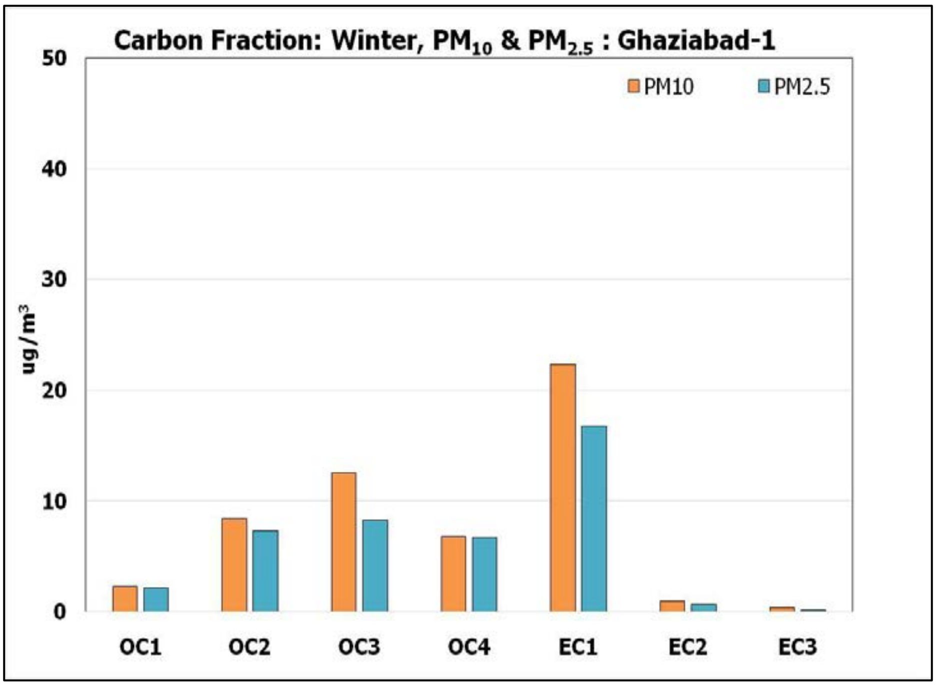


Figure 3.124: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Ghaziabad-1 in winter season

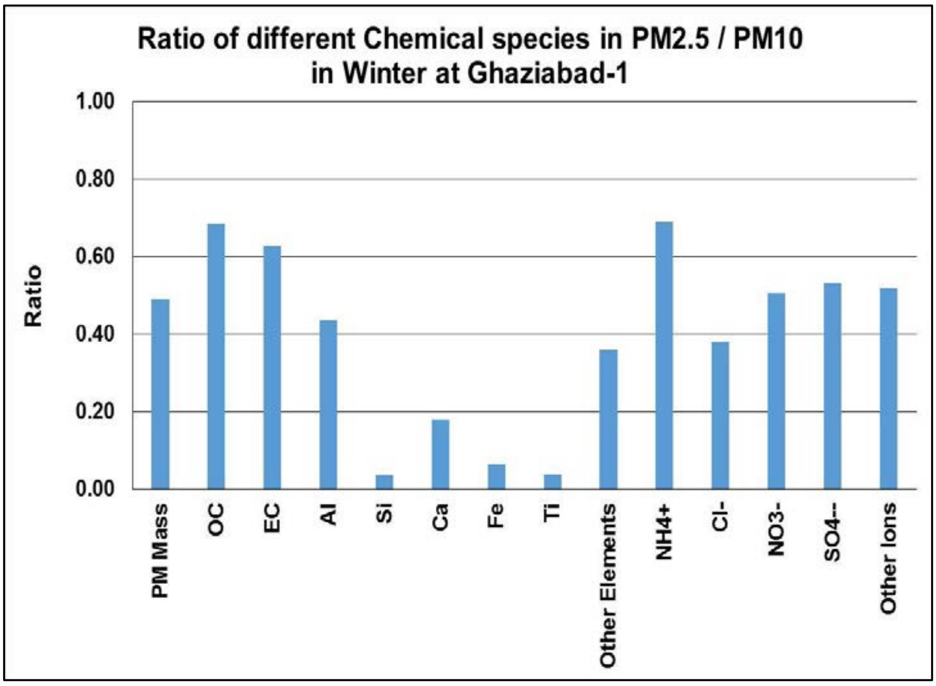


Figure 3.125: Ratio of the different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Ghaziabad-1

Average concentration of PM_{10} was found to be 227±44 $\mu g/m^3$ and that of $PM_{2.5}$ was found to be 111±21 $\mu g/m^3$. Concentration of PM_{10} varied from 155 to 307 $\mu g/m^3$ and $PM_{2.5}$ varied from 73 to 141 $\mu g/m^3$ (see Figure 3.121).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ are represented in Figure 3.122.

The carbon fraction of PM_{10} was found to be 64 $\mu g/m^3$ and in case of $PM_{2.5}$, it was found to be 42 $\mu g/m^3$. The % mass distribution showed the organic carbon and elemental carbon in $PM_{2.5}$ was higher than PM_{10}. The total ions In PM_{10} was found to be 31% and that of $PM_{2.5}$ was found to be 33%. The crustal element of PM_{10} was found to be 6% and that of $PM_{2.5}$ was found to be 1%(see Figure 3.123).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, Pb) was found to be 5% and 4% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed, was found to be 31% in PM_{10} and in case of $PM_{2.5}$, it was found to be 24%.

In PM_{10}, OC3 was found to be higher as compared to $PM_{2.5}$, followed by OC2, OC4, and OC1. EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.124) Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.125.

.

Table3.97: Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM_{10} at Ghaziabad-1 for Winter Season

$\mu g/m^3$																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	227	35.58	28.04	0.83	1.41	5.87	4.09	0.32	3.39	2.53	1.24	1.82	12.63	18.72	15.56	0.82	13.71	2.36	4.84
SD	44	4.29	4.53	0.27	0.38	1.78	1.34	0.09	0.86	0.75	0.49	0.76	5.04	3.56	4.09	0.44	3.40	0.75	2.10
Min	155	25.44	18.13	0.45	0.82	3.41	1.05	0.22	2.08	1.44	0.26	0.38	2.87	12.30	10.27	0.05	9.75	0.94	0.56
Max	307	41.15	33.72	1.25	2.07	8.26	5.90	0.47	4.62	3.53	1.82	2.79	20.72	25.51	22.22	1.49	19.40	3.44	8.11
C.V.	0.19	0.12	0.16	0.33	0.27	0.30	0.33	0.28	0.25	0.30	0.40	0.42	0.40	0.19	0.26	0.53	0.25	0.32	0.43
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	291	40.71	33.69	1.20	1.98	8.04	5.70	0.44	4.53	3.41	1.77	2.73	20.15	23.36	21.09	1.46	18.73	3.37	7.68
50 %ile	223	36.23	28.16	0.85	1.37	5.83	4.08	0.30	3.46	2.54	1.27	1.91	12.53	18.37	15.37	0.88	13.97	2.32	4.90
5 %ile	111	16.98	12.69	0.38	0.64	2.75	1.23	0.17	1.59	1.17	0.40	0.60	4.17	8.80	7.79	0.16	7.21	0.86	1.48

Table 3.98: Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of $PM_{2.5}$ at Ghaziabad-1 for Winter Season

$\mu g/m^3$																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	111	24.42	17.58	0.36	0.05	1.05	0.16	0.02	1.07	1.19	0.37	0.52	4.79	9.46	8.28	0.80	9.47	0.88	1.23
SD	21	6.14	5.93	0.18	0.02	1.01	0.05	0.02	0.29	0.37	0.14	0.25	2.99	3.49	3.15	0.38	4.27	0.29	0.74
Min	73	14.32	8.20	0.11	0.02	0.07	0.09	0.00	0.60	0.58	0.10	0.12	0.72	6.40	5.53	0.29	5.38	0.46	0.33
Max	141	35.37	27.79	0.66	0.08	2.70	0.23	0.06	1.45	1.79	0.54	0.94	10.64	17.54	16.29	1.38	16.57	1.28	2.81
C.V.	0.18	0.25	0.34	0.50	0.40	0.96	0.30	1.04	0.27	0.31	0.39	0.48	0.62	0.37	0.38	0.48	0.45	0.32	0.60
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	136	33.43	26.22	0.62	0.08	2.41	0.23	0.06	1.39	1.64	0.53	0.89	8.75	15.22	13.79	1.34	16.27	1.23	2.49
50 %ile	113	23.87	16.42	0.34	0.05	0.95	0.14	0.01	1.12	1.23	0.39	0.53	3.52	8.63	7.20	0.81	7.48	0.82	1.10
5 %ile	79	16.67	9.61	0.14	0.02	0.07	0.10	0.00	0.66	0.63	0.14	0.13	1.27	6.41	5.66	0.33	5.58	0.50	0.35

Table 3.99 Correlation matrix for PM_{10} and its composition for Winter Season at Ghaziabad-1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.74																			
	0.01																			
EC	0.67	0.70																		
	0.02	*0.02*																		
TC	0.76	0.92	0.93																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.26	0.31	0.26	0.31																
	0.44	*0.35*	*0.44*	*0.35*																
NO_3^-	0.30	0.46	0.51	0.52	0.22															
	0.36	*0.16*	*0.11*	*0.10*	*0.51*															
SO_4^{--}	0.37	0.33	0.40	0.40	0.06	0.73														
	0.27	*0.32*	*0.22*	*0.22*	*0.86*	*0.01*														
Na^+	0.36	0.01	0.27	0.16	0.75	0.16	0.30													
	0.28	*0.97*	*0.42*	*0.64*	*0.01*	*0.65*	*0.36*													
NH_4^+	0.46	0.26	0.08	0.18	0.15	0.18	0.48	0.36												
	0.16	*0.44*	*0.81*	*0.59*	*0.66*	*0.60*	*0.14*	*0.28*												
K^+	0.81	0.57	0.50	0.58	-0.03	0.10	0.27	0.20	0.61											
	0.00	*0.07*	*0.11*	*0.06*	*0.93*	*0.77*	*0.42*	*0.55*	*0.05*											
Ca^{++}	0.45	0.03	0.28	0.17	0.68	-0.10	-0.03	0.86	0.07	0.18										
	0.17	*0.94*	*0.41*	*0.62*	*0.02*	*0.78*	*0.92*	*0.00*	*0.84*	*0.59*										
Si	0.77	0.49	0.10	0.31	0.27	0.14	0.14	0.29	0.37	0.56	0.42									
	0.01	*0.13*	*0.76*	*0.35*	*0.43*	*0.69*	*0.68*	*0.39*	*0.26*	*0.07*	*0.20*									
Al	0.61	0.50	0.15	0.35	0.10	0.22	-0.04	-0.06	-0.10	0.30	0.19	0.84								
	0.05	*0.12*	*0.65*	*0.30*	*0.77*	*0.52*	*0.92*	*0.87*	*0.78*	*0.37*	*0.58*	*0.00*								
Ca	0.66	0.48	0.21	0.37	0.19	0.11	-0.16	0.03	-0.01	0.32	0.30	0.82	0.94							
	0.03	*0.14*	*0.55*	*0.27*	*0.57*	*0.75*	*0.64*	*0.94*	*0.98*	*0.34*	*0.37*	*0.00*	*0.00*							
Fe	0.88	0.80	0.65	0.78	0.37	0.42	0.27	0.24	0.10	0.52	0.40	0.76	0.81	0.81						
	0.00	*0.00*	*0.03*	*0.01*	*0.26*	*0.19*	*0.42*	*0.47*	*0.78*	*0.10*	*0.22*	*0.01*	*0.00*	*0.00*						
Ti	0.79	0.56	0.30	0.47	0.32	0.10	-0.02	0.25	0.16	0.47	0.46	0.90	0.89	0.95	0.86					
	0.00	*0.07*	*0.37*	*0.15*	*0.33*	*0.76*	*0.95*	*0.46*	*0.65*	*0.14*	*0.15*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.79	0.66	0.50	0.62	-0.05	0.32	0.13	-0.05	0.10	0.62	0.14	0.75	0.84	0.81	0.82	0.83				
	0.00	*0.03*	*0.12*	*0.04*	*0.88*	*0.33*	*0.70*	*0.88*	*0.78*	*0.04*	*0.68*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.67	0.47	0.32	0.43	-0.13	0.42	0.32	0.00	0.12	0.49	0.06	0.74	0.83	0.75	0.72	0.77	0.90			
	0.02	*0.15*	*0.34*	*0.19*	*0.71*	*0.20*	*0.34*	*1.00*	*0.72*	*0.13*	*0.85*	*0.01*	*0.00*	*0.01*	*0.01*	*0.01*	*0.00*			
Ni	0.33	0.39	-0.01	0.20	0.06	0.06	-0.32	-0.29	-0.32	0.00	0.02	0.62	0.91	0.89	0.62	0.76	0.69	0.62		
	0.33	*0.23*	*0.97*	*0.55*	*0.87*	*0.87*	*0.34*	*0.38*	*0.34*	*0.99*	*0.95*	*0.04*	*0.00*	*0.00*	*0.04*	*0.01*	*0.02*	*0.04*		
Pb	0.55	0.61	0.40	0.55	0.26	-0.12	-0.21	0.05	-0.21	0.47	0.29	0.50	0.60	0.57	0.68	0.61	0.55	0.38	0.51	
	0.08	*0.05*	*0.22*	*0.08*	*0.44*	*0.73*	*0.53*	*0.88*	*0.55*	*0.15*	*0.39*	*0.12*	*0.05*	*0.07*	*0.02*	*0.05*	*0.08*	*0.26*	*0.11*	
Zn	0.79	0.64	0.35	0.54	0.29	0.43	0.33	0.20	0.17	0.45	0.32	0.87	0.88	0.82	0.92	0.84	0.76	0.77	0.66	0.58
	0.00	*0.03*	*0.29*	*0.09*	*0.39*	*0.19*	*0.32*	*0.55*	*0.62*	*0.16*	*0.35*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*	*0.03*	*0.06*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.100: Correlation matrix for $PM_{2.5}$ and its composition for Winter Season at Ghaziabad-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.76																			
	0.01																			
EC	0.77	0.95																		
	0.01	*0.00*																		
TC	0.78	0.99	0.99																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.46	0.49	0.48	0.50																
	0.16	*0.12*	*0.13*	*0.12*																
NO_3^-	0.42	0.60	0.52	0.57	0.83															
	0.20	*0.05*	*0.10*	*0.07*	*0.00*															
SO_4^{--}	0.34	0.43	0.38	0.41	0.84	0.96														
	0.31	*0.19*	*0.25*	*0.21*	*0.00*	*0.00*														
Na^+	0.26	0.11	0.12	0.12	0.31	-0.05	0.03													
	0.45	*0.74*	*0.74*	*0.74*	*0.35*	*0.88*	*0.93*													
NH_4^+	0.47	0.68	0.55	0.63	0.80	0.93	0.83	-0.05												
	0.15	*0.02*	*0.08*	*0.04*	*0.00*	*0.00*	*0.00*	*0.88*												
K^+	0.65	0.51	0.48	0.50	0.36	0.55	0.51	-0.10	0.61											
	0.03	*0.11*	*0.14*	*0.12*	*0.28*	*0.08*	*0.11*	*0.77*	*0.05*											
Ca^{++}	0.11	-0.07	-0.19	-0.13	0.49	0.23	0.24	0.31	0.40	0.05										
	0.75	*0.85*	*0.57*	*0.70*	*0.13*	*0.51*	*0.48*	*0.35*	*0.23*	*0.88*										
Si	0.30	0.17	0.02	0.10	0.34	0.49	0.48	0.07	0.55	0.68	0.46									
	0.38	*0.63*	*0.95*	*0.78*	*0.30*	*0.13*	*0.14*	*0.84*	*0.08*	*0.02*	*0.15*									
Al	0.36	0.48	0.29	0.39	0.67	0.75	0.71	0.31	0.81	0.45	0.57	0.58								
	0.27	*0.14*	*0.39*	*0.24*	*0.02*	*0.01*	*0.01*	*0.36*	*0.00*	*0.16*	*0.07*	*0.06*								
Ca	0.14	0.35	0.12	0.24	0.52	0.66	0.61	0.19	0.74	0.31	0.51	0.50	0.95							
	0.69	*0.29*	*0.72*	*0.48*	*0.10*	*0.03*	*0.05*	*0.59*	*0.01*	*0.35*	*0.11*	*0.11*	*0.00*							
Fe	0.51	0.46	0.42	0.45	0.53	0.57	0.53	0.02	0.66	0.83	0.24	0.79	0.39	0.23						
	0.11	*0.16*	*0.20*	*0.17*	*0.10*	*0.07*	*0.09*	*0.97*	*0.03*	*0.00*	*0.48*	*0.00*	*0.24*	*0.50*						
Ti	0.46	0.68	0.55	0.62	0.60	0.90	0.78	-0.30	0.93	0.70	0.16	0.58	0.66	0.60	0.69					
	0.16	*0.02*	*0.08*	*0.04*	*0.05*	*0.00*	*0.01*	*0.37*	*0.00*	*0.02*	*0.64*	*0.06*	*0.03*	*0.05*	*0.02*					
K	0.81	0.61	0.53	0.58	0.48	0.60	0.55	0.14	0.66	0.88	0.25	0.69	0.66	0.51	0.68	0.66				
	0.00	*0.05*	*0.09*	*0.06*	*0.14*	*0.05*	*0.08*	*0.69*	*0.03*	*0.00*	*0.46*	*0.02*	*0.03*	*0.11*	*0.02*	*0.03*				
S	0.75	0.67	0.64	0.66	0.46	0.53	0.45	0.08	0.66	0.82	0.31	0.64	0.55	0.34	0.78	0.66	0.83			
	0.01	*0.02*	*0.03*	*0.03*	*0.15*	*0.10*	*0.17*	*0.82*	*0.03*	*0.00*	*0.35*	*0.03*	*0.08*	*0.30*	*0.01*	*0.03*	*0.00*			
Ni	0.21	0.41	0.20	0.31	0.40	0.64	0.57	0.09	0.69	0.36	0.38	0.48	0.92	0.96	0.18	0.61	0.58	0.42		
	0.54	*0.21*	*0.56*	*0.36*	*0.22*	*0.04*	*0.07*	*0.79*	*0.02*	*0.27*	*0.25*	*0.13*	*0.00*	*0.00*	*0.60*	*0.04*	*0.06*	*0.20*		
Pb	0.46	0.77	0.65	0.72	0.40	0.44	0.34	0.45	0.49	0.12	0.08	0.01	0.62	0.55	0.05	0.39	0.34	0.38	0.59	
	0.15	*0.01*	*0.03*	*0.01*	*0.23*	*0.18*	*0.32*	*0.16*	*0.13*	*0.72*	*0.82*	*0.97*	*0.04*	*0.08*	*0.87*	*0.23*	*0.31*	*0.25*	*0.06*	
Zn	0.64	0.81	0.77	0.80	0.54	0.47	0.37	0.56	0.52	0.21	0.20	0.15	0.60	0.45	0.24	0.37	0.48	0.57	0.49	0.89
	0.04	*0.00*	*0.01*	*0.00*	*0.09*	*0.15*	*0.26*	*0.08*	*0.10*	*0.54*	*0.55*	*0.67*	*0.05*	*0.16*	*0.48*	*0.26*	*0.14*	*0.07*	*0.13*	*0.00*

Note: Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.97 and Table 3.98 for PM mass and major species, respectively. Both PM_{10} Mass and $PM_{2.5}$ mass shows similar C.V. The crustal elements show a very high variation in $PM_{2.5}$, whereas PM_{10} shows very less C.V. The secondary particulates show less variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.99 and Table 3.100 for the PM mass and its major species. OC, EC, and TC show similar correlation with both PM_{10} mass and $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than in $PM_{2.5}$. The secondary particulates show better correlation with each other in $PM_{2.5}$ than in PM_{10}.

3.1.14 Site 14: Ghaziabad-2

3.1.14.1 Summer Season

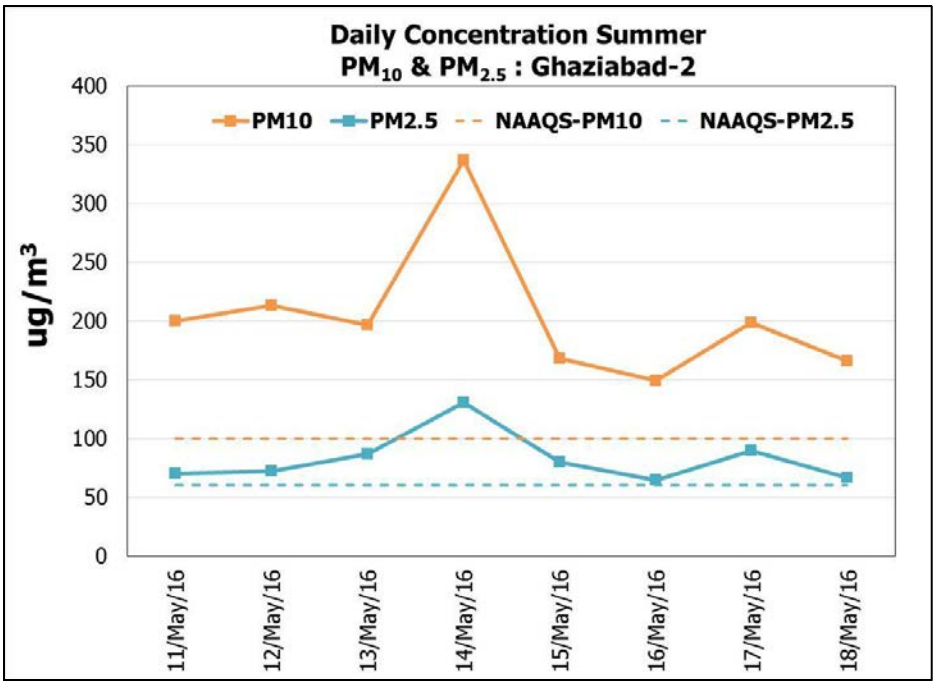


Figure 3.126*:* Variation in 24 hourly concentration of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in summer season

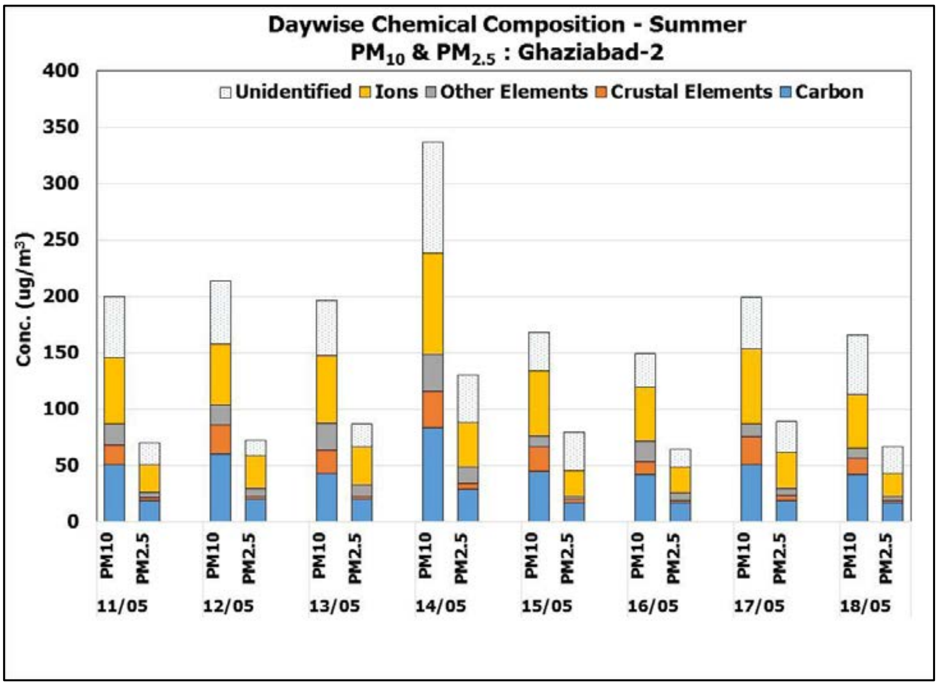


Figure 3.127: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in summer season

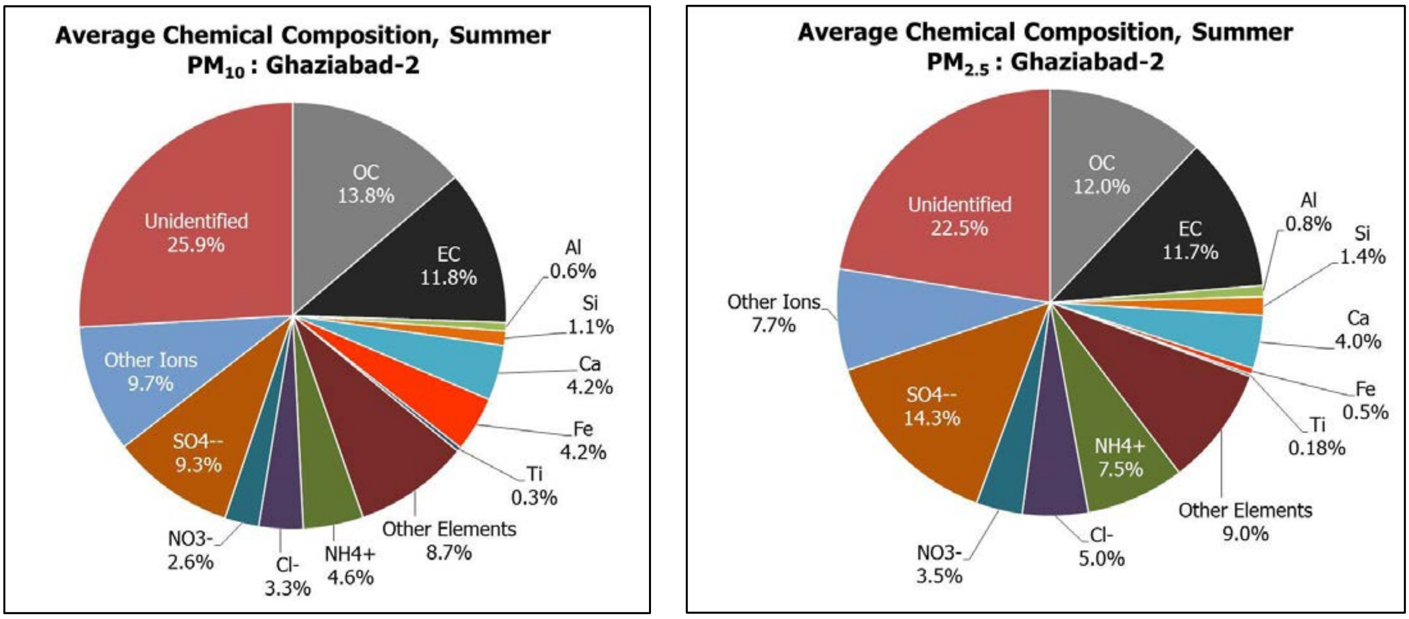


Figure 3.128*:* Average chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in summer season

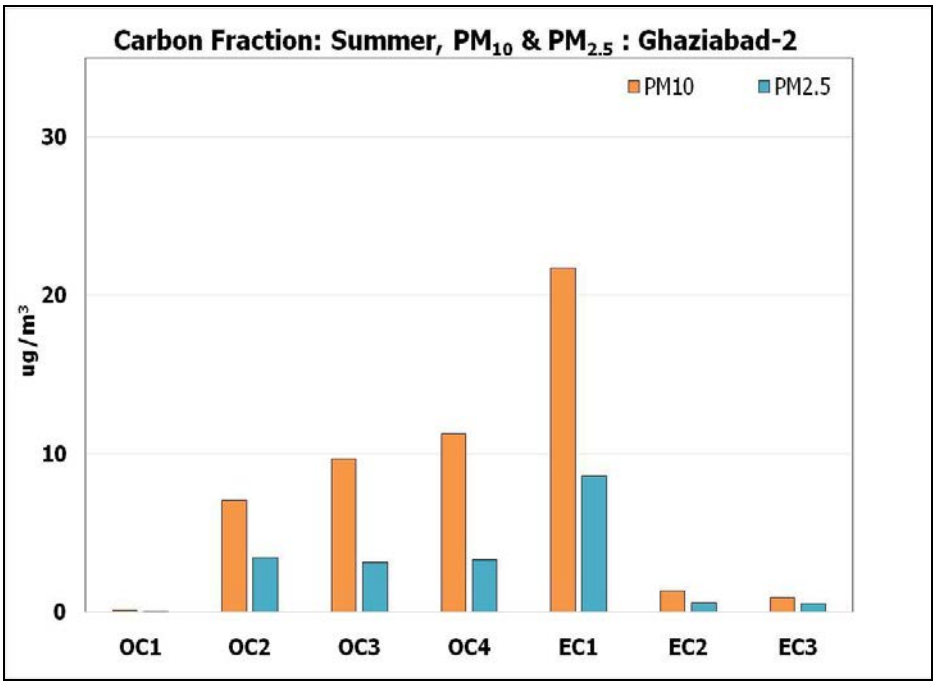


Figure 3.129: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in summer season

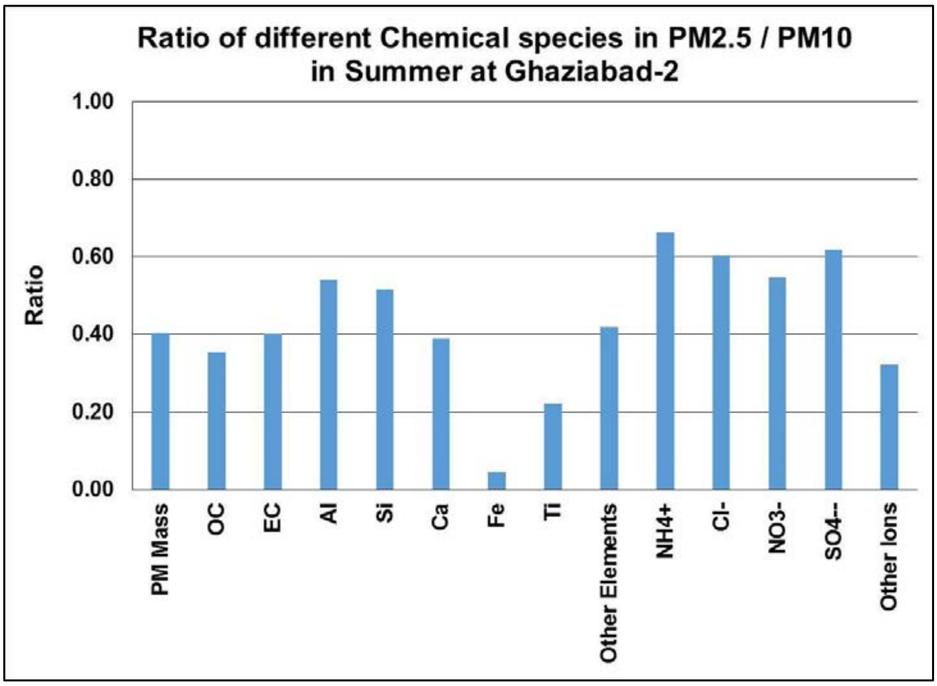


Figure 3.130: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in summer season at Ghaziabad-2

Average concentration observed at Ghaziabad-2 (GHZ2) was 203±58 µg/m³ and 82±21 µg/m³ for PM_{10} and $PM_{2.5}$, respectively. Average concentration of PM_{10} was twice that of the NAAQS, whereas $PM_{2.5}$ was 1.4 times that of the NAAQS. The observed daily concentration variation in PM_{10} was from 149 to 337 µg/m³. Similarly, for $PM_{2.5}$, Daily concentration variation was 64 to 130 µg/m³ (see Figure 3.126).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.127.

The ionic concentration was found to be highest in both PM_{10} and $PM_{2.5}$. In PM_{10}, the observed values of total Ions were 30%, whereas for $PM_{2.5}$ it was 34%. The average value of carbon fraction was 26% in PM_{10} and 24% in $PM_{2.5}$. The crustal elements were 10% in PM_{10} and 4% in $PM_{2.5}$ (see Figure 3.128).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 9% in both PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 26% in PM_{10} and 29% in $PM_{2.5}$.

EC1 was found to be the highest in PM_{10}, followed by OC4, OC3, OC2, EC2, and EC3. EC1 was the highest in $PM_{2.5}$, followed by OC2, OC3, OC4, EC2, and EC3. Concentration of OC2, OC3, and OC4 were similar and Concentration of EC2 and EC3 was similar in $PM_{2.5}$ (see Figure 3.129). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.130.

Table 3.101: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM_{10} at Ghaziabad-2 for Summer Season

$\mu g/m^3$																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	203	28.00	23.92	1.29	2.22	8.51	8.51	0.67	9.28	1.48	1.29	3.58	6.79	5.28	19.00	6.00	9.27	2.80	7.41
SD	58	8.71	7.04	0.79	1.10	1.77	3.56	0.25	3.56	0.59	1.44	2.56	4.79	0.83	3.34	3.37	1.81	0.58	2.03
Min	149	19.31	17.80	0.56	0.88	5.27	4.26	0.35	5.57	0.72	0.28	0.38	3.22	4.08	15.23	2.86	7.21	2.04	3.90
Max	337	43.20	40.22	2.66	3.90	10.59	14.59	1.05	15.77	2.53	4.11	6.40	17.93	6.43	24.40	12.56	12.14	3.56	10.34
C.V.	0.29	0.31	0.29	0.61	0.49	0.21	0.42	0.37	0.38	0.40	1.12	0.71	0.71	0.16	0.18	0.56	0.20	0.21	0.27
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95%ile	294	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50%ile	198	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5%ile	155	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.102: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at Ghaziabad-2 for Summer Season

$\mu g/m^3$																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	82	9.90	9.63	0.70	1.14	3.32	0.38	0.15	2.57	1.18	0.68	1.59	4.09	2.88	11.75	1.91	6.14	1.92	1.63
SD	21	2.20	1.84	0.36	0.47	0.76	0.27	0.05	1.28	0.47	0.91	1.68	2.33	0.80	2.40	2.37	1.15	0.66	0.43
Min	64	7.78	8.30	0.37	0.56	2.22	0.11	0.09	0.67	0.65	0.10	0.13	1.70	2.08	9.00	0.38	4.60	1.36	1.10
Max	130	14.47	13.99	1.46	1.83	4.08	0.88	0.20	5.27	2.15	2.77	4.05	8.97	4.60	15.11	7.54	7.92	3.15	2.51
C.V.	0.26	0.22	0.19	0.52	0.41	0.23	0.70	0.30	0.50	0.40	1.34	1.06	0.57	0.28	0.20	1.24	0.19	0.35	0.26
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95%ile	116	13.36	12.55	1.27	1.71	4.05	0.79	0.20	4.42	1.93	2.22	3.98	7.77	4.18	14.98	5.83	7.61	2.92	2.28
50%ile	76	9.48	9.13	0.55	1.17	3.56	0.32	0.16	2.34	1.02	0.36	0.73	3.70	2.69	11.50	1.02	6.00	1.55	1.63
5%ile	65	7.86	8.39	0.38	0.60	2.28	0.12	0.09	1.19	0.73	0.10	0.14	1.82	2.14	9.12	0.51	4.66	1.38	1.17

Table 3.103: Correlation matrix for PM_{10} and its composition for Summer Season at Ghaziabad-2

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.01																			
EC	0.88	0.60																		
	0.00	*0.12*																		
TC	0.97	0.92	0.87																	
	0.00	*0.00*	*0.01*																	
Cl^-	0.84	0.60	0.83	0.79																
	0.01	*0.11*	*0.01*	*0.02*																
NO_3^-	0.65	0.49	0.54	0.58	0.68															
	0.08	*0.22*	*0.16*	*0.14*	*0.07*															
SO_4^{--}	0.62	0.49	0.58	0.60	0.30	0.70														
	0.11	*0.22*	*0.13*	*0.12*	*0.48*	*0.05*														
Na^+	0.80	0.55	0.64	0.66	0.82	0.74	0.41													
	0.02	*0.16*	*0.09*	*0.08*	*0.01*	*0.03*	*0.32*													
NH_4^+	0.63	0.61	0.42	0.59	0.54	0.89	0.67	0.65												
	0.09	*0.11*	*0.31*	*0.13*	*0.17*	*0.00*	*0.07*	*0.08*												
K^+	0.71	0.73	0.44	0.67	0.41	0.14	0.23	0.52	0.41											
	0.05	*0.04*	*0.27*	*0.07*	*0.32*	*0.75*	*0.58*	*0.19*	*0.32*											
Ca^{++}	0.75	0.88	0.41	0.75	0.46	0.44	0.41	0.65	0.51	0.70										
	0.03	*0.00*	*0.32*	*0.03*	*0.25*	*0.28*	*0.31*	*0.08*	*0.20*	*0.05*										
Si	0.79	0.91	0.63	0.88	0.50	0.58	0.72	0.42	0.74	0.61	0.69									
	0.02	*0.00*	*0.09*	*0.00*	*0.21*	*0.13*	*0.05*	*0.30*	*0.04*	*0.11*	*0.06*									
Al	0.65	0.59	0.57	0.65	0.42	0.82	0.95	0.43	0.80	0.21	0.44	0.81								
	0.08	*0.12*	*0.14*	*0.08*	*0.30*	*0.01*	*0.00*	*0.29*	*0.02*	*0.62*	*0.27*	*0.02*								
Ca	0.63	0.68	0.25	0.55	0.40	0.50	0.41	0.65	0.50	0.55	0.87	0.48	0.45							
	0.10	*0.06*	*0.55*	*0.16*	*0.32*	*0.21*	*0.32*	*0.08*	*0.21*	*0.16*	*0.01*	*0.23*	*0.27*							
Fe	0.85	0.97	0.54	0.86	0.63	0.60	0.49	0.69	0.72	0.74	0.93	0.85	0.60	0.80						
	0.01	*0.00*	*0.17*	*0.01*	*0.09*	*0.11*	*0.21*	*0.06*	*0.05*	*0.04*	*0.00*	*0.01*	*0.12*	*0.02*						
Ti	0.80	0.96	0.47	0.83	0.53	0.54	0.48	0.62	0.69	0.75	0.94	0.86	0.57	0.77	0.99					
	0.02	*0.00*	*0.24*	*0.01*	*0.17*	*0.17*	*0.23*	*0.10*	*0.06*	*0.03*	*0.00*	*0.01*	*0.14*	*0.03*	*0.00*					
K	0.78	0.57	0.68	0.69	0.85	0.48	0.15	0.77	0.55	0.71	0.42	0.48	0.25	0.36	0.62	0.54				
	0.02	*0.14*	*0.07*	*0.06*	*0.01*	*0.23*	*0.72*	*0.03*	*0.16*	*0.05*	*0.30*	*0.23*	*0.55*	*0.39*	*0.10*	*0.17*				
S	0.79	0.68	0.85	0.84	0.54	0.58	0.83	0.43	0.57	0.42	0.46	0.86	0.81	0.22	0.59	0.58	0.41			
	0.02	*0.06*	*0.01*	*0.01*	*0.17*	*0.13*	*0.01*	*0.29*	*0.14*	*0.31*	*0.26*	*0.01*	*0.02*	*0.60*	*0.13*	*0.13*	*0.32*			
Ni	0.87	0.94	0.56	0.86	0.61	0.57	0.51	0.72	0.73	0.83	0.91	0.85	0.57	0.74	0.98	0.98	0.67	0.62		
	0.01	*0.00*	*0.15*	*0.01*	*0.11*	*0.14*	*0.20*	*0.05*	*0.04*	*0.01*	*0.00*	*0.01*	*0.14*	*0.03*	*0.00*	*0.00*	*0.07*	*0.10*		
Pb	0.80	0.52	0.66	0.65	0.88	0.66	0.28	0.91	0.60	0.56	0.50	0.39	0.37	0.60	0.64	0.53	0.90	0.35	0.65	
	0.02	*0.19*	*0.08*	*0.08*	*0.00*	*0.08*	*0.50*	*0.00*	*0.12*	*0.15*	*0.21*	*0.34*	*0.37*	*0.12*	*0.09*	*0.18*	*0.00*	*0.40*	*0.08*	
Zn	0.41	0.11	0.53	0.33	0.62	0.28	-0.02	0.46	0.34	0.37	-0.12	0.17	0.04	-0.23	0.13	0.07	0.81	0.28	0.23	0.60
	0.32	*0.80*	*0.18*	*0.42*	*0.10*	*0.51*	*0.97*	*0.25*	*0.41*	*0.36*	*0.78*	*0.69*	*0.93*	*0.59*	*0.76*	*0.87*	*0.01*	*0.50*	*0.58*	*0.12*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.104: Correlation matrix for $PM_{2.5}$ and its composition for Summer Season at Ghaziabad 2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.01																			
EC	0.94	0.90																		
	0.00	*0.00*																		
TC	0.92	0.98	0.97																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.68	0.66	0.80	0.74																
	0.06	*0.08*	*0.02*	*0.04*																
NO_3^-	0.95	0.83	0.92	0.89	0.67															
	0.00	*0.01*	*0.00*	*0.00*	*0.07*															
SO_4^{--}	0.79	0.80	0.71	0.78	0.37	0.87														
	0.02	*0.02*	*0.05*	*0.02*	*0.37*	*0.01*														
Na^+	0.35	0.32	0.32	0.33	0.36	0.26	0.34													
	0.40	*0.44*	*0.44*	*0.43*	*0.38*	*0.54*	*0.41*													
NH_4^+	0.89	0.90	0.89	0.92	0.64	0.96	0.92	0.36												
	0.00	*0.00*	*0.00*	*0.00*	*0.09*	*0.00*	*0.00*	*0.39*												
K^+	0.76	0.96	0.81	0.91	0.67	0.70	0.72	0.47	0.79											
	0.03	*0.00*	*0.01*	*0.00*	*0.07*	*0.06*	*0.05*	*0.24*	*0.02*											
Ca^{++}	0.67	0.63	0.69	0.68	0.44	0.57	0.29	-0.28	0.46	0.50										
	0.07	*0.09*	*0.06*	*0.07*	*0.28*	*0.14*	*0.49*	*0.50*	*0.25*	*0.21*										
Si	0.65	0.65	0.67	0.68	0.36	0.55	0.34	0.10	0.57	0.51	0.76									
	0.08	*0.08*	*0.07*	*0.07*	*0.38*	*0.15*	*0.41*	*0.81*	*0.14*	*0.20*	*0.03*									
Al	0.51	0.17	0.31	0.24	-0.04	0.61	0.60	-0.14	0.48	-0.03	0.21	0.11								
	0.20	*0.69*	*0.46*	*0.57*	*0.93*	*0.11*	*0.12*	*0.74*	*0.23*	*0.94*	*0.61*	*0.80*								
Ca	0.74	0.60	0.68	0.65	0.35	0.67	0.43	-0.30	0.55	0.42	0.95	0.73	0.50							
	0.04	*0.11*	*0.06*	*0.08*	*0.40*	*0.07*	*0.29*	*0.47*	*0.16*	*0.30*	*0.00*	*0.04*	*0.21*							
Fe	0.93	0.65	0.79	0.73	0.58	0.91	0.76	0.35	0.80	0.56	0.49	0.42	0.70	0.64						
	0.00	*0.08*	*0.02*	*0.04*	*0.13*	*0.00*	*0.03*	*0.40*	*0.02*	*0.15*	*0.22*	*0.30*	*0.05*	*0.09*						
Ti	0.79	0.63	0.64	0.65	0.27	0.84	0.79	-0.13	0.75	0.45	0.62	0.44	0.82	0.81	0.82					
	0.02	*0.10*	*0.09*	*0.08*	*0.51*	*0.01*	*0.02*	*0.76*	*0.03*	*0.26*	*0.10*	*0.28*	*0.01*	*0.02*	*0.01*					
K	0.81	0.85	0.93	0.91	0.77	0.86	0.73	0.31	0.85	0.79	0.49	0.41	0.26	0.47	0.67	0.54				
	0.01	*0.01*	*0.00*	*0.00*	*0.02*	*0.01*	*0.04*	*0.45*	*0.01*	*0.02*	*0.22*	*0.32*	*0.54*	*0.24*	*0.07*	*0.17*				
S	0.80	0.78	0.81	0.81	0.53	0.88	0.73	-0.21	0.82	0.59	0.75	0.54	0.57	0.83	0.70	0.88	0.77			
	0.02	*0.02*	*0.02*	*0.02*	*0.17*	*0.00*	*0.04*	*0.63*	*0.01*	*0.12*	*0.03*	*0.17*	*0.14*	*0.01*	*0.05*	*0.00*	*0.03*			
Ni	0.83	0.90	0.80	0.88	0.45	0.78	0.80	0.47	0.87	0.83	0.52	0.78	0.26	0.55	0.66	0.61	0.66	0.62		
	0.01	*0.00*	*0.02*	*0.00*	*0.27*	*0.02*	*0.02*	*0.24*	*0.01*	*0.01*	*0.18*	*0.02*	*0.54*	*0.16*	*0.08*	*0.11*	*0.07*	*0.10*		
Pb	0.92	0.87	0.97	0.94	0.88	0.87	0.67	0.48	0.85	0.85	0.58	0.56	0.20	0.55	0.80	0.54	0.90	0.69	0.76	
	0.00	*0.01*	*0.00*	*0.00*	*0.00*	*0.01*	*0.07*	*0.23*	*0.01*	*0.01*	*0.13*	*0.15*	*0.63*	*0.16*	*0.02*	*0.17*	*0.00*	*0.06*	*0.03*	
Zn	0.59	0.59	0.67	0.64	0.90	0.56	0.41	0.70	0.58	0.69	0.11	0.16	-0.12	0.03	0.53	0.10	0.70	0.26	0.45	0.82
	0.12	*0.13*	*0.07*	*0.09*	*0.00*	*0.15*	*0.31*	*0.05*	*0.13*	*0.06*	*0.80*	*0.71*	*0.77*	*0.95*	*0.17*	*0.81*	*0.06*	*0.53*	*0.27*	*0.01*

Note: Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.101 and Table 3.102 for PM mass and major species, respectively. Both in PM_{10} and $PM_{2.5}$, there is a variation in percentile with regard to the statistical parameter due to the distribution of PM mass. For crustal elements, C.V. for PM_{10} is less than that of $PM_{2.5}$. The secondary particulates show less C.V. in both $PM_{2.5}$ and PM_{10}.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.103 and Table 3.104 for PM mass and its major species. OC, EC, and TC show better correlation with $PM_{2.5}$ mass as compared to PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass as compared to $PM_{2.5}$. The secondary particulates showed a better correlation with each other in PM_{10}.

3.1.14.2 Winter season

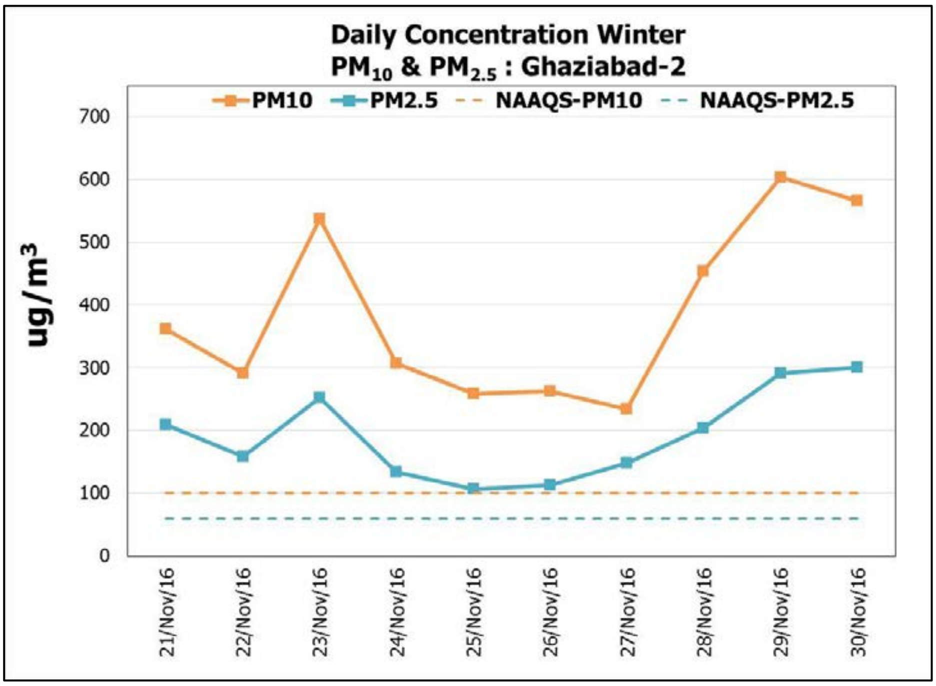


Figure 3.131: Variation in 24 hourly concentration of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in winter season

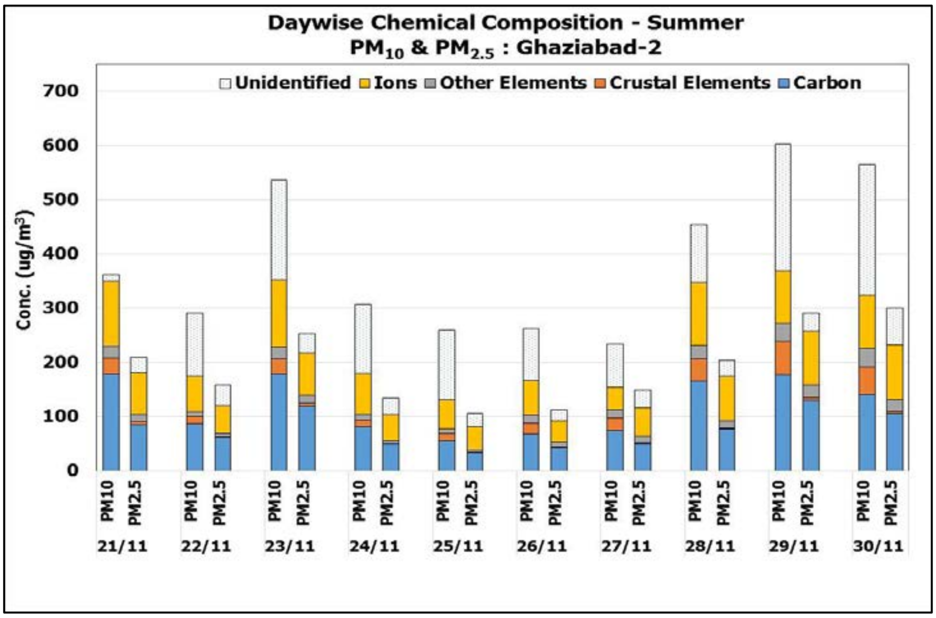


Figure 3.132: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in winter season

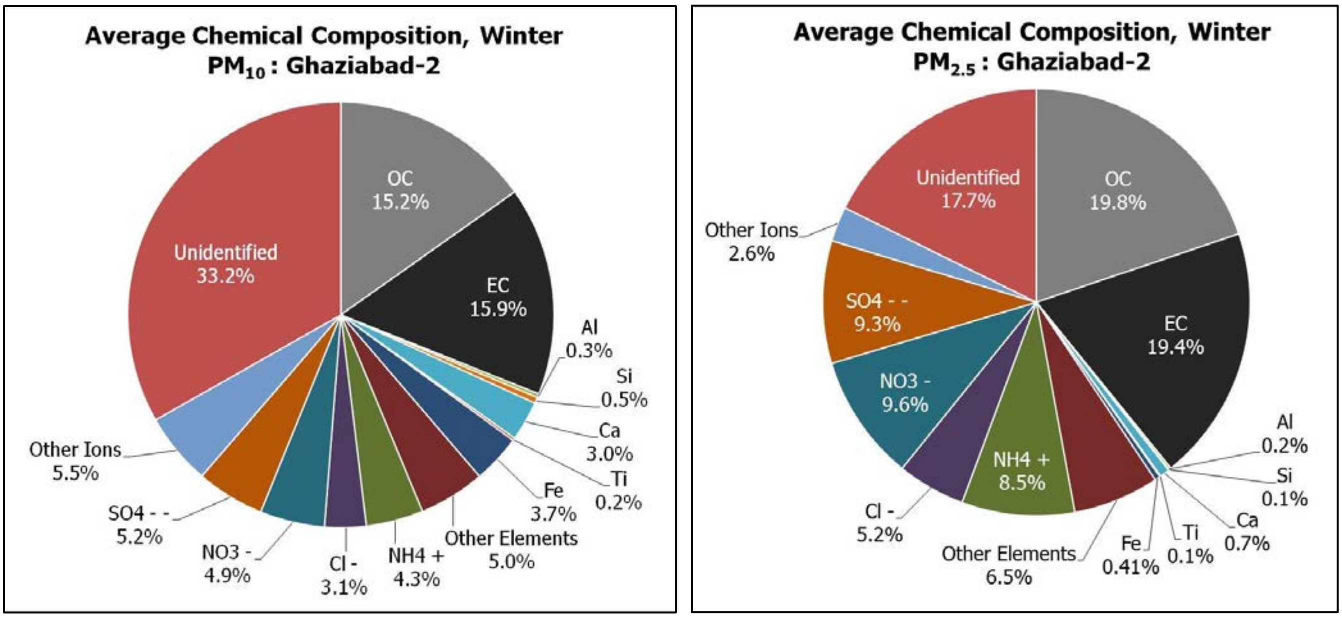


Figure 3.133: Average chemical composition of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in winter season

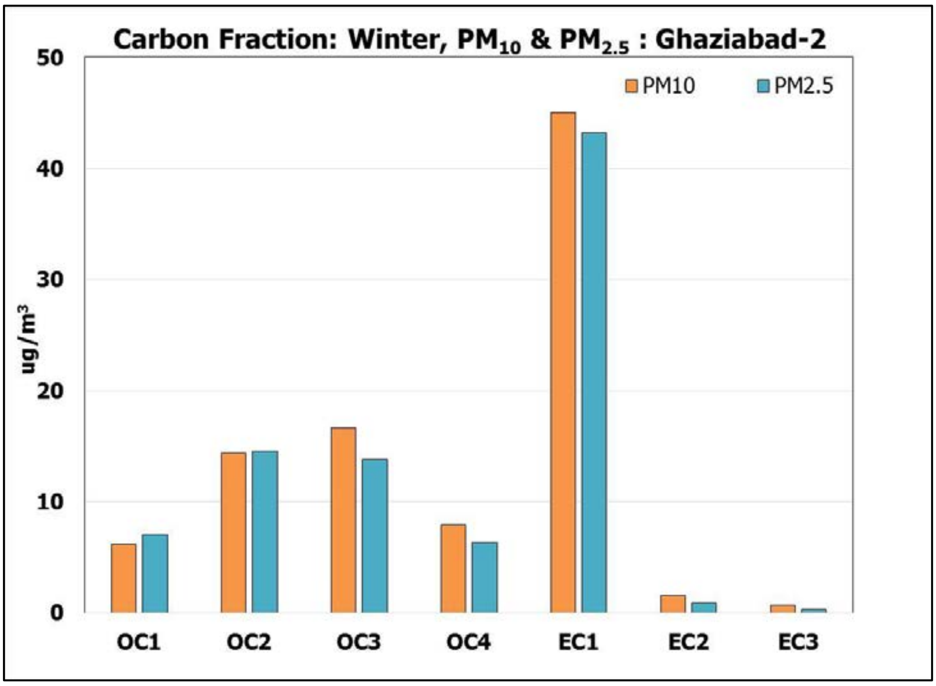


Figure 3.134: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Ghaziabad-2 in winter season

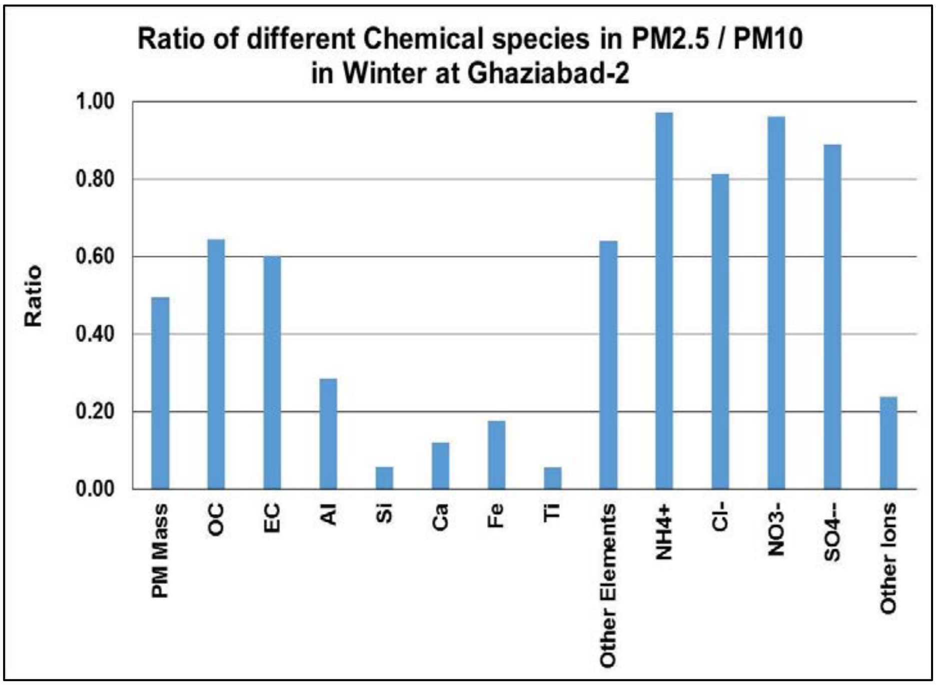


Figure 3.135: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Ghaziabad-2

Average concentration of PM_{10} was found to be 388±140 µg/m^3 and that of $PM_{2.5}$ was found to be 192±71 µg/m^3. Average concentration of PM_{10} was 3.8 times the permissible limit of NAAQS (100 µg/m^3). Concentration of PM_{10} varied from 233 to 603 µg/m^3 and the concentration in $PM_{2.5}$varied from 106 to 300 µg/m^3 (see Figure 3.131).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.132.

The carbon fraction of PM_{10} and $PM_{2.5}$ was found to be 120 µg/m^3 and 75 µg/m^3, respectively. The % mass distribution showed the OC and EC were higher in $PM_{2.5}$ as compared to PM_{10}. The crustal elements in PM_{10} was found to be 8% while it was 2% in PM2.5. The Total ions of PM_{10} was found to be 23% while this was found to be 35% in $PM_{2.5}$ (see Figure 3.133).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 5% and 7% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed in PM_{10} was found to be 33% while this was found to be 18% in $PM_{2.5}$.

The OC3 in PM_{10} was found to be higher, followed by OC2, OC4, and OC1. In $PM_{2.5}$, OC2 was found to be higher, followed by OC3, OC4, and OC1. The EC1 in PM_{10} was found to higher than that of $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.134).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.135.

Table 3.105: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of PM_{10} at Ghaziabad 2 for Winter season

	μg/m^3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	388	58.85	61.50	1.16	1.77	11.73	14.29	0.79	6.16	2.96	2.72	4.08	12.15	19.05	20.01	1.56	16.84	5.20	8.61
SD	140	26.39	26.90	0.72	0.92	7.37	7.79	0.44	2.98	0.94	1.73	2.02	9.99	6.78	6.42	0.84	5.80	2.29	3.86
Min	233	25.33	29.56	0.42	0.99	4.84	6.09	0.37	3.48	1.37	0.49	1.35	3.26	10.15	9.17	0.77	10.09	2.39	3.76
Max	603	96.48	97.84	2.54	3.45	24.86	30.07	1.57	12.47	3.96	5.54	7.00	29.10	29.18	27.72	3.27	28.35	9.70	15.35
C.V.	0.36	0.45	0.44	0.62	0.52	0.63	0.55	0.55	0.48	0.32	0.64	0.50	0.82	0.36	0.32	0.54	0.34	0.44	0.45
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	586	95.03	95.94	2.25	3.38	24.01	25.98	1.55	11.27	3.94	5.03	6.82	28.27	28.34	27.30	3.08	25.81	9.12	14.28
50 %ile	362	58.85	61.50	0.95	1.52	9.85	14.29	0.74	5.33	2.96	2.72	3.64	10.10	18.88	21.26	1.36	16.18	4.70	7.69
5 %ile	192	25.91	28.36	0.45	0.96	4.94	6.41	0.39	3.26	1.18	0.59	1.68	3.38	8.63	7.93	0.81	8.16	2.34	3.81

Table 3.106: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of $PM_{2.5}$ at Ghaziabad 2 for winter season

	μg/m^3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	192	37.94	37.14	0.33	0.10	1.42	0.79	0.14	2.62	2.45	1.74	1.81	9.89	18.34	17.80	1.07	16.38	1.68	0.89
SD	71	17.63	16.43	0.25	0.09	1.20	1.14	0.12	1.30	0.83	1.11	1.01	8.84	9.50	7.35	0.41	4.45	0.71	0.76
Min	106	16.27	16.38	0.08	0.00	0.21	0.00	0.02	1.29	1.15	0.25	0.62	2.11	10.15	12.15	0.19	11.38	0.87	0.15
Max	300	67.43	62.63	0.81	0.23	3.76	2.92	0.35	4.62	3.26	3.19	3.12	25.12	36.40	31.21	1.58	26.66	2.74	2.80
C.V.	0.37	0.46	0.44	0.77	0.84	0.84	1.45	0.85	0.50	0.34	0.64	0.56	0.89	0.52	0.41	0.38	0.27	0.42	0.86
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	296	63.75	61.44	0.78	0.23	3.59	2.84	0.32	4.55	3.26	3.11	3.11	24.97	35.82	31.12	1.53	23.39	2.62	2.14
50 %ile	182	35.19	33.39	0.28	0.08	0.98	0.21	0.12	1.98	2.69	1.65	1.36	7.48	15.06	14.83	1.06	15.17	1.52	0.71
5 %ile	109	18.04	18.83	0.08	0.01	0.32	0.00	0.02	1.37	1.26	0.33	0.75	2.17	10.71	12.40	0.46	12.19	0.90	0.21

Table 3.107: Correlation matrix for PM_{10} and its composition for winter season at Ghaziabad-2

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.91																			
	0.00																			
EC	0.82	0.94																		
	0.01	*0.00*																		
TC	0.88	0.98	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.34	0.91	0.98	0.96																
	0.34	*0.00*	*0.00*	*0.00*																
NO_3^-	0.88	0.80	0.92	0.88	0.45															
	0.00	*0.02*	*0.00*	*0.00*	*0.19*															
SO_4^{--}	0.75	0.83	0.84	0.85	0.68	0.74														
	0.01	*0.01*	*0.01*	*0.01*	*0.03*	*0.02*														
Na^+	0.20	0.90	0.84	0.88	0.82	0.18	0.67													
	0.58	*0.00*	*0.01*	*0.00*	*0.00*	*0.61*	*0.03*													
NH_4^+	0.72	0.91	0.83	0.88	0.73	0.58	0.79	0.63												
	0.02	*0.00*	*0.01*	*0.00*	*0.02*	*0.08*	*0.01*	*0.05*												
K^+	0.58	0.92	0.81	0.87	0.73	0.45	0.84	0.90	0.80											
	0.08	*0.00*	*0.02*	*0.01*	*0.02*	*0.19*	*0.00*	*0.00*	*0.01*											
Ca^{++}	0.93	0.75	0.56	0.66	0.28	0.67	0.73	0.27	0.78	0.65										
	0.00	*0.03*	*0.15*	*0.08*	*0.43*	*0.03*	*0.02*	*0.46*	*0.01*	*0.04*										
Si	0.91	0.82	0.87	0.86	0.11	0.89	0.55	-0.11	0.43	0.26	0.74									
	0.00	*0.01*	*0.01*	*0.01*	*0.77*	*0.00*	*0.10*	*0.77*	*0.21*	*0.47*	*0.02*									
Al	0.91	0.66	0.60	0.64	0.09	0.77	0.48	-0.06	0.49	0.32	0.77	0.92								
	0.00	*0.08*	*0.12*	*0.09*	*0.82*	*0.01*	*0.16*	*0.87*	*0.15*	*0.37*	*0.01*	*0.00*								
Ca	0.85	0.59	0.74	0.68	0.12	0.88	0.45	-0.16	0.36	0.16	0.60	0.97	0.91							
	0.00	*0.12*	*0.04*	*0.07*	*0.74*	*0.00*	*0.19*	*0.66*	*0.31*	*0.66*	*0.06*	*0.00*	*0.00*							
Fe	0.85	0.78	0.90	0.86	0.28	0.90	0.59	0.08	0.41	0.36	0.61	0.92	0.90	0.94						
	0.00	*0.02*	*0.00*	*0.01*	*0.43*	*0.00*	*0.08*	*0.83*	*0.24*	*0.31*	*0.06*	*0.00*	*0.00*	*0.00*						
Ti	0.86	0.72	0.84	0.79	0.08	0.86	0.49	-0.14	0.36	0.20	0.65	0.99	0.90	0.98	0.93					
	0.00	*0.04*	*0.01*	*0.02*	*0.82*	*0.00*	*0.15*	*0.71*	*0.31*	*0.58*	*0.04*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.88	0.79	0.83	0.82	0.14	0.85	0.49	-0.10	0.49	0.24	0.72	0.96	0.86	0.94	0.83	0.96				
	0.00	*0.02*	*0.01*	*0.01*	*0.70*	*0.00*	*0.15*	*0.78*	*0.15*	*0.50*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.69	0.72	0.83	0.79	0.52	0.78	0.61	0.36	0.55	0.50	0.44	0.69	0.72	0.76	0.85	0.72	0.68			
	0.03	*0.04*	*0.01*	*0.02*	*0.12*	*0.01*	*0.06*	*0.30*	*0.10*	*0.14*	*0.21*	*0.03*	*0.02*	*0.01*	*0.00*	*0.02*	*0.03*			
Ni	0.70	0.01	0.21	0.12	-0.16	0.72	0.27	-0.39	0.17	-0.07	0.49	0.91	0.79	0.92	0.78	0.94	0.93	0.58		
	0.02	*0.99*	*0.62*	*0.78*	*0.67*	*0.02*	*0.46*	*0.27*	*0.65*	*0.84*	*0.15*	*0.00*	*0.01*	*0.00*	*0.01*	*0.00*	*0.00*	*0.08*		
Pb	0.91	0.93	0.89	0.93	0.42	0.85	0.66	0.30	0.62	0.60	0.75	0.86	0.90	0.85	0.93	0.85	0.81	0.86	0.65	
	0.00	*0.00*	*0.00*	*0.00*	*0.23*	*0.00*	*0.04*	*0.39*	*0.05*	*0.07*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.04*	
Zn	0.75	0.64	0.82	0.75	0.34	0.92	0.46	0.01	0.35	0.23	0.47	0.88	0.74	0.93	0.91	0.91	0.88	0.87	0.81	0.83
	0.02	*0.12*	*0.02*	*0.05*	*0.37*	*0.00*	*0.21*	*0.99*	*0.36*	*0.55*	*0.21*	*0.00*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.108 : Correlation matrix for PM$_{2.5}$ and its composition for winter season at Ghaziabad-2

	PM$_{2.5}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.85	0.98																		
	0.01	*0.00*																		
TC	0.88	0.99	1.00																	
	0.00	*0.00*	*0.00*																	
Cl$^-$	0.82	0.91	0.96	0.94																
	0.01	*0.00*	*0.00*	*0.00*																
NO$_3^-$	0.95	0.87	0.81	0.84	0.82															
	0.00	*0.01*	*0.01*	*0.01*	*0.01*															
SO$_4^{--}$	0.77	0.58	0.48	0.53	0.40	0.68														
	0.03	*0.14*	*0.23*	*0.18*	*0.33*	*0.06*														
Na$^+$	0.71	0.81	0.81	0.82	0.88	0.73	0.26													
	0.05	*0.02*	*0.01*	*0.01*	*0.00*	*0.04*	*0.54*													
NH$_4^+$	0.93	0.82	0.73	0.77	0.69	0.92	0.89	0.62												
	0.00	*0.01*	*0.04*	*0.03*	*0.06*	*0.00*	*0.00*	*0.10*												
K$^+$	0.70	0.76	0.67	0.71	0.45	0.63	0.60	0.30	0.68											
	0.05	*0.03*	*0.07*	*0.05*	*0.27*	*0.09*	*0.12*	*0.47*	*0.07*											
Ca^{++}	0.52	0.41	0.36	0.38	0.55	0.61	0.14	0.73	0.46	-0.07										
	0.19	*0.32*	*0.38*	*0.35*	*0.16*	*0.11*	*0.74*	*0.04*	*0.25*	*0.87*										
Si	0.41	0.66	0.65	0.66	0.45	0.42	0.23	0.37	0.42	0.82	-0.18									
	0.32	*0.08*	*0.08*	*0.08*	*0.27*	*0.30*	*0.59*	*0.37*	*0.30*	*0.01*	*0.67*									
Al	0.47	0.34	0.31	0.33	0.47	0.41	0.19	0.68	0.34	-0.19	0.77	-0.37								
	0.24	*0.41*	*0.46*	*0.43*	*0.24*	*0.31*	*0.65*	*0.07*	*0.41*	*0.66*	*0.03*	*0.37*								
Ca	0.72	0.81	0.75	0.78	0.72	0.69	0.21	0.86	0.55	0.54	0.59	0.48	0.58							
	0.04	*0.01*	*0.03*	*0.02*	*0.05*	*0.06*	*0.61*	*0.01*	*0.16*	*0.16*	*0.12*	*0.23*	*0.14*							
Fe	0.71	0.79	0.70	0.74	0.49	0.66	0.54	0.40	0.67	0.99	0.02	0.84	-0.11	0.65						
	0.05	*0.02*	*0.06*	*0.04*	*0.22*	*0.07*	*0.17*	*0.33*	*0.07*	*0.00*	*0.96*	*0.01*	*0.79*	*0.08*						
Ti	0.68	0.47	0.37	0.42	0.40	0.60	0.66	0.56	0.68	0.20	0.51	-0.11	0.79	0.53	0.24					
	0.06	*0.24*	*0.36*	*0.30*	*0.32*	*0.12*	*0.08*	*0.15*	*0.06*	*0.64*	*0.19*	*0.79*	*0.02*	*0.18*	*0.58*					
K	0.81	0.77	0.64	0.70	0.46	0.74	0.74	0.42	0.82	0.93	0.15	0.66	0.09	0.64	0.94	0.52				
	0.01	*0.03*	*0.09*	*0.05*	*0.26*	*0.03*	*0.04*	*0.30*	*0.01*	*0.00*	*0.72*	*0.08*	*0.83*	*0.09*	*0.00*	*0.19*				
S	0.76	0.77	0.77	0.77	0.80	0.68	0.50	0.90	0.69	0.29	0.56	0.24	0.76	0.74	0.35	0.79	0.47			
	0.03	*0.02*	*0.03*	*0.02*	*0.02*	*0.06*	*0.21*	*0.00*	*0.06*	*0.48*	*0.15*	*0.58*	*0.03*	*0.04*	*0.40*	*0.02*	*0.24*			
Ni	0.00	0.13	0.22	0.18	0.32	-0.09	-0.22	0.47	-0.15	-0.36	0.16	-0.18	0.63	0.31	-0.30	0.36	-0.28	0.60		
	1.00	*0.76*	*0.59*	*0.67*	*0.45*	*0.83*	*0.60*	*0.24*	*0.73*	*0.38*	*0.71*	*0.66*	*0.10*	*0.46*	*0.47*	*0.39*	*0.50*	*0.12*		
Pb	0.91	0.87	0.78	0.82	0.73	0.83	0.63	0.82	0.83	0.62	0.58	0.39	0.64	0.88	0.67	0.80	0.80	0.87	0.23	
	0.00	*0.01*	*0.02*	*0.01*	*0.04*	*0.01*	*0.09*	*0.01*	*0.01*	*0.10*	*0.14*	*0.34*	*0.09*	*0.00*	*0.07*	*0.02*	*0.02*	*0.01*	*0.59*	
Zn	0.90	0.96	0.89	0.93	0.77	0.82	0.62	0.73	0.81	0.85	0.31	0.68	0.32	0.84	0.88	0.55	0.89	0.74	0.09	0.92
	0.00	*0.00*	*0.00*	*0.00*	*0.03*	*0.01*	*0.10*	*0.04*	*0.01*	*0.01*	*0.46*	*0.06*	*0.44*	*0.01*	*0.00*	*0.16*	*0.00*	*0.04*	*0.84*	*0.00*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.105 and Table 3.106 for PM mass and major species, respectively. PM_{10} mass and $PM_{2.5}$ mass both show a similar C.V. Crustal elements show a very high variation in $PM_{2.5}$, whereas PM_{10} shows a very less C.V. The secondary particulates show less variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.107 and Table 3.108 for the PM mass and its major species. OC, EC, and TC show a similar correlation with both PM_{10} mass and $PM_{2.5}$ mass. Crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass than in $PM_{2.5}$. The secondary particulates show a better correlation with each other in $PM_{2.5}$ than in PM_{10}.

3.1.15 Site 15: Noida-1

3.1.15.1 Summer season

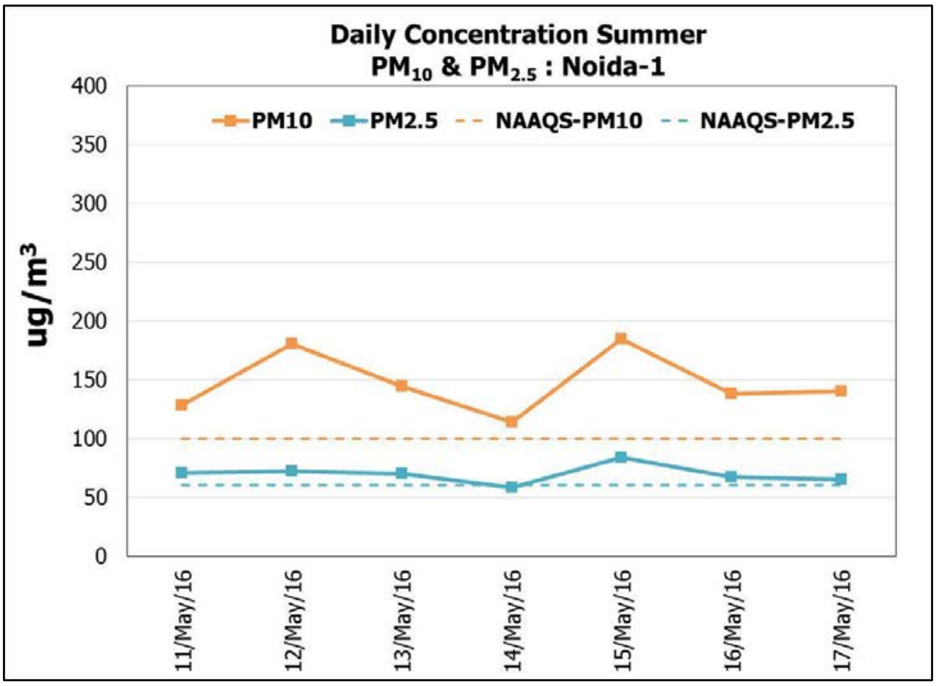


Figure 3.136: Variation in 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Noida-1 in summer season

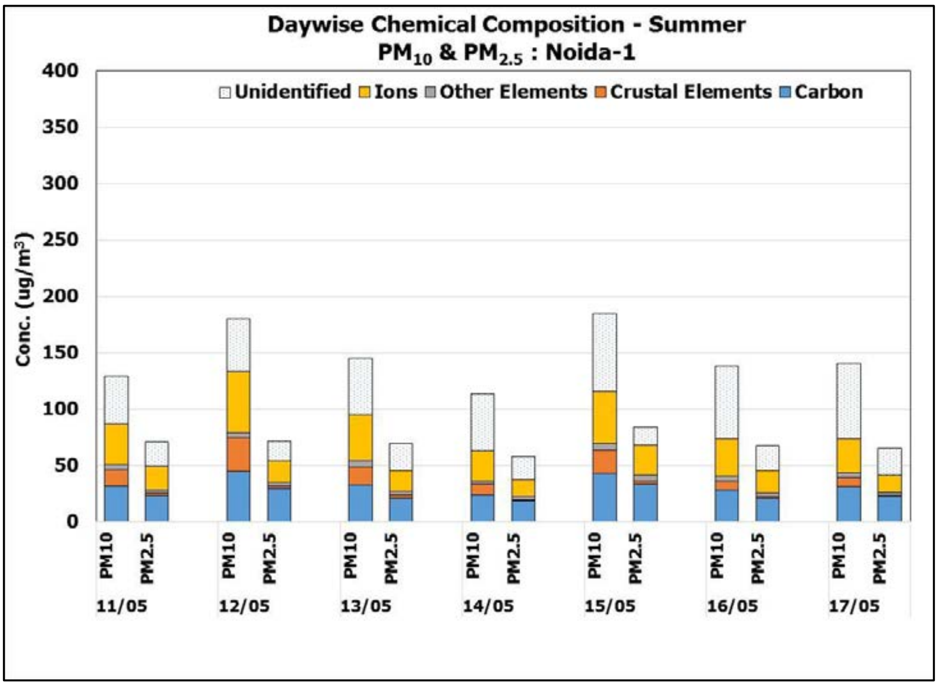


Figure 3.137: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Noida-1 in summer season

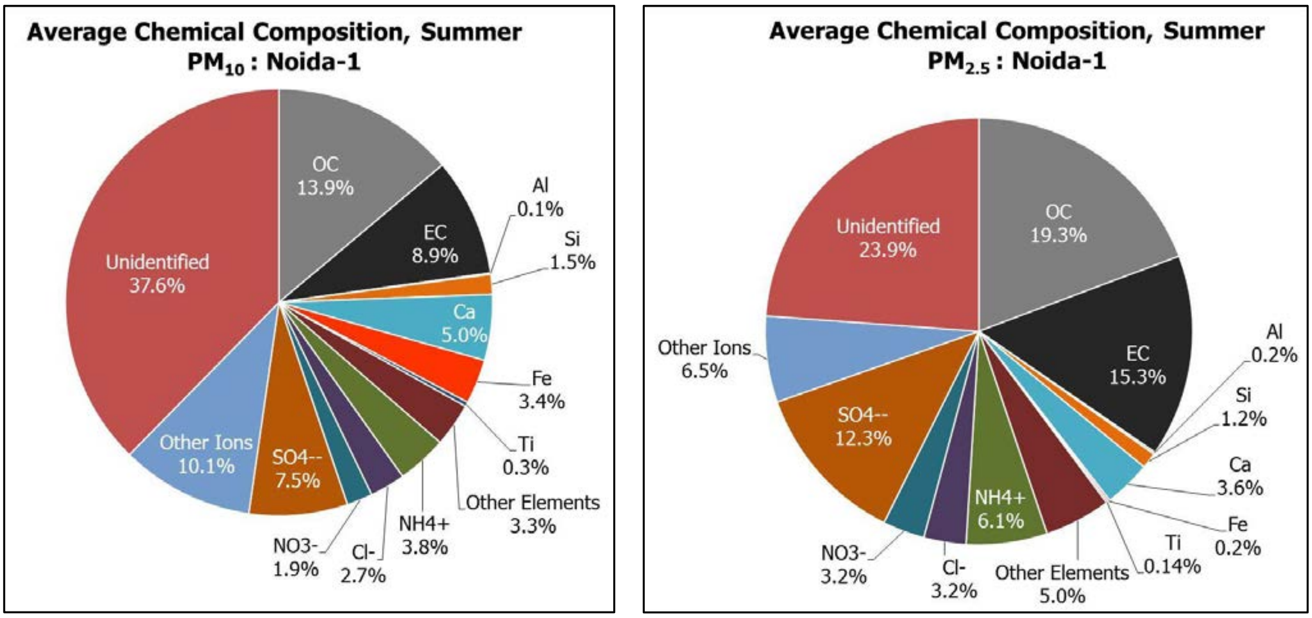


Figure 3.138: Average chemical composition of PM_{10} and $PM_{2.5}$ at Noida-1 in summer season

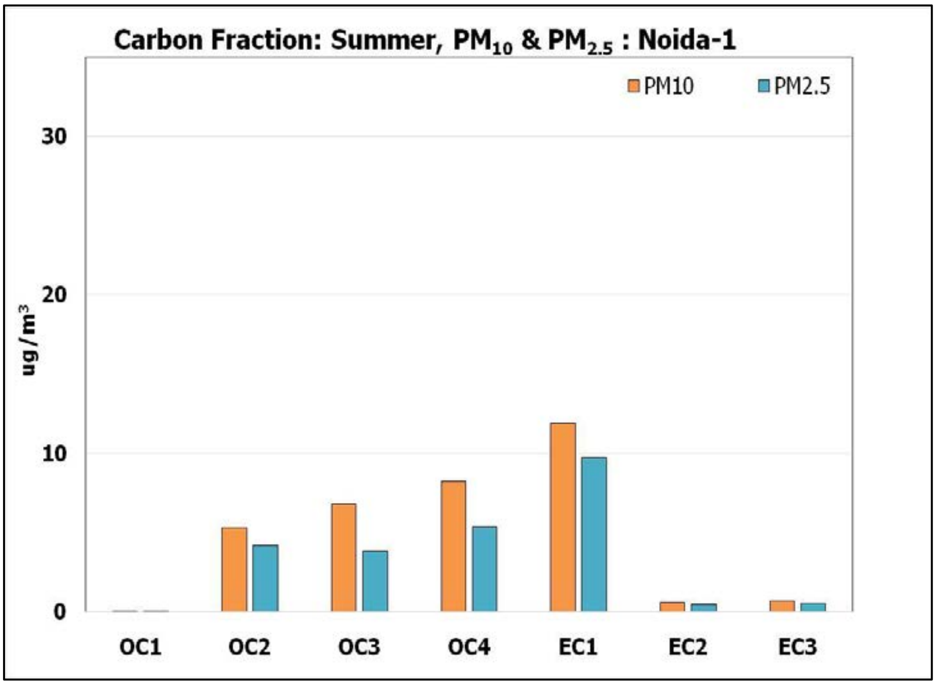


Figure 3.139: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Noida-1 in summer season

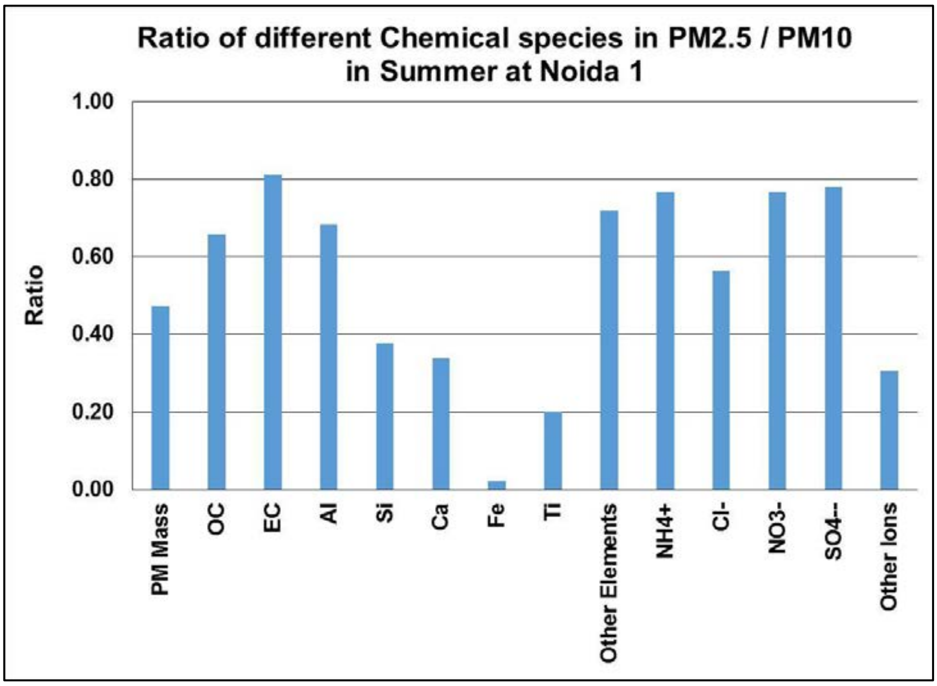


Figure 3.140: Ratio of different chemical species in $PM_{2.5}$/PM_{10} in summer season at Noida-1

Average Concentration observed at Noida-1 Sector 6 (NOI1) was 147±26 µg/m^3 and 70±8 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. Average concentration of PM_{10} was 1.5 times that of NAAQS. Observed daily concentration variation in PM_{10} was from 113 to 185 µg/m^3. Similarly, for $PM_{2.5}$, daily concentration variation was from 58 to 84 µg/m^3 (see Figure 3.136).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.137.

The ionic concentration was found to be highest in both PM_{10} and $PM_{2.5}$. In PM_{10}, the observed values of total Ions were 26% in PM_{10} and in $PM_{2.5}$ these were 28%. The carbon fraction concentration were highest with 35% in $PM_{2.5}$ and in PM_{10}, the average value of the carbon fraction was 23%. Concentrations of the observed crustal elements were 10% in PM_{10} and almost 3% in $PM_{2.5}$ (see Figure 3.138).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} and 5% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 38% in PM_{10} and 30% in $PM_{2.5}$.

OC4 was found to be the highest in both PM_{10} and $PM_{2.5}$, followed by OC2, OC3, and OC1. Similarly, EC1 was found to be highest in both PM_{10} and $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.139). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.140.

Table 3.109: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of PM_{10} at Noida-1 for summer season

μg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	147	20.39	13.13	0.16	2.21	7.31	4.96	0.50	1.72	1.26	0.08	0.33	3.95	2.87	10.96	2.75	5.55	1.28	6.48
SD	26	6.08	2.46	0.09	0.87	4.78	2.42	0.24	0.38	0.35	0.04	0.13	2.18	0.53	2.25	1.83	0.93	0.31	4.01
Min	113	14.17	9.81	0.05	1.25	2.52	3.00	0.26	1.28	0.90	0.04	0.17	1.90	1.98	8.53	0.76	4.59	0.95	2.67
Max	185	30.80	16.97	0.32	3.31	16.21	9.10	0.86	2.42	1.93	0.15	0.50	8.39	3.58	15.56	5.53	7.50	1.79	14.31
C.V.	0.18	0.30	0.19	0.54	0.39	0.65	0.49	0.48	0.22	0.28	0.49	0.40	0.55	0.18	0.20	0.67	0.17	0.24	0.62
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95%ile	183	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50%ile	140	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5%ile	118	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.110: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of $PM_{2.5}$ at Noida-1 for summer season

μg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	70	13.40	10.65	0.11	0.83	2.48	0.11	0.10	1.38	1.01	0.04	0.11	2.22	2.20	8.55	1.38	4.26	0.80	1.03
SD	8	3.50	2.25	0.02	0.10	0.86	0.07	0.01	0.33	0.38	0.02	0.04	1.00	0.49	1.46	0.99	0.75	0.32	0.46
Min	58	9.81	8.71	0.09	0.69	1.38	0.02	0.09	0.98	0.59	0.02	0.06	1.25	1.77	6.82	0.43	3.54	0.44	0.37
Max	84	18.52	15.43	0.13	0.99	3.69	0.20	0.11	2.01	1.80	0.06	0.17	4.22	3.13	10.88	2.83	5.62	1.48	1.51
C.V.	0.11	0.26	0.21	0.16	0.12	0.35	0.66	0.08	0.24	0.38	0.44	0.33	0.45	0.22	0.17	0.72	0.18	0.40	0.45
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95%ile	80	18.35	14.09	0.13	0.96	3.61	0.20	0.11	1.88	1.58	0.06	0.15	3.77	2.95	10.46	2.73	5.38	1.27	1.49
50%ile	70	11.43	9.59	0.11	0.87	2.47	0.09	0.10	1.30	0.96	0.03	0.13	2.02	1.98	8.50	0.77	3.97	0.74	1.16
5%ile	60	10.17	8.95	0.09	0.71	1.48	0.02	0.09	1.04	0.66	0.02	0.06	1.31	1.78	6.95	0.49	3.56	0.52	0.42

Table 3.111: correlation matrix for PM_{10} and its composition for summer season at Noida-1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.86																			
	0.01																			
EC	0.83	0.48																		
	0.02	*0.27*																		
TC	0.96	0.96	0.71																	
	0.00	*0.00*	*0.07*																	
Cl^-	0.44	0.72	0.05	0.60																
	0.33	*0.07*	*0.92*	*0.16*																
NO_3^-	0.77	0.60	0.80	0.74	0.23															
	0.05	*0.16*	*0.03*	*0.06*	*0.62*															
SO_4^{--}	0.72	0.45	0.72	0.60	-0.15	0.82														
	0.07	*0.31*	*0.07*	*0.16*	*0.75*	*0.02*														
Na^+	0.65	0.86	0.17	0.75	0.67	0.20	0.20													
	0.12	*0.01*	*0.72*	*0.05*	*0.10*	*0.66*	*0.66*													
NH_4^+	0.56	0.27	0.57	0.40	-0.05	0.72	0.85	0.09												
	0.19	*0.56*	*0.18*	*0.38*	*0.91*	*0.07*	*0.02*	*0.84*												
K^+	0.33	-0.07	0.65	0.16	-0.62	0.25	0.51	-0.13	0.24											
	0.47	*0.89*	*0.11*	*0.73*	*0.13*	*0.59*	*0.24*	*0.78*	*0.60*											
Ca^{++}	0.78	0.95	0.32	0.87	0.79	0.37	0.28	0.92	0.16	-0.19										
	0.04	*0.00*	*0.48*	*0.01*	*0.03*	*0.41*	*0.55*	*0.00*	*0.73*	*0.69*										
Si	0.76	0.90	0.52	0.89	0.57	0.76	0.52	0.62	0.24	-0.01	0.74									
	0.05	*0.01*	*0.23*	*0.01*	*0.18*	*0.05*	*0.23*	*0.14*	*0.60*	*0.98*	*0.06*									
Al	0.73	0.38	0.87	0.59	-0.18	0.66	0.77	0.26	0.62	0.80	0.22	0.37								
	0.07	*0.40*	*0.01*	*0.17*	*0.70*	*0.11*	*0.04*	*0.58*	*0.14*	*0.03*	*0.63*	*0.41*								
Ca	0.71	0.96	0.25	0.85	0.80	0.35	0.22	0.94	0.06	-0.23	0.98	0.80	0.17							
	0.07	*0.00*	*0.60*	*0.02*	*0.03*	*0.44*	*0.64*	*0.00*	*0.91*	*0.62*	*0.00*	*0.03*	*0.71*							
Fe	0.90	0.95	0.53	0.93	0.61	0.50	0.49	0.86	0.30	0.09	0.96	0.76	0.45	0.91						
	0.01	*0.00*	*0.22*	*0.00*	*0.15*	*0.26*	*0.27*	*0.01*	*0.52*	*0.85*	*0.00*	*0.05*	*0.31*	*0.01*						
Ti	0.77	0.89	0.48	0.87	0.41	0.71	0.67	0.68	0.36	0.09	0.74	0.94	0.46	0.79	0.80					
	0.04	*0.01*	*0.28*	*0.01*	*0.36*	*0.07*	*0.10*	*0.09*	*0.43*	*0.84*	*0.06*	*0.00*	*0.30*	*0.04*	*0.03*					
K	0.53	0.33	0.74	0.50	-0.28	0.62	0.64	0.09	0.24	0.78	0.08	0.54	0.79	0.13	0.30	0.56				
	0.22	*0.48*	*0.06*	*0.25*	*0.54*	*0.14*	*0.12*	*0.86*	*0.61*	*0.04*	*0.87*	*0.22*	*0.03*	*0.78*	*0.51*	*0.19*				
S	0.67	0.31	0.78	0.50	-0.30	0.63	0.87	0.21	0.74	0.77	0.16	0.29	0.96	0.10	0.40	0.44	0.71			
	0.10	*0.51*	*0.04*	*0.26*	*0.51*	*0.13*	*0.01*	*0.65*	*0.06*	*0.04*	*0.73*	*0.53*	*0.00*	*0.84*	*0.38*	*0.32*	*0.07*			
Ni	0.57	0.90	0.13	0.77	0.84	0.43	0.17	0.80	0.04	-0.44	0.87	0.86	0.01	0.93	0.75	0.80	0.08	-0.06		
	0.18	*0.01*	*0.79*	*0.05*	*0.02*	*0.34*	*0.71*	*0.03*	*0.93*	*0.33*	*0.01*	*0.01*	*0.99*	*0.00*	*0.05*	*0.03*	*0.87*	*0.89*		
Pb	0.28	0.32	0.05	0.27	0.45	-0.23	-0.22	0.64	-0.05	-0.04	0.49	-0.05	0.20	0.44	0.40	-0.05	-0.23	0.11	0.21	
	0.54	*0.49*	*0.92*	*0.56*	*0.31*	*0.62*	*0.63*	*0.12*	*0.92*	*0.94*	*0.27*	*0.91*	*0.68*	*0.32*	*0.37*	*0.91*	*0.62*	*0.82*	*0.65*	
Zn	0.18	0.30	-0.23	0.17	0.62	-0.13	-0.13	0.47	0.22	-0.61	0.53	-0.04	-0.29	0.42	0.37	-0.02	-0.73	-0.22	0.36	0.54
	0.70	*0.51*	*0.62*	*0.72*	*0.14*	*0.78*	*0.79*	*0.29*	*0.64*	*0.15*	*0.22*	*0.94*	*0.52*	*0.35*	*0.41*	*0.97*	*0.06*	*0.63*	*0.43*	*0.21*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.112: Correlation matrix for $PM_{2.5}$ and its composition for summer season at Noida-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.80																			
	0.03																			
EC	0.87	0.73																		
	0.01	*0.07*																		
TC	0.88	0.96	0.89																	
	0.01	*0.00*	*0.01*																	
Cl^-	0.69	0.39	0.74	0.57																
	0.09	*0.39*	*0.06*	*0.19*																
NO_3^-	0.88	0.75	0.81	0.83	0.38															
	0.01	*0.05*	*0.03*	*0.02*	*0.40*															
SO_4^{--}	0.83	0.66	0.70	0.72	0.68	0.75														
	0.02	*0.11*	*0.08*	*0.07*	*0.09*	*0.05*														
Na^+	0.75	0.57	0.63	0.64	0.54	0.58	0.33													
	0.05	*0.18*	*0.13*	*0.12*	*0.22*	*0.17*	*0.47*													
NH_4^+	0.83	0.89	0.79	0.91	0.41	0.89	0.65	0.72												
	0.02	*0.01*	*0.03*	*0.00*	*0.36*	*0.01*	*0.11*	*0.07*												
K^+	0.62	0.26	0.78	0.50	0.68	0.67	0.60	0.46	0.56											
	0.14	*0.58*	*0.04*	*0.26*	*0.09*	*0.10*	*0.16*	*0.30*	*0.20*											
Ca^{++}	0.57	0.59	0.15	0.45	0.05	0.47	0.33	0.66	0.57	-0.11										
	0.19	*0.17*	*0.75*	*0.32*	*0.92*	*0.29*	*0.48*	*0.11*	*0.18*	*0.82*										
Si	0.39	-0.19	0.12	-0.07	0.28	0.31	0.36	0.23	-0.04	0.37	0.23									
	0.39	*0.68*	*0.80*	*0.88*	*0.54*	*0.50*	*0.43*	*0.63*	*0.93*	*0.42*	*0.62*									
Al	0.32	0.08	0.59	0.30	0.55	0.21	0.29	-0.01	-0.01	0.47	-0.50	0.21								
	0.49	*0.86*	*0.16*	*0.51*	*0.21*	*0.65*	*0.53*	*0.99*	*0.99*	*0.29*	*0.25*	*0.66*								
Ca	0.75	0.52	0.47	0.54	0.41	0.60	0.38	0.94	0.66	0.34	0.83	0.44	-0.17							
	0.05	*0.24*	*0.28*	*0.22*	*0.36*	*0.15*	*0.40*	*0.00*	*0.11*	*0.45*	*0.02*	*0.33*	*0.72*							
Fe	0.62	0.91	0.60	0.84	0.31	0.67	0.69	0.34	0.85	0.28	0.43	-0.35	-0.08	0.28						
	0.14	*0.01*	*0.16*	*0.02*	*0.51*	*0.10*	*0.09*	*0.46*	*0.02*	*0.54*	*0.34*	*0.45*	*0.87*	*0.54*						
Ti	0.72	0.67	0.84	0.79	0.70	0.71	0.89	0.24	0.67	0.72	0.00	0.05	0.50	0.15	0.74					
	0.07	*0.10*	*0.02*	*0.04*	*0.08*	*0.07*	*0.01*	*0.60*	*0.10*	*0.07*	*1.00*	*0.92*	*0.26*	*0.76*	*0.06*					
K	0.71	0.51	0.88	0.70	0.43	0.83	0.47	0.53	0.69	0.80	0.05	0.23	0.57	0.41	0.36	0.63				
	0.08	*0.25*	*0.01*	*0.08*	*0.33*	*0.02*	*0.29*	*0.22*	*0.09*	*0.03*	*0.92*	*0.61*	*0.18*	*0.36*	*0.42*	*0.13*				
S	0.89	0.66	0.98	0.84	0.82	0.79	0.79	0.57	0.70	0.80	0.13	0.28	0.65	0.46	0.53	0.87	0.83			
	0.01	*0.11*	*0.00*	*0.02*	*0.03*	*0.04*	*0.04*	*0.18*	*0.08*	*0.03*	*0.78*	*0.55*	*0.11*	*0.30*	*0.22*	*0.01*	*0.02*			
Ni	0.62	0.63	0.37	0.57	0.50	0.47	0.87	0.22	0.52	0.20	0.49	0.14	-0.09	0.32	0.72	0.66	0.02	0.45		
	0.14	*0.13*	*0.42*	*0.18*	*0.25*	*0.29*	*0.01*	*0.64*	*0.24*	*0.67*	*0.26*	*0.77*	*0.85*	*0.49*	*0.07*	*0.11*	*0.98*	*0.31*		
Pb	0.09	0.07	0.06	0.07	0.06	-0.14	-0.44	0.60	0.02	-0.22	0.34	-0.05	0.00	0.50	-0.27	-0.45	0.06	-0.03	-0.41	
	0.85	*0.88*	*0.90*	*0.88*	*0.90*	*0.77*	*0.33*	*0.16*	*0.96*	*0.64*	*0.46*	*0.92*	*0.99*	*0.25*	*0.56*	*0.31*	*0.90*	*0.96*	*0.36*	
Zn	-0.25	0.12	-0.48	-0.12	-0.27	-0.38	-0.24	0.07	-0.02	-0.65	0.50	-0.46	-0.80	0.13	0.20	-0.40	-0.71	-0.54	0.25	0.23
	0.60	*0.80*	*0.28*	*0.79*	*0.56*	*0.40*	*0.61*	*0.89*	*0.96*	*0.12*	*0.26*	*0.30*	*0.03*	*0.78*	*0.67*	*0.38*	*0.08*	*0.21*	*0.58*	*0.63*

Note: Bold values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.109 and Table 3.110 for PM mass and major species, respectively. Both in PM_{10} and $PM_{2.5}$, a lower level of C.V. was seen. For the crustal elements, C.V. for both PM_{10} and $PM_{2.5}$ is very less. In both PM_{10} and $PM_{2.5}$, the secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show less C.V.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.111 and Table 3.112 for PM mass and its major species. OC, EC, and TC show similar correlation with both $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass as compared to $PM_{2.5}$ mass. The secondary particulates showed a better correlation with each other in PM_{10} and $PM_{2.5}$ mass.

3.1.15.2 Winter season

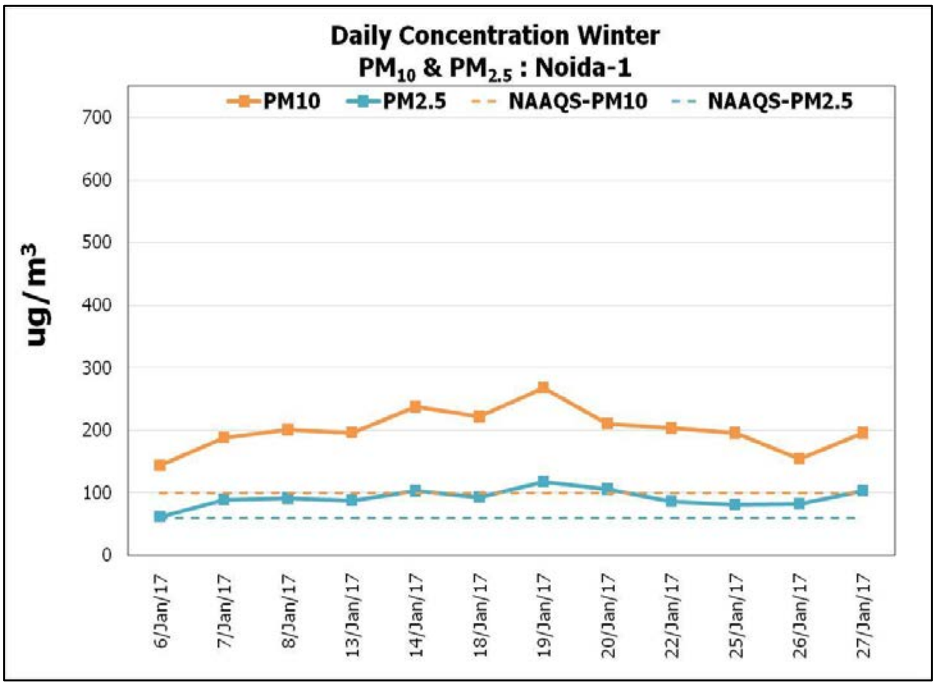


Figure 3.141: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Noida-1 in winter season

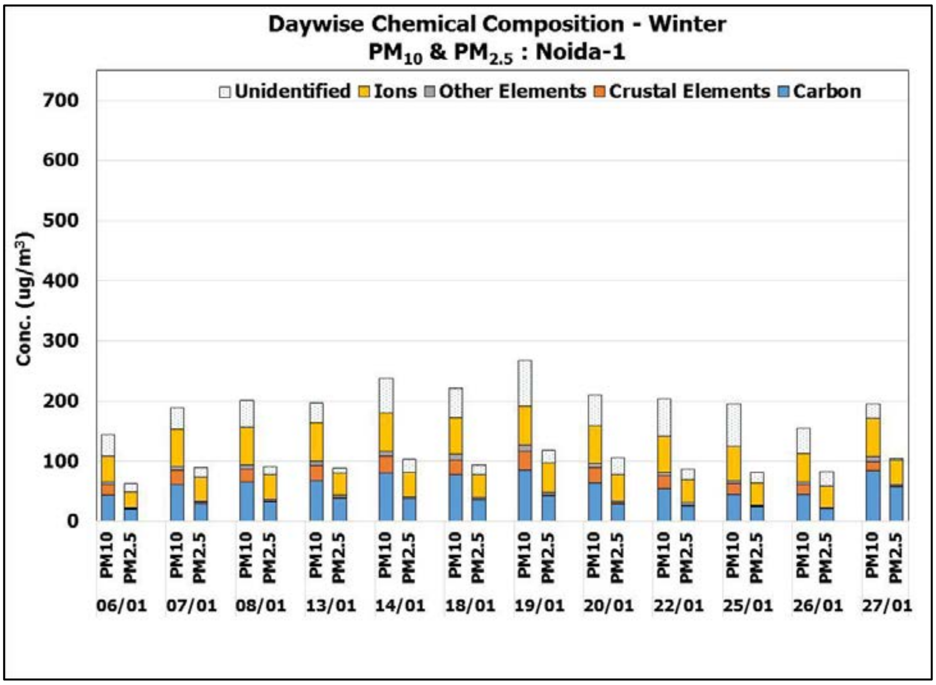


Figure 3.142: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Noida-1 in winter season

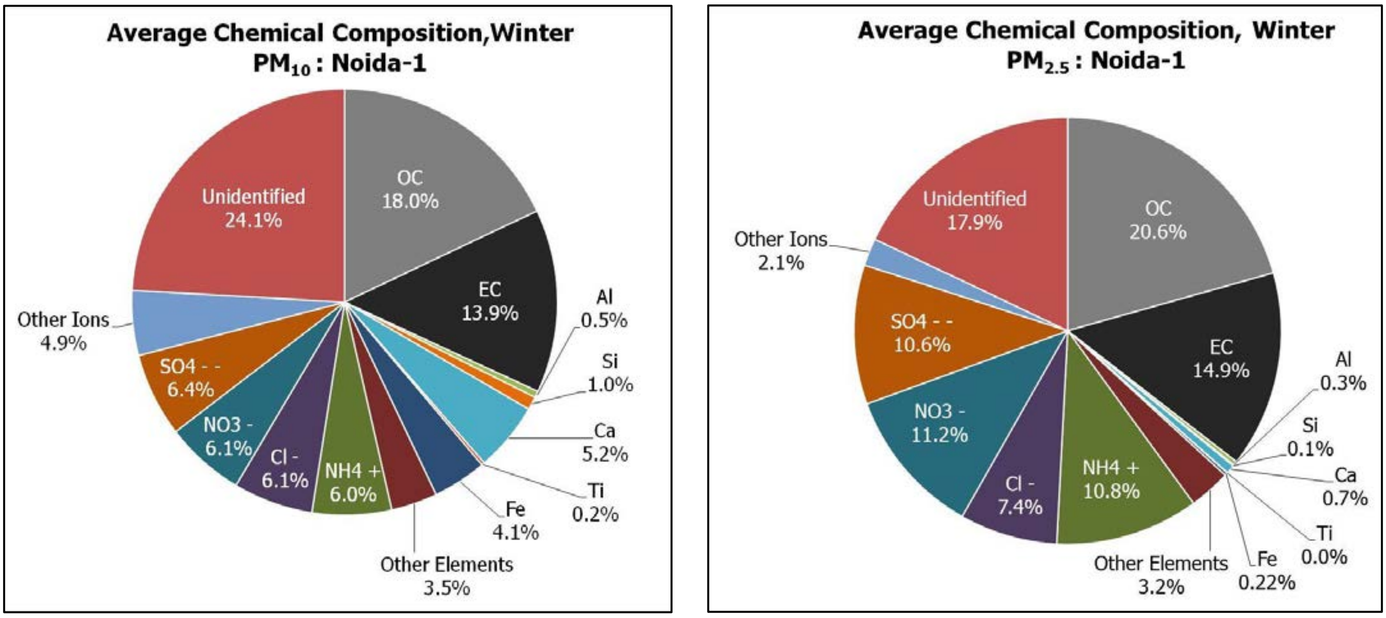


Figure 3.143: Average chemical composition of PM$_{10}$ and PM$_{2.5}$ at Noida-1 in winter season

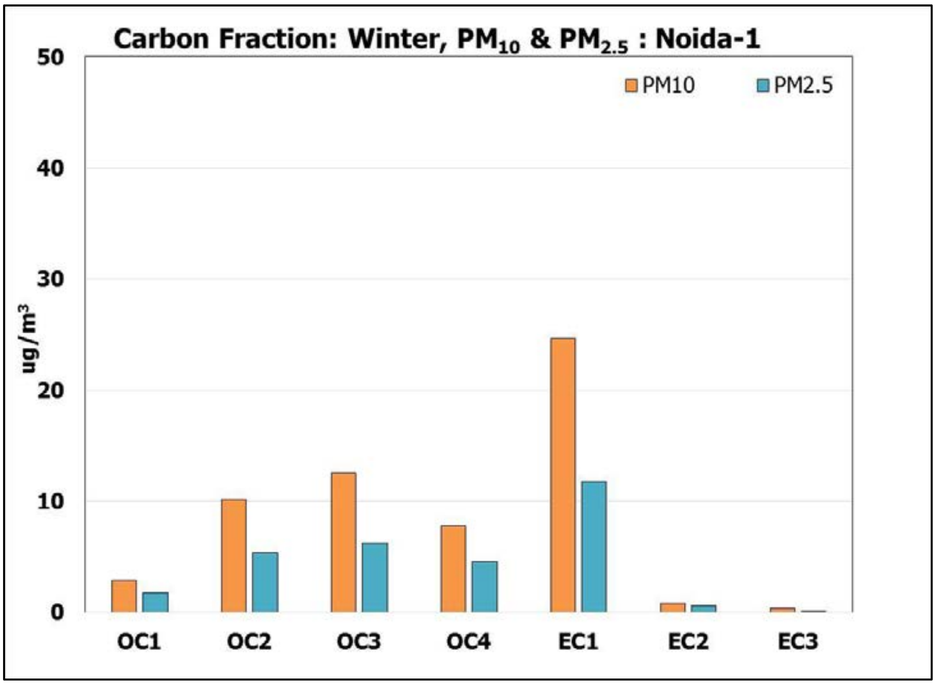


Figure 3.144: Average concentration of carbon fractions of PM$_{10}$ and PM$_{2.5}$ at Noida-1 in winter season

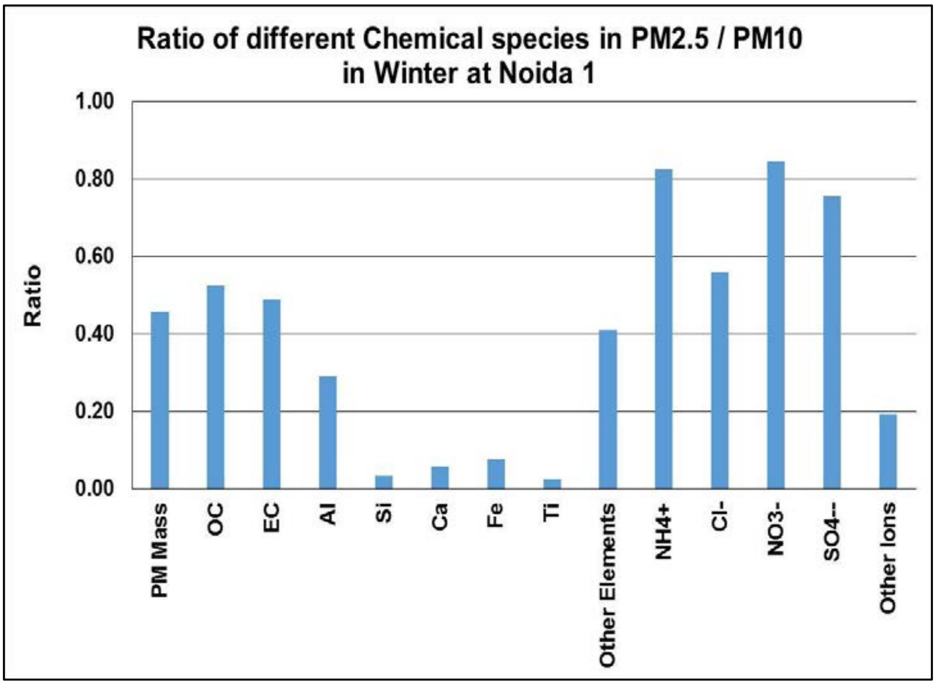


Figure 3.145: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Noida-1

Average concentration of PM_{10} and $PM_{2.5}$ was found to be 201±33 µg/m^3 and 92±14 µg/m^3, respectively. The PM_{10} concentration varied from 144 to 268 µg/m^3 and that of $PM_{2.5}$ varied from 62 to 118 µg/m^3 (see Figure 3.141).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.142.

The total ions were found to be the major fraction, followed by the carbon fraction and crustal elements. The total ion of PM_{10} was found to be 29% while $PM_{2.5}$ was found to be higher than that of PM_{10}, that is, 42%. The carbon fraction of PM_{10} showed 64 µg/m^3 while that of $PM_{2.5}$ showed 33 µg/m^3. The % of the mass distribution showed that the OC and EC of $PM_{2.5}$ were a little higher as compared to PM_{10}. The crustal elements of PM_{10} was found to be 11% while that of $PM_{2.5}$ was found to be very less, that is, 1% (see Figure 3.143).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% and 3% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed for PM_{10} was found to be 24% and in case of $PM_{2.5}$, it was found to be 18%.

The OC3 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by OC2, OC4, and OC1. The EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.144). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.145.

Table 3.113: Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of PM_{10} at Noida-1 for winter season

$\mu g/m^3$																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	201	36.14	28.07	1.00	2.01	10.55	8.23	0.45	2.82	1.84	0.44	0.87	12.19	12.21	12.84	0.81	12.11	2.14	5.89
SD	33	8.32	7.93	0.30	0.53	2.25	1.93	0.26	0.92	0.53	0.21	0.37	1.85	1.75	1.85	0.24	1.54	0.70	1.17
Min	144	23.91	17.34	0.53	1.20	7.01	5.40	0.20	1.35	1.04	0.11	0.29	10.10	7.80	8.84	0.43	8.82	1.18	4.02
Max	268	49.66	39.79	1.56	2.85	14.27	11.89	0.96	4.64	2.69	0.86	1.50	15.19	14.41	14.42	1.31	13.94	3.08	8.03
C.V.	0.16	0.23	0.28	0.30	0.26	0.21	0.23	0.57	0.33	0.29	0.47	0.42	0.15	0.14	0.14	0.29	0.13	0.33	0.20
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95%ile	251	46.84	38.01	1.43	2.81	13.69	11.06	0.93	4.13	2.55	0.80	1.43	14.97	13.88	14.30	1.14	13.74	3.07	7.54
50%ile	201	36.48	28.75	0.97	2.08	10.77	8.23	0.39	2.82	1.84	0.40	0.82	12.00	12.33	13.65	0.81	12.26	2.14	5.72
5 %ile	105	18.45	14.05	0.45	0.96	5.34	4.18	0.21	1.20	0.86	0.17	0.34	7.21	5.68	6.39	0.36	6.27	1.01	3.02

Table 3.114 : Statistical **evaluation of concentrations ($\mu g/m^3$)** of mass and major species of $PM_{2.5}$ at Noida-1 for winter season

$\mu g/m^3$																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	92	18.99	13.69	0.29	0.07	0.61	0.21	0.03	0.99	0.87	0.22	0.41	6.82	10.32	9.71	0.36	9.98	0.76	0.41
SD	14	5.36	5.25	0.26	0.04	0.36	0.08	0.04	0.15	0.31	0.08	0.13	1.98	1.38	1.40	0.17	1.32	0.15	0.22
Min	62	12.33	7.27	0.08	0.02	0.10	0.11	0.00	0.72	0.38	0.09	0.14	3.72	7.09	6.84	0.16	7.14	0.51	0.11
Max	118	29.57	27.66	0.83	0.15	1.19	0.33	0.12	1.24	1.37	0.35	0.54	10.25	12.26	12.46	0.62	12.55	0.92	0.84
C.V.	0.16	0.28	0.38	0.89	0.55	0.58	0.38	1.21	0.15	0.35	0.37	0.32	0.29	0.13	0.14	0.47	0.13	0.19	0.55
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95%ile	111	26.62	21.90	0.75	0.15	1.19	0.33	0.10	1.17	1.31	0.32	0.53	9.82	11.98	11.48	0.59	11.93	0.92	0.81
50%ile	90	18.99	12.92	0.17	0.06	0.53	0.19	0.01	1.01	0.85	0.23	0.42	6.41	10.08	9.79	0.27	10.11	0.78	0.33
5%ile	73	12.77	7.97	0.08	0.03	0.22	0.11	0.00	0.73	0.41	0.10	0.17	4.47	8.30	7.62	0.18	8.04	0.52	0.17

Table 3.115: Correlation matrix for PM_{10} and its composition for winter season at Noida-1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.81																			
	0.00																			
EC	0.67	0.81																		
	0.02	*0.00*																		
TC	0.78	0.95	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.41	0.64	0.71	0.71																
	0.18	*0.03*	*0.01*	*0.01*																
NO_3^-	0.61	0.49	0.45	0.49	0.44															
	0.04	*0.10*	*0.15*	*0.10*	*0.15*															
SO_4^{--}	0.63	0.58	0.36	0.50	0.26	0.71														
	0.03	*0.05*	*0.25*	*0.10*	*0.41*	*0.01*														
Na^+	0.85	0.75	0.53	0.68	0.47	0.37	0.56													
	0.00	*0.01*	*0.08*	*0.02*	*0.12*	*0.24*	*0.06*													
NH_4^+	0.71	0.78	0.55	0.70	0.52	0.65	0.86	0.70												
	0.01	*0.00*	*0.07*	*0.01*	*0.08*	*0.02*	*0.00*	*0.01*												
K^+	0.60	0.67	0.79	0.76	0.40	0.27	0.35	0.45	0.52											
	0.04	*0.02*	*0.00*	*0.00*	*0.20*	*0.39*	*0.27*	*0.14*	*0.08*											
Ca^{++}	0.66	0.56	0.45	0.53	0.23	0.17	0.37	0.66	0.38	0.22										
	0.02	*0.06*	*0.15*	*0.08*	*0.47*	*0.59*	*0.23*	*0.02*	*0.22*	*0.50*										
Si	0.80	0.61	0.39	0.53	0.36	0.54	0.38	0.62	0.52	0.16	0.66									
	0.00	*0.04*	*0.21*	*0.08*	*0.25*	*0.07*	*0.22*	*0.03*	*0.09*	*0.61*	*0.02*									
Al	0.72	0.53	0.36	0.47	0.46	0.58	0.28	0.58	0.53	0.17	0.42	0.92								
	0.01	*0.07*	*0.25*	*0.12*	*0.14*	*0.05*	*0.37*	*0.05*	*0.08*	*0.60*	*0.18*	*0.00*								
Ca	0.75	0.61	0.41	0.54	0.33	0.43	0.28	0.63	0.50	0.18	0.69	0.94	0.91							
	0.01	*0.04*	*0.19*	*0.07*	*0.29*	*0.17*	*0.37*	*0.03*	*0.10*	*0.57*	*0.01*	*0.00*	*0.00*							
Fe	0.81	0.59	0.34	0.49	0.16	0.46	0.37	0.69	0.51	0.20	0.61	0.89	0.86	0.94						
	0.00	*0.05*	*0.28*	*0.11*	*0.63*	*0.13*	*0.23*	*0.01*	*0.09*	*0.54*	*0.04*	*0.00*	*0.00*	*0.00*						
Ti	0.72	0.68	0.53	0.63	0.56	0.14	0.07	0.77	0.36	0.39	0.51	0.70	0.72	0.72	0.69					
	0.01	*0.02*	*0.08*	*0.03*	*0.06*	*0.66*	*0.84*	*0.00*	*0.25*	*0.21*	*0.09*	*0.01*	*0.01*	*0.01*	*0.01*					
K	0.79	0.65	0.72	0.72	0.32	0.33	0.50	0.73	0.56	0.85	0.45	0.34	0.27	0.30	0.39	0.51				
	0.00	*0.02*	*0.01*	*0.01*	*0.31*	*0.30*	*0.10*	*0.01*	*0.06*	*0.00*	*0.14*	*0.28*	*0.40*	*0.35*	*0.21*	*0.09*				
S	0.62	0.81	0.68	0.78	0.57	0.44	0.52	0.61	0.76	0.65	0.60	0.49	0.44	0.55	0.43	0.43	0.55			
	0.03	*0.00*	*0.02*	*0.00*	*0.05*	*0.16*	*0.08*	*0.04*	*0.00*	*0.02*	*0.04*	*0.11*	*0.15*	*0.06*	*0.16*	*0.17*	*0.07*			
Ni	0.25	0.42	0.17	0.32	0.48	0.08	0.20	0.47	0.57	0.28	0.25	0.33	0.43	0.40	0.25	0.41	0.19	0.70		
	0.43	*0.17*	*0.59*	*0.32*	*0.12*	*0.80*	*0.54*	*0.12*	*0.05*	*0.38*	*0.44*	*0.30*	*0.17*	*0.20*	*0.44*	*0.18*	*0.55*	*0.01*		
Pb	0.41	0.63	0.79	0.74	0.54	0.43	0.33	0.36	0.43	0.78	0.12	0.01	0.01	-0.02	-0.03	0.20	0.66	0.61	0.17	
	0.18	*0.03*	*0.00*	*0.01*	*0.07*	*0.17*	*0.30*	*0.25*	*0.17*	*0.00*	*0.71*	*0.97*	*0.98*	*0.95*	*0.94*	*0.54*	*0.02*	*0.04*	*0.59*	
Zn	0.57	0.63	0.54	0.61	0.55	0.40	0.46	0.53	0.65	0.49	0.63	0.57	0.46	0.52	0.33	0.39	0.48	0.88	0.72	0.46
	0.05	*0.03*	*0.07*	*0.03*	*0.06*	*0.19*	*0.13*	*0.08*	*0.02*	*0.10*	*0.03*	*0.05*	*0.13*	*0.08*	*0.29*	*0.21*	*0.11*	*0.00*	*0.01*	*0.13*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.116: Correlation matrix for $PM_{2.5}$ and its composition for winter season at Noida-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.67																			
	0.02																			
EC	0.65	0.89																		
	0.02	*0.00*																		
TC	0.68	0.97	0.97																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.87	0.69	0.72	0.72																
	0.00	*0.01*	*0.01*	*0.01*																
NO_3^-	0.71	0.44	0.41	0.44	0.40															
	0.01	*0.15*	*0.18*	*0.15*	*0.20*															
SO_4^{--}	0.72	0.25	0.41	0.34	0.48	0.68														
	0.01	*0.44*	*0.19*	*0.29*	*0.12*	*0.02*														
Na^+	0.55	0.61	0.57	0.61	0.44	0.24	0.22													
	0.06	*0.03*	*0.06*	*0.04*	*0.15*	*0.46*	*0.50*													
NH_4^+	0.80	0.40	0.34	0.38	0.43	0.78	0.84	0.45												
	0.00	*0.20*	*0.28*	*0.23*	*0.16*	*0.00*	*0.00*	*0.15*												
K^+	0.63	0.62	0.59	0.62	0.57	0.44	0.47	0.21	0.46											
	0.03	*0.03*	*0.04*	*0.03*	*0.06*	*0.16*	*0.13*	*0.51*	*0.13*											
Ca^{++}	0.43	0.06	0.20	0.14	0.18	0.36	0.76	0.01	0.63	0.22										
	0.17	*0.84*	*0.53*	*0.68*	*0.57*	*0.26*	*0.00*	*0.99*	*0.03*	*0.50*										
Si	0.63	0.25	0.32	0.29	0.54	0.45	0.70	0.02	0.52	0.40	0.67									
	0.03	*0.43*	*0.31*	*0.36*	*0.07*	*0.14*	*0.01*	*0.95*	*0.08*	*0.20*	*0.02*									
Al	0.20	0.25	-0.03	0.12	-0.03	0.42	0.19	-0.19	0.38	0.32	0.24	0.06								
	0.53	*0.43*	*0.93*	*0.72*	*0.93*	*0.17*	*0.55*	*0.56*	*0.22*	*0.32*	*0.45*	*0.84*								
Ca	0.49	-0.01	0.15	0.08	0.28	0.46	0.78	-0.14	0.58	0.32	0.91	0.83	0.18							
	0.11	*0.98*	*0.63*	*0.82*	*0.37*	*0.14*	*0.00*	*0.67*	*0.05*	*0.32*	*0.00*	*0.00*	*0.57*							
Fe	0.66	0.31	0.42	0.37	0.39	0.68	0.73	0.39	0.74	0.29	0.67	0.73	-0.09	0.72						
	0.02	*0.33*	*0.18*	*0.23*	*0.22*	*0.02*	*0.01*	*0.21*	*0.01*	*0.36*	*0.02*	*0.01*	*0.78*	*0.01*						
Ti	0.21	0.25	0.01	0.13	-0.04	0.45	0.27	-0.20	0.40	0.32	0.35	0.18	0.98	0.30	0.01					
	0.52	*0.44*	*0.97*	*0.68*	*0.90*	*0.14*	*0.40*	*0.54*	*0.20*	*0.30*	*0.26*	*0.58*	*0.00*	*0.34*	*0.99*					
K	0.78	0.66	0.65	0.67	0.63	0.58	0.71	0.35	0.77	0.79	0.57	0.47	0.42	0.53	0.52	0.43				
	0.00	*0.02*	*0.02*	*0.02*	*0.03*	*0.05*	*0.01*	*0.26*	*0.00*	*0.00*	*0.05*	*0.13*	*0.17*	*0.08*	*0.08*	*0.16*				
S	0.69	0.20	0.18	0.19	0.43	0.57	0.70	0.12	0.79	0.57	0.70	0.57	0.40	0.76	0.62	0.43	0.79			
	0.01	*0.53*	*0.58*	*0.55*	*0.17*	*0.05*	*0.01*	*0.71*	*0.00*	*0.06*	*0.01*	*0.05*	*0.19*	*0.00*	*0.03*	*0.17*	*0.00*			
Ni	0.24	-0.11	-0.31	-0.22	-0.14	0.58	0.41	0.01	0.61	0.06	0.21	0.31	0.46	0.29	0.40	0.47	0.18	0.42		
	0.46	*0.73*	*0.33*	*0.50*	*0.67*	*0.05*	*0.18*	*0.98*	*0.04*	*0.86*	*0.50*	*0.33*	*0.13*	*0.36*	*0.20*	*0.12*	*0.58*	*0.18*		
Pb	0.78	0.80	0.83	0.84	0.69	0.56	0.40	0.64	0.51	0.66	0.26	0.32	0.08	0.27	0.55	0.10	0.72	0.51	-0.13	
	0.00	*0.00*	*0.00*	*0.00*	*0.01*	*0.06*	*0.20*	*0.02*	*0.09*	*0.02*	*0.42*	*0.32*	*0.80*	*0.39*	*0.06*	*0.76*	*0.01*	*0.09*	*0.70*	
Zn	0.75	0.67	0.63	0.67	0.69	0.55	0.46	0.30	0.58	0.82	0.30	0.41	0.29	0.38	0.47	0.28	0.89	0.74	0.09	0.79
	0.01	*0.02*	*0.03*	*0.02*	*0.01*	*0.07*	*0.13*	*0.34*	*0.05*	*0.00*	*0.34*	*0.19*	*0.36*	*0.22*	*0.13*	*0.39*	*0.00*	*0.01*	*0.78*	*0.00*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.113 and Table 3.114 for PM mass and major species, respectively. Both PM_{10} mass and $PM_{2.5}$ mass shows a similar C.V. The crustal elements show a very high variation in $PM_{2.5}$, whereas PM_{10} shows less C.V. The secondary particulates show less variation in PM_{10} as compared to $PM_{2.5}$.

Correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.115 and Table 3.116 for the PM mass and its major species. OC, EC, and TC show a similar correlation with both PM_{10} mass and $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass as compared to $PM_{2.5}$. The secondary particulates show a better correlation with each other in $PM_{2.5}$ than in PM_{10}.

3.1.16 Site 16: Noida-2

3.1.16.1 Summer season

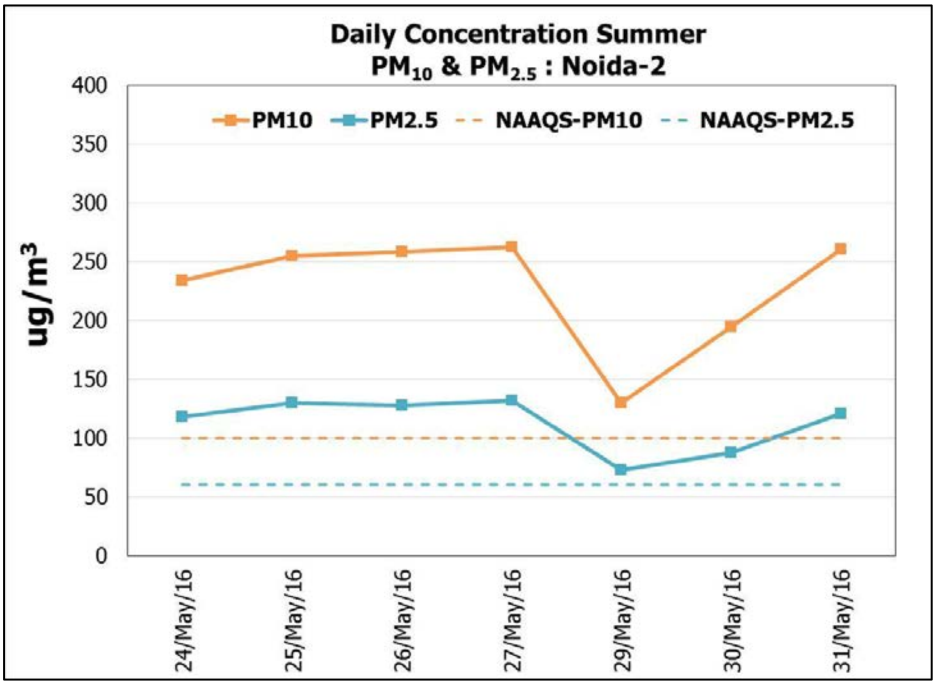


Figure 3.146: Variation in 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Noida-2 in summer season

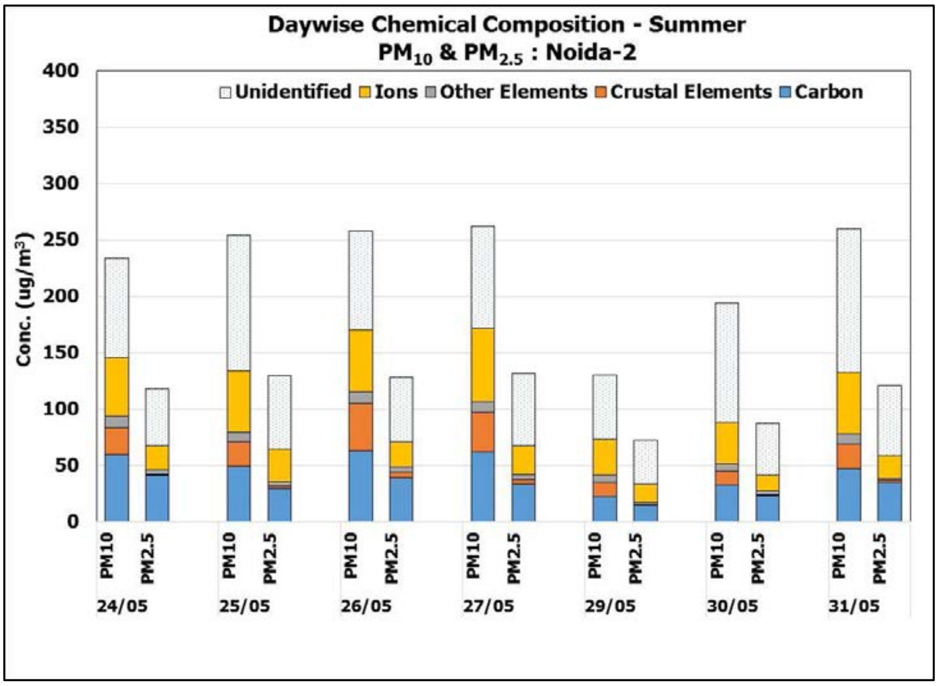


Figure 3.147: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Noida-2 in summer season

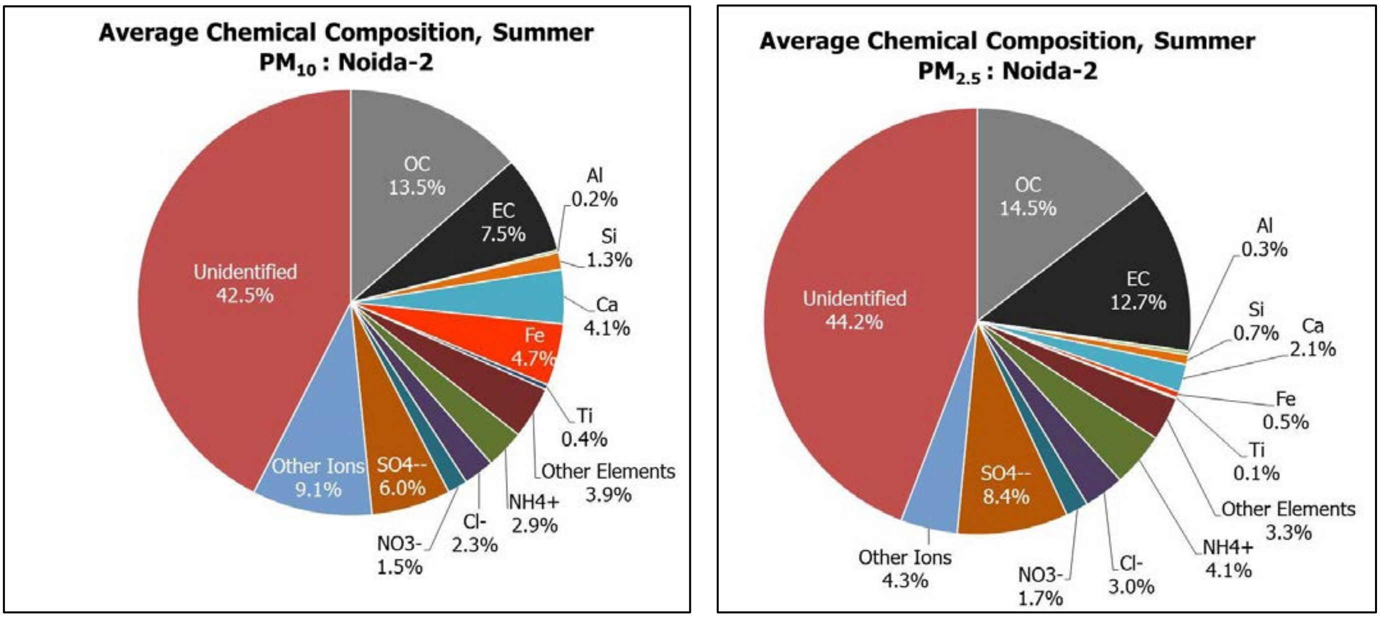


Figure 3.148: average chemical composition of PM_{10} and $PM_{2.5}$ at Noida-2 in summer season

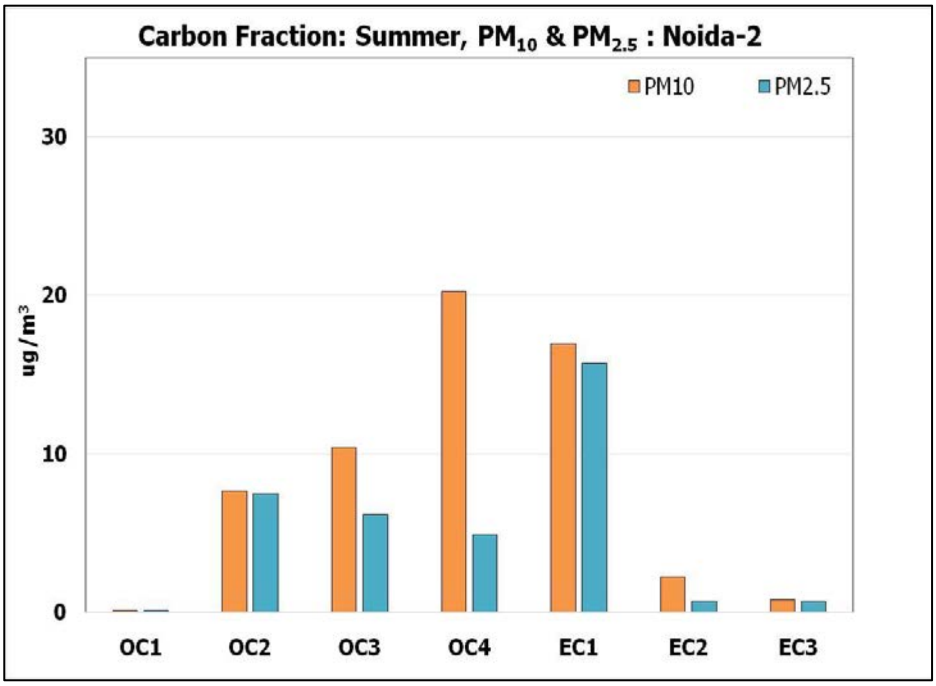


Figure 3.149: average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Noida-2 in summer season

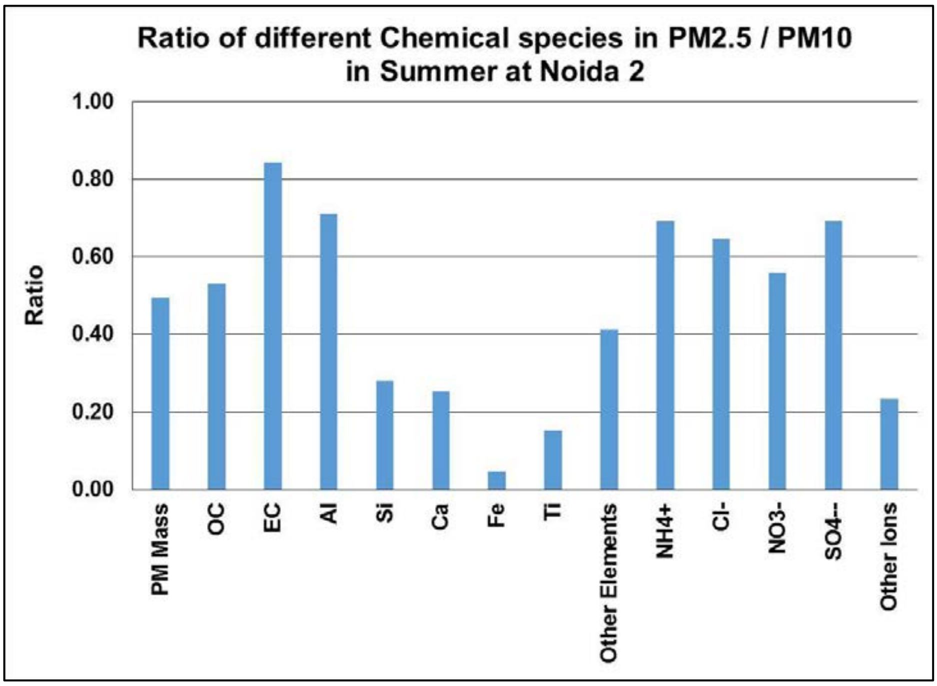


Figure 3.150: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in summer season at Noida-2

Average concentration of PM_{10} at Sector-1, Noida (NOI-2) site was found to be 228±49 µg/m^3, which is 2.3 times the permissible limit of 100 µg/m^{3}as per the NAAQS and Concentration of PM_{10} varied from 130 to 262 µg/m^3. $PM_{2.5}$ was found to follow a similar trend with values ranging from 72 to 132 µg/m^3 with an average concentration of 112±23 µg/m^3 (see Figure 3.146).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.147.

The average of organic and elemental carbon in PM_{10} was found to be 48 µg/m^3 and 31 µg/m^3 in case of $PM_{2.5}$. The % of mass distribution showed that the organic carbon and elemental carbon in $PM_{2.5}$ was higher as compared to PM_{10}. The total ions observed in PM_{10} and $PM_{2.5}$ is 22% in PM_{10} and 19% in $PM_{2.5}$. The crustal element were found to be 11% in PM_{10} and 2% in $PM_{2.5}$ (see Figure 3.148.

Concentration of the other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% in PM_{10} and 3% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 43% in PM_{10} and 49% in $PM_{2.5}$.

In Elemental carbon, EC1 was found to be highest in both PM_{10} and $PM_{2.5}$, followed by EC2 and EC3. In case of organic carbon, OC4 was found to be highest in PM_{10}, followed by Oc3 and OC2, whereas in $PM_{2.5}$, OC2 was found to be highest followed by OC3, and OC4 (see Figure 3.149). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.150.

Table 3.117: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Noida-2 for summer season

µg/m^3																			
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	228	30.83	16.99	0.44	2.97	9.32	10.71	0.87	4.48	1.70	0.22	0.61	5.30	3.42	13.66	6.00	6.70	3.22	7.51
SD	49	11.60	4.75	0.12	1.41	4.14	5.11	0.40	0.81	0.46	0.03	0.11	1.35	1.45	3.73	1.55	1.83	0.79	3.51
Min	130	12.28	9.81	0.30	1.09	4.31	5.39	0.47	3.14	0.86	0.19	0.47	3.37	1.52	9.22	3.12	4.50	1.78	3.12
Max	262	44.10	24.47	0.57	4.58	16.61	18.93	1.59	5.47	2.33	0.27	0.76	7.09	4.86	18.47	8.11	9.40	4.11	12.28
C.V.	0.22	0.38	0.28	0.26	0.47	0.44	0.48	0.46	0.18	0.27	0.12	0.18	0.26	0.42	0.27	0.26	0.27	0.25	0.47
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95%ile	262	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50%ile	254	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5%ile	149	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.118: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Noida 2 for summer season

µg/m^3																			
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	112	16.33	14.32	0.31	0.83	2.36	0.52	0.13	1.43	1.18	0.13	0.15	3.43	1.92	9.44	1.04	4.63	1.06	1.72
SD	23	5.30	4.69	0.14	0.18	1.06	0.48	0.04	0.27	0.54	0.04	0.06	0.68	1.09	2.68	0.21	1.42	0.23	2.14
Min	72	7.01	7.41	0.18	0.65	1.25	0.11	0.09	0.96	0.70	0.10	0.08	2.60	0.77	6.09	0.66	3.10	0.77	0.02
Max	132	22.65	22.41	0.56	1.17	3.85	1.37	0.20	1.69	2.15	0.21	0.27	4.57	3.67	13.96	1.39	7.46	1.39	6.39
C.V.	0.21	0.32	0.33	0.46	0.21	0.45	0.92	0.29	0.19	0.46	0.32	0.40	0.20	0.57	0.28	0.21	0.31	0.22	1.25
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	131	22.03	20.60	0.51	1.10	3.82	1.25	0.19	1.69	1.93	0.19	0.24	4.35	3.38	13.09	1.31	6.74	1.37	5.00
50 %ile	121	17.91	14.50	0.25	0.81	1.89	0.24	0.11	1.44	1.25	0.12	0.16	3.37	1.96	9.92	1.02	4.53	0.98	1.25
5 %ile	77	8.65	8.35	0.19	0.66	1.35	0.13	0.10	1.06	0.70	0.10	0.09	2.69	0.82	6.42	0.76	3.25	0.81	0.17

Table 3.119: correlation matrix for PM$_{10}$ and its composition for summer season at Noida-2

	PM$_{10}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.90																			
	0.01																			
EC	0.70	0.79																		
	0.08	*0.03*																		
TC	0.88	0.98	0.89																	
	0.01	*0.00*	*0.01*																	
Cl$^-$	0.67	0.74	0.48	0.69																
	0.10	*0.06*	*0.28*	*0.09*																
NO$_3^-$	0.82	0.70	0.45	0.66	0.37															
	0.02	*0.08*	*0.31*	*0.11*	*0.41*															
SO$_4^{--}$	0.73	0.62	0.42	0.59	0.17	0.92														
	0.06	*0.14*	*0.35*	*0.17*	*0.71*	*0.00*														
Na$^+$	0.85	0.83	0.81	0.86	0.63	0.45	0.34													
	0.02	*0.02*	*0.03*	*0.01*	*0.13*	*0.31*	*0.46*													
NH$_4^+$	0.81	0.66	0.46	0.63	0.29	0.97	0.98	0.42												
	0.03	*0.11*	*0.30*	*0.13*	*0.53*	*0.00*	*0.00*	*0.35*												
K$^+$	0.49	0.73	0.79	0.78	0.34	0.47	0.35	0.57	0.37											
	0.26	*0.06*	*0.04*	*0.04*	*0.46*	*0.29*	*0.44*	*0.18*	*0.41*											
Ca^{++}	0.74	0.95	0.67	0.91	0.77	0.49	0.43	0.74	0.44	0.69										
	0.06	*0.00*	*0.10*	*0.01*	*0.04*	*0.26*	*0.34*	*0.06*	*0.32*	*0.09*										
Si	0.82	0.99	0.79	0.97	0.70	0.63	0.54	0.80	0.57	0.81	0.97									
	0.03	*0.00*	*0.04*	*0.00*	*0.08*	*0.13*	*0.21*	*0.03*	*0.18*	*0.03*	*0.00*									
Al	0.71	0.79	0.60	0.77	0.25	0.54	0.64	0.71	0.58	0.57	0.74	0.79								
	0.07	*0.04*	*0.16*	*0.05*	*0.59*	*0.21*	*0.13*	*0.08*	*0.18*	*0.18*	*0.06*	*0.04*								
Ca	0.71	0.88	0.64	0.85	0.73	0.48	0.28	0.79	0.34	0.77	0.91	0.92	0.65							
	0.07	*0.01*	*0.13*	*0.02*	*0.06*	*0.28*	*0.54*	*0.04*	*0.45*	*0.04*	*0.00*	*0.00*	*0.11*							
Fe	0.67	0.90	0.60	0.85	0.77	0.41	0.29	0.73	0.32	0.69	0.98	0.94	0.70	0.96						
	0.10	*0.01*	*0.15*	*0.02*	*0.04*	*0.36*	*0.52*	*0.06*	*0.48*	*0.09*	*0.00*	*0.00*	*0.08*	*0.00*						
Ti	0.67	0.86	0.58	0.81	0.71	0.39	0.23	0.78	0.28	0.69	0.92	0.90	0.70	0.98	0.98					
	0.10	*0.01*	*0.18*	*0.03*	*0.07*	*0.39*	*0.62*	*0.04*	*0.55*	*0.09*	*0.00*	*0.01*	*0.08*	*0.00*	*0.00*					
K	0.85	0.78	0.88	0.84	0.37	0.77	0.73	0.76	0.79	0.68	0.55	0.72	0.64	0.54	0.46	0.45				
	0.02	*0.04*	*0.01*	*0.02*	*0.42*	*0.04*	*0.06*	*0.05*	*0.04*	*0.09*	*0.20*	*0.07*	*0.13*	*0.21*	*0.31*	*0.31*				
S	0.51	0.57	0.71	0.64	-0.02	0.66	0.65	0.43	0.64	0.84	0.39	0.60	0.59	0.44	0.33	0.34	0.82			
	0.25	*0.18*	*0.08*	*0.12*	*0.96*	*0.11*	*0.11*	*0.34*	*0.12*	*0.02*	*0.38*	*0.16*	*0.17*	*0.33*	*0.46*	*0.46*	*0.03*			
Ni	0.60	0.83	0.58	0.79	0.76	0.29	0.13	0.73	0.18	0.68	0.93	0.88	0.62	0.97	0.98	0.98	0.38	0.27		
	0.16	*0.02*	*0.18*	*0.03*	*0.05*	*0.53*	*0.78*	*0.06*	*0.70*	*0.09*	*0.00*	*0.01*	*0.14*	*0.00*	*0.00*	*0.00*	*0.40*	*0.57*		
Pb	0.26	0.38	0.72	0.50	0.22	-0.01	0.18	0.40	0.14	0.31	0.35	0.37	0.32	0.09	0.22	0.10	0.48	0.28	0.17	
	0.57	*0.40*	*0.07*	*0.25*	*0.64*	*0.98*	*0.70*	*0.38*	*0.76*	*0.50*	*0.44*	*0.42*	*0.49*	*0.85*	*0.63*	*0.83*	*0.28*	*0.54*	*0.71*	
Zn	0.31	0.28	0.18	0.26	-0.37	0.61	0.80	0.05	0.69	0.32	0.14	0.27	0.63	0.05	0.05	0.03	0.46	0.69	-0.09	0.03
	0.50	*0.54*	*0.71*	*0.57*	*0.41*	*0.14*	*0.03*	*0.92*	*0.09*	*0.49*	*0.76*	*0.55*	*0.13*	*0.92*	*0.91*	*0.95*	*0.30*	*0.08*	*0.86*	*0.95*

Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.120: correlation matrix for $PM_{2.5}$ and its composition for summer season at Noida-2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.86																			
	0.03																			
EC	0.72	0.79																		
	0.11	*0.06*																		
TC	0.83	0.95	0.94																	
	0.04	*0.00*	*0.01*																	
Cl^-	0.64	0.85	0.78	0.86																
	0.17	*0.03*	*0.07*	*0.03*																
NO_3^-	0.87	0.61	0.56	0.62	0.37															
	0.02	*0.20*	*0.25*	*0.19*	*0.47*															
SO_4^{--}	0.81	0.44	0.47	0.48	0.39	0.78														
	0.05	*0.38*	*0.35*	*0.34*	*0.45*	*0.07*														
Na^+	0.54	0.32	0.31	0.34	-0.03	0.83	0.36													
	0.27	*0.53*	*0.55*	*0.52*	*0.96*	*0.04*	*0.48*													
NH_4^+	0.88	0.54	0.60	0.60	0.35	0.92	0.94	0.63												
	0.02	*0.27*	*0.21*	*0.21*	*0.50*	*0.01*	*0.01*	*0.18*												
K^+	0.57	0.52	0.18	0.37	0.40	0.18	0.50	-0.26	0.36											
	0.24	*0.29*	*0.74*	*0.47*	*0.43*	*0.73*	*0.31*	*0.63*	*0.49*											
Ca^{++}	0.92	0.77	0.45	0.65	0.43	0.87	0.66	0.65	0.77	0.54										
	0.01	*0.07*	*0.37*	*0.16*	*0.40*	*0.03*	*0.15*	*0.16*	*0.08*	*0.27*										
Si	0.86	0.64	0.28	0.49	0.40	0.79	0.78	0.46	0.76	0.67	0.93									
	0.03	*0.18*	*0.59*	*0.33*	*0.43*	*0.06*	*0.07*	*0.36*	*0.08*	*0.15*	*0.01*									
Al	0.45	0.58	0.05	0.34	0.27	0.46	0.01	0.50	0.14	0.21	0.71	0.59								
	0.37	*0.23*	*0.92*	*0.51*	*0.61*	*0.36*	*0.99*	*0.31*	*0.79*	*0.68*	*0.11*	*0.22*								
Ca	0.81	0.79	0.35	0.61	0.50	0.75	0.46	0.58	0.55	0.46	0.94	0.87	0.88							
	0.05	*0.06*	*0.50*	*0.20*	*0.31*	*0.08*	*0.35*	*0.23*	*0.26*	*0.36*	*0.01*	*0.02*	*0.02*							
Fe	0.54	0.70	0.22	0.50	0.59	0.48	0.18	0.33	0.20	0.31	0.69	0.65	0.90	0.89						
	0.26	*0.12*	*0.67*	*0.32*	*0.22*	*0.34*	*0.74*	*0.52*	*0.70*	*0.55*	*0.13*	*0.16*	*0.01*	*0.02*						
Ti	0.56	0.68	0.20	0.47	0.54	0.52	0.20	0.40	0.24	0.28	0.72	0.68	0.92	0.91	1.00					
	0.25	*0.14*	*0.71*	*0.35*	*0.27*	*0.29*	*0.71*	*0.43*	*0.65*	*0.59*	*0.11*	*0.14*	*0.01*	*0.01*	*0.00*					
K	0.80	0.81	0.64	0.77	0.66	0.42	0.58	0.01	0.57	0.86	0.66	0.64	0.23	0.54	0.33	0.30				
	0.06	*0.05*	*0.17*	*0.07*	*0.16*	*0.41*	*0.23*	*0.99*	*0.24*	*0.03*	*0.15*	*0.17*	*0.67*	*0.27*	*0.52*	*0.56*				
S	0.67	0.69	0.97	0.88	0.73	0.62	0.51	0.41	0.64	0.01	0.40	0.24	0.00	0.31	0.19	0.17	0.48			
	0.14	*0.13*	*0.00*	*0.02*	*0.10*	*0.19*	*0.31*	*0.42*	*0.18*	*0.99*	*0.43*	*0.64*	*1.00*	*0.56*	*0.72*	*0.74*	*0.33*			
Ni	0.45	0.60	0.11	0.38	0.52	0.42	0.13	0.29	0.13	0.26	0.62	0.61	0.89	0.85	0.99	0.99	0.23	0.09		
	0.37	*0.21*	*0.84*	*0.46*	*0.29*	*0.41*	*0.81*	*0.57*	*0.81*	*0.62*	*0.19*	*0.20*	*0.02*	*0.03*	*0.00*	*0.00*	*0.66*	*0.87*		
Pb	0.68	0.36	0.37	0.38	0.03	0.93	0.62	0.95	0.82	-0.05	0.74	0.61	0.39	0.59	0.26	0.33	0.18	0.46	0.22	
	0.14	*0.49*	*0.47*	*0.45*	*0.96*	*0.01*	*0.19*	*0.00*	*0.04*	*0.92*	*0.10*	*0.20*	*0.45*	*0.22*	*0.61*	*0.52*	*0.74*	*0.36*	*0.68*	
Zn	0.72	0.50	0.37	0.47	0.16	0.94	0.54	0.96	0.75	0.00	0.83	0.69	0.63	0.77	0.52	0.58	0.22	0.44	0.48	0.96
	0.11	*0.31*	*0.47*	*0.35*	*0.76*	*0.01*	*0.27*	*0.00*	*0.09*	*1.00*	*0.04*	*0.13*	*0.19*	*0.07*	*0.29*	*0.22*	*0.68*	*0.38*	*0.33*	*0.00*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For Summer Season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.117 and Table 3.118 for PM mass and major species respectively. Both in PM_{10} and $PM_{2.5}$, PM mass has a similar C.V. For crustal elements, C.V. for PM10 is less as compared to PM2.5. In both PM_{10} and $PM_{2.5}$, the secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show a similar C.V.

The correlation matrix for PM_{10} and $PM_{2.5}$ is given in Table 3.119 and Table 3.120 for PM mass and its major species. OC, EC, and TC show a similar correlation with both $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass as compared to $PM_{2.5}$ mass. The secondary particulates showed a better correlation with each other in both PM_{10} and $PM_{2.5}$.

3.1.16.2 Winter season:

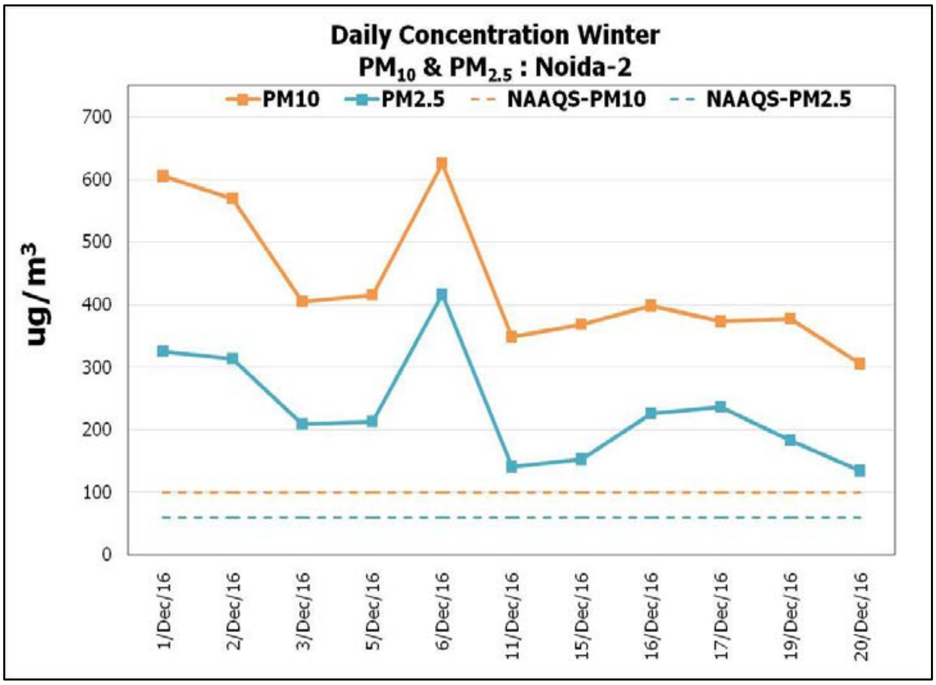


Figure 3.151: Variation in 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Noida-2 in winter season

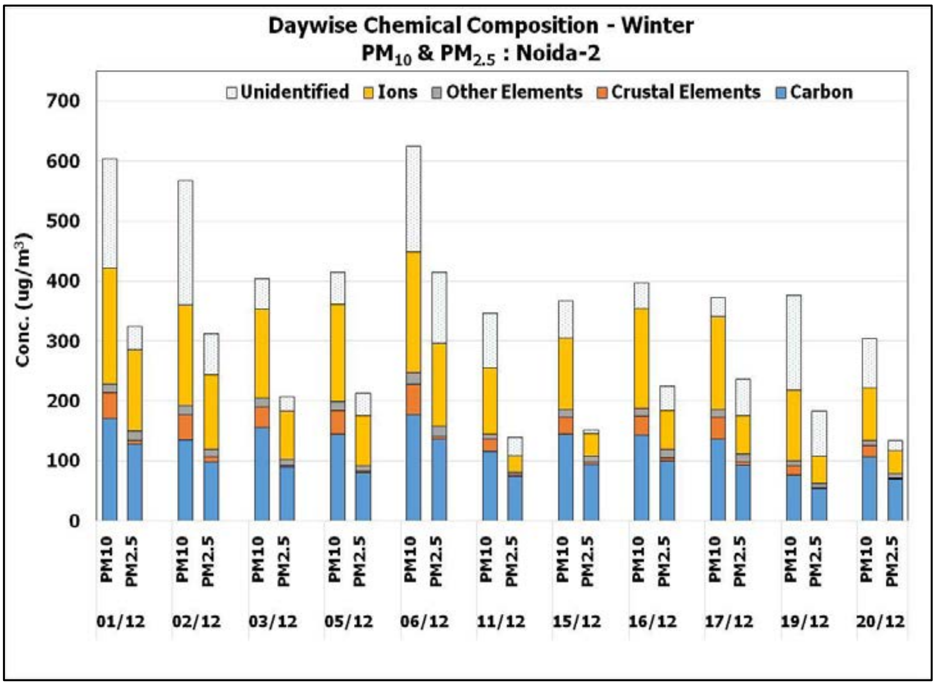


Figure 3.152: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Noida-2 in winter season

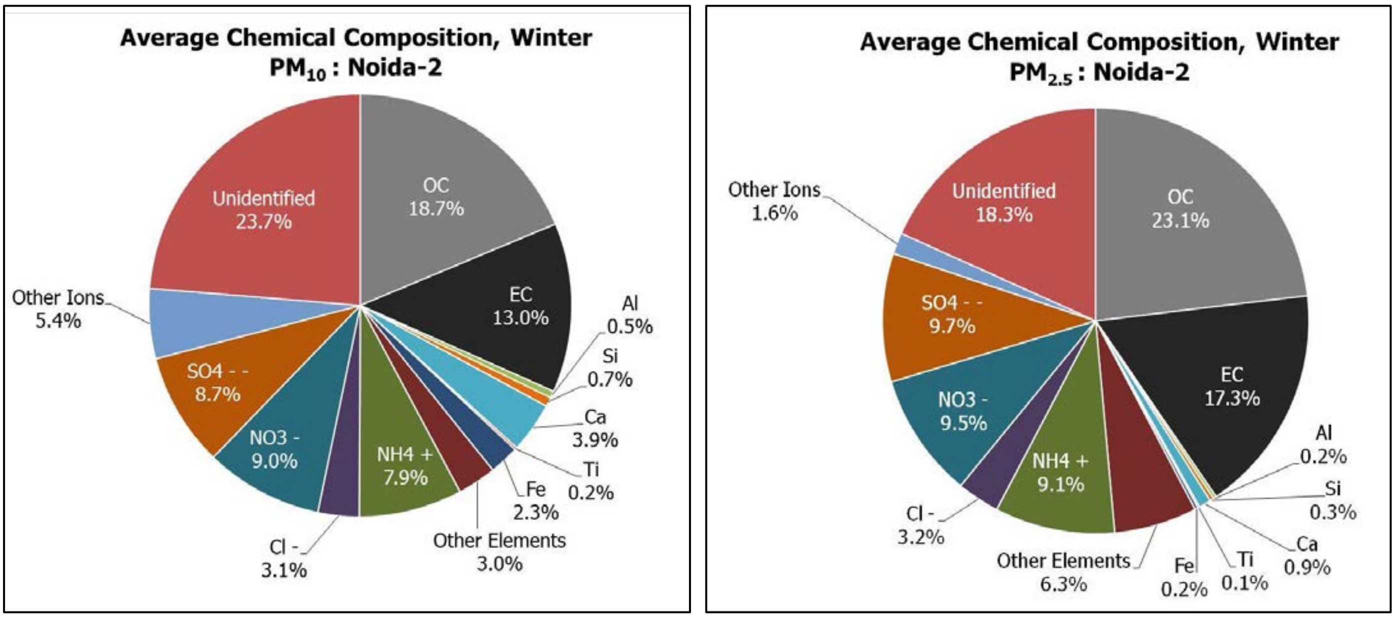


Figure 3.153: Average chemical composition of PM_{10} and $PM_{2.5}$ at Noida-2 in winter season

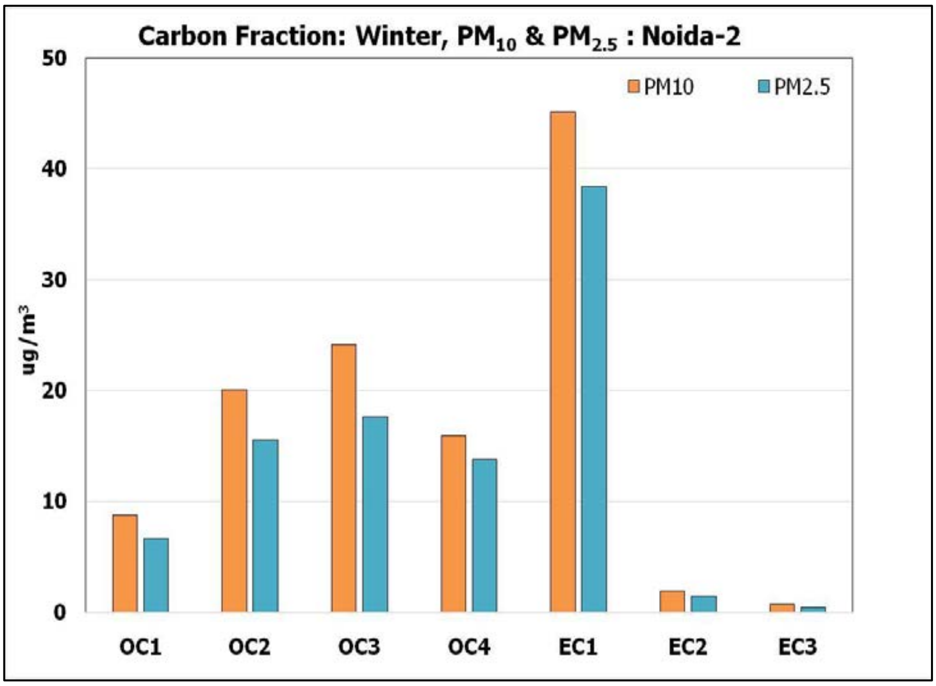


Figure 3.154: average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Noida-2 in winter season

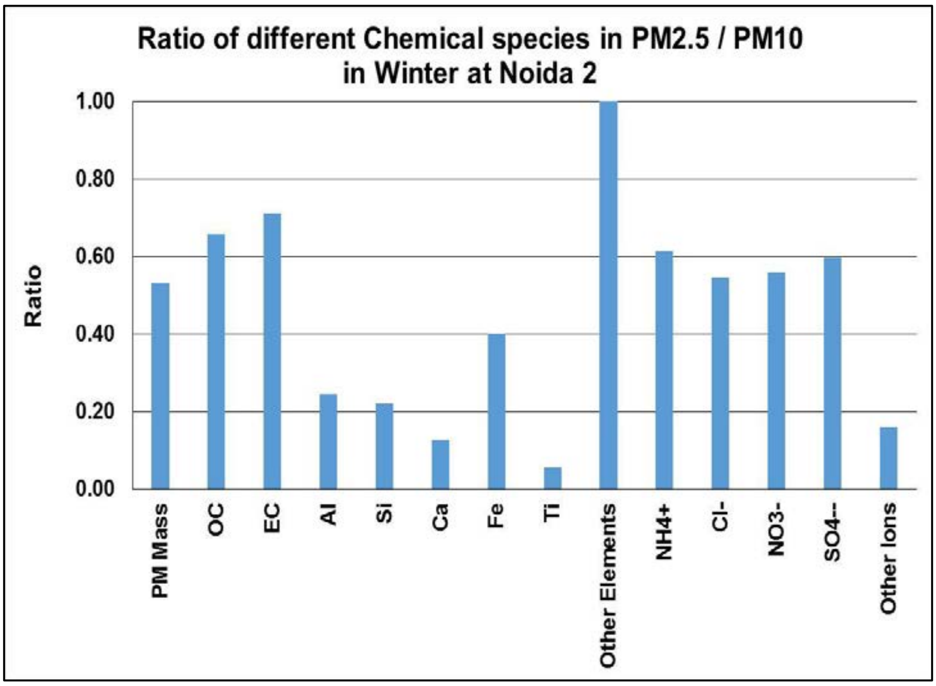


Figure 3.155: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Noida-2

Average concentration of PM_{10} was found to be 436±110 µg/m³ and that of $PM_{2.5}$ was found to be 232±88 µg/m³. Concentration of PM_{10} was 4.3 times higher than the permissible limit of NAAQS(100 µg/m³). The concentration varied from 305 to 626 µg/m³ for PM_{10} and $PM_{2.5}$ varied from 134 to 416 µg/m³ (see Figure 3.151).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.152.

The carbon fraction of PM_{10} was found to be 138 µg/m³ and that of $PM_{2.5}$ was found to be 94 µg/m³. The % mass distribution showed that OC and EC of $PM_{2.5}$ was much higher than of PM_{10}. The total ions in PM_{10} was found to be 34% while in case of $PM_{2.5}$ it was found to be 33%. The crustal elements were found to be 8% and 2% for PM_{10} and $PM_{2.5}$, respectively (see Figure 3.153).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} while $PM_{2.5}$ was found to be 6% in $PM_{2.5}$, respectively

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed for PM_{10} was 24% while that of $PM_{2.5}$ was 18%.

The OC3 was found to be higher in PM_{10} as compared to $PM_{2.5}$ and to OC2, OC4, and OC1. Similarly, EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.154). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.155.

Table 3.121: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Noida-2 for winter season

	µg/m^3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	436	81.48	56.42	2.32	3.10	16.83	9.92	0.78	5.71	4.30	0.43	0.97	13.70	39.26	37.86	1.73	34.41	4.02	15.13
SD	110	18.92	11.37	1.23	1.15	5.29	3.97	0.30	1.41	1.65	0.12	0.33	3.91	9.40	11.06	0.41	13.92	1.45	2.24
Min	305	43.00	34.29	0.61	1.48	7.14	4.86	0.32	3.57	1.98	0.20	0.40	9.18	18.47	24.15	1.31	8.83	2.13	11.38
Max	626	106.20	72.73	3.84	5.15	24.43	15.39	1.23	8.25	7.27	0.61	1.37	18.93	52.00	54.38	2.69	49.69	7.38	19.33
C.V.	0.25	0.23	0.20	0.53	0.37	0.31	0.40	0.38	0.25	0.38	0.29	0.34	0.29	0.24	0.29	0.24	0.40	0.36	0.15
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	615	104.03	72.19	3.78	5.08	22.66	15.34	1.22	7.71	6.84	0.61	1.33	18.92	49.20	54.07	2.41	47.47	6.33	18.78
50 %ile	402	81.58	55.95	2.30	2.97	18.57	9.66	0.79	5.80	4.23	0.41	0.94	12.84	41.68	38.40	1.73	39.67	3.68	15.01
5 %ile	227	33.37	25.13	0.65	1.35	6.40	4.51	0.31	2.71	1.84	0.17	0.37	7.08	14.85	18.91	0.95	9.67	1.86	7.73

Table 3.122: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Noida-2 for winter season

	µg/m^3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	232	53.61	40.20	0.57	0.68	2.15	0.56	0.31	1.92	2.00	0.67	0.37	7.49	21.95	22.61	0.50	21.14	1.32	0.70
SD	88	15.85	8.33	0.30	0.49	0.90	0.51	0.10	0.78	1.41	0.53	0.14	2.75	13.80	13.59	0.16	12.82	0.60	0.53
Min	134	29.87	25.81	0.07	0.20	0.99	0.19	0.20	0.97	0.44	0.12	0.15	2.77	5.62	9.33	0.27	3.99	0.41	0.07
Max	416	81.51	55.83	0.84	1.65	3.45	1.79	0.48	3.75	4.33	1.95	0.61	11.29	46.36	43.34	0.78	40.08	2.29	1.57
C.V.	0.38	0.30	0.21	0.52	0.72	0.42	0.91	0.31	0.41	0.70	0.80	0.37	0.37	0.63	0.60	0.33	0.61	0.45	0.76
N	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
95 %ile	371	79.76	53.35	0.82	1.45	3.40	1.54	0.45	3.10	4.24	1.52	0.56	11.22	43.13	42.73	0.76	39.10	2.27	1.43
50 %ile	214	54.65	40.55	0.67	0.64	2.16	0.38	0.32	1.88	1.31	0.63	0.35	7.11	17.24	15.18	0.50	21.83	1.15	0.75
5 %ile	138	33.50	29.06	0.17	0.20	1.04	0.19	0.21	1.00	0.68	0.15	0.18	3.14	6.34	9.53	0.29	5.34	0.64	0.07

Table 3.123: Correlation matrix for PM_{10} and its composition for winter season at Noida-2

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.64																			
	0.03																			
EC	0.63	0.82																		
	0.04	*0.00*																		
TC	0.67	0.97	0.93																	
	0.03	*0.00*	*0.00*																	
Cl^-	0.30	0.10	0.55	0.28																
	0.37	*0.78*	*0.08*	*0.40*																
NO_3^-	0.71	0.62	0.49	0.60	0.02															
	0.01	*0.04*	*0.13*	*0.05*	*0.96*															
SO_4^{--}	0.91	0.70	0.68	0.73	0.33	0.83														
	0.00	*0.02*	*0.02*	*0.01*	*0.33*	*0.00*														
Na^+	0.78	0.56	0.77	0.67	0.66	0.39	0.66													
	0.00	*0.07*	*0.01*	*0.03*	*0.03*	*0.24*	*0.03*													
NH_4^+	0.69	0.90	0.75	0.88	0.02	0.79	0.81	0.41												
	0.02	*0.00*	*0.01*	*0.00*	*0.96*	*0.00*	*0.00*	*0.21*												
K^+	0.62	0.50	0.68	0.59	0.72	0.48	0.63	0.79	0.41											
	0.04	*0.12*	*0.02*	*0.06*	*0.01*	*0.13*	*0.04*	*0.00*	*0.21*											
Ca^{++}	0.87	0.81	0.84	0.86	0.42	0.63	0.88	0.79	0.81	0.73										
	0.00	*0.00*	*0.00*	*0.00*	*0.20*	*0.04*	*0.00*	*0.00*	*0.00*	*0.01*										
Si	0.77	0.65	0.86	0.76	0.63	0.57	0.76	0.84	0.59	0.79	0.81									
	0.01	*0.03*	*0.00*	*0.01*	*0.04*	*0.07*	*0.01*	*0.00*	*0.05*	*0.00*	*0.00*									
Al	0.79	0.79	0.71	0.80	0.08	0.81	0.88	0.58	0.87	0.38	0.79	0.65								
	0.00	*0.00*	*0.01*	*0.00*	*0.82*	*0.00*	*0.00*	*0.06*	*0.00*	*0.25*	*0.00*	*0.03*								
Ca	0.63	0.89	0.82	0.91	0.12	0.75	0.75	0.56	0.89	0.57	0.81	0.70	0.87							
	0.04	*0.00*	*0.00*	*0.00*	*0.72*	*0.01*	*0.01*	*0.08*	*0.00*	*0.07*	*0.00*	*0.02*	*0.00*							
Fe	0.89	0.74	0.58	0.71	0.09	0.68	0.90	0.60	0.79	0.43	0.88	0.60	0.87	0.71						
	0.00	*0.01*	*0.06*	*0.01*	*0.79*	*0.02*	*0.00*	*0.05*	*0.00*	*0.19*	*0.00*	*0.05*	*0.00*	*0.01*						
Ti	0.78	0.90	0.86	0.92	0.30	0.74	0.88	0.65	0.90	0.56	0.89	0.80	0.89	0.86	0.84					
	0.00	*0.00*	*0.00*	*0.00*	*0.37*	*0.01*	*0.00*	*0.03*	*0.00*	*0.07*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.60	0.80	0.72	0.80	0.22	0.79	0.78	0.56	0.77	0.57	0.74	0.67	0.86	0.90	0.71	0.85				
	0.05	*0.00*	*0.01*	*0.00*	*0.52*	*0.00*	*0.01*	*0.08*	*0.01*	*0.07*	*0.01*	*0.03*	*0.00*	*0.00*	*0.01*	*0.00*				
S	0.88	0.76	0.64	0.75	0.07	0.80	0.83	0.72	0.76	0.52	0.77	0.66	0.89	0.78	0.82	0.77	0.75			
	0.00	*0.01*	*0.04*	*0.01*	*0.83*	*0.00*	*0.00*	*0.01*	*0.01*	*0.10*	*0.01*	*0.03*	*0.00*	*0.00*	*0.00*	*0.01*	*0.01*			
Ni	0.57	0.49	0.82	0.70	0.69	0.66	0.76	0.56	0.75	0.55	0.63	0.83	0.68	0.74	0.47	0.75	0.64	0.46		
	0.11	*0.18*	*0.01*	*0.04*	*0.04*	*0.05*	*0.02*	*0.12*	*0.02*	*0.13*	*0.07*	*0.01*	*0.04*	*0.02*	*0.20*	*0.02*	*0.07*	*0.21*		
Pb	0.76	0.69	0.74	0.74	0.18	0.41	0.71	0.65	0.72	0.28	0.81	0.63	0.82	0.66	0.83	0.78	0.54	0.70	0.55	
	0.01	*0.02*	*0.01*	*0.01*	*0.60*	*0.21*	*0.02*	*0.03*	*0.01*	*0.41*	*0.00*	*0.04*	*0.00*	*0.03*	*0.00*	*0.01*	*0.09*	*0.02*	*0.13*	
Zn	0.69	0.89	0.74	0.87	0.11	0.64	0.79	0.60	0.82	0.38	0.75	0.61	0.92	0.84	0.82	0.87	0.86	0.84	0.59	0.77
	0.02	*0.00*	*0.01*	*0.00*	*0.75*	*0.03*	*0.00*	*0.05*	*0.00*	*0.25*	*0.01*	*0.05*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.09*	*0.01*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.124: Correlation matrix for $PM_{2.5}$ and its composition for winter season at Noida-2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.88																			
	0.00																			
EC	0.82	0.90																		
	0.01	*0.00*																		
TC	0.88	0.99	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.73	0.71	0.79	0.76																
	0.03	*0.03*	*0.01*	*0.02*																
NO_3^-	0.96	0.81	0.68	0.78	0.58															
	0.00	*0.01*	*0.04*	*0.01*	*0.10*															
SO_4^{--}	0.87	0.79	0.60	0.74	0.40	0.96														
	0.00	*0.01*	*0.09*	*0.02*	*0.28*	*0.00*														
Na^+	0.37	0.45	0.26	0.40	0.15	0.51	0.64													
	0.33	*0.22*	*0.50*	*0.29*	*0.69*	*0.16*	*0.06*													
NH_4^+	0.84	0.72	0.52	0.67	0.49	0.93	0.90	0.68												
	0.01	*0.03*	*0.16*	*0.05*	*0.18*	*0.00*	*0.00*	*0.04*												
K^+	0.82	0.86	0.79	0.86	0.83	0.74	0.60	0.22	0.71											
	0.01	*0.00*	*0.01*	*0.00*	*0.01*	*0.02*	*0.09*	*0.56*	*0.03*											
Ca^{++}	-0.51	-0.59	-0.38	-0.53	0.08	-0.59	-0.78	-0.63	-0.56	-0.18										
	0.17	*0.10*	*0.31*	*0.14*	*0.85*	*0.09*	*0.01*	*0.07*	*0.12*	*0.64*										
Si	0.21	0.02	0.08	0.04	0.24	0.16	0.07	0.33	0.34	0.19	0.05									
	0.60	*0.95*	*0.84*	*0.91*	*0.54*	*0.69*	*0.85*	*0.39*	*0.37*	*0.63*	*0.91*									
Al	0.83	0.97	0.78	0.97	0.79	0.72	0.60	0.60	0.83	0.75	-0.19	0.66								
	0.08	*0.01*	*0.12*	*0.01*	*0.11*	*0.17*	*0.29*	*0.28*	*0.09*	*0.14*	*0.77*	*0.23*								
Ca	0.48	0.56	0.52	0.56	0.56	0.40	0.42	0.67	0.51	0.47	-0.34	0.67	0.84							
	0.20	*0.12*	*0.16*	*0.12*	*0.12*	*0.29*	*0.26*	*0.05*	*0.16*	*0.21*	*0.37*	*0.05*	*0.08*							
Fe	0.80	0.87	0.83	0.88	0.60	0.81	0.80	0.53	0.74	0.78	-0.57	0.12	0.59	0.53						
	0.01	*0.00*	*0.01*	*0.00*	*0.09*	*0.01*	*0.01*	*0.14*	*0.02*	*0.01*	*0.11*	*0.77*	*0.29*	*0.15*						
Ti	0.57	0.69	0.69	0.70	0.48	0.54	0.59	0.79	0.59	0.47	-0.58	0.47	0.65	0.86	0.73					
	0.11	*0.04*	*0.04*	*0.04*	*0.19*	*0.13*	*0.10*	*0.01*	*0.09*	*0.20*	*0.11*	*0.20*	*0.24*	*0.00*	*0.03*					
K	0.87	0.81	0.71	0.80	0.66	0.83	0.74	0.10	0.66	0.79	-0.36	-0.23	0.92	0.09	0.65	0.21				
	0.00	*0.01*	*0.03*	*0.01*	*0.06*	*0.01*	*0.02*	*0.81*	*0.05*	*0.01*	*0.35*	*0.55*	*0.03*	*0.81*	*0.06*	*0.59*				
S	0.94	0.84	0.80	0.85	0.66	0.92	0.88	0.56	0.85	0.74	-0.60	0.37	0.66	0.66	0.88	0.76	0.68			
	0.00	*0.00*	*0.01*	*0.00*	*0.05*	*0.00*	*0.00*	*0.12*	*0.00*	*0.02*	*0.09*	*0.33*	*0.22*	*0.05*	*0.00*	*0.02*	*0.05*			
Ni	1.00	0.00	0.53	0.35	0.61	1.00	0.28	-0.55	1.00	0.88	0.67	0.99	0.93	-0.88	0.99	-0.23	0.93	1.00		
	0.04	*1.00*	*0.64*	*0.77*	*0.58*	*0.03*	*0.82*	*0.63*	*0.05*	*0.32*	*0.53*	*0.09*	*0.24*	*0.31*	*0.08*	*0.85*	*0.25*	*0.00*		
Pb	0.76	0.85	0.88	0.88	0.62	0.62	0.53	0.00	0.44	0.78	-0.37	-0.18	0.51	0.17	0.67	0.37	0.84	0.61	0.80	
	0.02	*0.00*	*0.00*	*0.00*	*0.08*	*0.08*	*0.14*	*0.99*	*0.24*	*0.01*	*0.33*	*0.64*	*0.38*	*0.66*	*0.05*	*0.33*	*0.01*	*0.08*	*0.41*	
Zn	0.89	0.74	0.64	0.72	0.72	0.87	0.78	0.57	0.91	0.77	-0.38	0.54	0.89	0.69	0.68	0.67	0.64	0.89	1.00	0.48
	0.00	*0.02*	*0.06*	*0.03*	*0.03*	*0.00*	*0.01*	*0.11*	*0.00*	*0.02*	*0.31*	*0.13*	*0.04*	*0.04*	*0.04*	*0.05*	*0.06*	*0.00*	*0.04*	*0.19*

Note: **Bold values** represents "Correlation Coefficient"and *Italic* represents "*P-value*

For winter Season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.121 and Table 3.122 for PM mass and major species, respectively. PM_{10} mass has lesser C.V. than $PM_{2.5}$ mass. The crustal elements show very high variation in $PM_{2.5}$, whereas PM_{10} shows lesser C.V. The secondary particulates show less variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is given in Table 3.123 and Table 3.124 for PM mass and its major species. OC, EC, and TC show a better correlation with $PM_{2.5}$ mass than PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass as compared to $PM_{2.5}$. The secondary particulates show a better correlation with each other in $PM_{2.5}$ than in PM_{10}.

3.1.17 Site 17: Gurgaon-1

3.1.17.1 Summer season:

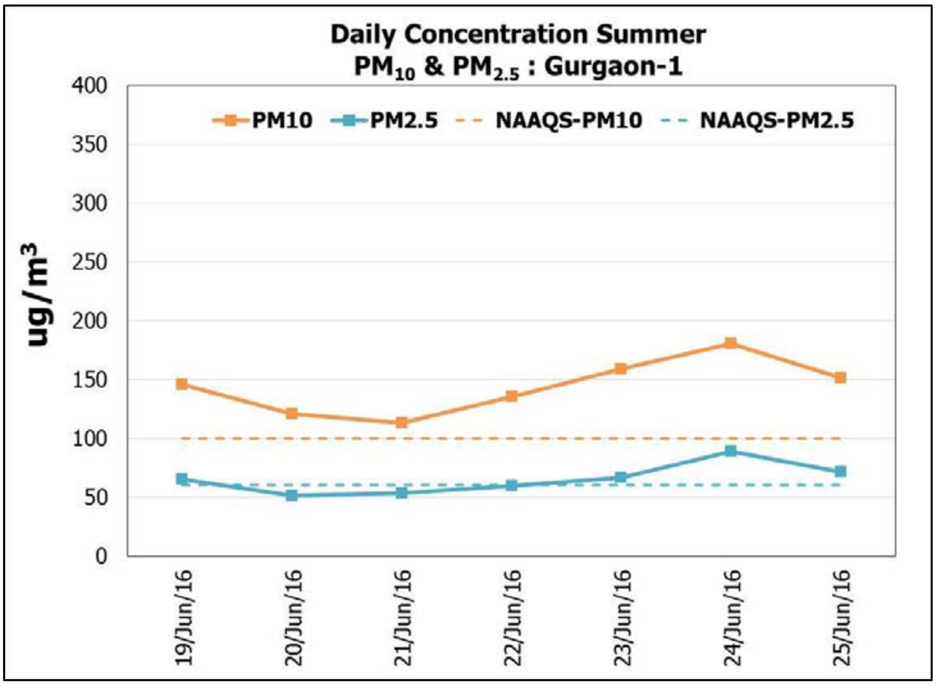


Figure 3.156: Variation in 24 hourly concentration of PM_{10} and $PM_{2.5}$ at Gurgaon-1 in summer season

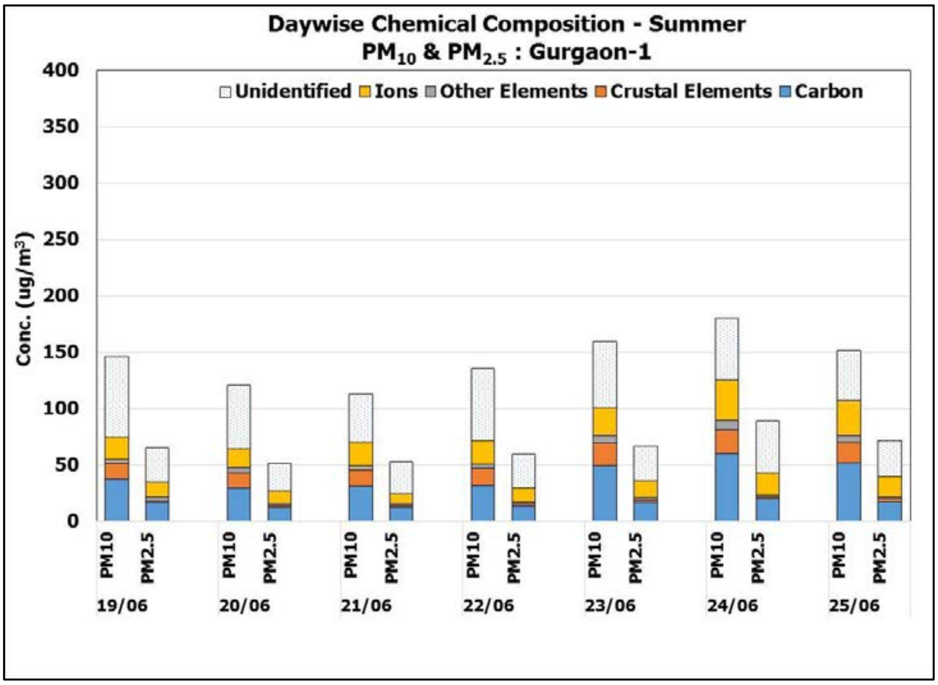


Figure 3.157: Variation in chemical composition of PM10 and PM2.5 at Gurgaon-1 in summer season

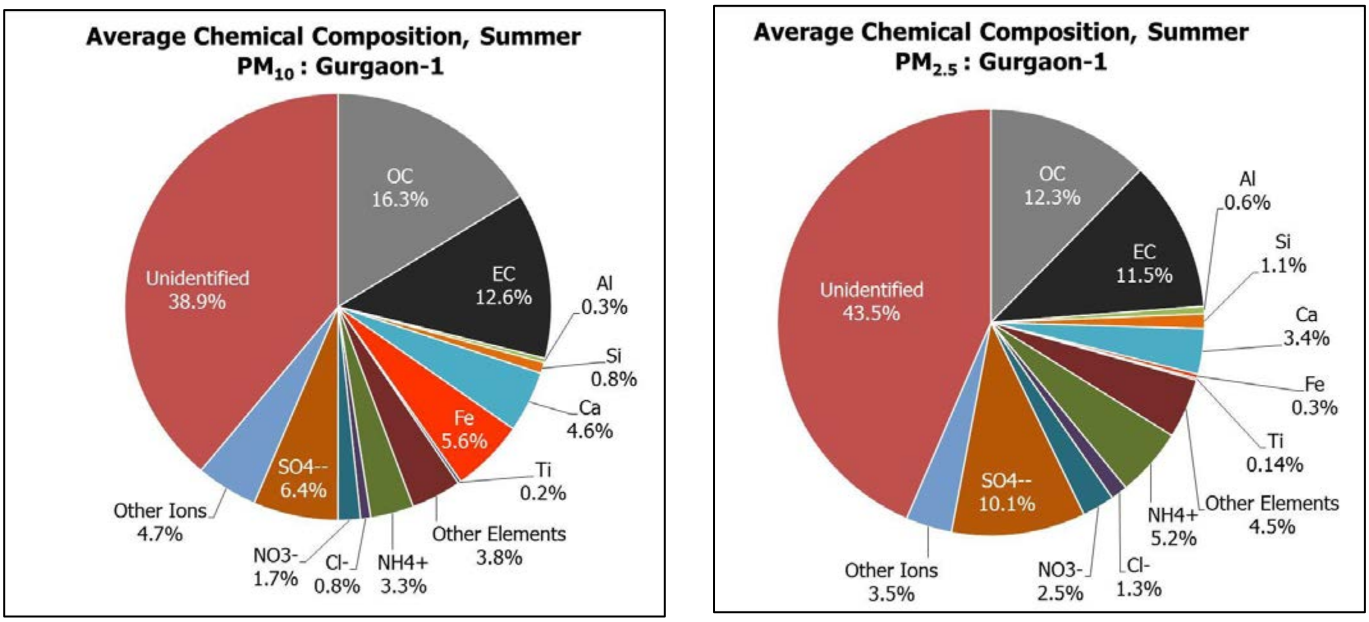


Figure 3.158: Average chemical composition of PM_{10} and $PM_{2.5}$ at Gurgaon-1 in summer season

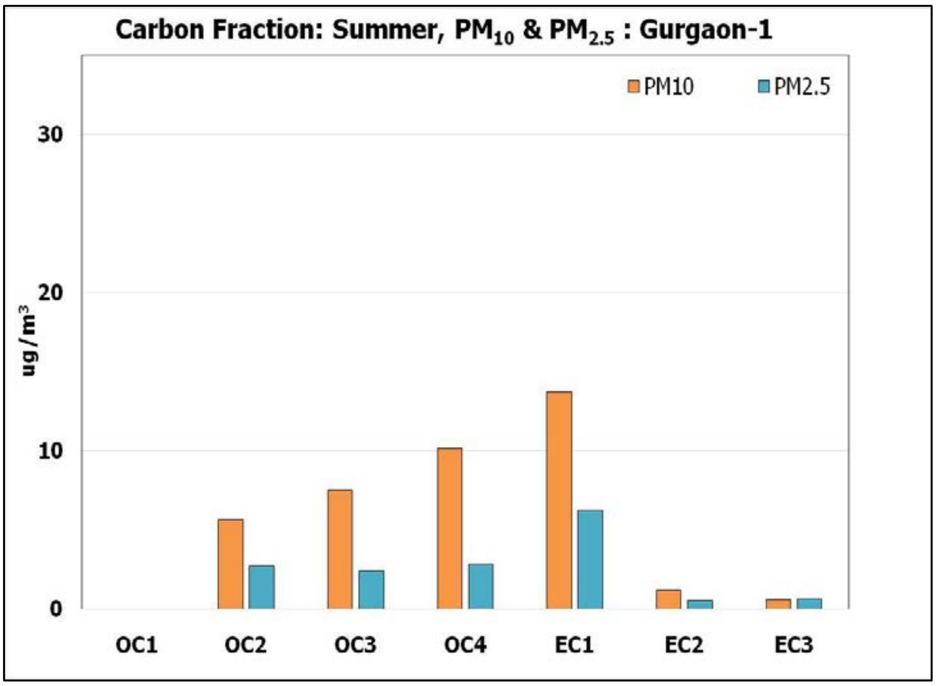


Figure 3.159: Average concentration of carbon fractions of PM_{10} and $PM_{2.5}$ at Gurgaon-1 in summer season

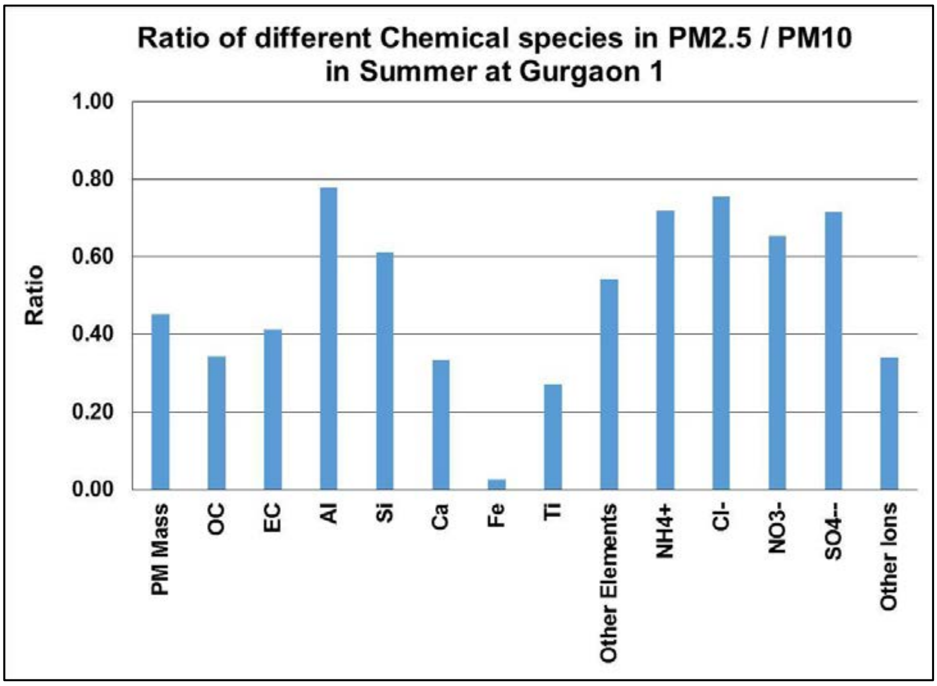


Figure 3.160: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in summer season at Gurgaon-1

Average concentration of PM_{10} at HUDA Sector 43, Gurgaon (GRG1) site was found to be144±23 $\mu g/m^3$, which is 1.4 times as per NAAQS, and concentration of PM_{10} varied from 113 to 181 $\mu g/m^3$. Average concentration of $PM_{2.5}$ was 65±13 $\mu g/m^3$. $PM_{2.5}$ was found to be in range with values from 51 to 89 $\mu g/m^3$ (see Figure 3.156).

Daily variation in the components of the different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.157.

Average concentration of carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 29% and 24%, respectively. The total Ions found in PM_{10} were found to be higher in $PM_{2.5}$, that is, 22% while that of PM_{10} were found to be 17%. Concentration of the crustal elements were 11% in PM_{10} & 3% in $PM_{2.5}$ (see Figure 3.158).

The other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) concentration were found to be 4% and 5% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 39% and 47% for PM_{10} and $PM_{2.5}$, respectively.

In PM_{10}, concentration of EC1 was highest, followed by OC4, OC3, OC2, EC2, and EC3, while in case of $PM_{2.5}$, EC1 was highest, followed by OC2, OC3, OC4, EC2, and EC3 (see Figure 3.159).

Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.160.

Table 3.125: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM$_{10}$ at Gurgaon 1 for summer season

	µg/m^3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	144	23.39	18.10	0.47	1.18	6.67	7.99	0.34	3.11	0.97	0.08	0.19	1.09	2.44	9.23	1.97	4.71	2.10	1.37
SD	23	9.00	3.25	0.23	1.18	1.05	1.48	0.26	1.51	0.32	0.05	0.09	0.57	0.80	2.41	1.21	1.06	0.81	0.31
Min	113	14.45	14.55	0.27	0.26	5.33	6.15	0.10	1.56	0.68	0.04	0.11	0.63	1.49	6.55	0.88	3.65	1.37	1.11
Max	181	37.21	22.51	0.84	3.40	8.72	10.18	0.75	5.79	1.43	0.16	0.38	2.25	3.45	12.67	4.40	6.41	3.10	1.92
C.V.	0.16	0.38	0.18	0.49	1.00	0.16	0.18	0.76	0.49	0.33	0.55	0.49	0.52	0.33	0.26	0.61	0.23	0.39	0.22
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	174	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	146	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	115	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.126: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM$_{2.5}$ at Gurgaon 1 for summer season

	µg/m^3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	65	8.03	7.46	0.37	0.72	2.24	0.20	0.09	1.15	0.68	0.05	0.08	0.83	1.60	6.61	0.96	3.39	1.06	0.09
SD	13	1.52	1.68	0.26	0.10	0.28	0.20	0.02	0.95	0.16	0.03	0.04	0.32	0.64	1.66	0.56	0.83	0.69	0.06
Min	51	6.32	5.73	0.21	0.56	2.05	0.05	0.07	0.16	0.54	0.02	0.05	0.58	0.95	4.04	0.27	2.17	0.47	0.02
Max	89	10.16	10.34	0.94	0.83	2.85	0.50	0.12	2.51	0.93	0.10	0.15	1.50	2.54	8.68	1.80	4.72	2.36	0.16
C.V.	0.20	0.19	0.23	0.71	0.14	0.13	0.97	0.21	0.82	0.23	0.57	0.51	0.38	0.40	0.25	0.59	0.25	0.65	0.61
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	84	9.96	9.86	0.78	0.82	2.67	0.49	0.12	2.46	0.90	0.09	0.14	1.33	2.48	8.66	1.69	4.55	2.08	0.15
50 %ile	65	8.08	6.68	0.26	0.76	2.18	0.08	0.08	0.92	0.60	0.05	0.07	0.70	1.51	6.04	1.00	3.16	0.77	0.11
5 %ile	52	6.34	5.84	0.21	0.58	2.05	0.05	0.08	0.19	0.54	0.02	0.05	0.59	0.97	4.59	0.31	2.40	0.49	0.02

Table 3.127: Correlation matrix for PM_{10} and its composition for summer season at Gurgaon 1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.84	0.86																		
	0.02	*0.01*																		
TC	0.93	0.99	0.92																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.56	0.60	0.18	0.50																
	0.20	*0.15*	*0.70*	*0.25*																
NO_3^-	0.81	0.93	0.77	0.91	0.57															
	0.03	*0.00*	*0.05*	*0.01*	*0.18*															
SO_4^{--}	0.77	0.90	0.92	0.93	0.26	0.91														
	0.05	*0.01*	*0.00*	*0.00*	*0.57*	*0.01*														
Na^+	0.50	0.56	0.51	0.56	0.02	0.50	0.61													
	0.25	*0.20*	*0.25*	*0.19*	*0.97*	*0.25*	*0.14*													
NH_4^+	0.69	0.81	0.81	0.83	0.24	0.78	0.89	0.78												
	0.09	*0.03*	*0.03*	*0.02*	*0.60*	*0.04*	*0.01*	*0.04*												
K^+	0.78	0.94	0.83	0.94	0.56	0.92	0.92	0.38	0.75											
	0.04	*0.00*	*0.02*	*0.00*	*0.20*	*0.00*	*0.00*	*0.40*	*0.06*											
Ca^{++}	0.62	0.44	0.34	0.42	0.18	0.38	0.32	0.77	0.47	0.14										
	0.14	*0.33*	*0.46*	*0.35*	*0.70*	*0.41*	*0.49*	*0.04*	*0.28*	*0.77*										
Si	0.73	0.81	0.50	0.75	0.93	0.74	0.55	0.12	0.47	0.80	0.15									
	0.06	*0.03*	*0.25*	*0.05*	*0.00*	*0.06*	*0.20*	*0.80*	*0.29*	*0.03*	*0.75*									
Al	0.74	0.88	0.85	0.89	0.26	0.92	0.97	0.60	0.79	0.90	0.34	0.52								
	0.06	*0.01*	*0.02*	*0.01*	*0.57*	*0.00*	*0.00*	*0.15*	*0.03*	*0.01*	*0.46*	*0.24*								
Ca	0.52	0.48	0.30	0.45	0.40	0.25	0.27	0.71	0.56	0.24	0.70	0.39	0.18							
	0.23	*0.27*	*0.51*	*0.32*	*0.38*	*0.58*	*0.56*	*0.08*	*0.19*	*0.60*	*0.08*	*0.38*	*0.71*							
Fe	0.70	0.85	0.72	0.84	0.52	0.97	0.88	0.33	0.69	0.92	0.16	0.71	0.90	0.04						
	0.08	*0.02*	*0.07*	*0.02*	*0.23*	*0.00*	*0.01*	*0.47*	*0.09*	*0.00*	*0.74*	*0.07*	*0.01*	*0.94*						
Ti	0.85	0.91	0.62	0.85	0.88	0.81	0.66	0.34	0.61	0.83	0.37	0.97	0.62	0.55	0.73					
	0.02	*0.01*	*0.14*	*0.02*	*0.01*	*0.03*	*0.11*	*0.46*	*0.14*	*0.02*	*0.42*	*0.00*	*0.14*	*0.21*	*0.06*					
K	0.69	0.77	0.66	0.76	0.39	0.54	0.63	0.54	0.52	0.71	0.36	0.57	0.64	0.57	0.44	0.68				
	0.09	*0.04*	*0.11*	*0.05*	*0.39*	*0.21*	*0.13*	*0.21*	*0.24*	*0.08*	*0.43*	*0.18*	*0.12*	*0.18*	*0.32*	*0.09*				
S	0.82	0.93	0.94	0.95	0.32	0.91	0.98	0.49	0.79	0.95	0.27	0.61	0.97	0.20	0.89	0.70	0.69			
	0.02	*0.00*	*0.00*	*0.00*	*0.48*	*0.01*	*0.00*	*0.26*	*0.04*	*0.00*	*0.55*	*0.14*	*0.00*	*0.67*	*0.01*	*0.08*	*0.09*			
Ni	0.86	0.92	0.63	0.87	0.85	0.82	0.68	0.40	0.64	0.84	0.40	0.95	0.65	0.58	0.73	1.00	0.72	0.72		
	0.01	*0.00*	*0.13*	*0.01*	*0.01*	*0.02*	*0.09*	*0.38*	*0.12*	*0.02*	*0.37*	*0.00*	*0.12*	*0.18*	*0.06*	*0.00*	*0.07*	*0.07*		
Pb	0.71	0.81	0.51	0.75	0.84	0.66	0.54	0.21	0.41	0.80	0.17	0.93	0.54	0.46	0.62	0.92	0.81	0.63	0.93	
	0.08	*0.03*	*0.25*	*0.05*	*0.02*	*0.11*	*0.21*	*0.65*	*0.36*	*0.03*	*0.72*	*0.00*	*0.21*	*0.30*	*0.14*	*0.00*	*0.03*	*0.13*	*0.00*	
Zn	0.86	0.87	0.63	0.83	0.64	0.69	0.64	0.66	0.65	0.70	0.66	0.73	0.63	0.78	0.53	0.87	0.87	0.66	0.90	0.83
	0.01	*0.01*	*0.13*	*0.02*	*0.12*	*0.09*	*0.13*	*0.11*	*0.12*	*0.08*	*0.11*	*0.06*	*0.13*	*0.04*	*0.23*	*0.01*	*0.01*	*0.11*	*0.01*	*0.02*

Note: Bold values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.128: Correlation matrix for $PM_{2.5}$ and its composition for summer season at Gurgaon 1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.79																			
	0.04																			
EC	0.93	0.58																		
	0.00	*0.17*																		
TC	0.97	0.88	0.90																	
	0.00	*0.01*	*0.01*																	
Cl^-	0.33	0.22	0.14	0.20																
	0.47	*0.64*	*0.77*	*0.67*																
NO_3^-	0.91	0.81	0.84	0.93	0.21															
	0.00	*0.03*	*0.02*	*0.00*	*0.65*															
SO_4^{--}	0.84	0.76	0.80	0.88	-0.01	0.91														
	0.02	*0.05*	*0.03*	*0.01*	*0.99*	*0.00*														
Na^+	0.54	0.07	0.50	0.33	0.26	0.34	0.24													
	0.22	*0.88*	*0.25*	*0.47*	*0.58*	*0.45*	*0.60*													
NH_4^+	0.91	0.72	0.89	0.91	0.11	0.98	0.90	0.45												
	0.01	*0.07*	*0.01*	*0.00*	*0.82*	*0.00*	*0.01*	*0.32*												
K^+	0.48	0.86	0.22	0.59	0.39	0.46	0.39	-0.24	0.31											
	0.28	*0.01*	*0.63*	*0.16*	*0.39*	*0.30*	*0.39*	*0.60*	*0.49*											
Ca^{++}	0.37	0.32	0.22	0.30	0.37	0.13	0.34	0.20	0.06	0.36										
	0.41	*0.49*	*0.64*	*0.52*	*0.41*	*0.79*	*0.46*	*0.66*	*0.90*	*0.44*										
Si	-0.58	-0.27	-0.65	-0.53	-0.27	-0.69	-0.73	-0.23	-0.69	0.04	-0.22									
	0.17	*0.56*	*0.12*	*0.23*	*0.57*	*0.09*	*0.06*	*0.62*	*0.09*	*0.94*	*0.63*									
Al	0.47	0.40	0.54	0.53	-0.41	0.72	0.71	0.19	0.78	-0.05	-0.37	-0.52								
	0.29	*0.37*	*0.21*	*0.22*	*0.36*	*0.07*	*0.07*	*0.69*	*0.04*	*0.92*	*0.42*	*0.23*								
Ca	0.17	0.20	0.24	0.25	-0.65	0.44	0.47	0.07	0.52	-0.19	-0.52	-0.24	0.93							
	0.72	*0.66*	*0.60*	*0.59*	*0.12*	*0.32*	*0.29*	*0.88*	*0.23*	*0.68*	*0.24*	*0.61*	*0.00*							
Fe	0.75	0.85	0.47	0.73	0.61	0.74	0.67	0.25	0.62	0.77	0.54	-0.42	0.17	-0.07						
	0.05	*0.01*	*0.29*	*0.06*	*0.15*	*0.06*	*0.10*	*0.59*	*0.14*	*0.04*	*0.21*	*0.34*	*0.71*	*0.87*						
Ti	0.67	0.92	0.33	0.71	0.62	0.74	0.70	0.21	0.60	0.80	0.30	-0.30	0.24	0.05	0.97					
	0.15	*0.01*	*0.52*	*0.11*	*0.19*	*0.10*	*0.12*	*0.70*	*0.21*	*0.06*	*0.57*	*0.57*	*0.65*	*0.93*	*0.00*					
K	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00				
	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*				
S	0.85	0.48	0.87	0.77	0.04	0.80	0.82	0.72	0.87	0.01	0.30	-0.67	0.64	0.41	0.48	0.35	1.00			
	0.02	*0.28*	*0.01*	*0.05*	*0.94*	*0.03*	*0.02*	*0.07*	*0.01*	*0.98*	*0.51*	*0.10*	*0.12*	*0.36*	*0.28*	*0.49*	*			
Ni	0.86	0.86	0.63	0.83	0.54	0.87	0.79	0.35	0.78	0.67	0.45	-0.57	0.36	0.09	0.97	0.95	-1.00	0.64		
	0.01	*0.01*	*0.13*	*0.02*	*0.21*	*0.01*	*0.04*	*0.44*	*0.04*	*0.10*	*0.31*	*0.18*	*0.42*	*0.85*	*0.00*	*0.00*	*	*0.12*		
Pb	0.43	0.71	0.18	0.48	0.49	0.56	0.57	-0.23	0.40	0.74	0.44	-0.46	0.14	-0.05	0.85	0.87	-1.00	0.16	0.79	
	0.34	*0.07*	*0.71*	*0.27*	*0.27*	*0.19*	*0.18*	*0.63*	*0.37*	*0.06*	*0.33*	*0.30*	*0.76*	*0.91*	*0.02*	*0.03*	*	*0.74*	*0.03*	
Zn	0.66	0.75	0.38	0.62	0.66	0.60	0.58	0.22	0.47	0.73	0.70	-0.40	-0.01	-0.25	0.97	0.90	-1.00	0.41	0.91	0.85
	0.11	*0.05*	*0.41*	*0.14*	*0.11*	*0.16*	*0.17*	*0.63*	*0.28*	*0.06*	*0.08*	*0.37*	*0.98*	*0.59*	*0.00*	*0.01*	*	*0.37*	*0.01*	*0.02*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.125 and Table 3.126 for PM mass and major species, respectively. Both in PM_{10} and $PM_{2.5}$, PM mass has a similar C.V. For crustal elements, C.V. in both PM_{10} and $PM_{2.5}$ is higher. In both PM_{10} and $PM_{2.5}$, the secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show a similar C.V.

Correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.127 and Table 3.128 for the PM mass and its major species. OC, EC, and TC show a similar correlation with both $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass as compared to $PM_{2.5}$ mass. The secondary particulates showed a better correlation with each other $PM_{2.5}$ and with $PM_{2.5}$ mass as compared to PM_{10} and PM_{10} mass.

3.1.17.2 Winter season:

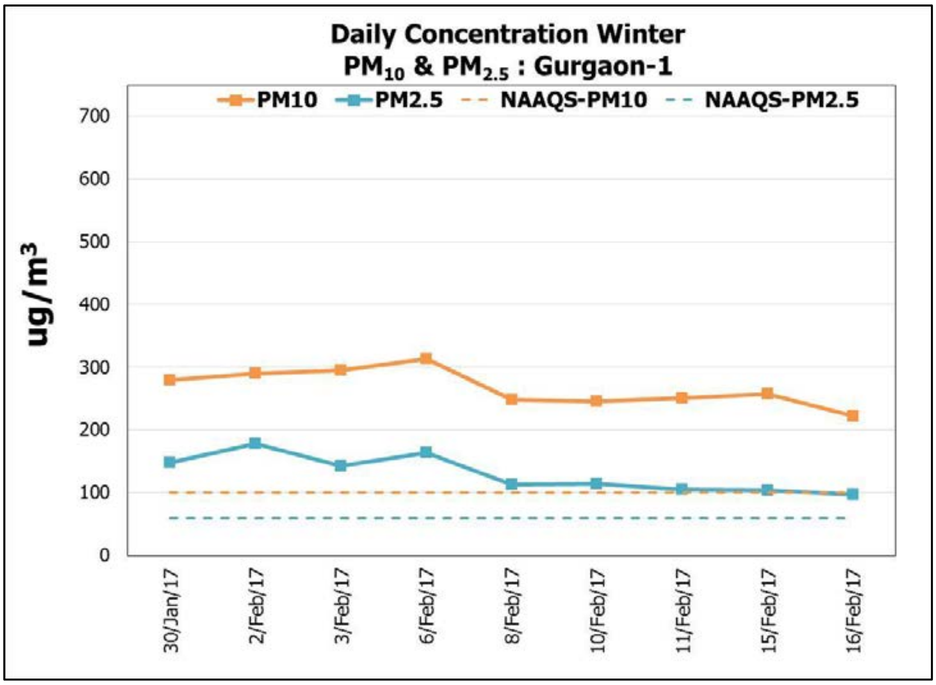


Figure 3.161: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Gurgaon-1 in winter season

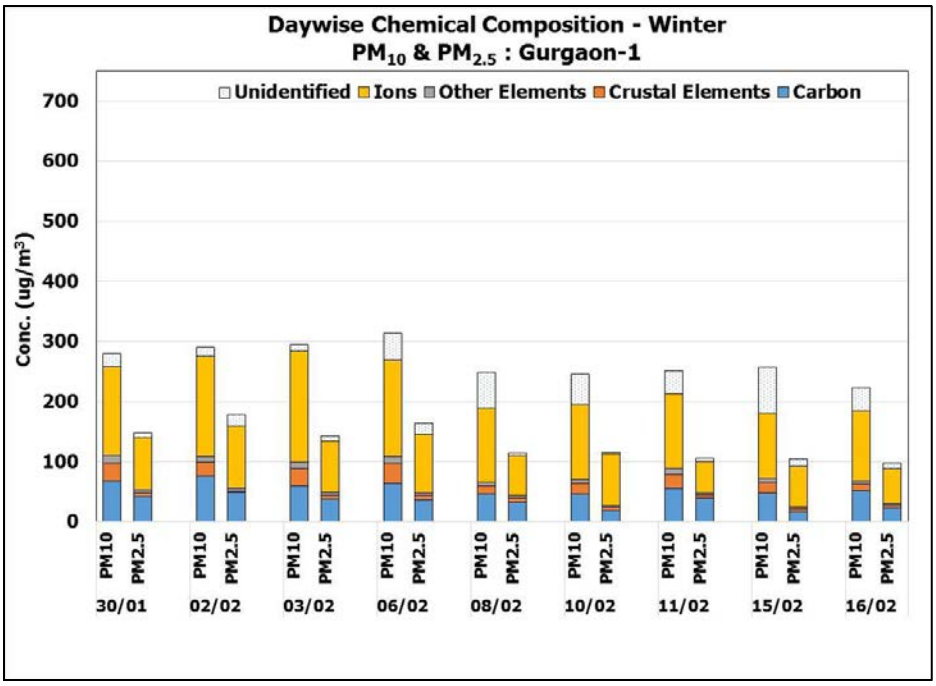


Figure 3.162: Variation in chemical composition of PM_{10} and $PM_{2.5}$ at Gurgaon-1 in winter season

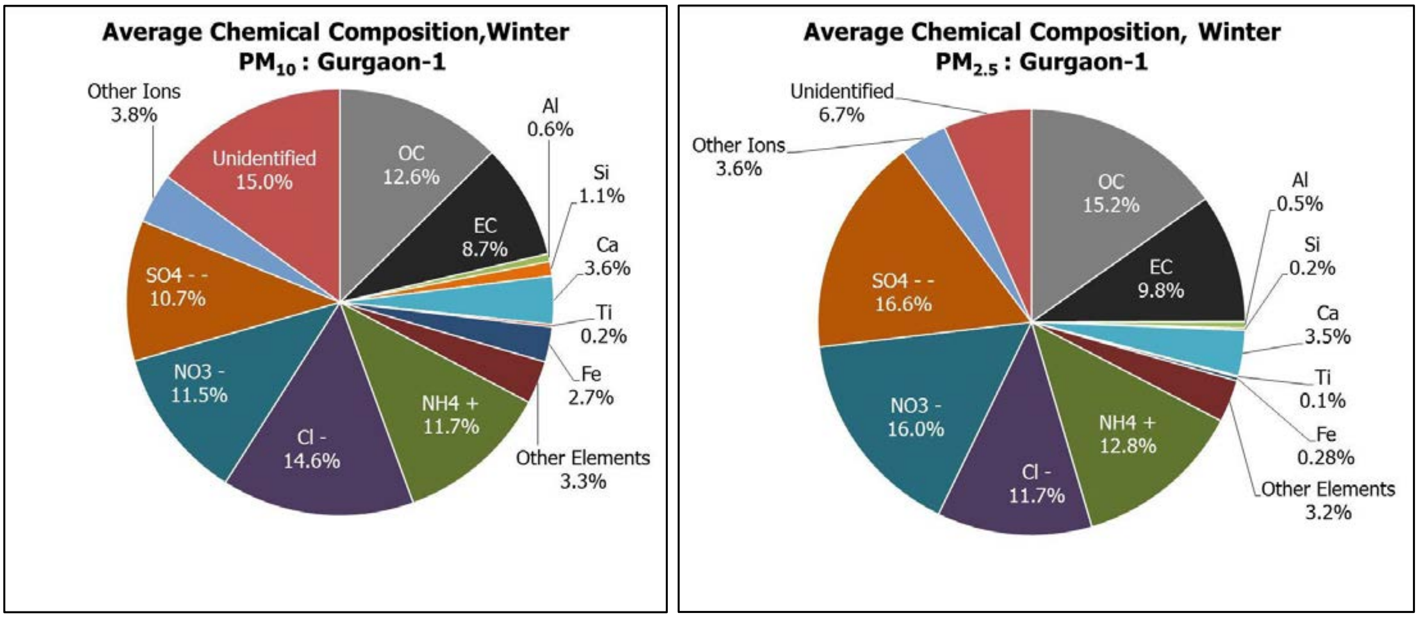


Figure 3.163: Average chemical composition of PM10 and PM2.5 at Gurgaon-1 in winter season

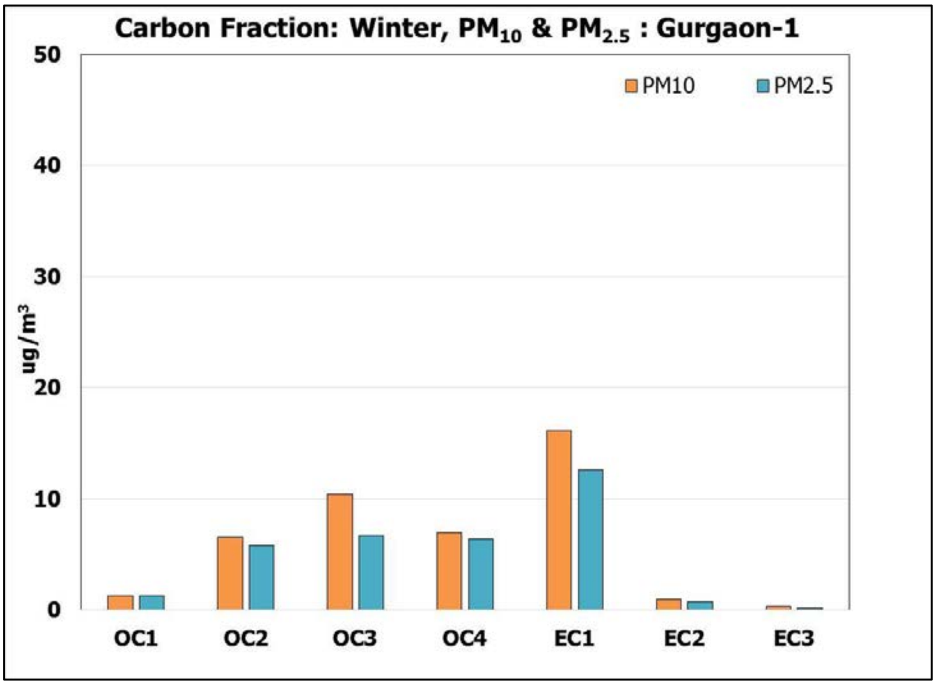


Figure 3.164: Average concentration of carbon fractions of PM10 and PM2.5 at Gurgaon-1 in winter season

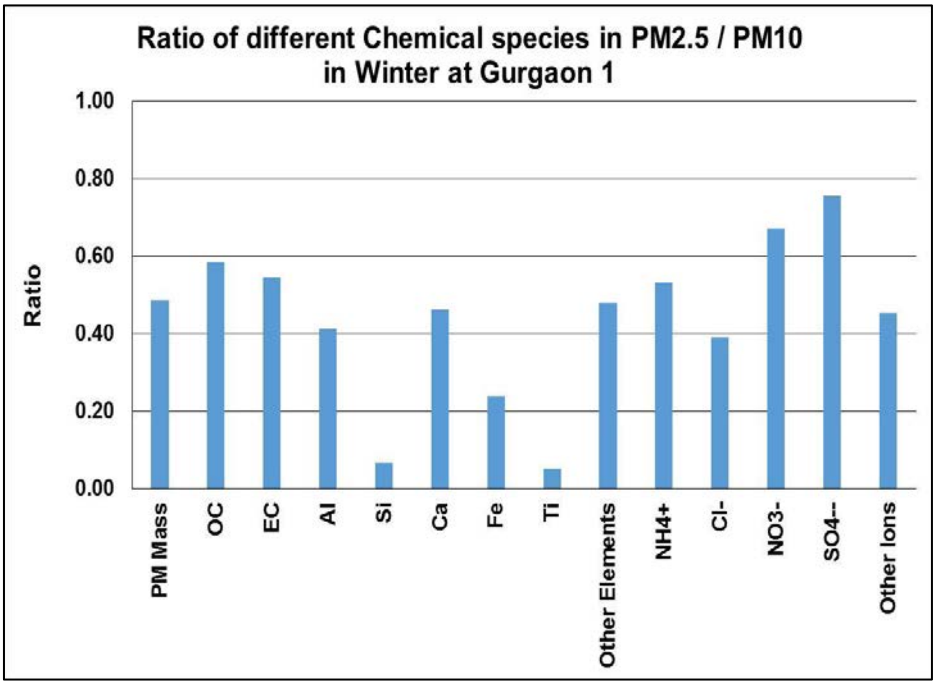


Figure3.165: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Gurgaon-1

Average concentration of PM_{10} and $PM_{2.5}$ was found to be 267±29 μg/m³ and 130±29 μg/m³, respectively. The PM_{10} concentration varied from 222 to 314 μg/m³, while concentration in $PM_{2.5}$ varied from 97 to 178 μg/m³ (see Figure 3.161).

Daily variation in the components of the different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.162.

The total ions were observed to be major portion followed by carbon fraction and crustal element. The total ions for PM_{10} was observed to be 53% and for $PM_{2.5}$ it was observed to be 61%. The carbon fraction of PM_{10} was found to be 57μg/m³ and that of $PM_{2.5}$ was found to be 32μg/m³. The% of the mass distribution showed that the organic carbon and elemental carbon of $PM_{2.5}$ was higher as compared to that of PM_{10}. The crustal element was 8% for PM_{10} and 5% for $PM_{2.5}$ (see Figure 3.163).

The other concentration of elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in both PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed of PM_{10} was found to be 15% while for $PM_{2.5}$, it was found to be 7%.

The OC3 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by OC4, OC2, and OC1. EC1 was found to be higher in PM_{10} as compared to PM2.5, followed by EC2 and EC3 (see Figure 3.164). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.165.

Table 3.129: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of PM_{10} at Gurgaon 1 for winter season

$\mu g/m^3$																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	267	33.61	23.32	1.57	2.94	9.69	7.08	0.54	3.04	2.42	0.97	1.16	38.92	30.82	28.49	0.75	31.13	1.39	6.32
SD	29	5.06	6.38	0.62	1.24	3.98	2.09	0.28	1.02	0.79	0.30	0.38	6.13	5.63	6.67	0.28	7.35	1.32	2.73
Min	222	28.11	16.91	0.65	0.91	5.07	4.06	0.14	1.42	1.31	0.42	0.60	25.12	24.49	22.25	0.41	21.85	0.10	2.00
Max	314	40.69	35.37	2.54	4.78	15.74	9.63	0.96	4.01	4.01	1.33	1.61	45.01	43.25	40.08	1.23	44.62	3.39	9.45
C.V.	0.11	0.15	0.27	0.40	0.42	0.41	0.29	0.51	0.33	0.33	0.31	0.33	0.16	0.18	0.23	0.38	0.24	0.95	0.43
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	306	40.55	33.70	2.32	4.57	15.11	9.34	0.91	4.01	3.54	1.30	1.58	44.44	40.02	37.94	1.21	42.72	3.28	9.43
50 %ile	262	34.47	23.03	1.70	2.99	9.01	7.80	0.55	3.38	2.43	1.02	1.15	39.81	29.27	26.38	0.70	29.54	1.12	6.79
5 %ile	126	16.58	11.65	0.64	1.07	4.52	3.07	0.18	1.22	1.05	0.36	0.49	15.62	15.06	14.46	0.34	14.60	0.10	2.37

Table 3.130: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at Gurgaon 1 for winter season

$\mu g/m^3$																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	130	19.65	12.68	0.65	0.19	4.48	0.36	0.13	1.23	1.37	0.47	0.56	15.20	20.69	21.53	0.20	16.57	0.71	3.04
SD	29	5.98	5.27	0.29	0.07	0.83	0.14	0.04	0.18	0.45	0.17	0.22	6.06	6.81	7.45	0.08	4.38	0.20	0.63
Min	97	10.37	5.19	0.22	0.09	2.56	0.19	0.07	1.00	0.93	0.27	0.35	8.41	10.85	12.01	0.10	10.06	0.48	1.89
Max	178	27.32	21.00	1.21	0.29	5.26	0.59	0.21	1.46	2.15	0.74	0.95	24.65	30.46	33.02	0.30	22.72	0.98	4.17
C.V.	0.23	0.30	0.42	0.44	0.35	0.19	0.39	0.32	0.15	0.33	0.36	0.39	0.40	0.33	0.35	0.38	0.26	0.28	0.21
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	172	26.25	19.85	1.11	0.29	5.18	0.59	0.19	1.45	2.11	0.73	0.93	24.37	28.54	31.28	0.29	22.08	0.98	3.90
50 %ile	114	21.89	13.99	0.60	0.17	4.66	0.34	0.13	1.22	1.13	0.46	0.52	12.97	23.98	21.06	0.22	16.46	0.67	3.13
5 %ile	100	11.04	5.55	0.32	0.11	3.15	0.21	0.08	1.02	0.96	0.28	0.36	8.62	12.14	12.14	0.11	10.27	0.48	2.14

Table 3.131: Correlation matrix for PM_{10} and its composition for winter season at Gurgaon 1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.86																			
	0.00																			
EC	0.54	0.71																		
	0.14	*0.03*																		
TC	0.73	0.91	0.94																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.49	0.66	0.76	0.77																
	0.18	*0.05*	*0.02*	*0.01*																
NO_3^-	0.66	0.41	0.36	0.41	0.37															
	0.06	*0.28*	*0.35*	*0.28*	*0.33*															
SO_4^{--}	0.88	0.75	0.64	0.74	0.67	0.87														
	0.00	*0.02*	*0.07*	*0.02*	*0.05*	*0.00*														
Na^+	0.81	0.80	0.56	0.72	0.45	0.34	0.62													
	0.01	*0.01*	*0.12*	*0.03*	*0.23*	*0.37*	*0.08*													
NH_4^+	0.83	0.66	0.58	0.66	0.54	0.92	0.96	0.58												
	0.01	*0.05*	*0.11*	*0.05*	*0.14*	*0.00*	*0.00*	*0.10*												
K^+	0.88	0.85	0.64	0.79	0.76	0.62	0.89	0.65	0.83											
	0.00	*0.00*	*0.07*	*0.01*	*0.02*	*0.08*	*0.00*	*0.06*	*0.01*											
Ca^{++}	0.83	0.82	0.55	0.72	0.57	0.47	0.77	0.50	0.71	0.91										
	0.01	*0.01*	*0.13*	*0.03*	*0.11*	*0.20*	*0.02*	*0.17*	*0.03*	*0.00*										
Si	0.81	0.78	0.34	0.58	0.31	0.23	0.56	0.55	0.46	0.74	0.87									
	0.01	*0.01*	*0.37*	*0.10*	*0.41*	*0.56*	*0.12*	*0.13*	*0.21*	*0.02*	*0.00*									
Al	0.85	0.85	0.46	0.68	0.69	0.43	0.76	0.75	0.67	0.92	0.83	0.74								
	0.00	*0.00*	*0.21*	*0.04*	*0.04*	*0.25*	*0.02*	*0.02*	*0.05*	*0.00*	*0.01*	*0.02*								
Ca	0.86	0.70	0.45	0.61	0.62	0.54	0.82	0.55	0.68	0.89	0.84	0.81	0.82							
	0.00	*0.04*	*0.22*	*0.08*	*0.07*	*0.14*	*0.01*	*0.13*	*0.04*	*0.00*	*0.00*	*0.01*	*0.01*							
Fe	0.79	0.86	0.48	0.70	0.32	0.25	0.56	0.56	0.48	0.69	0.86	0.94	0.67	0.67						
	0.01	*0.00*	*0.20*	*0.04*	*0.41*	*0.52*	*0.12*	*0.12*	*0.19*	*0.04*	*0.00*	*0.00*	*0.05*	*0.05*						
Ti	0.80	0.79	0.48	0.66	0.74	0.38	0.74	0.57	0.60	0.92	0.88	0.80	0.93	0.94	0.70					
	0.01	*0.01*	*0.19*	*0.05*	*0.02*	*0.32*	*0.02*	*0.11*	*0.09*	*0.00*	*0.00*	*0.01*	*0.00*	*0.00*	*0.04*					
K	0.80	0.88	0.56	0.76	0.66	0.36	0.71	0.61	0.64	0.92	0.95	0.83	0.92	0.78	0.82	0.90				
	0.01	*0.00*	*0.12*	*0.02*	*0.05*	*0.35*	*0.03*	*0.08*	*0.06*	*0.00*	*0.00*	*0.01*	*0.00*	*0.01*	*0.01*	*0.00*				
S	0.53	0.63	0.63	0.68	0.54	0.13	0.49	0.22	0.36	0.65	0.83	0.75	0.51	0.68	0.77	0.70	0.73			
	0.14	*0.07*	*0.07*	*0.04*	*0.14*	*0.75*	*0.18*	*0.57*	*0.35*	*0.06*	*0.01*	*0.02*	*0.16*	*0.04*	*0.02*	*0.03*	*0.03*			
Ni	0.29	0.02	-0.38	-0.22	-0.17	0.03	0.13	-0.02	0.08	0.24	0.45	0.50	0.36	0.46	0.32	0.43	0.33	0.30		
	0.44	*0.96*	*0.32*	*0.57*	*0.67*	*0.95*	*0.74*	*0.96*	*0.85*	*0.53*	*0.23*	*0.17*	*0.35*	*0.22*	*0.40*	*0.25*	*0.38*	*0.43*		
Pb	0.76	0.90	0.66	0.82	0.47	0.36	0.65	0.56	0.54	0.66	0.76	0.79	0.60	0.62	0.92	0.63	0.73	0.74	0.02	
	0.02	*0.00*	*0.06*	*0.01*	*0.20*	*0.34*	*0.06*	*0.12*	*0.13*	*0.05*	*0.02*	*0.01*	*0.09*	*0.08*	*0.00*	*0.07*	*0.03*	*0.02*	*0.96*	
Zn	0.79	0.77	0.44	0.63	0.40	0.36	0.66	0.42	0.57	0.79	0.96	0.94	0.73	0.81	0.93	0.81	0.87	0.86	0.52	0.82
	0.01	*0.02*	*0.24*	*0.07*	*0.28*	*0.34*	*0.06*	*0.26*	*0.11*	*0.01*	*0.00*	*0.00*	*0.03*	*0.01*	*0.00*	*0.01*	*0.00*	*0.00*	*0.16*	*0.01*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.132: correlation matrix for $PM_{2.5}$ and its composition for winter season at Gurgaon 1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.69																			
	0.04																			
EC	0.78	0.95																		
	0.01	*0.00*																		
TC	0.74	0.99	0.99																	
	0.02	*0.00*	*0.00*																	
Cl^-	0.79	0.78	0.78	0.79																
	0.01	*0.01*	*0.01*	*0.01*																
NO_3^-	0.81	0.51	0.56	0.54	0.43															
	0.01	*0.16*	*0.11*	*0.13*	*0.24*															
SO_4^{--}	0.93	0.73	0.75	0.75	0.75	0.89														
	0.00	*0.03*	*0.02*	*0.02*	*0.02*	*0.00*														
Na^+	0.71	0.55	0.70	0.63	0.52	0.61	0.58													
	0.03	*0.13*	*0.04*	*0.07*	*0.16*	*0.08*	*0.10*													
NH_4^+	0.86	0.72	0.77	0.75	0.57	0.95	0.93	0.61												
	0.00	*0.03*	*0.02*	*0.02*	*0.11*	*0.00*	*0.00*	*0.08*												
K^+	0.92	0.67	0.78	0.73	0.70	0.66	0.80	0.74	0.75											
	0.00	*0.05*	*0.01*	*0.03*	*0.03*	*0.05*	*0.01*	*0.02*	*0.02*											
Ca^{++}	0.83	0.71	0.77	0.75	0.69	0.88	0.88	0.76	0.90	0.66										
	0.01	*0.03*	*0.02*	*0.02*	*0.04*	*0.00*	*0.00*	*0.02*	*0.00*	*0.05*										
Si	0.71	0.70	0.83	0.77	0.57	0.68	0.73	0.76	0.77	0.67	0.86									
	0.03	*0.04*	*0.01*	*0.02*	*0.11*	*0.04*	*0.03*	*0.02*	*0.02*	*0.05*	*0.00*									
Al	0.06	-0.07	-0.08	-0.08	0.07	-0.21	-0.12	0.36	-0.29	0.22	-0.17	-0.18								
	0.87	*0.85*	*0.85*	*0.85*	*0.87*	*0.59*	*0.75*	*0.34*	*0.46*	*0.57*	*0.67*	*0.65*								
Ca	0.36	0.21	0.20	0.21	0.35	0.58	0.51	0.56	0.43	0.10	0.82	0.51	0.27							
	0.38	*0.62*	*0.64*	*0.63*	*0.40*	*0.14*	*0.20*	*0.15*	*0.29*	*0.82*	*0.01*	*0.20*	*0.52*							
Fe	0.85	0.62	0.79	0.71	0.60	0.72	0.77	0.76	0.79	0.81	0.82	0.93	-0.11	0.33						
	0.00	*0.07*	*0.01*	*0.03*	*0.09*	*0.03*	*0.02*	*0.02*	*0.01*	*0.01*	*0.01*	*0.00*	*0.79*	*0.42*						
Ti	0.71	0.51	0.52	0.52	0.83	0.40	0.68	0.60	0.42	0.67	0.59	0.39	0.75	0.55	0.36					
	0.05	*0.20*	*0.19*	*0.19*	*0.01*	*0.33*	*0.06*	*0.11*	*0.30*	*0.07*	*0.13*	*0.35*	*0.03*	*0.16*	*0.38*					
K	0.81	0.74	0.83	0.79	0.75	0.47	0.66	0.86	0.57	0.87	0.66	0.73	0.44	0.32	0.77	0.73				
	0.01	*0.02*	*0.01*	*0.01*	*0.02*	*0.21*	*0.05*	*0.00*	*0.11*	*0.00*	*0.05*	*0.03*	*0.24*	*0.44*	*0.02*	*0.04*				
S	0.87	0.73	0.87	0.80	0.67	0.67	0.79	0.65	0.82	0.89	0.73	0.85	-0.17	0.03	0.94	0.38	0.77			
	0.00	*0.03*	*0.00*	*0.01*	*0.05*	*0.05*	*0.01*	*0.06*	*0.01*	*0.00*	*0.03*	*0.00*	*0.67*	*0.95*	*0.00*	*0.35*	*0.02*			
Ni	0.69	0.56	0.62	0.59	0.57	0.61	0.67	0.85	0.63	0.71	0.75	0.59	0.72	0.62	0.50	0.87	0.78	0.46		
	0.06	*0.15*	*0.10*	*0.12*	*0.14*	*0.11*	*0.07*	*0.01*	*0.10*	*0.05*	*0.03*	*0.13*	*0.04*	*0.10*	*0.21*	*0.01*	*0.02*	*0.25*		
Pb	0.90	0.59	0.65	0.62	0.82	0.71	0.89	0.54	0.75	0.86	0.70	0.55	0.05	0.31	0.65	0.87	0.67	0.74	0.71	
	0.00	*0.09*	*0.06*	*0.07*	*0.01*	*0.03*	*0.00*	*0.13*	*0.02*	*0.00*	*0.04*	*0.12*	*0.90*	*0.46*	*0.06*	*0.01*	*0.05*	*0.02*	*0.05*	
Zn	0.83	0.68	0.85	0.77	0.67	0.65	0.76	0.70	0.78	0.85	0.76	0.90	-0.18	0.16	0.96	0.41	0.77	0.98	0.51	0.71
	0.01	*0.04*	*0.00*	*0.02*	*0.05*	*0.06*	*0.02*	*0.04*	*0.01*	*0.00*	*0.02*	*0.00*	*0.65*	*0.71*	*0.00*	*0.31*	*0.02*	*0.00*	*0.20*	*0.03*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.129 and Table 3.130 for PM mass and major species, respectively. $PM_{2.5}$ mass showed lesser C.V. as compared to PM_{10} mass. The crustal elements show a higher variation in $PM_{2.5}$ than that of in PM_{10}. The secondary particulates show a similar variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.131 and Table 3.132 for PM mass and its major species. OC, EC, and TC show a higher correlation with PM_{10} mass than that of $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass than that of $PM_{2.5}$. The secondary particulates show a better correlation with each other in $PM_{2.5}$ and also with $PM_{2.5}$ mass.

3.1.18 Site 18: Gurgaon-2

3.1.18.1 Summer season:

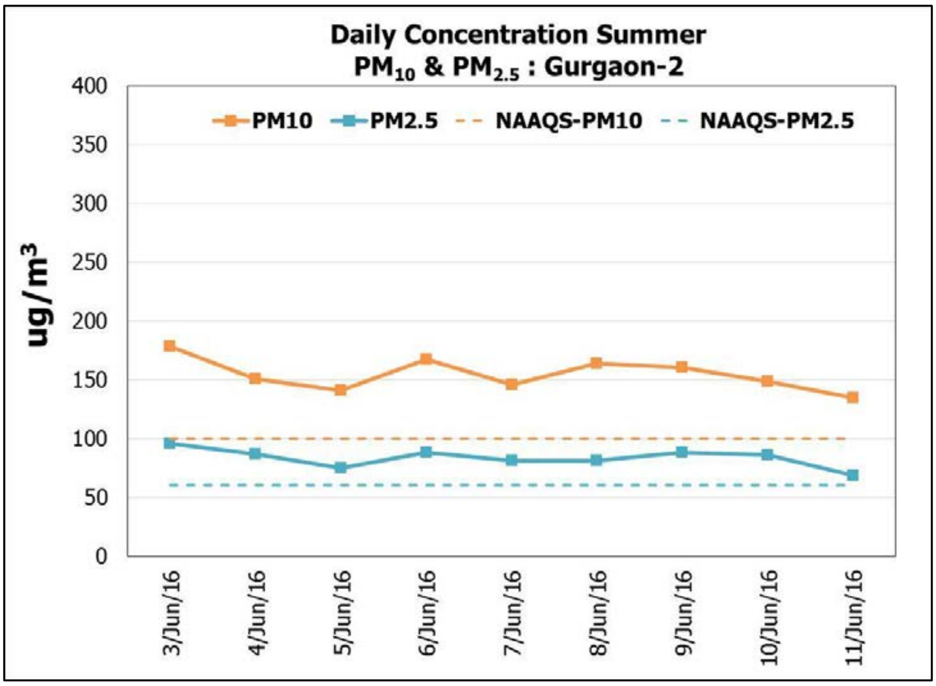


Figure 3.166: Variation in 24 hourly concentration of PM10 and PM2.5 at Gurgaon-2 in summer season

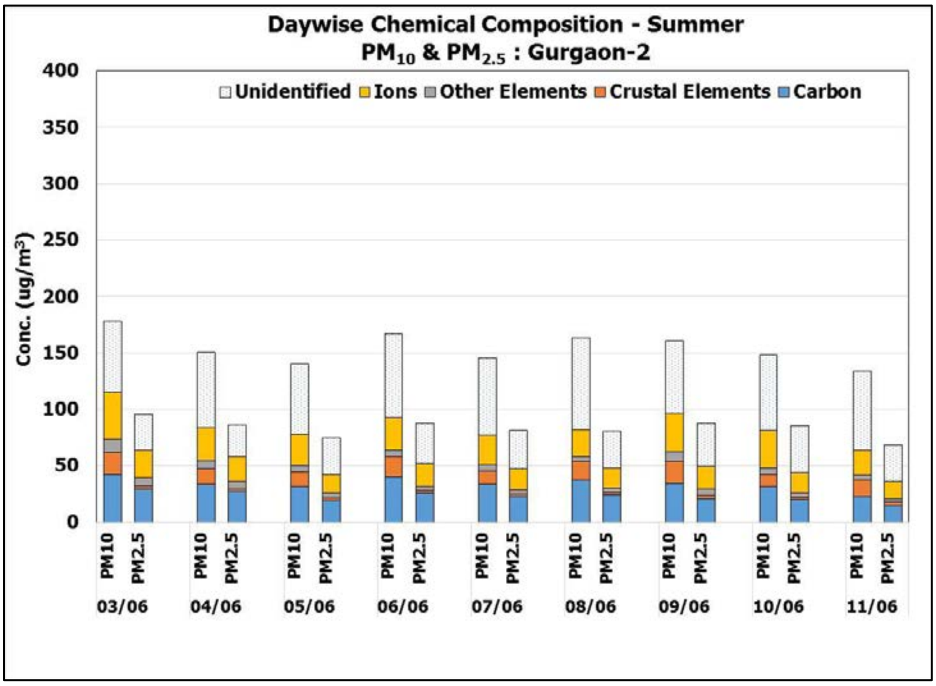


Figure 3.167: Variation in chemical composition of PM10 and PM2.5 at Gurgaon-2 in summer season

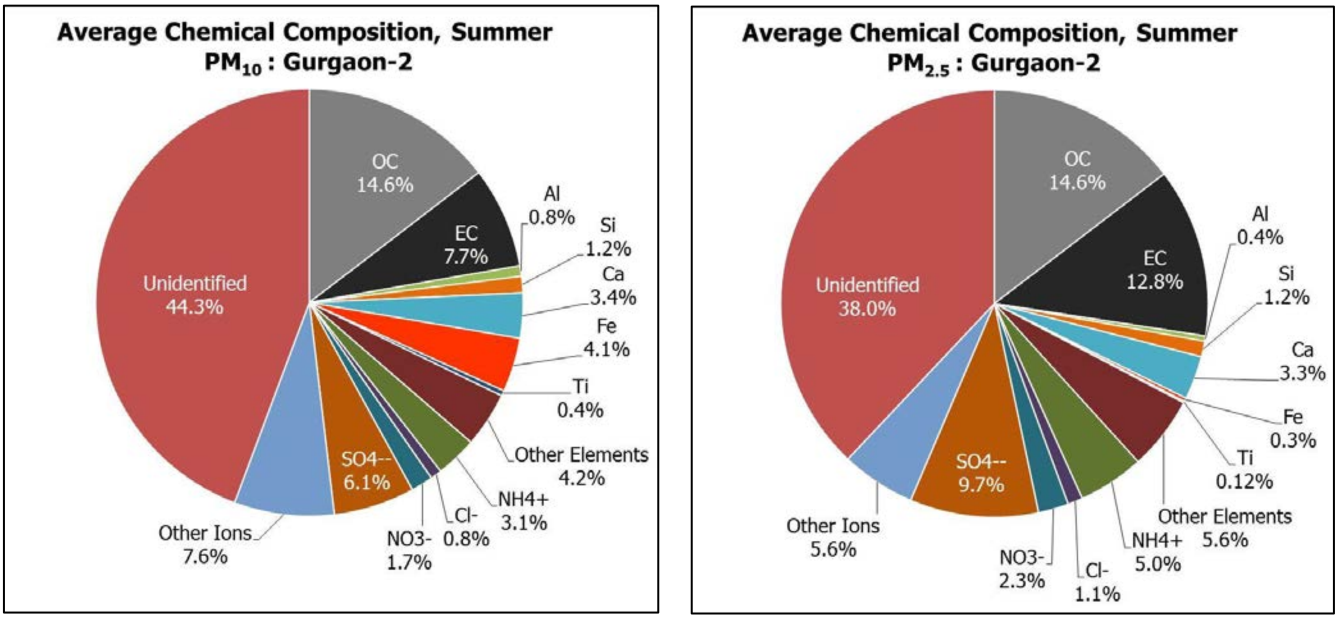


Figure 3.168: Average chemical composition of PM10 and PM2.5 at Gurgaon-2 in summer season

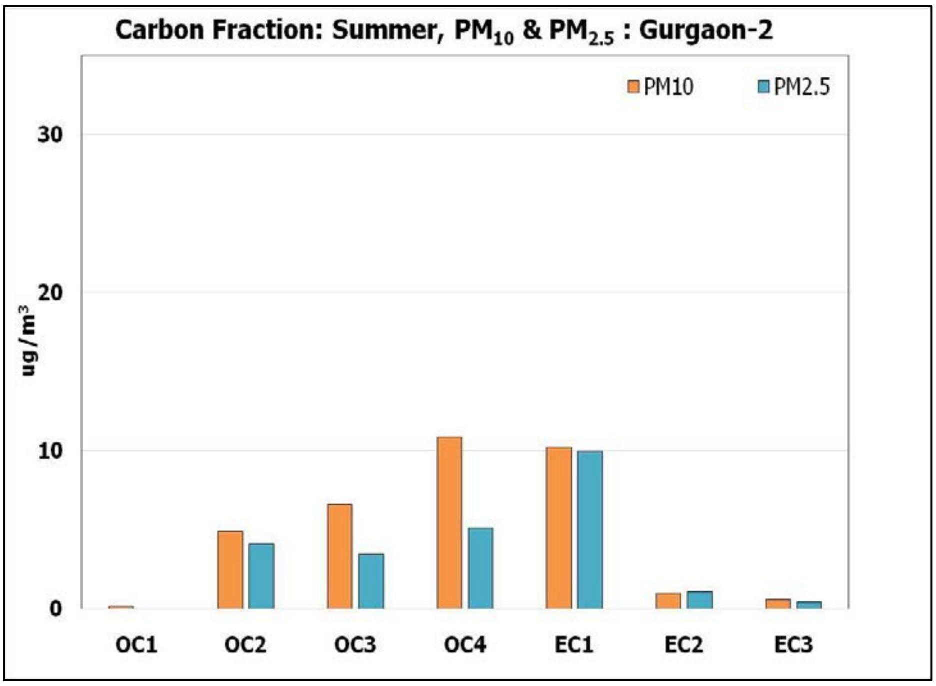


Figure 3.169: Average concentration of carbon fractions of PM10 and PM2.5 at Gurgaon-2 in summer

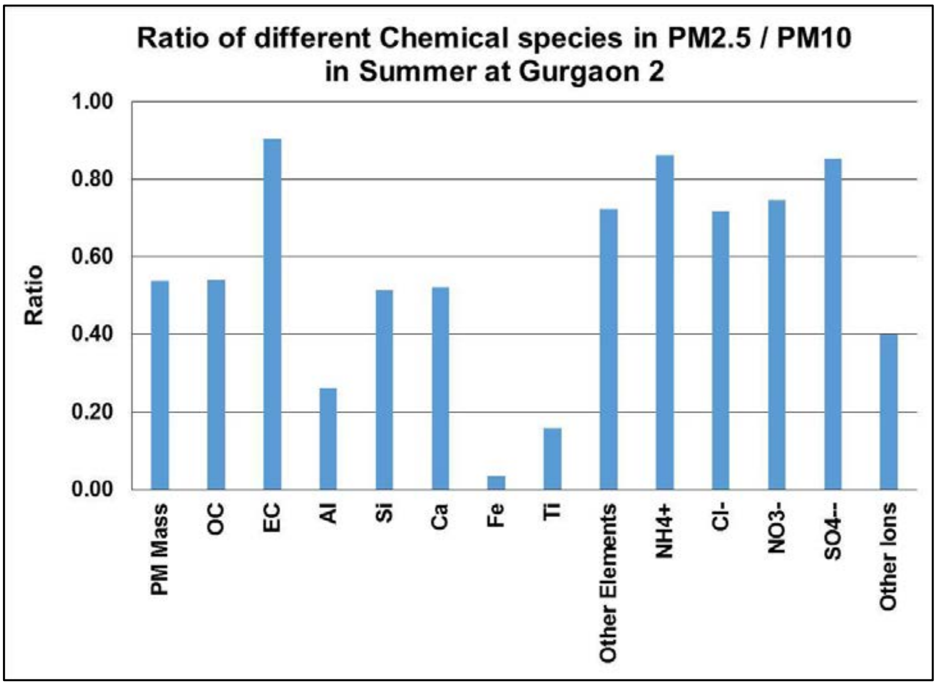


Figure 3.170: Ratio of different Chemical species in PM2.5 / PM10 in summer season at Gurgaon-2

Average concentration of PM_{10} at Palam vihar, Gurgaon(GRG2), site was found to be 154±14 $\mu g/m^3$, which is 1.6 times as per NAAQS. Concentration of PM_{10} varied from 134 to 178 $\mu g/m^3$. Average concentration of $PM_{2.5}$ was 83±8 $\mu g/m^3$; $PM_{2.5}$ was found to be in range from 69 to 96 $\mu g/m^3$. The standard deviation was found to be very less in case of $PM_{2.5}$ during monitoring period (see Figure 3.166).

Daily variation in the components of the different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.167.

Average concentration of carbon fraction for PM_{10} and $PM_{2.5}$ was found to be 22% and 27%, respectively. The total Ions found was 19% and 23% for PM_{10} and $PM_{2.5}$, respectively. Concentration of the crustal elements was 10% in PM_{10} and 3% in the case of $PM_{2.5}$ (see Figure 3.168).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% in PM_{10} and 6% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was found to be 44% and 41% for PM_{10} and $PM_{2.5}$, respectively.

In PM_{10}, concentration of OC4 was highest, followed by EC1, OC3, OC2, EC2, and EC3, while, in case of $PM_{2.5}$, EC1 is highest, followed by OC4, OC2, OC3, EC2, and EC3 (see Figure 3.169). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.170.

Table 3.133: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Gurgaon 2 for summer season

µg/m3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	$NO3^-$	SO_4^{--}	Na^+	$NH4^+$	K^+	Ca^{++}
Mean	154	22.51	11.82	1.25	1.92	5.26	6.33	0.62	3.18	1.15	0.22	0.52	1.31	2.57	9.49	3.94	4.83	2.32	3.39
SD	14	3.63	2.30	0.21	0.82	0.95	1.32	0.13	1.47	0.32	0.21	0.73	0.79	0.23	1.39	2.13	0.72	1.07	0.79
Min	134	15.39	7.76	0.94	1.13	3.82	4.61	0.45	1.88	0.74	0.06	0.00	0.65	2.20	7.38	1.10	3.94	1.16	2.42
Max	178	28.39	15.01	1.65	3.75	6.54	8.42	0.87	5.98	1.86	0.61	2.45	2.80	2.83	11.52	8.71	5.96	4.35	4.73
C.V.	0.09	0.16	0.19	0.17	0.43	0.18	0.21	0.21	0.46	0.28	0.93	1.42	0.60	0.09	0.15	0.54	0.15	0.46	0.23
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95 %ile	174	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	151	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	137	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.134: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Gurgaon 2 for summer season

µg/m3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	$NO3^-$	SO_4^{--}	Na^+	$NH4^+$	K^+	Ca^{++}
Mean	83	12.17	10.68	0.33	0.99	2.75	0.22	0.10	2.65	0.99	0.06	0.16	0.94	1.92	8.10	1.13	4.16	1.30	1.52
SD	8	2.84	2.15	0.03	0.16	0.35	0.19	0.02	1.01	0.26	0.04	0.21	0.43	0.20	0.89	0.56	0.59	0.68	0.31
Min	69	8.82	6.50	0.30	0.76	2.34	0.06	0.08	1.75	0.64	0.02	0.06	0.55	1.51	6.58	0.61	3.33	0.20	1.18
Max	96	16.73	13.11	0.39	1.18	3.36	0.53	0.13	4.26	1.46	0.17	0.73	1.92	2.14	9.44	2.53	4.99	2.49	1.98
C.V.	0.10	0.23	0.20	0.09	0.17	0.13	0.89	0.17	0.38	0.26	0.74	1.31	0.45	0.10	0.11	0.49	0.14	0.52	0.20
N	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
95%ile	93	16.63	12.93	0.38	1.17	3.29	0.53	0.13	4.10	1.37	0.13	0.50	1.68	2.14	9.32	1.99	4.96	2.25	1.96
50%ile	86	11.61	11.54	0.31	1.04	2.69	0.12	0.10	2.04	0.95	0.04	0.10	0.82	1.93	8.02	1.04	3.88	1.33	1.51
5%ile	71	8.96	7.34	0.30	0.77	2.34	0.06	0.08	1.79	0.69	0.02	0.07	0.57	1.60	6.91	0.67	3.46	0.39	1.18

Table 3.135: Correlation matrix for PM_{10} and its composition for summer season at Gurgaon 2

	PM_{10}	OC	EC	TC	Cl-	NO3-	SO_4^{--}	Na+	NH4+	K+	Ca++	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.83	0.79																		
	0.01	*0.01*																		
TC	0.93	0.97	0.92																	
	0.00	*0.00*	*0.00*																	
Cl-	0.25	0.21	-0.07	0.11																
	0.53	*0.58*	*0.86*	*0.78*																
NO3-	0.84	0.79	0.59	0.75	0.48															
	0.01	*0.01*	*0.09*	*0.02*	*0.19*															
SO_4^{--}	*0.42*	*0.47*	*0.29*	*0.42*	*0.49*	*0.46*														
	0.27	*0.21*	*0.45*	*0.26*	*0.18*	*0.21*														
Na+	0.53	0.49	0.31	0.44	0.70	0.59	0.57													
	0.14	*0.18*	*0.42*	*0.23*	*0.04*	*0.10*	*0.11*													
NH4+	0.52	0.54	0.42	0.52	0.57	0.67	0.70	0.59												
	0.15	*0.14*	*0.26*	*0.15*	*0.11*	*0.05*	*0.03*	*0.10*												
K+	0.58	0.60	0.44	0.57	0.21	0.66	0.20	0.69	0.20											
	0.10	*0.09*	*0.23*	*0.11*	*0.60*	*0.05*	*0.62*	*0.04*	*0.60*											
Ca++	0.76	0.61	0.74	0.70	0.10	0.75	0.11	0.54	0.51	0.68										
	0.02	*0.08*	*0.02*	*0.04*	*0.79*	*0.02*	*0.77*	*0.14*	*0.16*	*0.04*										
Si	0.89	0.79	0.64	0.77	0.28	0.73	0.19	0.63	0.27	0.74	0.72									
	0.00	*0.01*	*0.07*	*0.02*	*0.47*	*0.03*	*0.64*	*0.07*	*0.49*	*0.02*	*0.03*									
Al	0.53	0.36	0.61	0.48	-0.50	0.34	0.18	-0.03	0.05	0.30	0.54	0.38								
	0.14	*0.34*	*0.08*	*0.19*	*0.17*	*0.38*	*0.65*	*0.95*	*0.90*	*0.43*	*0.13*	*0.31*								
Ca	0.79	0.63	0.67	0.68	-0.10	0.59	0.21	0.44	0.11	0.71	0.72	0.84	0.79							
	0.01	*0.07*	*0.05*	*0.05*	*0.79*	*0.09*	*0.59*	*0.23*	*0.79*	*0.03*	*0.03*	*0.01*	*0.01*							
Fe	0.62	0.36	0.45	0.42	-0.23	0.38	0.12	0.16	-0.02	0.33	0.51	0.63	0.84	0.88						
	0.07	*0.34*	*0.23*	*0.27*	*0.56*	*0.31*	*0.76*	*0.68*	*0.96*	*0.39*	*0.16*	*0.07*	*0.00*	*0.00*						
Ti	0.73	0.67	0.33	0.57	0.64	0.68	0.71	0.77	0.63	0.44	0.39	0.71	0.16	0.52	0.44					
	0.03	*0.05*	*0.39*	*0.11*	*0.06*	*0.04*	*0.03*	*0.02*	*0.07*	*0.23*	*0.29*	*0.03*	*0.69*	*0.15*	*0.24*					
K	0.56	0.48	0.42	0.48	0.29	0.67	0.26	0.79	0.32	0.94	0.78	0.70	0.35	0.72	0.40	0.48				
	0.12	*0.20*	*0.26*	*0.19*	*0.45*	*0.05*	*0.51*	*0.01*	*0.40*	*0.00*	*0.01*	*0.04*	*0.36*	*0.03*	*0.29*	*0.19*				
S	0.59	0.62	0.66	0.67	0.10	0.26	0.63	0.35	0.22	0.23	0.13	0.44	0.36	0.47	0.32	0.49	0.16			
	0.09	*0.07*	*0.05*	*0.05*	*0.81*	*0.49*	*0.07*	*0.36*	*0.58*	*0.55*	*0.74*	*0.24*	*0.35*	*0.20*	*0.40*	*0.18*	*0.69*			
Ni	0.59	0.45	0.19	0.37	0.53	0.59	0.76	0.53	0.58	0.17	0.24	0.47	0.30	0.44	0.53	0.90	0.28	0.40		
	0.10	*0.22*	*0.62*	*0.33*	*0.14*	*0.09*	*0.02*	*0.15*	*0.10*	*0.65*	*0.54*	*0.20*	*0.44*	*0.24*	*0.14*	*0.00*	*0.47*	*0.28*		
Pb	-0.20	-0.38	-0.53	-0.46	0.64	-0.13	-0.04	0.35	0.00	-0.17	-0.21	0.04	-0.54	-0.23	-0.08	0.31	-0.02	-0.29	0.30	
	0.61	*0.32*	*0.14*	*0.21*	*0.07*	*0.74*	*0.91*	*0.36*	*0.99*	*0.66*	*0.60*	*0.92*	*0.13*	*0.56*	*0.85*	*0.42*	*0.96*	*0.45*	*0.44*	
Zn	0.71	0.69	0.49	0.65	0.50	0.66	0.22	0.84	0.48	0.76	0.71	0.85	0.02	0.55	0.24	0.68	0.76	0.26	0.33	0.19
	0.03	0.04	*0.18*	*0.06*	*0.17*	*0.05*	*0.58*	*0.01*	*0.20*	*0.02*	*0.03*	*0.00*	*0.96*	*0.13*	*0.54*	*0.04*	*0.02*	*0.51*	*0.39*	*0.62*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.136: Correlation matrix for $PM_{2.5}$ and its composition for summer season at Gurgaon 2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.64																			
	0.06																			
EC	0.81	0.53																		
	0.01	*0.14*																		
TC	0.81	0.91	0.84																	
	0.01	*0.00*	*0.01*																	
Cl^-	0.59	0.43	0.17	0.36																
	0.10	*0.25*	*0.66*	*0.34*																
NO_3^-	0.82	0.52	0.69	0.68	0.29															
	0.01	*0.15*	*0.04*	*0.05*	*0.45*															
SO_4^{--}	0.76	0.71	0.62	0.77	0.29	0.59														
	0.02	*0.03*	*0.08*	*0.02*	*0.46*	*0.09*														
Na^+	0.50	0.46	0.41	0.50	0.56	0.36	0.26													
	0.17	*0.22*	*0.27*	*0.17*	*0.12*	*0.34*	*0.51*													
NH_4^+	0.81	0.34	0.71	0.57	0.36	0.62	0.60	0.66												
	0.01	*0.38*	*0.03*	*0.11*	*0.35*	*0.07*	*0.09*	*0.06*												
K^+	0.54	0.89	0.59	0.87	0.06	0.60	0.62	0.25	0.25											
	0.13	*0.00*	*0.10*	*0.00*	*0.88*	*0.09*	*0.07*	*0.51*	*0.52*											
Ca^{++}	0.72	0.42	0.48	0.51	0.29	0.72	0.74	0.39	0.79	0.33										
	0.03	*0.26*	*0.20*	*0.16*	*0.46*	*0.03*	*0.02*	*0.30*	*0.01*	*0.38*										
Si	0.52	0.18	0.11	0.18	0.66	0.13	0.50	0.29	0.47	-0.09	0.34									
	0.15	*0.64*	*0.77*	*0.65*	*0.06*	*0.73*	*0.17*	*0.45*	*0.20*	*0.82*	*0.37*									
Al	0.59	0.23	0.51	0.40	-0.04	0.65	0.71	0.32	0.76	0.31	0.79	0.39								
	0.09	*0.55*	*0.16*	*0.29*	*0.92*	*0.06*	*0.03*	*0.41*	*0.02*	*0.42*	*0.01*	*0.30*								
Ca	0.46	0.18	0.20	0.21	0.25	0.42	0.62	0.41	0.68	0.01	0.88	0.46	0.76							
	0.22	*0.65*	*0.61*	*0.59*	*0.51*	*0.26*	*0.07*	*0.28*	*0.04*	*0.99*	*0.00*	*0.21*	*0.02*							
Fe	0.32	0.20	0.19	0.23	0.32	0.37	-0.08	0.72	0.42	0.22	0.10	0.21	0.26	0.04						
	0.41	*0.60*	*0.62*	*0.56*	*0.40*	*0.33*	*0.85*	*0.03*	*0.26*	*0.57*	*0.80*	*0.59*	*0.50*	*0.93*						
Ti	0.64	0.02	0.51	0.26	0.26	0.37	0.53	0.39	0.87	-0.07	0.63	0.69	0.77	0.66	0.25					
	0.06	*0.96*	*0.16*	*0.49*	*0.50*	*0.32*	*0.14*	*0.31*	*0.00*	*0.86*	*0.07*	*0.04*	*0.02*	*0.05*	*0.51*					
K	0.59	0.55	0.29	0.50	0.22	0.64	0.70	0.46	0.66	0.51	0.84	0.40	0.80	0.76	0.39	0.50				
	0.09	*0.13*	*0.44*	*0.17*	*0.57*	*0.06*	*0.04*	*0.21*	*0.05*	*0.16*	*0.00*	*0.29*	*0.01*	*0.02*	*0.30*	*0.17*				
S	0.68	0.61	0.63	0.70	0.30	0.58	0.53	0.33	0.40	0.68	0.16	0.42	0.41	-0.06	0.53	0.33	0.39			
	0.04	*0.08*	*0.07*	*0.04*	*0.43*	*0.10*	*0.14*	*0.39*	*0.29*	*0.04*	*0.68*	*0.27*	*0.27*	*0.87*	*0.14*	*0.38*	*0.31*			
Ni	0.76	0.44	0.62	0.59	0.56	0.49	0.56	0.77	0.81	0.29	0.46	0.69	0.60	0.44	0.63	0.76	0.53	0.70		
	0.02	*0.24*	*0.07*	*0.09*	*0.12*	*0.19*	*0.12*	*0.02*	*0.01*	*0.44*	*0.22*	*0.04*	*0.09*	*0.23*	*0.07*	*0.02*	*0.14*	*0.04*		
Pb	0.79	0.72	0.54	0.73	0.63	0.59	0.70	0.82	0.80	0.51	0.71	0.56	0.59	0.62	0.55	0.58	0.79	0.54	0.84	
	0.01	*0.03*	*0.14*	*0.03*	*0.07*	*0.09*	*0.04*	*0.01*	*0.01*	*0.16*	*0.03*	*0.12*	*0.10*	*0.07*	*0.13*	*0.10*	*0.01*	*0.13*	*0.00*	
Zn	0.63	0.67	0.40	0.63	0.68	0.44	0.54	0.92	0.67	0.41	0.57	0.49	0.41	0.56	0.57	0.42	0.66	0.41	0.79	0.95
	0.07	*0.05*	*0.29*	*0.07*	*0.04*	*0.23*	*0.14*	*0.00*	*0.05*	*0.28*	*0.11*	*0.18*	*0.27*	*0.12*	*0.11*	*0.26*	*0.05*	*0.27*	*0.01*	*0.00*

Note: Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.133 and Table 3.134 for PM mass and major species, respectively. Both PM10 mass and PM2.5 mass have a similar C.V. For crustal elements, C.V. in both PM_{10} and $PM_{2.5}$ is lesser. In PM_{10} and $PM_{2.5}$, secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show a similar C.V.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.135 and Table 3.136 for the PM mass and its major species. OC, EC, and TC show a higher correlation with PM_{10} mass as compared to $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with $PM_{2.5}$ mass than that of PM_{10} mass. The secondary particulates showed better correlation with each other in $PM_{2.5}$ and with $PM_{2.5}$ mass.

3.1.18.2 Winter season:

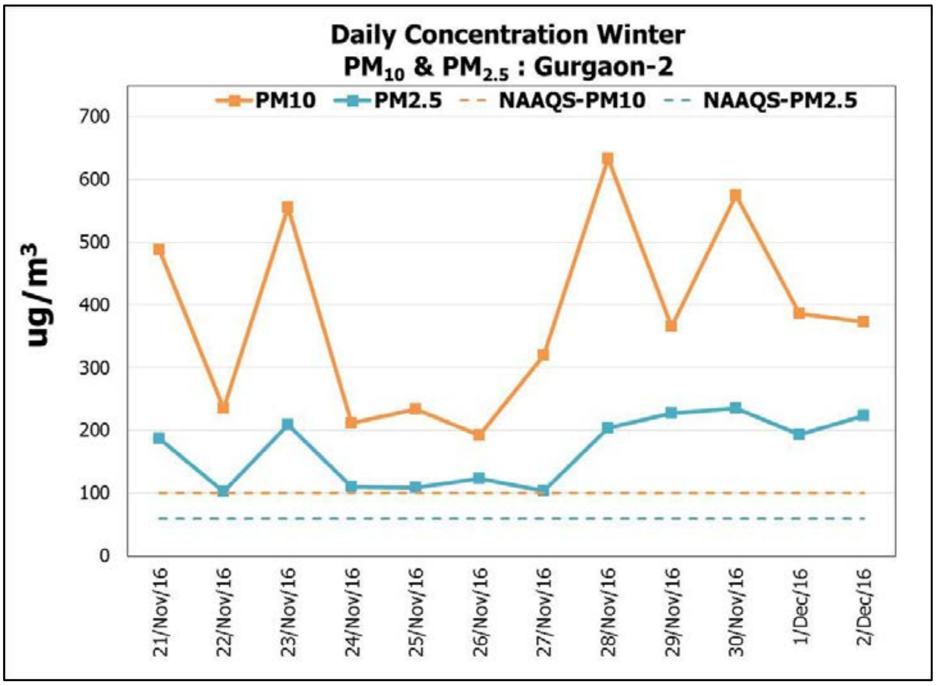


Figure 3.171: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Gurgaon-2 in winter season

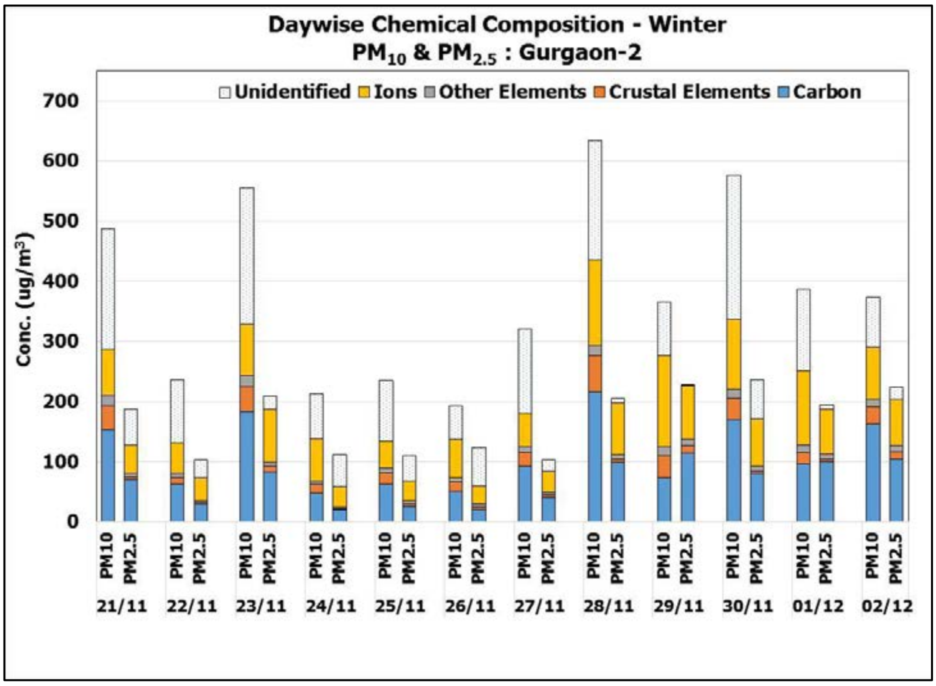


Figure 3.172: Variation in chemical composition of PM10 and PM2.5 at Gurgaon-2 in winter season

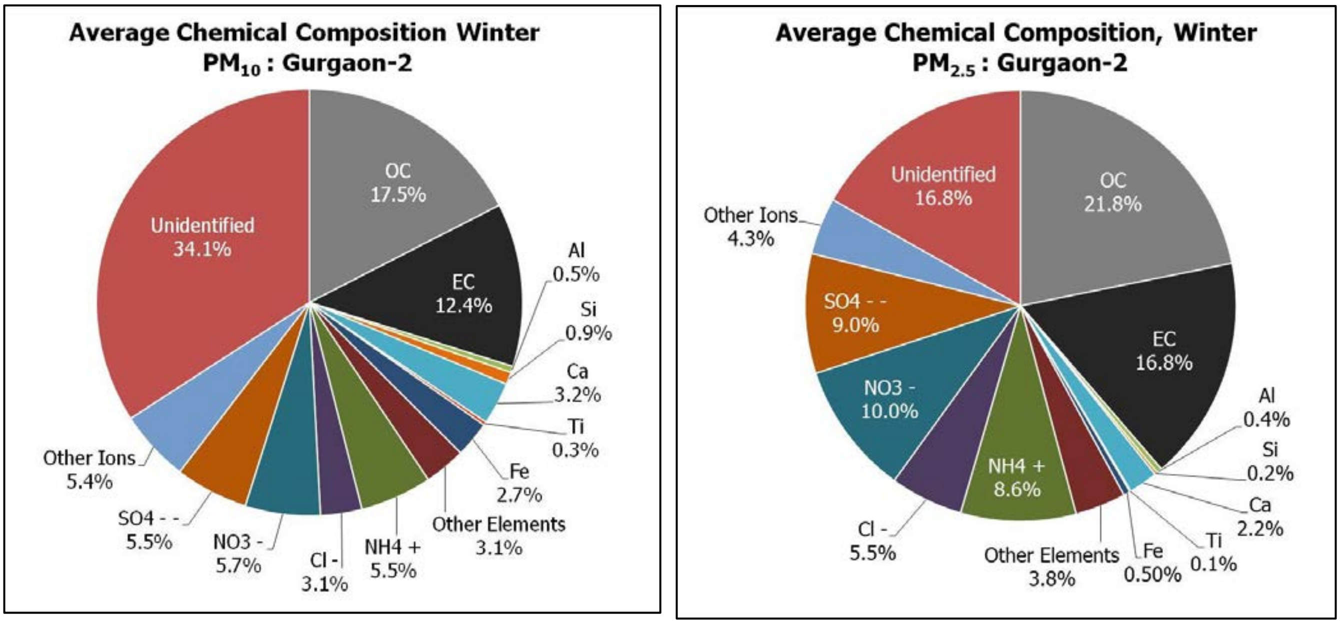


Figure 3.173: Average chemical composition of PM10 and PM2.5 at Gurgaon-2 in winter season

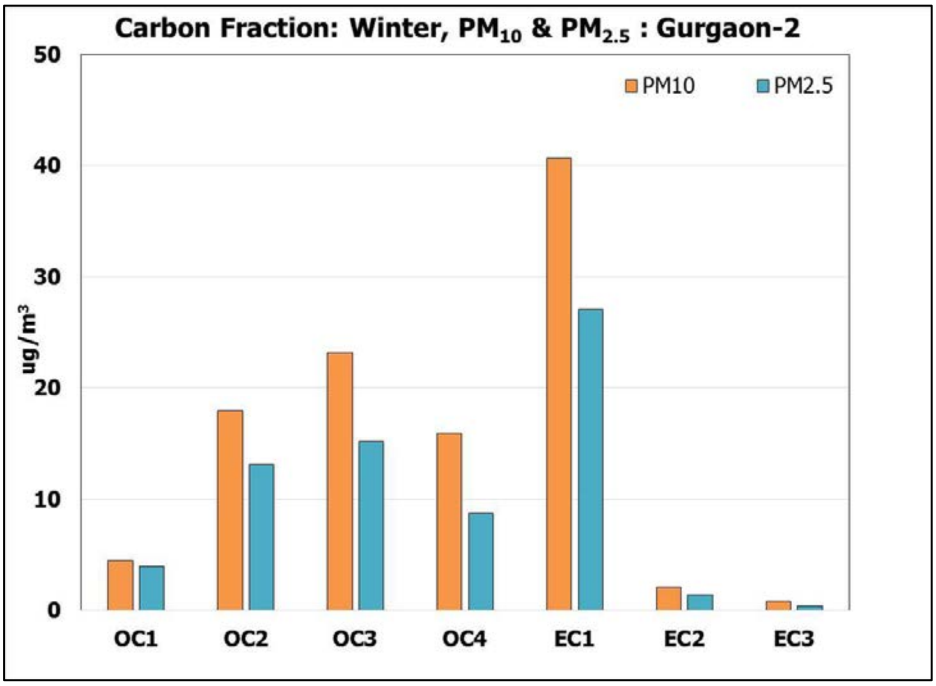


Figure 3.174: Average concentration of carbon fractions of PM10 and PM2.5 at Gurgaon-2 in winter season

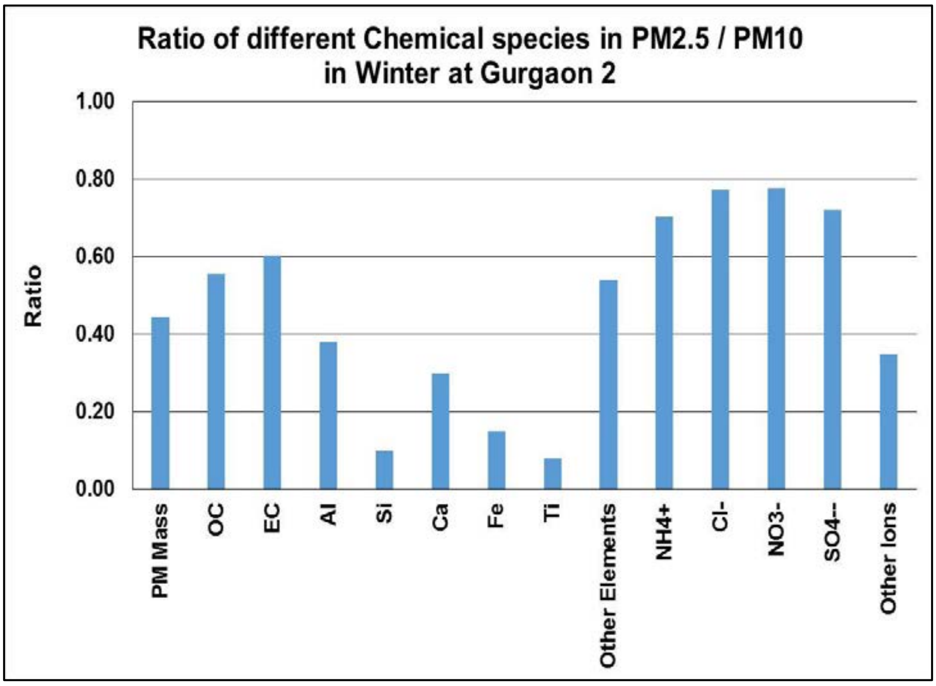


Figure 3.175: Ratio of different chemical species in $PM_{2.5}$/PM_{10} in winter season at Gurgaon-2

Average concentration of PM_{10} was found to be 381±152 µg/m^3 and the average concentration in $PM_{2.5}$ was found to be 169±54 µg/m^3. Concentration of PM_{10} varied from 193 µg/m^3 and 633 µg/m^3, and, in the case of $PM_{2.5}$, it varied from 103 to 236 µg/m^3 (see Figure3.171).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.172.

The average carbon fraction concentration in $PM_{2.5}$ was found to be higher, that is, 39% and 30% in PM_{10}. The total ion in PM_{10} was found to be 25%, while, in case of $PM_{2.5}$, it was found to be 37%. The crustal element was found to be 8% and 3% for PM_{10} and $PM_{2.5}$, respectively (see Figure 3.173).

Concentration of the other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% and 4% in PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was found to be 34% in PM_{10} while it was found to be 17% in $PM_{2.5}$.

In carbon fraction, OC3 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by OC2, OC4, and OC1. EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$, followed by EC2 and EC3 (see Figure 3.174). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.175.

Table 3.137: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Gurgaon 2 for winter season

µg/m^3																			
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	381	66.58	47.15	1.84	3.52	12.28	10.35	1.00	6.03	3.37	0.61	0.68	11.96	21.70	21.12	2.40	20.78	4.66	8.84
SD	152	33.00	27.66	0.80	1.81	6.56	4.99	0.62	2.27	1.49	0.27	0.32	5.31	6.57	7.91	0.70	7.66	2.17	5.62
Min	193	26.82	9.32	0.54	1.35	4.62	4.85	0.32	2.88	1.35	0.13	0.24	4.29	12.42	9.85	1.11	10.85	1.49	3.14
Max	633	124.59	90.71	3.06	7.36	27.03	22.13	2.49	9.39	5.51	1.20	1.18	19.62	32.99	31.56	3.47	34.20	8.79	22.86
C.V.	0.40	0.50	0.59	0.43	0.51	0.53	0.48	0.62	0.38	0.44	0.44	0.47	0.44	0.30	0.37	0.29	0.37	0.47	0.64
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95%ile	601	116.31	87.44	3.05	6.15	22.63	18.72	1.97	8.93	5.35	1.00	1.13	18.86	30.80	31.45	3.28	32.56	7.81	17.28
50%ile	374	63.87	40.26	1.84	3.52	12.28	9.09	1.00	5.75	3.37	0.61	0.68	11.46	21.70	20.14	2.40	18.49	4.59	8.84
5%ile	178	30.84	18.47	0.70	1.55	5.20	4.94	0.38	2.67	1.38	0.22	0.28	4.70	10.37	9.17	0.96	9.74	1.93	3.24

Table 3.138: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Gurgaon 2 for winter season

µg/m^3																			
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	169	36.95	28.48	0.70	0.35	3.67	0.84	0.15	2.48	2.59	0.43	0.42	9.26	16.86	15.20	1.32	14.63	1.75	1.86
SD	54	20.61	16.98	0.50	0.22	2.71	0.56	0.12	0.90	1.27	0.20	0.22	5.76	6.29	5.81	0.43	5.42	0.66	0.96
Min	103	11.68	7.85	0.14	0.12	1.28	0.28	0.02	1.41	0.70	0.08	0.09	1.75	8.85	8.74	0.83	7.75	1.09	0.99
Max	236	69.46	58.79	1.69	0.88	9.01	2.34	0.33	4.12	4.44	0.87	0.75	17.58	27.50	22.60	2.24	22.14	2.86	3.67
C.V.	0.32	0.56	0.60	0.72	0.63	0.74	0.67	0.77	0.36	0.49	0.46	0.51	0.62	0.37	0.38	0.33	0.37	0.38	0.51
N	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
95%ile	231	62.53	52.59	1.62	0.71	8.77	1.77	0.33	3.80	4.38	0.73	0.72	16.56	26.02	22.42	2.12	21.74	2.85	3.44
50%ile	190	39.74	30.29	0.55	0.25	2.35	0.65	0.12	2.34	2.32	0.43	0.39	9.22	16.23	15.19	1.19	15.55	1.54	1.47
5%ile	103	12.28	8.18	0.14	0.15	1.79	0.30	0.03	1.41	0.83	0.17	0.12	2.39	9.19	8.92	0.91	8.04	1.09	0.99

Table 3.139: Correlation matrix for PM_{10} and its composition for winter season at Gurgaon 2

	PM_{10}	OC	EC	TC	Cl^-	$NO3^-$	SO_4^{--}	Na^+	$NH4^+$	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.94																			
	0.00																			
EC	0.88	0.90																		
	0.00	*0.00*																		
TC	0.94	0.98	0.97																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.34	0.14	0.19	0.17																
	0.46	*0.76*	*0.68*	*0.72*																
NO_3^-	0.60	0.52	0.33	0.44	0.75															
	0.04	*0.08*	*0.29*	*0.15*	*0.05*															
SO_4^{--}	0.55	0.48	0.23	0.38	0.63	0.95														
	0.06	*0.11*	*0.48*	*0.23*	*0.13*	*0.00*														
Na^+	0.73	0.62	0.61	0.63	0.62	0.55	0.43													
	0.01	*0.03*	*0.04*	*0.03*	*0.13*	*0.06*	*0.16*													
NH_4^+	0.74	0.69	0.44	0.59	0.51	0.88	0.94	0.54												
	0.01	*0.01*	*0.15*	*0.04*	*0.24*	*0.00*	*0.00*	*0.07*												
K^+	0.72	0.51	0.62	0.58	0.46	0.45	0.33	0.51	0.40											
	0.01	*0.09*	*0.03*	*0.05*	*0.29*	*0.14*	*0.29*	*0.09*	*0.20*											
Ca^{++}	0.84	0.82	0.75	0.81	0.32	0.66	0.59	0.62	0.71	0.57										
	0.00	*0.00*	*0.01*	*0.00*	*0.49*	*0.02*	*0.04*	*0.03*	*0.01*	*0.06*										
Si	0.90	0.88	0.83	0.88	0.31	0.68	0.61	0.67	0.71	0.65	0.97									
	0.00	*0.00*	*0.00*	*0.00*	*0.50*	*0.02*	*0.04*	*0.02*	*0.01*	*0.02*	*0.00*									
Al	0.85	0.76	0.76	0.78	0.51	0.67	0.56	0.87	0.64	0.69	0.86	0.92								
	0.00	*0.00*	*0.00*	*0.00*	*0.24*	*0.02*	*0.06*	*0.00*	*0.03*	*0.01*	*0.00*	*0.00*								
Ca	0.87	0.80	0.85	0.84	0.31	0.55	0.48	0.61	0.60	0.72	0.94	0.95	0.86							
	0.00	*0.00*	*0.00*	*0.00*	*0.50*	*0.07*	*0.12*	*0.04*	*0.04*	*0.01*	*0.00*	*0.00*	*0.00*							
Fe	0.90	0.83	0.83	0.85	0.33	0.58	0.53	0.67	0.67	0.69	0.94	0.96	0.91	0.97						
	0.00	*0.00*	*0.00*	*0.00*	*0.48*	*0.05*	*0.07*	*0.02*	*0.02*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*						
Ti	0.86	0.81	0.85	0.85	0.31	0.53	0.47	0.63	0.60	0.67	0.95	0.96	0.89	0.98	0.99					
	0.00	*0.00*	*0.00*	*0.00*	*0.50*	*0.08*	*0.13*	*0.03*	*0.04*	*0.02*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*					
K	0.86	0.69	0.76	0.74	0.48	0.56	0.44	0.69	0.53	0.95	0.76	0.83	0.86	0.87	0.85	0.83				
	0.00	*0.01*	*0.00*	*0.01*	*0.27*	*0.06*	*0.15*	*0.01*	*0.08*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				
S	0.75	0.67	0.60	0.65	0.56	0.58	0.50	0.72	0.59	0.59	0.39	0.52	0.62	0.45	0.46	0.40	0.66			
	0.01	*0.02*	*0.04*	*0.02*	*0.19*	*0.05*	*0.10*	*0.01*	*0.05*	*0.04*	*0.21*	*0.08*	*0.03*	*0.14*	*0.14*	*0.20*	*0.02*			
Ni	0.27	0.22	0.40	0.31	0.33	0.37	0.11	0.43	-0.01	0.51	0.34	0.45	0.57	0.42	0.35	0.40	0.56	0.34		
	0.40	*0.49*	*0.19*	*0.33*	*0.47*	*0.24*	*0.73*	*0.16*	*0.99*	*0.09*	*0.28*	*0.14*	*0.05*	*0.18*	*0.27*	*0.20*	*0.06*	*0.29*		
Pb	0.42	0.30	0.57	0.43	0.41	-0.01	-0.23	0.55	-0.14	0.60	0.23	0.34	0.52	0.36	0.39	0.39	0.59	0.41	0.65	
	0.18	*0.35*	*0.05*	*0.16*	*0.36*	*0.99*	*0.46*	*0.07*	*0.66*	*0.04*	*0.47*	*0.28*	*0.09*	*0.25*	*0.22*	*0.21*	*0.05*	*0.18*	*0.02*	
Zn	0.81	0.71	0.75	0.75	0.80	0.68	0.60	0.68	0.65	0.73	0.74	0.82	0.87	0.82	0.84	0.83	0.84	0.68	0.50	0.48
	0.00	*0.01*	*0.01*	*0.01*	*0.03*	*0.01*	*0.04*	*0.01*	*0.02*	*0.01*	*0.01*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.01*	*0.10*	*0.11*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.140 : Correlation Matrix for PM2.5 and its composition for Winter Season at Gurgaon 2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.84																			
	0.00																			
EC	0.86	0.87																		
	0.00	*0.00*																		
TC	0.87	0.98	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.47	0.56	0.62	0.62																
	0.29	*0.19*	*0.14*	*0.14*																
NO_3^-	0.93	0.84	0.90	0.89	0.25															
	0.00	*0.00*	*0.00*	*0.00*	*0.59*															
SO_4^{--}	0.94	0.88	0.84	0.89	0.44	0.94														
	0.00	*0.00*	*0.00*	*0.00*	*0.33*	*0.00*														
Na^+	0.43	0.03	0.08	0.05	-0.06	0.27	0.36													
	0.22	*0.94*	*0.84*	*0.90*	*0.91*	*0.46*	*0.30*													
NH_4^+	0.92	0.88	0.85	0.90	0.31	0.97	0.98	0.34												
	0.00	*0.00*	*0.00*	*0.00*	*0.51*	*0.00*	*0.00*	*0.34*												
K^+	0.85	0.70	0.86	0.79	0.26	0.85	0.81	0.45	0.82											
	0.00	*0.02*	*0.00*	*0.01*	*0.57*	*0.00*	*0.00*	*0.19*	*0.00*											
Ca^{++}	0.56	0.45	0.72	0.58	0.40	0.50	0.43	0.25	0.42	0.82										
	0.09	*0.19*	*0.02*	*0.08*	*0.37*	*0.14*	*0.22*	*0.48*	*0.23*	*0.00*										
Si	0.41	0.34	0.65	0.48	0.57	0.47	0.47	0.05	0.40	0.53	0.59									
	0.24	*0.34*	*0.04*	*0.17*	*0.18*	*0.17*	*0.18*	*0.90*	*0.25*	*0.11*	*0.07*									
Al	0.60	0.55	0.79	0.66	0.44	0.56	0.44	0.08	0.45	0.76	0.90	0.49								
	0.07	*0.10*	*0.01*	*0.04*	*0.32*	*0.09*	*0.21*	*0.84*	*0.19*	*0.01*	*0.00*	*0.15*								
Ca	0.61	0.56	0.77	0.66	0.40	0.56	0.43	0.07	0.44	0.76	0.92	0.45	0.99							
	0.06	*0.10*	*0.01*	*0.04*	*0.38*	*0.10*	*0.22*	*0.85*	*0.20*	*0.01*	*0.00*	*0.19*	*0.00*							
Fe	0.56	0.46	0.68	0.57	0.67	0.60	0.65	0.17	0.58	0.53	0.42	0.92	0.35	0.29						
	0.09	*0.18*	*0.03*	*0.09*	*0.10*	*0.07*	*0.04*	*0.64*	*0.08*	*0.11*	*0.22*	*0.00*	*0.33*	*0.41*						
Ti	0.51	0.43	0.78	0.59	0.60	0.53	0.44	0.06	0.41	0.70	0.86	0.86	0.86	0.82	0.71					
	0.13	*0.21*	*0.01*	*0.07*	*0.16*	*0.12*	*0.20*	*0.87*	*0.23*	*0.03*	*0.00*	*0.00*	*0.00*	*0.00*	*0.02*					
K	0.93	0.85	0.94	0.92	0.51	0.91	0.88	0.22	0.87	0.87	0.66	0.55	0.78	0.76	0.61	0.71				
	0.00	*0.00*	*0.00*	*0.00*	*0.24*	*0.00*	*0.00*	*0.53*	*0.00*	*0.00*	*0.04*	*0.10*	*0.01*	*0.01*	*0.06*	*0.02*				
S	0.84	0.86	0.72	0.83	0.29	0.77	0.78	0.21	0.81	0.66	0.36	0.03	0.57	0.56	0.19	0.28	0.84			
	0.00	*0.00*	*0.02*	*0.00*	*0.52*	*0.01*	*0.01*	*0.56*	*0.00*	*0.04*	*0.31*	*0.94*	*0.09*	*0.09*	*0.59*	*0.43*	*0.00*			
Ni	0.74	0.75	0.73	0.74	0.39	0.62	0.54	0.18	0.58	0.75	0.89	0.24	0.98	0.99	0.13	0.75	0.78	0.92		
	0.04	*0.03*	*0.04*	*0.04*	*0.52*	*0.10*	*0.17*	*0.66*	*0.13*	*0.03*	*0.00*	*0.57*	*0.00*	*0.00*	*0.76*	*0.03*	*0.02*	*0.00*		
Pb	0.70	0.83	0.52	0.73	0.41	0.58	0.76	0.29	0.73	0.46	0.14	-0.01	0.23	0.23	0.23	0.06	0.62	0.84	0.74	
	0.03	*0.00*	*0.13*	*0.02*	*0.36*	*0.08*	*0.01*	*0.42*	*0.02*	*0.18*	*0.70*	*0.99*	*0.52*	*0.53*	*0.53*	*0.88*	*0.06*	*0.00*	*0.04*	
Zn	0.73	0.80	0.90	0.86	0.76	0.71	0.76	0.12	0.72	0.78	0.74	0.78	0.73	0.70	0.77	0.83	0.84	0.56	0.66	0.54
	0.02	*0.01*	*0.00*	*0.00*	*0.05*	*0.02*	*0.01*	*0.74*	*0.02*	*0.01*	*0.01*	*0.01*	*0.02*	*0.02*	*0.01*	*0.00*	*0.00*	*0.10*	*0.08*	*0.11*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.137 and Table 3.138 for PM mass and major species, respectively. PM_{10} mass showed a higher C.V. as compared to $PM_{2.5}$ mass. The crustal elements showed lesser variation in PM_{10} than in $PM_{2.5}$. The secondary particulates showed a similar variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.139 and Table 3.140 for PM mass and its major species. OC, EC, and TC show a similar correlation with $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass as compared to $PM_{2.5}$. secondary particulates show better correlation with each other in $PM_{2.5}$ and with $PM_{2.5}$ mass.

3.1.19 Site 19: Faridabad-1

3.1.19.1 Summer season:

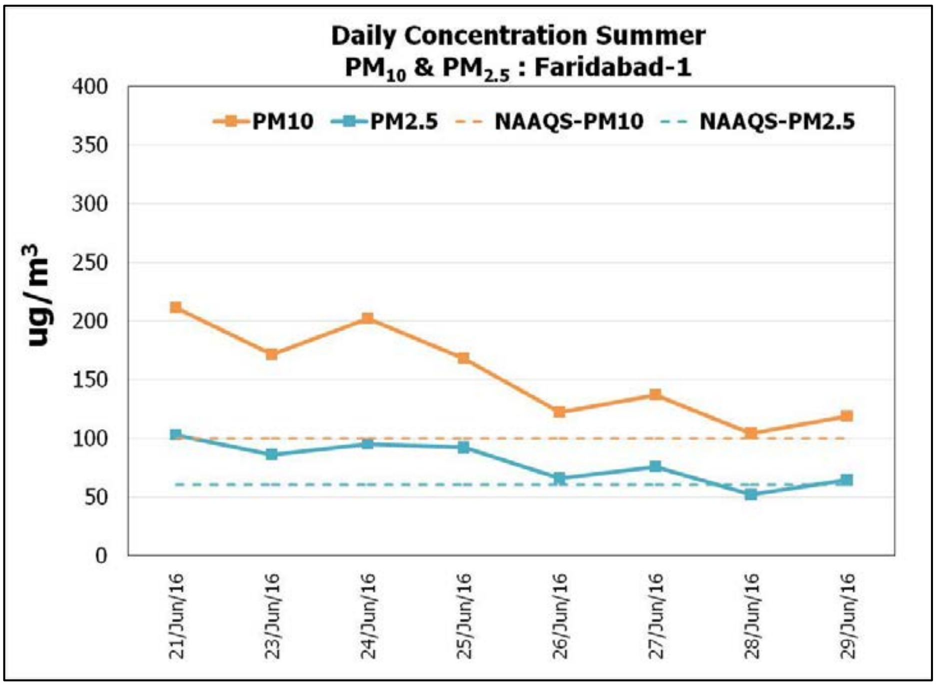


Figure 3.176: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Faridabad-1 in summer season

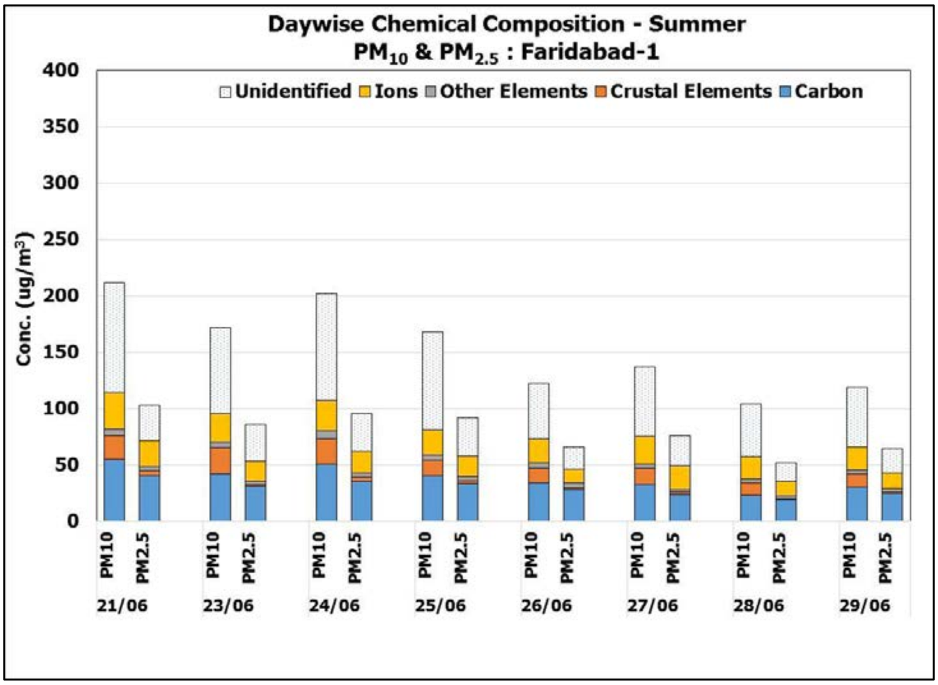


Figure 3.177: Variation in chemical composition of PM10 and PM2.5 at Faridabad-1 in summer season

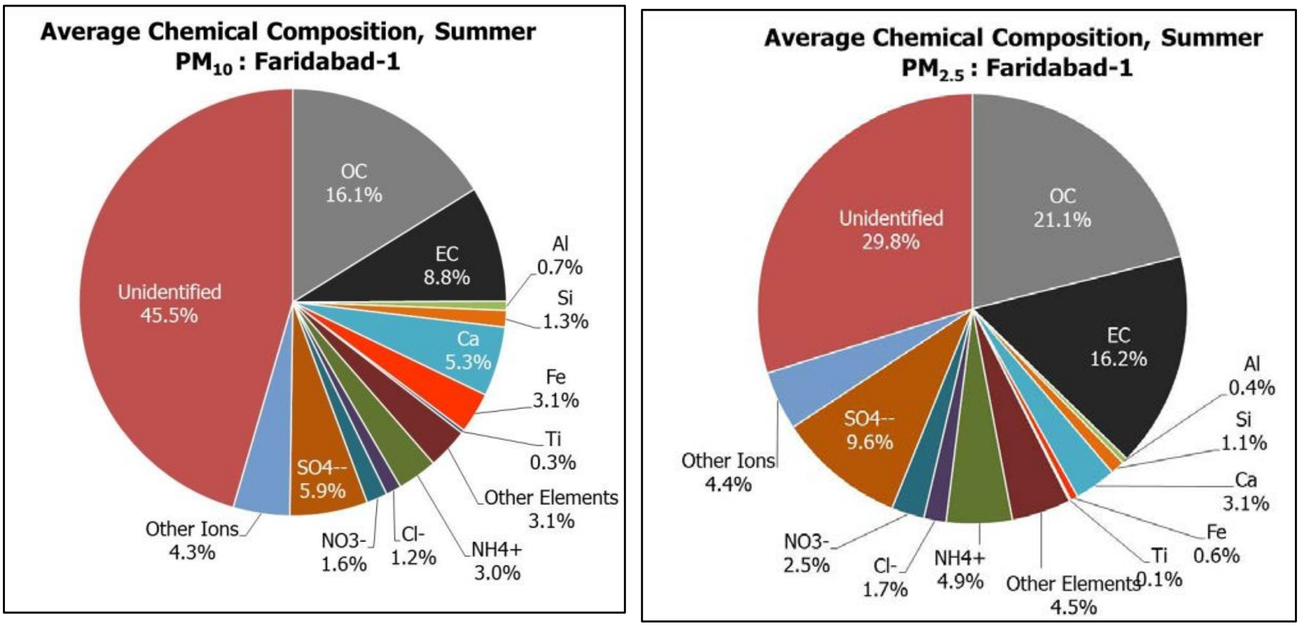


Figure 3.178: Average chemical composition of PM10 and PM2.5 at Faridabad-1 in summer season

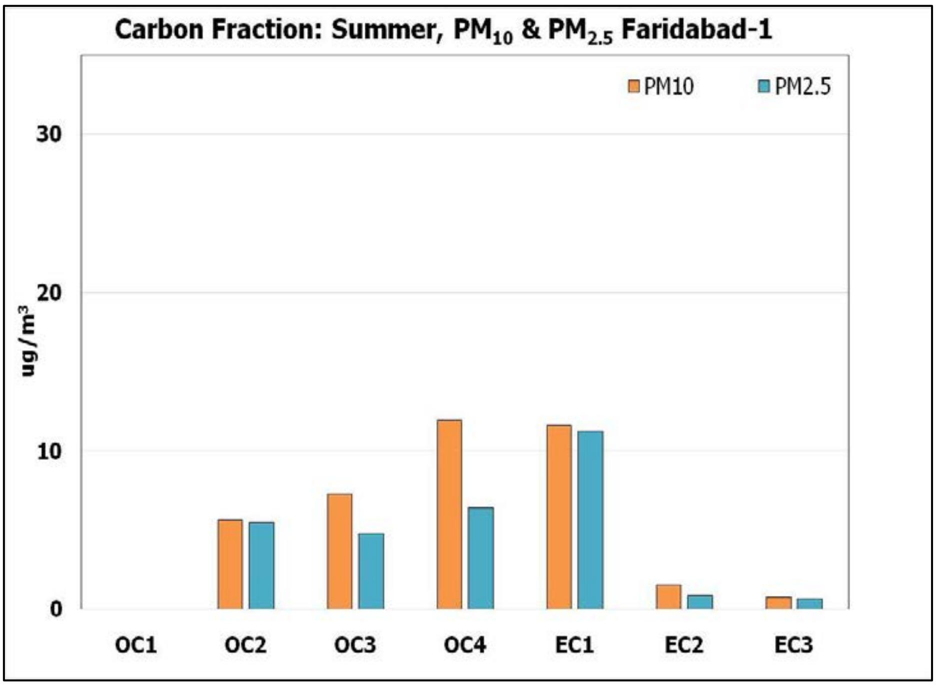


Figure 3.179: Average concentration of carbon fractions of PM10 and PM2.5 at Faridabad-1 in summer season

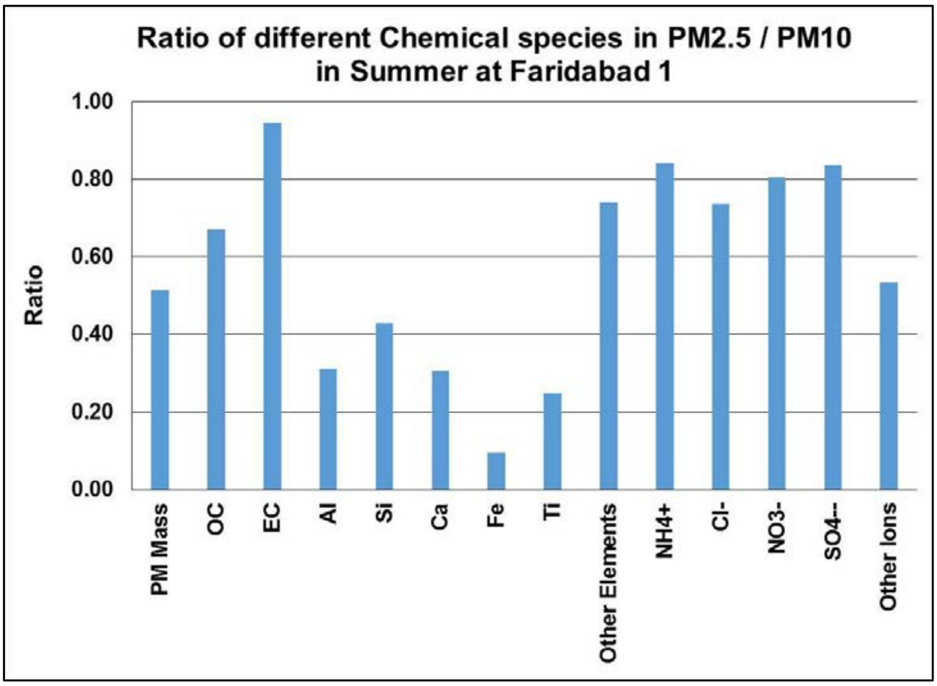


Figure 3.180: Ratio of different Chemical species in PM2.5 / PM10 in summer season at Faridabad-1

Average concentration of PM_{10} at Housing Board Colony, Sector 21 D, Faridabad (FBD1) site, was found to be 154±40 µg/m^3, which is 1.5 times as per the NAAQS. Daily concentration of PM_{10} varied from 104 to 211 µg/m^3. Average concentration of $PM_{2.5}$ was 79±18 µg/m^3. $PM_{2.5}$ was found to be in range with values ranging from 52 to 103 µg/m^3.

Daily variation in the components of the different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.177.

observed concentration of the crustal elements was 11%, whereas it was 3% in the case of $PM_{2.5}$. Average concentration of the carbon fraction in PM_{10} was 25%, while in $PM_{2.5}$, it was 37%. The total Ions found was 16% and 22% for PM_{10} and $PM_{2.5}$, respectively (see Figure 3.178).

Concentration of the other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in PM_{10} and 4% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 46% in PM_{10} and 34% in $PM_{2.5}$.

In PM_{10}, concentration of OC4 was highest, followed by EC1, OC3, OC2, EC2, and EC3, while, in case of $PM_{2.5}$, EC1 is highest, followed by OC4, OC2, OC3, EC2, and EC3 (see Figure 3.179). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.180.

Table 3.141: Statistical results of the chemical c**haracterization (µg/m**^{3}) of PM_{10} at Faridabad-1 for summer season

µg/m^3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	154	24.87	13.55	1.07	1.94	8.13	4.75	0.40	2.12	1.11	0.08	0.20	1.80	2.43	9.08	1.23	4.65	1.28	2.65
SD	40	8.42	2.52	0.24	1.02	0.80	3.48	0.29	0.60	0.13	0.04	0.08	1.10	0.47	1.77	0.45	1.05	0.29	0.40
Min	104	13.51	9.67	0.79	1.00	7.00	1.57	0.14	1.34	0.87	0.04	0.09	0.78	1.93	7.60	0.73	3.78	0.93	2.16
Max	211	37.63	17.27	1.56	3.55	9.54	9.87	0.81	2.89	1.32	0.14	0.31	3.58	3.43	12.88	1.94	6.95	1.68	3.27
C.V.	0.26	0.34	0.19	0.22	0.52	0.10	0.73	0.72	0.28	0.12	0.49	0.40	0.61	0.19	0.20	0.36	0.23	0.23	0.15
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95%ile	208	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50%ile	152	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5%ile	109	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.142: Statistical **evaluation of concentrations (µg/m**^{3}) of mass and major species of $PM_{2.5}$ at Faridabad 1-for summer season

µg/m^3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	79	16.68	12.80	0.33	0.84	2.48	0.45	0.10	1.67	0.80	0.06	0.04	1.32	1.96	7.60	0.80	3.91	0.80	1.08
SD	18	4.65	2.40	0.04	0.15	1.03	0.26	0.01	0.52	0.14	0.03	0.01	0.68	0.43	1.99	0.33	0.75	0.14	0.62
Min	52	10.04	9.04	0.29	0.65	1.51	0.03	0.08	1.12	0.59	0.02	0.03	0.76	1.56	5.25	0.43	3.03	0.63	0.25
Max	103	24.42	15.73	0.41	1.07	4.37	0.75	0.12	2.25	0.98	0.11	0.05	2.36	2.86	10.49	1.30	4.89	0.99	2.10
C.V.	0.22	0.28	0.19	0.11	0.17	0.42	0.59	0.15	0.31	0.17	0.49	0.20	0.51	0.22	0.26	0.42	0.19	0.17	0.57
N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
95%ile	100	23.25	15.71	0.39	1.05	4.05	0.72	0.12	2.22	0.98	0.10	0.05	2.32	2.61	10.23	1.28	4.83	0.98	1.90
50%ile	81	16.88	12.75	0.33	0.79	2.33	0.51	0.10	1.65	0.80	0.06	0.04	0.96	1.84	7.85	0.78	4.06	0.77	1.04
5%ile	56	11.05	9.57	0.30	0.67	1.52	0.05	0.08	1.15	0.61	0.02	0.03	0.77	1.56	5.30	0.45	3.05	0.64	0.35

Table 3.143: Correlation matrix for PM$_{10}$ and its composition for summer season at Faridabad-1

	PM$_{10}$	OC	EC	TC	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.97																			
	0.00																			
EC	0.87	0.82																		
	0.01	*0.01*																		
TC	0.98	0.99	0.89																	
	0.00	*0.00*	*0.00*																	
Cl$^-$	0.75	0.81	0.54	0.77																
	0.03	*0.02*	*0.17*	*0.03*																
NO$_3^-$	0.79	0.80	0.76	0.82	0.48															
	0.02	*0.02*	*0.03*	*0.01*	*0.23*															
SO$_4^{--}$	0.70	0.71	0.56	0.70	0.50	0.91														
	0.05	*0.05*	*0.15*	*0.05*	*0.21*	*0.00*														
Na$^+$	0.48	0.43	0.26	0.40	0.57	-0.12	-0.05													
	0.23	*0.29*	*0.53*	*0.32*	*0.14*	*0.77*	*0.91*													
NH$_4^+$	0.62	0.61	0.30	0.56	0.45	0.34	0.54	0.56												
	0.10	*0.11*	*0.48*	*0.15*	*0.27*	*0.40*	*0.17*	*0.15*												
K$^+$	0.31	0.32	0.60	0.40	-0.08	0.43	0.13	-0.34	-0.07											
	0.45	*0.44*	*0.12*	*0.33*	*0.84*	*0.28*	*0.76*	*0.41*	*0.88*											
Ca^{++}	0.88	0.86	0.61	0.83	0.62	0.82	0.87	0.33	0.74	0.06										
	0.00	*0.01*	*0.11*	*0.01*	*0.11*	*0.01*	*0.01*	*0.43*	*0.04*	*0.89*										
Si	0.73	0.74	0.43	0.69	0.83	0.23	0.25	0.86	0.66	-0.15	0.61									
	0.04	*0.04*	*0.29*	*0.06*	*0.01*	*0.59*	*0.56*	*0.01*	*0.07*	*0.73*	*0.11*									
Al	0.77	0.77	0.71	0.78	0.61	0.88	0.94	0.06	0.54	0.25	0.81	0.34								
	0.03	*0.03*	*0.05*	*0.02*	*0.11*	*0.00*	*0.00*	*0.88*	*0.17*	*0.55*	*0.01*	*0.41*								
Ca	0.74	0.76	0.54	0.73	0.42	0.48	0.40	0.38	0.76	0.47	0.67	0.65	0.44							
	0.04	*0.03*	*0.17*	*0.04*	*0.30*	*0.22*	*0.32*	*0.36*	*0.03*	*0.24*	*0.07*	*0.08*	*0.28*							
Fe	0.84	0.86	0.58	0.83	0.97	0.53	0.55	0.66	0.57	-0.10	0.74	0.90	0.63	0.53						
	0.01	*0.01*	*0.13*	*0.01*	*0.00*	*0.18*	*0.16*	*0.07*	*0.14*	*0.81*	*0.04*	*0.00*	*0.09*	*0.18*						
Ti	0.86	0.89	0.64	0.86	0.97	0.64	0.65	0.56	0.53	-0.06	0.77	0.82	0.73	0.49	0.99					
	0.01	*0.00*	*0.09*	*0.01*	*0.00*	*0.09*	*0.08*	*0.15*	*0.18*	*0.89*	*0.02*	*0.01*	*0.04*	*0.22*	*0.00*					
K	0.44	0.53	0.55	0.55	0.24	0.46	0.10	-0.11	-0.09	0.76	0.17	0.17	0.14	0.52	0.22	0.24				
	0.28	*0.18*	*0.16*	*0.16*	*0.56*	*0.26*	*0.81*	*0.79*	*0.84*	*0.03*	*0.69*	*0.69*	*0.74*	*0.18*	*0.61*	*0.57*				
S	0.78	0.80	0.52	0.76	0.66	0.79	0.72	0.09	0.41	0.19	0.83	0.55	0.66	0.61	0.71	0.74	0.42			
	0.02	*0.02*	*0.19*	*0.03*	*0.08*	*0.02*	*0.05*	*0.83*	*0.31*	*0.66*	*0.01*	*0.16*	*0.08*	*0.11*	*0.05*	*0.04*	*0.30*			
Ni	0.45	0.45	0.15	0.39	0.68	-0.13	-0.07	0.90	0.56	-0.31	0.32	0.93	0.05	0.47	0.73	0.61	-0.03	0.28		
	0.27	*0.27*	*0.73*	*0.34*	*0.06*	*0.75*	*0.88*	*0.00*	*0.15*	*0.46*	*0.44*	*0.00*	*0.90*	*0.24*	*0.04*	*0.11*	*0.94*	*0.50*		
Pb	0.80	0.82	0.67	0.81	0.87	0.59	0.56	0.59	0.37	-0.09	0.67	0.71	0.62	0.31	0.90	0.92	0.26	0.56	0.49	
	0.02	*0.01*	*0.07*	*0.02*	*0.01*	*0.13*	*0.15*	*0.13*	*0.37*	*0.83*	*0.07*	*0.05*	*0.10*	*0.45*	*0.00*	*0.00*	*0.53*	*0.15*	*0.22*	
Zn	0.63	0.66	0.25	0.58	0.61	0.58	0.76	0.39	0.69	-0.37	0.87	0.58	0.62	0.41	0.71	0.73	-0.07	0.66	0.37	0.68
	0.09	*0.08*	*0.56*	*0.13*	*0.11*	*0.13*	*0.03*	*0.34*	*0.06*	*0.36*	*0.01*	*0.14*	*0.10*	*0.32*	*0.05*	*0.04*	*0.86*	*0.08*	*0.37*	*0.07*

Note: Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.144: Correlation matrix for $PM_{2.5}$ and its composition for summer season at Faridabad-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.91	0.90																		
	0.00	*0.00*																		
TC	0.94	0.99	0.95																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.43	0.37	0.31	0.36																
	0.29	*0.37*	*0.46*	*0.39*																
NO_3^-	0.71	0.69	0.62	0.68	0.02															
	0.05	*0.06*	*0.10*	*0.06*	*0.96*															
SO_4^{--}	0.79	0.64	0.49	0.60	0.43	0.74														
	0.02	*0.09*	*0.22*	*0.11*	*0.29*	*0.04*														
Na^+	0.37	0.19	0.24	0.21	0.60	-0.29	0.21													
	0.37	*0.65*	*0.57*	*0.61*	*0.11*	*0.49*	*0.61*													
NH_4^+	0.79	0.58	0.52	0.57	0.28	0.58	0.90	0.32												
	0.02	*0.13*	*0.19*	*0.14*	*0.51*	*0.14*	*0.00*	*0.44*												
K^+	0.74	0.54	0.64	0.59	0.02	0.54	0.54	0.33	0.74											
	0.04	*0.17*	*0.09*	*0.12*	*0.96*	*0.17*	*0.17*	*0.43*	*0.04*											
Ca^{++}	0.66	0.62	0.52	0.60	-0.26	0.88	0.70	-0.26	0.70	0.65										
	0.08	*0.10*	*0.19*	*0.11*	*0.53*	*0.00*	*0.05*	*0.54*	*0.05*	*0.08*										
Si	0.31	0.36	0.48	0.41	0.11	0.36	0.04	0.11	-0.19	0.05	0.10									
	0.46	*0.38*	*0.23*	*0.31*	*0.79*	*0.38*	*0.92*	*0.79*	*0.65*	*0.91*	*0.82*									
Al	0.41	0.36	0.37	0.37	0.19	0.53	0.33	-0.14	0.32	0.60	0.37	-0.08								
	0.31	*0.38*	*0.37*	*0.36*	*0.65*	*0.18*	*0.43*	*0.75*	*0.44*	*0.12*	*0.37*	*0.85*								
Ca	0.81	0.82	0.68	0.79	-0.03	0.88	0.74	-0.05	0.72	0.72	0.94	0.19	0.47							
	0.01	*0.01*	*0.06*	*0.02*	*0.94*	*0.00*	*0.04*	*0.91*	*0.04*	*0.04*	*0.00*	*0.65*	*0.24*							
Fe	0.51	0.45	0.58	0.51	0.48	0.48	0.26	0.19	0.09	0.42	0.11	0.62	0.66	0.29						
	0.20	*0.26*	*0.14*	*0.20*	*0.23*	*0.23*	*0.53*	*0.65*	*0.84*	*0.31*	*0.80*	*0.10*	*0.07*	*0.48*						
Ti	0.34	0.32	0.19	0.28	0.73	-0.29	0.23	0.89	0.24	0.10	-0.30	0.01	-0.14	-0.03	0.11					
	0.41	*0.44*	*0.65*	*0.50*	*0.04*	*0.48*	*0.59*	*0.00*	*0.56*	*0.81*	*0.48*	*0.98*	*0.74*	*0.95*	*0.80*					
K	0.58	0.72	0.72	0.74	-0.27	0.44	0.13	-0.13	0.30	0.53	0.60	0.14	0.26	0.68	0.09	-0.08				
	0.14	*0.05*	*0.04*	*0.04*	*0.52*	*0.27*	*0.75*	*0.77*	*0.48*	*0.18*	*0.12*	*0.74*	*0.54*	*0.06*	*0.83*	*0.85*				
S	0.92	0.95	0.80	0.92	0.38	0.60	0.73	0.34	0.73	0.57	0.64	0.17	0.23	0.81	0.24	0.46	0.65			
	0.00	*0.00*	*0.02*	*0.00*	*0.35*	*0.12*	*0.04*	*0.42*	*0.04*	*0.14*	*0.09*	*0.69*	*0.58*	*0.01*	*0.57*	*0.26*	*0.08*			
Ni	0.41	0.16	0.38	0.24	0.56	-0.16	0.22	0.88	0.31	0.36	-0.23	0.32	-0.12	-0.09	0.37	0.63	-0.16	0.22		
	0.32	*0.71*	*0.36*	*0.57*	*0.15*	*0.70*	*0.61*	*0.00*	*0.46*	*0.38*	*0.59*	*0.44*	*0.79*	*0.83*	*0.37*	*0.09*	*0.71*	*0.60*		
Pb	0.57	0.63	0.58	0.63	0.83	0.17	0.30	0.57	0.12	0.14	-0.12	0.51	0.22	0.18	0.68	0.71	0.11	0.55	0.52	
	0.14	*0.09*	*0.13*	*0.10*	*0.01*	*0.69*	*0.47*	*0.14*	*0.78*	*0.75*	*0.77*	*0.20*	*0.60*	*0.66*	*0.07*	*0.05*	*0.80*	*0.16*	*0.19*	
Zn	0.44	0.51	0.52	0.52	-0.44	0.83	0.30	-0.56	0.28	0.51	0.83	0.25	0.54	0.77	0.32	-0.60	0.69	0.36	-0.44	-0.15
	0.27	*0.20*	*0.19*	*0.18*	*0.28*	*0.01*	*0.47*	*0.15*	*0.51*	*0.20*	*0.01*	*0.55*	*0.17*	*0.03*	*0.44*	*0.12*	*0.06*	*0.38*	*0.28*	*0.73*

Note: Bold values represents "Correlation Coefficient"and *Italic* represents "*P-value*

For summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.141 and Table 3.142 for PM mass and major species, respectively. Both PM10 mass and PM2.5 mass have a similar C.V. For crustal elements, C.V. in both PM_{10} and $PM_{2.5}$ is similar. In both PM_{10} and $PM_{2.5}$, secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show a similar C.V.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.143 and Table 3.144 for the PM mass and its major species. OC, EC, and TC show a similar correlation with PM_{10} mass and $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a better correlation with PM_{10} mass. The secondary particulates showed a better correlation with each other in $PM_{2.5}$ and with $PM_{2.5}$ mass as well.

3.1.19.2 Winter season:

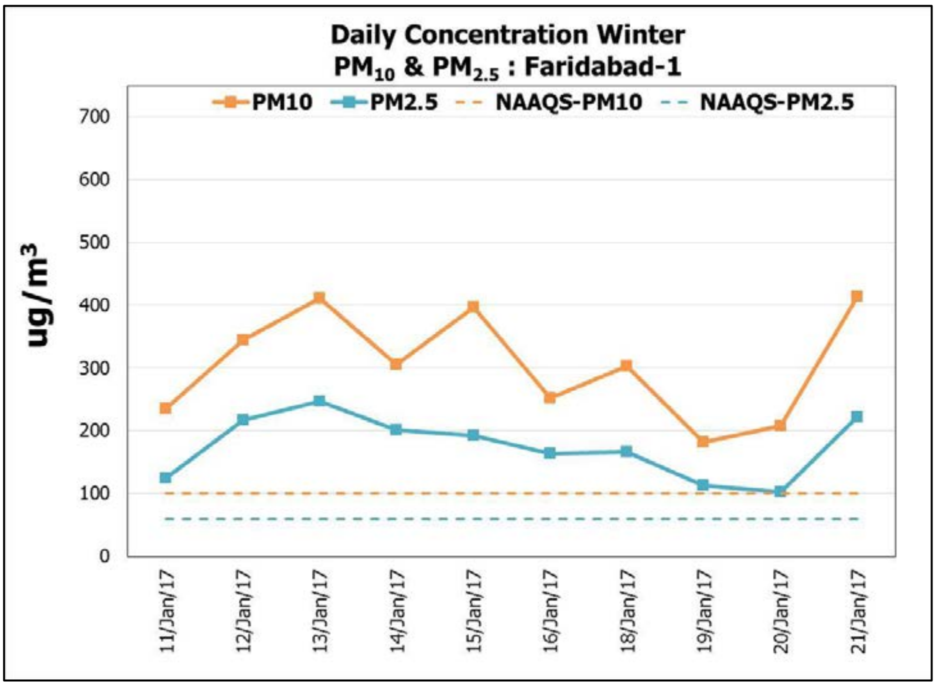


Figure 3.181: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Faridabad-1 in winter season

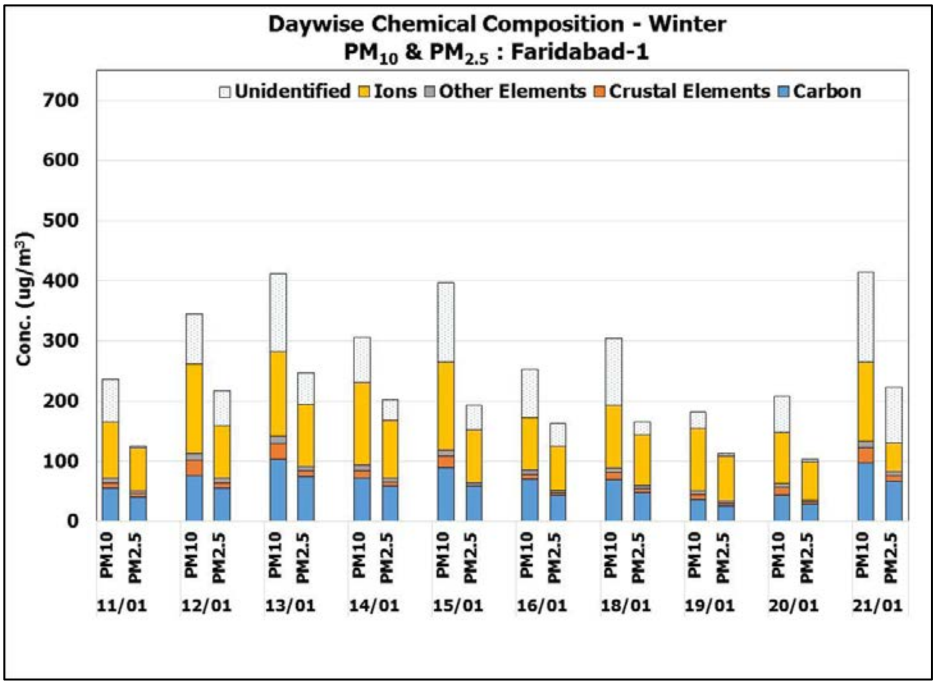


Figure 3.182: Variation in chemical composition of PM10 and PM2.5 at Faridabad-1 in winter season

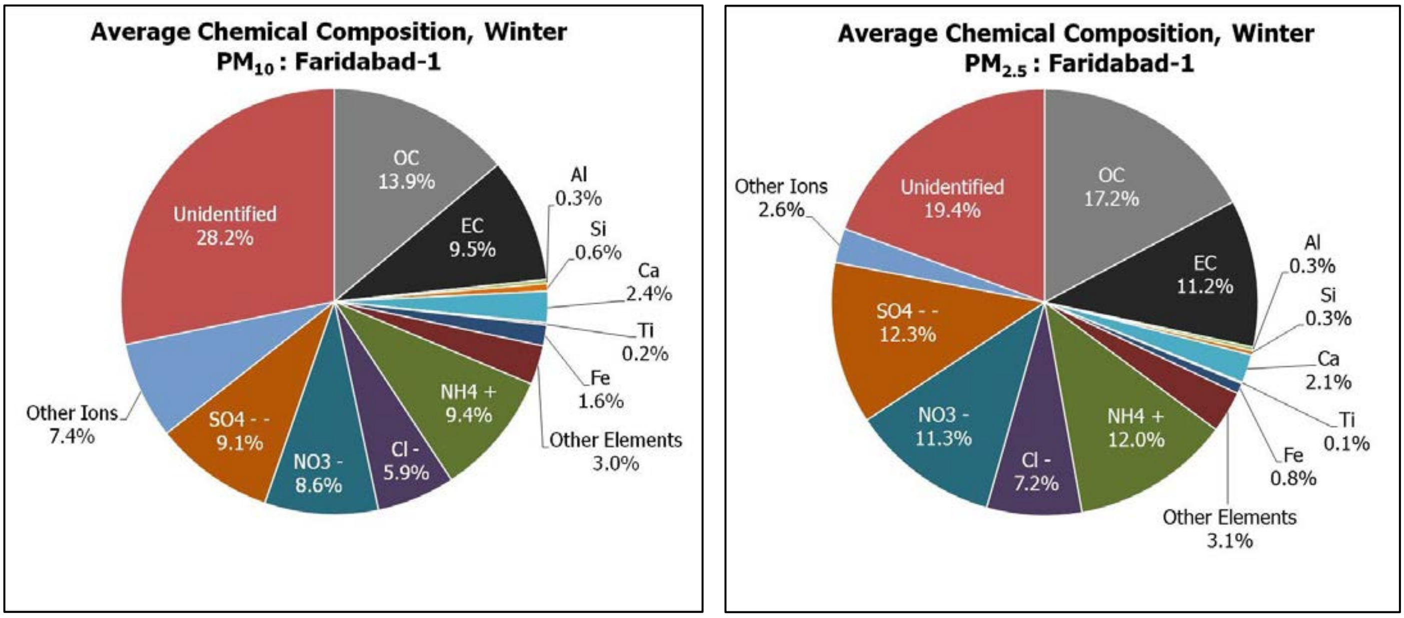


Figure 3.183: Average chemical composition of PM10 and PM2.5 at Faridabad-1 in winter season

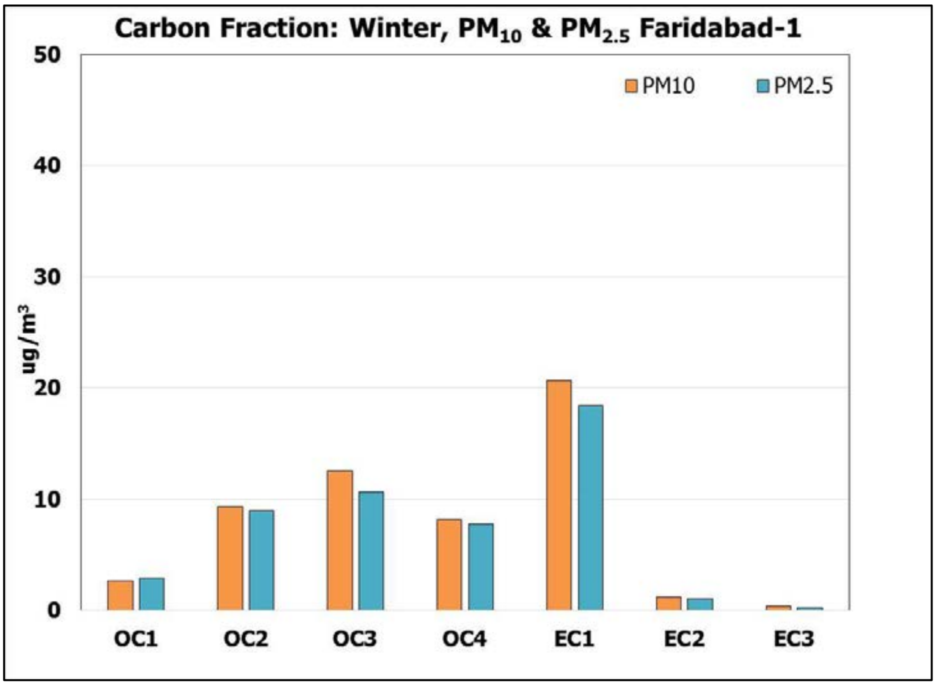


Figure 3.184: Average concentration of carbon fractions of PM10 and PM2.5 at Faridabad-1 in winter season

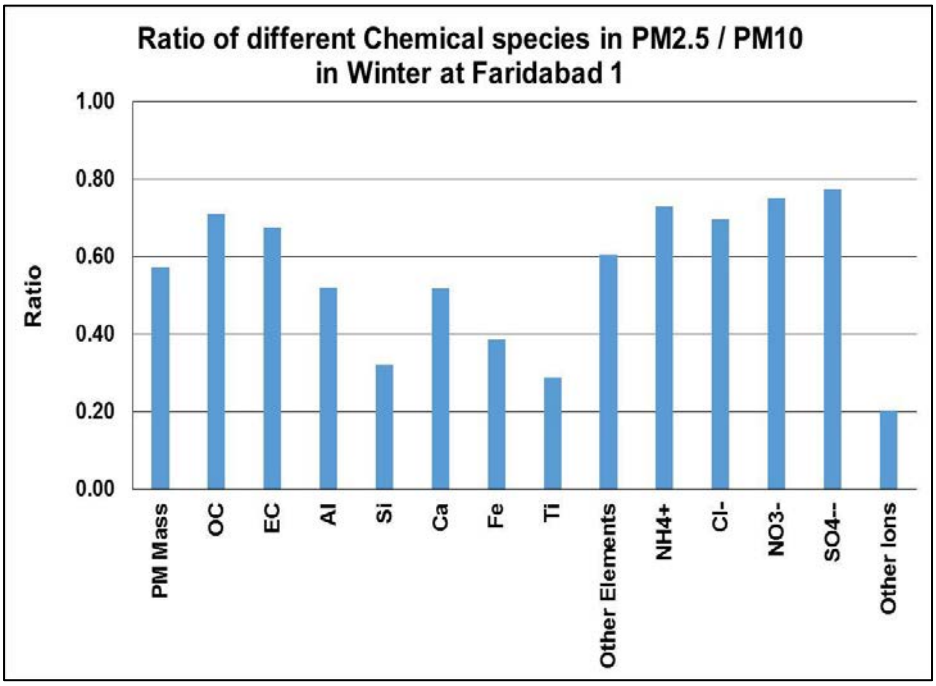


Figure 3.185: Ratio of different chemical species in $PM_{2.5}/PM_{10}$ in winter season at Faridabad-1

Average concentration of PM_{10} and $PM_{2.5}$ was found to be 305±85 µg/m³ and 175±49 µg/m³. Concentration of PM_{10} was found to be thrice the permissible limit of 100 µg/m³ of NAAQS. Concentration of PM_{10} varied from 182 to 414µg/m³ while Concentration of $PM_{2.5}$ varied from 103 to 247µg/m³ (see Figure3.181).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.182.

The carbon fraction concentration of PM_{10} was found to be 71 µg/m³, while in case of PM2.5 it was found to be 50 µg/m³. The % mass distribution showed that the organic carbon and the elemental carbon were higher in $PM_{2.5}$ as compared to PM10. The crustal element in PM_{10} was found to be 5% and in $PM_{2.5}$, it was found to be 4%. The total ion in PM_{10} was found to be 40% and this was found to 38% in $PM_{2.5}$ (see Figure 3.183).

Concentration of other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 3% in both PM_{10} and $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was found to be 28% and 19% for PM_{10} and $PM_{2.5}$, respectively.

The OC3 was higher in PM_{10} as compared to $PM_{2.5}$ and was followed by OC2, OC4, and OC1. Also EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$ and was followed by EC2 and EC3 (see Figure 3.184). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.185.

Table 3.145 : Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{10}$ at Faridabad-1 for winter season

	µg/m3																		
	PM$_{10}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	305	42.37	28.91	0.92	1.76	7.25	4.83	0.49	3.22	3.01	0.47	1.46	18.07	26.28	27.79	0.69	28.85	2.19	5.31
SD	85	12.58	9.51	0.39	0.45	4.02	2.70	0.11	1.17	0.94	0.18	0.40	4.00	5.90	4.47	0.15	5.45	1.02	3.28
Min	182	20.98	16.04	0.47	1.04	3.18	1.81	0.31	1.66	1.38	0.29	1.04	12.04	14.48	20.80	0.45	20.21	0.98	2.46
Max	414	60.56	42.48	1.62	2.26	13.40	8.26	0.64	5.04	4.58	0.75	2.32	26.42	35.07	34.52	0.90	36.14	3.60	11.19
C.V.	0.28	0.30	0.33	0.43	0.26	0.55	0.56	0.23	0.36	0.31	0.38	0.27	0.22	0.22	0.16	0.22	0.19	0.47	0.62
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	413	58.74	41.80	1.58	2.19	12.93	8.23	0.63	4.89	4.24	0.74	2.07	24.44	33.69	34.39	0.88	35.51	3.51	11.07
50 %ile	305	42.37	28.91	0.82	1.95	6.76	4.83	0.51	3.22	2.89	0.42	1.29	18.02	28.01	27.79	0.69	29.24	2.01	4.47
5 %ile	138	17.20	13.11	0.43	0.78	3.19	1.87	0.22	1.44	1.18	0.24	0.75	8.42	10.62	13.45	0.31	13.57	1.01	2.67

Table 3.146: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM$_{2.5}$ at Faridabad-1 for winter season

	µg/m3																		
	PM$_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl$^-$	NO$_3^-$	SO$_4^{--}$	Na$^+$	NH$_4^+$	K$^+$	Ca^{++}
Mean	175	30.05	19.54	0.48	0.56	3.76	1.40	0.19	1.78	2.08	0.36	0.63	12.58	19.75	21.53	0.40	21.02	1.06	2.05
SD	49	9.26	6.62	0.36	0.26	1.36	0.78	0.06	0.61	0.63	0.17	0.34	2.45	4.40	4.18	0.19	8.00	0.55	1.29
Min	103	15.28	10.03	0.15	0.09	1.72	0.51	0.11	0.90	1.09	0.18	0.30	9.43	9.71	14.89	0.00	0.00	0.00	0.00
Max	247	45.12	29.09	1.14	0.94	5.99	2.66	0.28	2.80	2.90	0.67	1.24	16.01	25.83	28.79	0.70	29.69	2.07	3.87
C.V.	0.28	0.31	0.34	0.76	0.46	0.36	0.56	0.33	0.34	0.30	0.48	0.54	0.19	0.22	0.19	0.47	0.38	0.52	0.63
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	236	42.62	28.05	1.10	0.90	5.68	2.57	0.27	2.70	2.90	0.64	1.17	15.91	25.01	27.55	0.65	28.18	1.86	3.86
50 %ile	179	31.17	19.82	0.33	0.58	3.76	1.33	0.17	1.64	2.03	0.30	0.51	12.56	19.60	21.25	0.42	21.90	0.92	1.93
5 %ile	107	16.50	10.03	0.17	0.16	2.06	0.51	0.11	1.02	1.21	0.20	0.31	9.69	13.06	16.40	0.13	8.46	0.36	0.38

Table 3.147 : Correlation Matrix for PM10 and its composition for winter season at Faridabad 1

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.96																			
	0.00																			
EC	0.97	0.96																		
	0.00	0.00																		
TC	0.97	0.99	0.99																	
	0.00	0.00	0.00																	
Cl^-	0.61	0.43	0.56	0.49																
	0.06	0.21	0.09	0.15																
NO_3^-	0.62	0.51	0.64	0.57	0.61															
	0.06	0.13	0.05	0.09	0.06															
SO_4^{--}	0.90	0.84	0.93	0.89	0.61	0.81														
	0.00	0.00	0.00	0.00	0.06	0.01														
Na^+	0.84	0.72	0.74	0.74	0.62	0.48	0.61													
	0.00	0.02	0.01	0.02	0.06	0.16	0.06													
NH_4^+	0.75	0.65	0.74	0.70	0.62	0.83	0.84	0.69												
	0.01	0.04	0.01	0.03	0.06	0.00	0.00	0.03												
K^+	0.69	0.59	0.62	0.61	0.56	0.28	0.45	0.84	0.57											
	0.03	0.07	0.06	0.06	0.10	0.43	0.19	0.00	0.08											
Ca^{++}	0.69	0.64	0.60	0.63	0.28	0.21	0.50	0.58	0.50	0.77										
	0.03	0.05	0.07	0.05	0.44	0.57	0.14	0.08	0.14	0.01										
Si	0.78	0.66	0.76	0.71	0.48	0.61	0.73	0.67	0.59	0.57	0.62									
	0.01	0.04	0.01	0.02	0.16	0.06	0.02	0.04	0.07	0.08	0.06									
Al	0.72	0.71	0.67	0.70	0.20	0.17	0.51	0.62	0.47	0.80	0.96	0.68								
	0.02	0.02	0.04	0.02	0.58	0.63	0.14	0.06	0.17	0.01	0.00	0.03								
Ca	0.79	0.73	0.70	0.73	0.43	0.21	0.64	0.68	0.59	0.66	0.83	0.55	0.77							
	0.01	0.02	0.02	0.02	0.22	0.57	0.05	0.03	0.07	0.04	0.00	0.10	0.01							
Fe	0.83	0.73	0.71	0.73	0.60	0.27	0.63	0.81	0.62	0.75	0.78	0.59	0.72	0.96						
	0.00	0.02	0.02	0.02	0.07	0.45	0.05	0.01	0.06	0.01	0.01	0.08	0.02	0.00						
Ti	0.91	0.87	0.86	0.87	0.31	0.41	0.75	0.79	0.61	0.66	0.77	0.83	0.83	0.82	0.80					
	0.00	0.00	0.00	0.00	0.38	0.25	0.01	0.01	0.06	0.04	0.01	0.00	0.00	0.00	0.01					
K	0.76	0.74	0.72	0.74	0.34	0.27	0.53	0.80	0.61	0.92	0.85	0.63	0.93	0.74	0.75	0.81				
	0.01	0.01	0.02	0.01	0.34	0.45	0.11	0.01	0.06	0.00	0.00	0.05	0.00	0.02	0.01	0.01				
S	0.73	0.76	0.80	0.78	0.12	0.55	0.80	0.48	0.57	0.19	0.28	0.63	0.40	0.46	0.38	0.76	0.42			
	0.02	0.01	0.01	0.01	0.75	0.10	0.01	0.16	0.09	0.59	0.44	0.05	0.26	0.19	0.29	0.01	0.23			
Ni	0.74	0.66	0.81	0.73	0.52	0.66	0.79	0.62	0.56	0.48	0.25	0.70	0.36	0.33	0.37	0.63	0.44	0.75		
	0.01	0.04	0.01	0.02	0.12	0.04	0.01	0.06	0.09	0.16	0.49	0.03	0.31	0.36	0.29	0.05	0.20	0.01		
Pb	0.63	0.58	0.56	0.58	0.17	-0.01	0.48	0.51	0.39	0.55	0.81	0.55	0.79	0.92	0.83	0.80	0.68	0.45	0.26	
	0.05	0.08	0.09	0.08	0.65	0.98	0.16	0.14	0.27	0.10	0.01	0.10	0.01	0.00	0.00	0.01	0.03	0.20	0.48	
Zn	0.87	0.80	0.83	0.82	0.60	0.62	0.86	0.75	0.84	0.48	0.52	0.64	0.49	0.81	0.83	0.79	0.58	0.69	0.53	0.63
	0.00	0.01	0.00	0.00	0.07	0.05	0.00	0.01	0.00	0.16	0.12	0.05	0.15	0.00	0.00	0.01	0.08	0.03	0.11	0.05

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.148: correlation matrix for $PM_{2.5}$ and its composition for winter season at Faridabad-1

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.95																			
	0.00																			
EC	0.97	0.97																		
	0.00	*0.00*																		
TC	0.97	1.00	0.99																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.31	0.17	0.29	0.22																
	0.38	*0.63*	*0.43*	*0.54*																
NO_3^-	0.73	0.72	0.75	0.74	0.37															
	0.02	*0.02*	*0.01*	*0.01*	*0.30*															
SO_4^{--}	0.59	0.56	0.59	0.58	0.51	0.73														
	0.07	*0.09*	*0.07*	*0.08*	*0.13*	*0.02*														
Na^+	0.15	0.07	0.04	0.06	0.69	0.30	0.52													
	0.67	*0.84*	*0.91*	*0.87*	*0.03*	*0.40*	*0.13*													
NH_4^+	-0.04	-0.05	-0.08	-0.07	0.48	0.40	0.61	0.83												
	0.92	*0.89*	*0.82*	*0.86*	*0.16*	*0.25*	*0.06*	*0.00*												
K^+	0.21	0.20	0.11	0.16	0.28	0.37	0.65	0.79	0.85											
	0.56	*0.59*	*0.75*	*0.65*	*0.44*	*0.29*	*0.04*	*0.01*	*0.00*											
Ca^{++}	0.18	0.15	0.04	0.11	0.17	0.26	0.55	0.74	0.69	0.88										
	0.62	*0.68*	*0.92*	*0.77*	*0.64*	*0.47*	*0.10*	*0.01*	*0.03*	*0.00*										
Si	0.45	0.39	0.43	0.41	-0.23	0.30	0.21	-0.28	-0.38	-0.15	-0.02									
	0.19	*0.27*	*0.22*	*0.24*	*0.52*	*0.40*	*0.57*	*0.44*	*0.28*	*0.68*	*0.95*									
Al	0.80	0.74	0.68	0.72	0.23	0.65	0.55	0.45	0.35	0.64	0.64	0.23								
	0.01	*0.02*	*0.04*	*0.03*	*0.54*	*0.06*	*0.12*	*0.22*	*0.36*	*0.06*	*0.07*	*0.55*								
Ca	0.73	0.70	0.64	0.68	0.13	0.40	0.23	0.24	-0.13	0.21	0.40	0.38	0.70							
	0.03	*0.04*	*0.06*	*0.04*	*0.73*	*0.29*	*0.55*	*0.54*	*0.75*	*0.58*	*0.29*	*0.31*	*0.04*							
Fe	0.55	0.59	0.62	0.60	-0.30	0.50	0.42	-0.37	-0.25	-0.03	-0.08	0.84	0.28	0.21						
	0.10	*0.07*	*0.06*	*0.06*	*0.41*	*0.14*	*0.23*	*0.29*	*0.48*	*0.94*	*0.83*	*0.00*	*0.46*	*0.60*						
Ti	0.36	0.43	0.46	0.44	0.01	0.37	0.07	-0.24	-0.44	-0.46	-0.23	0.73	-0.10	0.41	0.47					
	0.34	*0.25*	*0.22*	*0.23*	*0.98*	*0.33*	*0.85*	*0.54*	*0.24*	*0.22*	*0.54*	*0.03*	*0.81*	*0.27*	*0.21*					
K	0.93	0.93	0.92	0.93	-0.01	0.63	0.33	-0.11	-0.28	0.02	0.03	0.56	0.69	0.76	0.65	0.48				
	0.00	*0.00*	*0.00*	*0.00*	*0.99*	*0.05*	*0.35*	*0.77*	*0.43*	*0.95*	*0.95*	*0.09*	*0.04*	*0.02*	*0.04*	*0.19*				
S	0.73	0.73	0.76	0.75	0.11	0.55	0.45	-0.06	-0.27	-0.10	0.02	0.81	0.34	0.51	0.75	0.80	0.75			
	0.02	*0.02*	*0.01*	*0.01*	*0.77*	*0.10*	*0.20*	*0.87*	*0.46*	*0.79*	*0.96*	*0.00*	*0.38*	*0.16*	*0.01*	*0.01*	*0.01*			
Ni	0.64	0.61	0.68	0.64	0.21	0.39	0.40	-0.20	-0.23	-0.17	-0.20	0.59	0.30	0.05	0.59	0.24	0.54	0.66		
	0.07	*0.08*	*0.05*	*0.06*	*0.59*	*0.30*	*0.29*	*0.62*	*0.55*	*0.67*	*0.62*	*0.09*	*0.43*	*0.90*	*0.09*	*0.53*	*0.14*	*0.05*		
Pb	0.79	0.77	0.68	0.73	-0.04	0.43	0.47	0.24	0.03	0.48	0.57	0.45	0.92	0.85	0.46	0.14	0.78	0.55	0.35	
	0.01	*0.01*	*0.03*	*0.02*	*0.91*	*0.21*	*0.18*	*0.51*	*0.94*	*0.17*	*0.08*	*0.19*	*0.00*	*0.00*	*0.18*	*0.72*	*0.01*	*0.10*	*0.36*	
Zn	0.81	0.77	0.71	0.75	0.29	0.61	0.42	0.41	0.20	0.45	0.46	0.04	0.95	0.87	0.10	0.09	0.74	0.31	0.21	0.80
	0.00	*0.01*	*0.02*	*0.01*	*0.41*	*0.06*	*0.22*	*0.24*	*0.57*	*0.19*	*0.18*	*0.91*	*0.00*	*0.00*	*0.78*	*0.83*	*0.01*	*0.39*	*0.60*	*0.01*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For the winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.145 and Table 3.146 for PM mass and major species, respectively. Both PM_{10} Mass and $PM_{2.5}$ mass showed a similar C.V. The crustal elements show a similar variation in both PM_{10} and $PM_{2.5}$. The secondary particulates show a similar variation in PM_{10} than in $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.147 and Table 3.148 PM mass and it's major species. OC, EC, and TC show similar correlation with $PM_{2.5}$ mass and PM_{10} mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show better correlation with PM_{10} mass than that of $PM_{2.5}$. The secondary particulates show better correlation with each other in PM_{10} mass.

3.1.20 Site 20: Faridabad-2

3.1.20.1 Summer season:

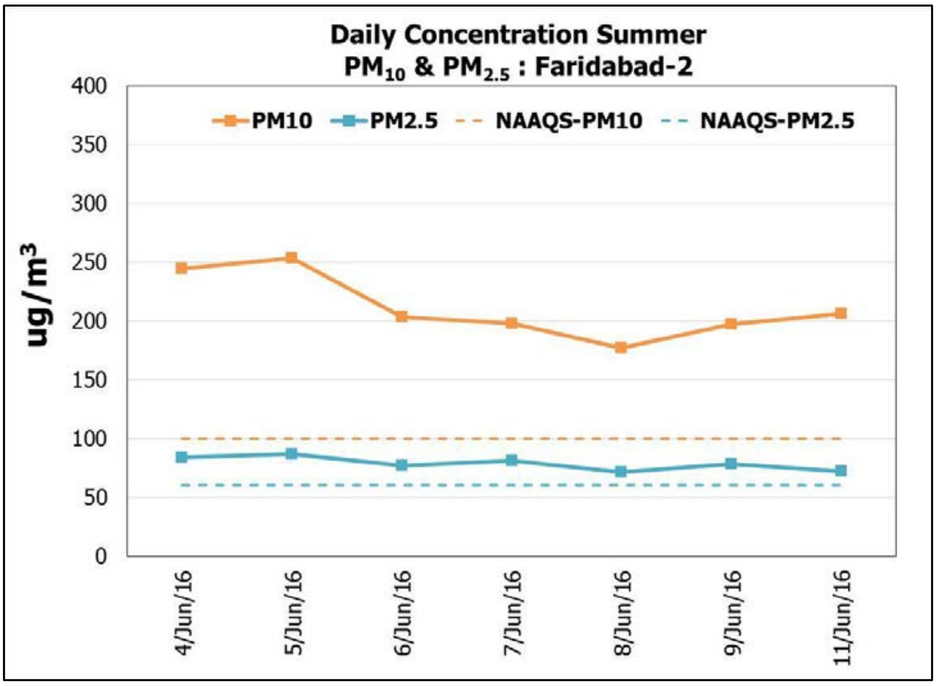


Figure 3.186: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Faridabad-2 in summer season

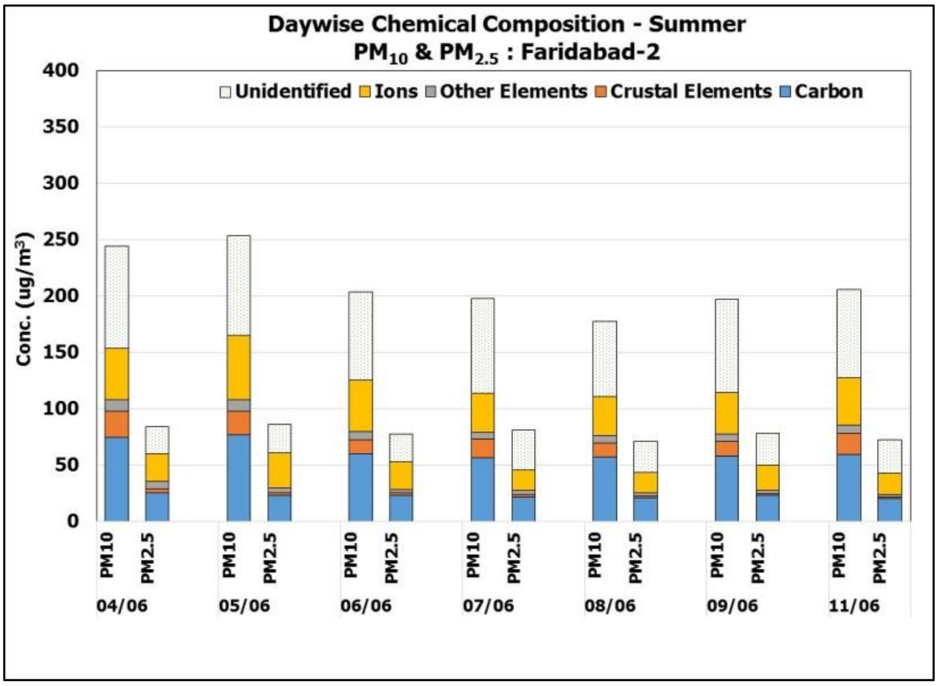


Figure 3.187: Variation in chemical composition of PM10 and PM2.5 at Faridabad-2 in summer season

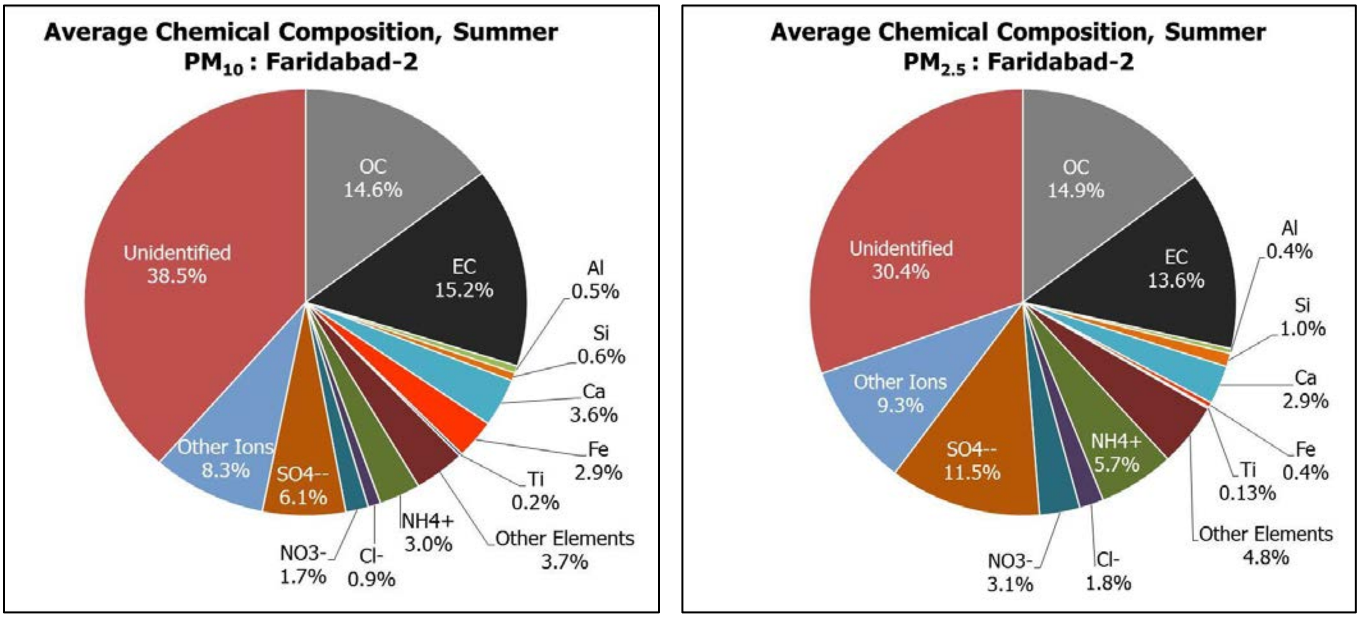


Figure 3.188: Average chemical composition of PM10 and PM2.5 at Faridabad-2 in summer season

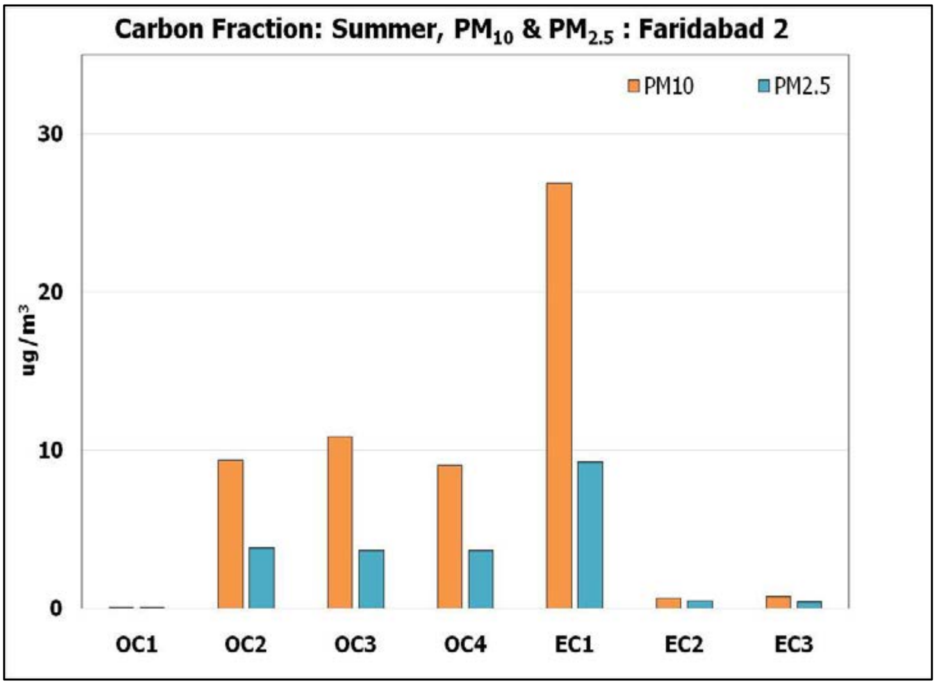


Figure 3.189: Average concentration of carbon fractions of PM10 and PM2.5 at Faridabad-2 in summer season

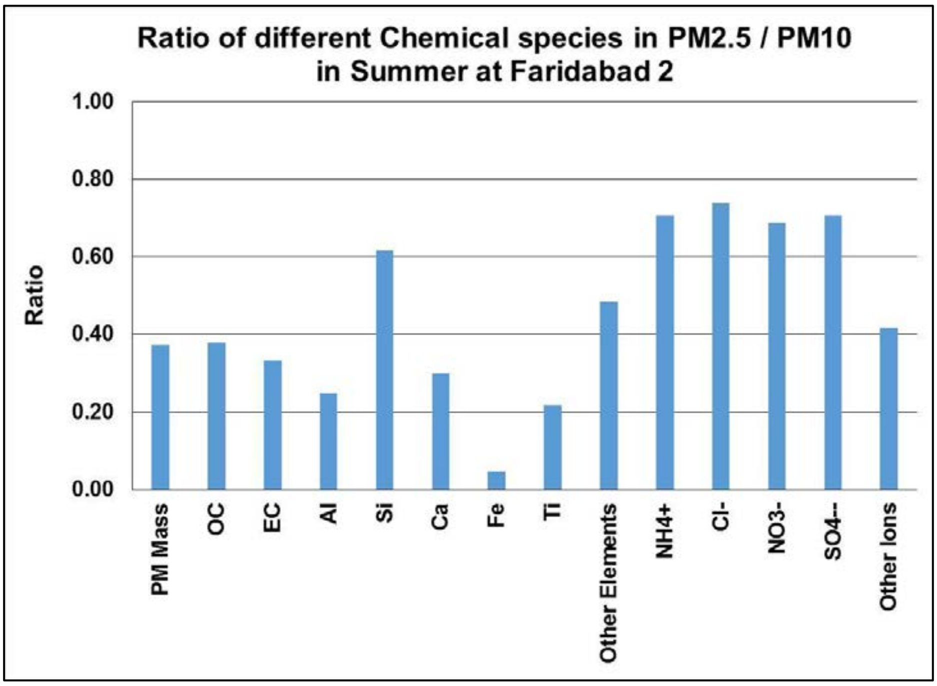


Figure 3.190: Ratio of different Chemical species in PM2.5 / PM10 in summer season at Faridabad-2

Average concentration of PM_{10} near the DAV College, Faridabad (FBD2) site, was found to be 211±27 µg/m^3, which is 2.1 times as per the NAAQS. The PM_{10} concentration varied from 177 to 253 µg/m^3. Average concentration of $PM_{2.5}$ was 79±6 µg/m^3. $PM_{2.5}$ was found to vary in range from 71 to 86 µg/m^3 (see Figure3.186).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.187.

In PM_{10}, average concentration of carbon fraction was highest while in the case of $PM_{2.5}$, the ionic concentration was the highest. The observed concentration of carbon fraction was 63 µg/m^3 in PM_{10} and 22 µg/m^3 in PM2.5. The average ion concentration observed was 20% and 30% in PM_{10} and $PM_{2.5}$, respectively. The crustal elements observed were 8% in PM_{10} and 3% in $PM_{2.5}$ (see Figure 3.188).

Concentration of the other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 4% in PM_{10} and 5% in $PM_{2.5}$, respectively.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed was 39% and 34% for PM_{10} and $PM_{2.5}$, respectively.

In PM_{10}, concentration of EC1 was highest, followed by OC3, OC2, OC4, EC3, and EC2, while, in case of $PM_{2.5}$, EC1 was the highest. Concentration of OC2, OC3, and OC4 was comparable in $PM_{2.5}$. Similarly, the EC2 and EC3 concentrations were comparable in $PM_{2.5}$ and PM_{10}. In PM_{10}, the average concentration of EC1 was almost 43% of total carbon (see Figure 3.189). Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.190.

Table 3.149: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of PM_{10} at Faridabad-2 for summer season

	μg/m3																		
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	211	30.92	32.06	1.16	1.30	7.67	6.22	0.47	4.43	1.45	0.12	0.47	1.95	3.49	12.79	5.16	6.38	3.54	6.18
SD	27	4.61	6.09	0.53	0.37	1.14	2.64	0.22	1.34	0.34	0.06	0.25	1.20	0.48	2.11	3.43	0.79	1.44	0.47
Min	177	24.62	24.56	0.48	0.67	6.31	2.42	0.07	2.94	0.99	0.07	0.23	0.67	2.96	10.56	1.00	5.41	2.05	5.49
Max	253	36.12	40.43	1.86	1.78	9.40	9.73	0.70	6.64	1.85	0.24	0.82	3.77	4.44	16.90	10.19	7.97	5.74	6.78
C.V.	0.13	0.15	0.19	0.45	0.29	0.15	0.42	0.47	0.30	0.23	0.48	0.54	0.62	0.14	0.17	0.66	0.12	0.41	0.08
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	251	64.41	40.66	1.49	3.87	9.56	8.53	0.74	14.79	1.54	0.97	1.04	10.97	4.31	16.34	12.17	8.09	9.34	9.83
50 %ile	204	47.63	26.11	0.71	2.89	6.55	6.58	0.62	11.48	1.17	0.59	0.55	7.26	3.37	11.69	4.31	5.50	6.32	6.15
5 %ile	183	32.03	13.22	0.61	2.09	5.03	4.72	0.48	5.42	0.94	0.20	0.38	4.00	1.40	7.60	2.31	3.66	4.37	4.12

Table 3.150: Statistical **evaluation of concentrations (μg/m^3)** of mass and major species of $PM_{2.5}$ at Faridabad-2 for summer season

	μg/m3																		
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	79	11.70	10.67	0.29	0.80	2.30	0.29	0.10	1.73	1.03	0.07	0.22	1.44	2.40	9.03	2.88	4.51	2.00	0.76
SD	6	0.99	0.65	0.04	0.06	0.66	0.19	0.02	1.14	0.41	0.05	0.13	0.82	0.31	1.14	2.51	0.72	0.78	0.27
Min	71	10.26	9.93	0.25	0.67	1.61	0.09	0.09	0.97	0.65	0.03	0.09	0.58	1.97	7.74	0.38	3.75	1.02	0.42
Max	86	13.06	11.80	0.37	0.86	3.65	0.60	0.13	4.09	1.68	0.16	0.42	2.86	2.97	10.90	6.85	5.77	3.54	1.17
C.V.	0.07	0.08	0.06	0.15	0.08	0.29	0.64	0.15	0.66	0.40	0.66	0.59	0.57	0.13	0.13	0.87	0.16	0.39	0.36
N	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
95 %ile	86	12.81	11.56	0.35	0.86	3.27	0.56	0.12	3.56	1.61	0.14	0.40	2.64	2.83	10.55	6.46	5.54	3.15	1.11
50 %ile	78	12.14	10.73	0.27	0.82	2.30	0.26	0.10	1.22	0.81	0.06	0.21	1.42	2.40	8.84	1.62	4.42	1.92	0.79
5 %ile	71	10.38	10.00	0.25	0.70	1.70	0.11	0.09	0.99	0.66	0.03	0.09	0.61	2.04	7.82	0.47	3.76	1.21	0.43

Table 3.151 : Correlation Matrix for PM10 and its composition for Summer season at Faridabad 2

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.85																			
	0.02																			
EC	0.73	0.30																		
	0.07	*0.51*																		
TC	0.96	0.74	0.86																	
	0.00	*0.06*	*0.01*																	
Cl^-	0.53	0.86	-0.03	0.43																
	0.22	*0.01*	*0.95*	*0.33*																
NO_3^-	0.58	0.42	0.34	0.47	-0.07															
	0.18	*0.35*	*0.45*	*0.29*	*0.88*															
SO_4^{--}	0.66	0.41	0.64	0.66	0.03	0.65														
	0.10	*0.36*	*0.13*	*0.10*	*0.95*	*0.12*														
Na^+	0.77	0.58	0.68	0.79	0.35	0.37	0.88													
	0.04	*0.17*	*0.10*	*0.04*	*0.45*	*0.42*	*0.01*													
NH_4^+	0.74	0.58	0.57	0.71	0.13	0.84	0.79	0.57												
	0.06	*0.17*	*0.18*	*0.07*	*0.78*	*0.02*	*0.04*	*0.18*												
K^+	0.92	0.61	0.86	0.93	0.22	0.61	0.66	0.72	0.67											
	0.00	*0.15*	*0.01*	*0.00*	*0.64*	*0.14*	*0.11*	*0.07*	*0.10*											
Ca^{++}	0.43	0.58	-0.01	0.30	0.30	0.71	0.19	-0.03	0.71	0.26										
	0.34	*0.18*	*0.98*	*0.51*	*0.51*	*0.07*	*0.69*	*0.95*	*0.07*	*0.57*										
Si	0.59	0.60	0.46	0.64	0.53	0.09	0.08	0.17	0.47	0.42	0.50									
	0.16	*0.16*	*0.30*	*0.12*	*0.22*	*0.85*	*0.87*	*0.71*	*0.29*	*0.35*	*0.26*									
Al	0.76	0.65	0.53	0.72	0.49	0.34	0.26	0.33	0.55	0.63	0.50	0.86								
	0.05	*0.11*	*0.22*	*0.07*	*0.27*	*0.46*	*0.57*	*0.47*	*0.20*	*0.13*	*0.25*	*0.01*								
Ca	0.85	0.76	0.63	0.85	0.42	0.62	0.38	0.41	0.73	0.82	0.66	0.69	0.71							
	0.01	*0.05*	*0.13*	*0.02*	*0.35*	*0.14*	*0.40*	*0.36*	*0.06*	*0.02*	*0.11*	*0.09*	*0.08*							
Fe	0.72	0.92	0.24	0.66	0.91	0.11	0.22	0.54	0.28	0.51	0.29	0.49	0.45	0.63						
	0.07	*0.00*	*0.61*	*0.11*	*0.00*	*0.82*	*0.64*	*0.21*	*0.55*	*0.25*	*0.53*	*0.27*	*0.31*	*0.13*						
Ti	0.60	0.83	0.15	0.54	0.85	0.05	0.22	0.54	0.17	0.41	0.16	0.28	0.22	0.50	0.97					
	0.16	*0.02*	*0.75*	*0.21*	*0.01*	*0.92*	*0.64*	*0.21*	*0.71*	*0.36*	*0.73*	*0.54*	*0.63*	*0.26*	*0.00*					
K	0.80	0.49	0.91	0.90	0.11	0.49	0.64	0.69	0.65	0.92	0.18	0.41	0.44	0.80	0.46	0.40				
	0.03	*0.26*	*0.00*	*0.01*	*0.82*	*0.26*	*0.13*	*0.09*	*0.11*	*0.00*	*0.70*	*0.36*	*0.32*	*0.03*	*0.31*	*0.37*				
S	0.75	0.79	0.47	0.75	0.78	0.06	0.47	0.70	0.46	0.50	0.21	0.72	0.71	0.50	0.75	0.64	0.43			
	0.05	*0.03*	*0.29*	*0.05*	*0.04*	*0.90*	*0.29*	*0.08*	*0.30*	*0.26*	*0.65*	*0.07*	*0.08*	*0.25*	*0.06*	*0.12*	*0.34*			
Ni	0.73	0.94	0.25	0.67	0.94	0.11	0.22	0.53	0.32	0.49	0.34	0.57	0.52	0.65	0.99	0.94	0.44	0.80		
	0.06	*0.00*	*0.59*	*0.10*	*0.00*	*0.82*	*0.63*	*0.22*	*0.49*	*0.26*	*0.46*	*0.18*	*0.23*	*0.12*	*0.00*	*0.00*	*0.32*	*0.03*		
Pb	0.79	0.82	0.50	0.79	0.82	-0.01	0.23	0.59	0.26	0.63	0.12	0.66	0.65	0.65	0.91	0.82	0.57	0.85	0.92	
	0.04	*0.02*	*0.25*	*0.03*	*0.02*	*0.98*	*0.62*	*0.16*	*0.58*	*0.13*	*0.80*	*0.10*	*0.11*	*0.11*	*0.01*	*0.02*	*0.18*	*0.02*	*0.00*	
Zn	0.87	0.86	0.61	0.88	0.68	0.31	0.54	0.68	0.69	0.67	0.45	0.81	0.75	0.77	0.76	0.64	0.66	0.92	0.81	0.83
	0.01	*0.01*	*0.15*	*0.01*	*0.09*	*0.50*	*0.21*	*0.10*	*0.09*	*0.10*	*0.31*	*0.03*	*0.05*	*0.04*	*0.05*	*0.12*	*0.11*	*0.00*	*0.03*	*0.02*

Note: Bold values represents “Correlation Coefficient”and *Italic* represents “*P-value*

Table 3.152: Correlation matrix for $PM_{2.5}$ and its composition for summer season at Faridabad-2

	$PM_{2.5}$	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.78																			
	0.04																			
EC	0.70	0.95																		
	0.08	*0.00*																		
TC	0.76	0.99	0.98																	
	0.05	*0.00*	*0.00*																	
Cl^-	0.18	0.16	0.09	0.13																
	0.69	*0.74*	*0.85*	*0.78*																
NO_3^-	0.87	0.66	0.60	0.64	0.62															
	0.01	*0.11*	*0.15*	*0.12*	*0.14*															
SO_4^{--}	0.90	0.71	0.63	0.69	0.21	0.76														
	0.01	*0.07*	*0.13*	*0.09*	*0.64*	*0.05*														
Na^+	0.36	0.46	0.55	0.51	0.76	0.72	0.25													
	0.43	*0.30*	*0.20*	*0.25*	*0.05*	*0.07*	*0.59*													
NH_4^+	0.78	0.58	0.50	0.55	0.48	0.80	0.91	0.40												
	0.04	*0.18*	*0.26*	*0.20*	*0.28*	*0.03*	*0.01*	*0.37*												
K^+	0.46	0.35	0.38	0.37	0.53	0.59	0.72	0.46	0.87											
	0.30	*0.44*	*0.39*	*0.42*	*0.22*	*0.17*	*0.07*	*0.30*	*0.01*											
Ca^{++}	0.98	0.81	0.73	0.79	0.28	0.89	0.94	0.41	0.87	0.59										
	0.00	*0.03*	*0.06*	*0.04*	*0.54*	*0.01*	*0.00*	*0.36*	*0.01*	*0.16*										
Si	0.65	0.61	0.55	0.60	0.27	0.63	0.50	0.41	0.65	0.36	0.67									
	0.12	*0.15*	*0.20*	*0.16*	*0.57*	*0.13*	*0.26*	*0.36*	*0.12*	*0.43*	*0.10*									
Al	0.41	0.34	0.49	0.41	-0.61	0.11	0.23	-0.05	-0.09	-0.19	0.29	-0.02								
	0.37	*0.45*	*0.26*	*0.37*	*0.15*	*0.82*	*0.61*	*0.91*	*0.84*	*0.68*	*0.53*	*0.97*								
Ca	0.70	0.81	0.89	0.85	-0.21	0.50	0.48	0.37	0.29	0.07	0.64	0.58	0.74							
	0.08	*0.03*	*0.01*	*0.02*	*0.66*	*0.26*	*0.28*	*0.42*	*0.53*	*0.88*	*0.12*	*0.17*	*0.06*							
Fe	0.35	0.33	0.51	0.41	-0.38	0.15	0.39	0.06	0.08	0.18	0.31	-0.25	0.85	0.53						
	0.44	*0.47*	*0.25*	*0.36*	*0.40*	*0.75*	*0.39*	*0.89*	*0.86*	*0.71*	*0.50*	*0.59*	*0.02*	*0.22*						
Ti	-0.06	0.29	0.38	0.33	0.40	0.22	-0.24	0.71	-0.27	-0.16	-0.06	-0.10	0.11	0.28	0.15					
	0.90	*0.52*	*0.40*	*0.47*	*0.38*	*0.64*	*0.61*	*0.08*	*0.56*	*0.73*	*0.89*	*0.83*	*0.82*	*0.55*	*0.74*					
K	0.55	0.56	0.63	0.60	-0.61	0.18	0.34	-0.08	0.05	-0.19	0.44	0.33	0.90	0.88	0.63	0.00				
	0.21	*0.19*	*0.13*	*0.16*	*0.14*	*0.70*	*0.46*	*0.87*	*0.91*	*0.69*	*0.32*	*0.48*	*0.01*	*0.01*	*0.13*	*1.00*				
S	0.83	0.72	0.78	0.75	0.45	0.91	0.73	0.78	0.74	0.64	0.85	0.63	0.34	0.69	0.40	0.29	0.37			
	0.02	*0.07*	*0.04*	*0.05*	*0.31*	*0.00*	*0.06*	*0.04*	*0.06*	*0.12*	*0.02*	*0.13*	*0.46*	*0.09*	*0.38*	*0.53*	*0.41*			
Ni	0.25	0.30	0.51	0.39	-0.24	0.16	0.29	0.24	0.03	0.21	0.22	-0.28	0.77	0.49	0.97	0.34	0.51	0.43		
	0.59	*0.52*	*0.24*	*0.39*	*0.61*	*0.73*	*0.53*	*0.60*	*0.95*	*0.66*	*0.63*	*0.54*	*0.04*	*0.26*	*0.00*	*0.45*	*0.24*	*0.33*		
Pb	0.46	0.56	0.77	0.65	-0.30	0.30	0.34	0.35	0.14	0.15	0.41	0.23	0.85	0.86	0.81	0.32	0.81	0.62	0.82	
	0.30	*0.19*	*0.04*	*0.11*	*0.51*	*0.52*	*0.46*	*0.44*	*0.77*	*0.75*	*0.36*	*0.62*	*0.02*	*0.01*	*0.03*	*0.49*	*0.03*	*0.14*	*0.02*	
Zn	0.57	0.51	0.66	0.58	-0.18	0.39	0.69	0.20	0.49	0.57	0.58	0.09	0.67	0.58	0.89	-0.03	0.57	0.63	0.84	0.79
	0.19	*0.24*	*0.11*	*0.17*	*0.70*	*0.39*	*0.09*	*0.66*	*0.27*	*0.19*	*0.17*	*0.84*	*0.10*	*0.17*	*0.01*	*0.95*	*0.19*	*0.13*	*0.02*	*0.03*

Note: **Bold** values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For the summer season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.149 and Table 3.150 for PM mass and major species, respectively. $PM_{2.5}$ mass has lesser C.V. as compared to PM_{10} mass. For crustal elements, C.V. in both PM_{10} and $PM_{2.5}$ is similar. In both PM_{10} and $PM_{2.5}$, the secondary particulates (NO_3^-, SO_4^{--}, and NH_4^+) show a similar C.V.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.151 and Table 3.152 for the PM mass and its major species. OC, EC, and TC showed a better correlation with PM_{10} mass than $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) showed a better correlation with PM_{10} mass. Secondary particulates showed a better correlation with each other in PM2.5 and with $PM_{2.5}$ mass as well.

3.1.20.2 Winter season:

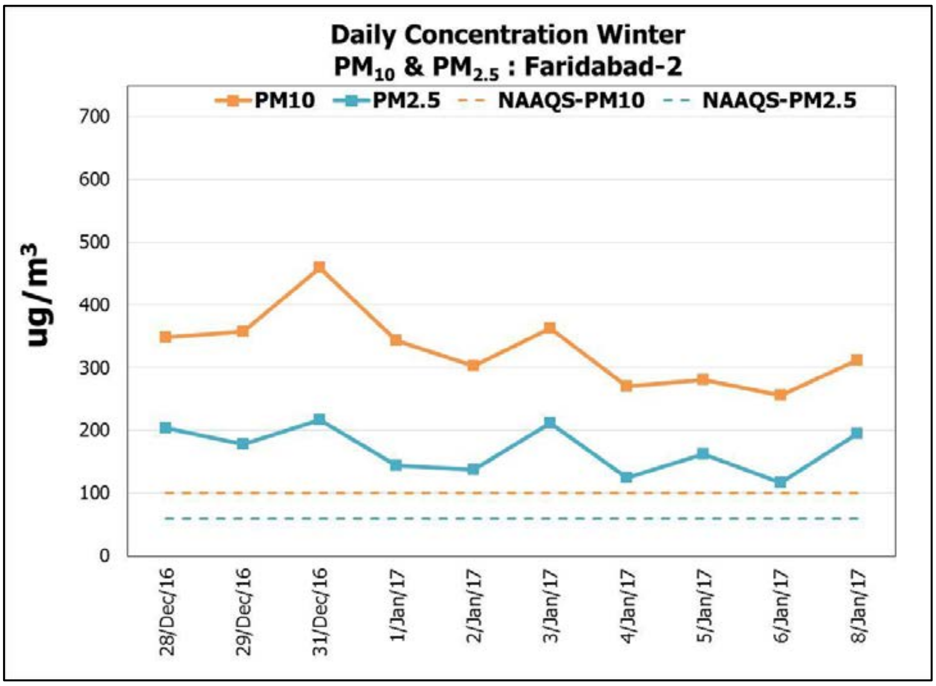


Figure 3.191: Variation in a 24-hourly concentration of PM_{10} and $PM_{2.5}$ at Faridabad-2 in winter season

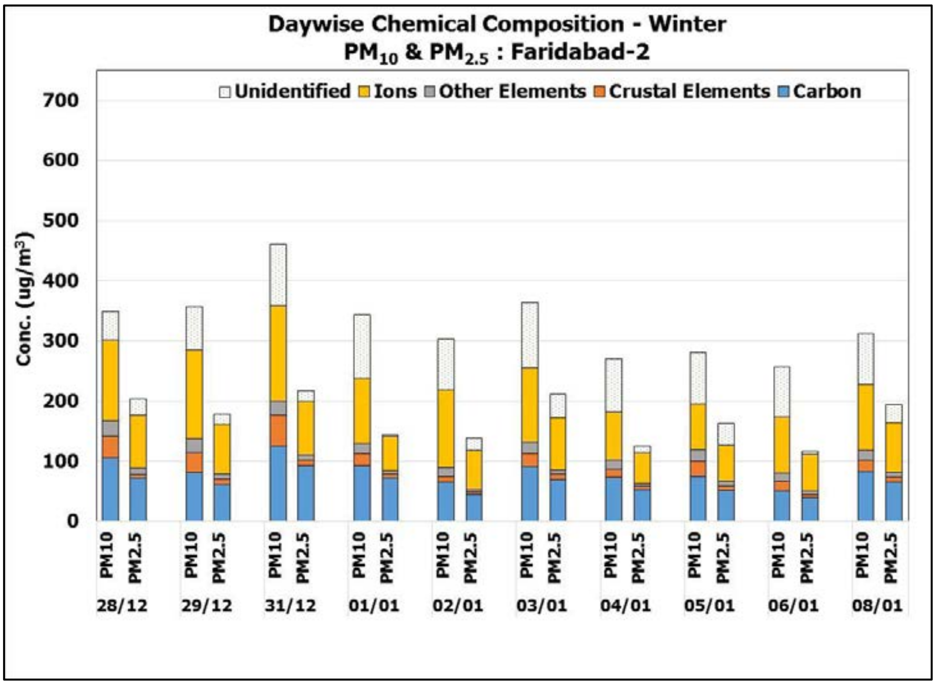


Figure 3.192: Variation in chemical composition of PM10 and PM2.5 at Faridabad-2 in winter season

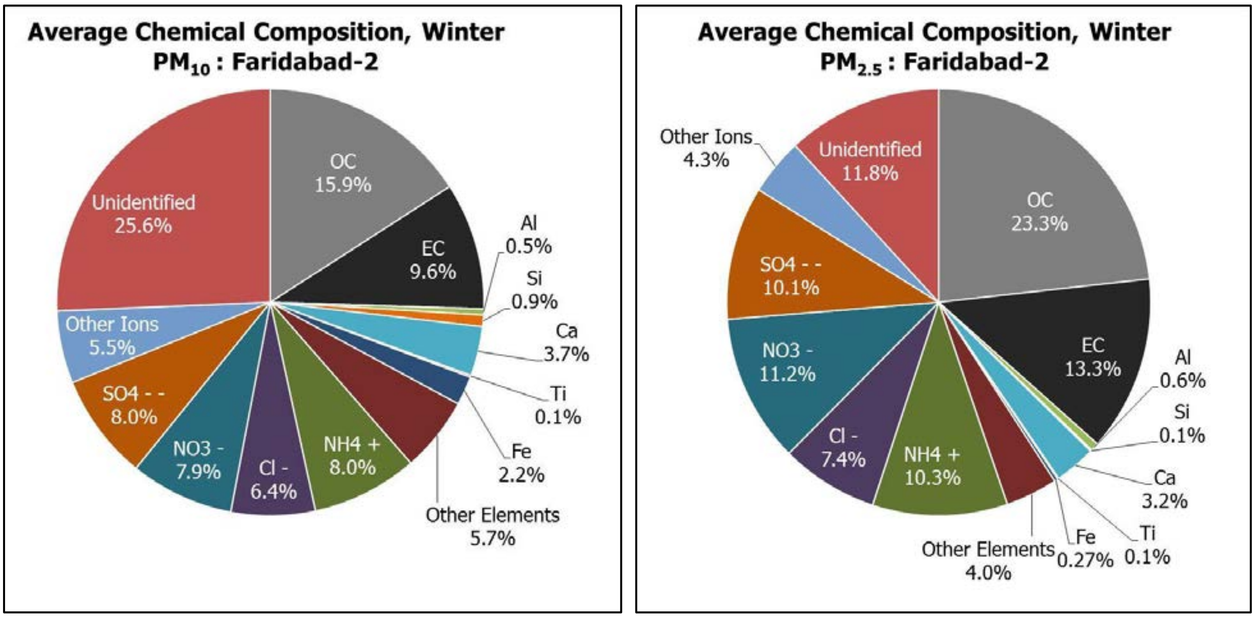


Figure 3.193: Average chemical composition of PM10 and PM2.5 at Faridabad-2 in winter season

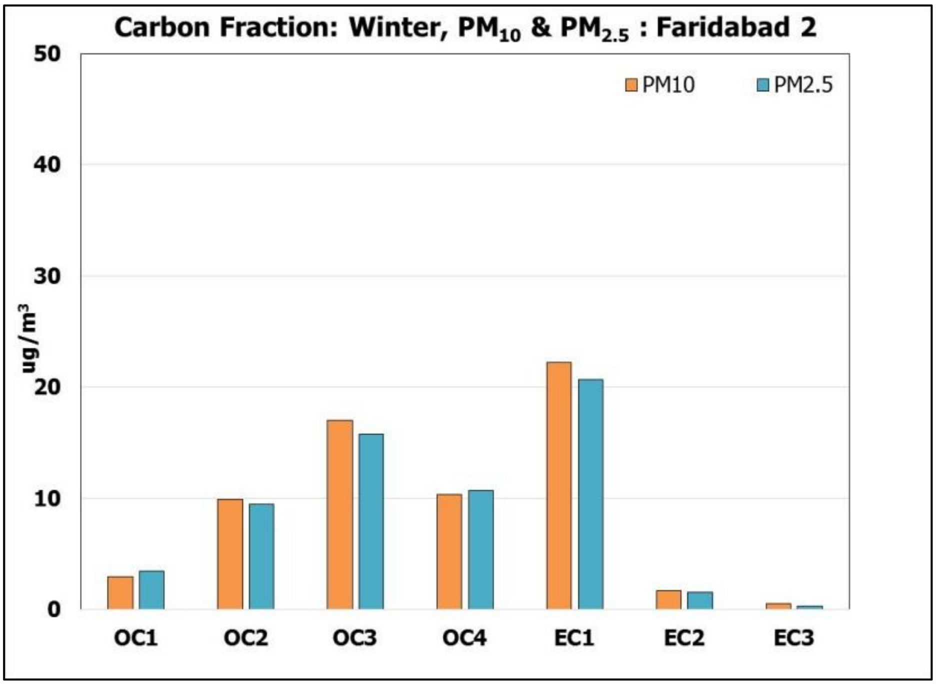


Figure 3.194: Average concentration of carbon fractions of PM10 and PM2.5 at Faridabad-2 in winter season

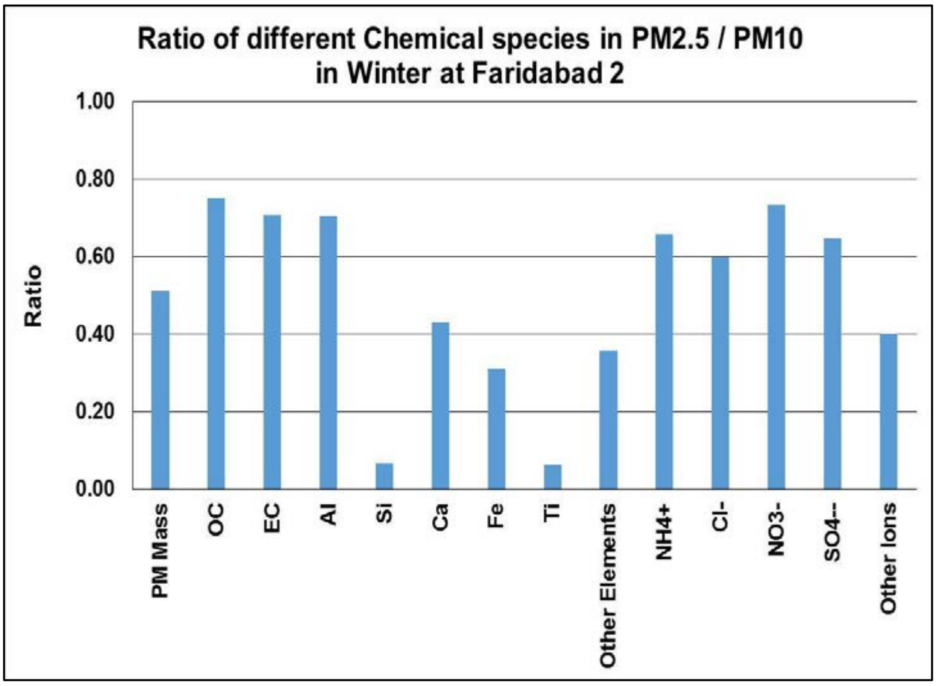


Figure 3.195: Ratio of different Chemical species in PM2.5 / PM10 in winter season at Faridabad-2

Average concentration of PM_{10} was found to be 330±59 µg/m^3 and in the case of $PM_{2.5}$, it was found to be 169±37 µg/m^3. It was observed that the PM_{10} concentration was 3.3 times higher than the permissible limit of NAAQS (100 µg/m^3). Concentration of PM_{10} and $PM_{2.5}$ varied from 257 to 460 µg/m^3 and 117 to 217 µg/m^3, respectively (see Figure3.191).

Daily variation in the components of different species in PM_{10} and $PM_{2.5}$ is represented in Figure 3.192.

The total ions were observed to be the major portion, followed by carbon fraction and the crustal element. The total ions were observed to be 36% in PM_{10} and in the case of $PM_{2.5}$, it was observed to be 43%. The carbon fraction showed that PM_{10} was 26% and $PM_{2.5}$ was 37%, which is higher than that of PM_{10}. The crustal element in PM_{10} was found to be 7% and in PM2.5, it was found to be 4% (see Figure 3.193).

Concentration of the other elements (S, K, V, Cr, Mn, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Mo, Pd, Cd, Sn, Te, Cs, Ba, La, and Pb) was found to be 6% in PM_{10} and 4% in $PM_{2.5}$.

The unidentified portion, which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed in PM_{10} was observed to be 26% and in case of $PM_{2.5}$, it was observed to be 12%.

The OC3 in PM_{10} was found to be higher as compared to $PM_{2.5}$, followed by OC4,OC2, and OC1. EC1 was found to be higher in PM_{10} as compared to $PM_{2.5}$ and was followed by EC2 and EC3 (see Figure 3.194).Ratio of concentration of mass and major species of $PM_{2.5}$ to PM_{10} is presented in Figure 3.195.

Table 3.153: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of PM_{10} at Faridabad-2 for winter season

	µg/m3																	
	PM_{10} Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	330	52.29	31.73	1.50	2.89	12.32	7.18	0.49	3.98	4.03	7.62	1.53	20.98	25.91	26.47	1.99	26.49	3.41	9.02
SD	59	12.14	9.94	0.56	1.37	6.52	4.52	0.18	1.34	1.11	1.17	0.74	6.89	6.04	5.33	0.43	7.22	1.18	5.29
Min	257	35.20	15.38	0.75	1.16	3.44	3.19	0.25	2.62	2.45	6.23	0.58	12.37	15.47	14.75	1.51	14.08	1.89	3.20
Max	460	79.20	48.92	2.55	5.04	25.90	16.61	0.81	6.45	5.80	9.32	2.87	34.05	32.14	32.45	2.90	34.34	5.34	18.69
C.V.	0.18	0.23	0.31	0.37	0.47	0.53	0.63	0.36	0.34	0.28	0.15	0.48	0.33	0.23	0.20	0.21	0.27	0.35	0.59
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	416	70.16	47.43	2.43	4.81	22.35	14.54	0.75	6.06	5.46	9.12	2.69	32.61	31.83	31.97	2.73	33.67	5.20	17.72
50 %ile	330	52.29	31.73	1.50	2.62	10.58	7.18	0.46	3.57	4.03	7.46	1.36	20.18	25.91	27.15	1.87	28.14	3.35	8.78
5 %ile	168	24.82	12.94	0.66	1.17	5.13	3.26	0.22	2.04	1.85	3.95	0.67	9.90	11.23	10.51	1.02	10.99	1.57	3.57

Table 3.154: Statistical **evaluation of concentrations (µg/m^3)** of mass and major species of $PM_{2.5}$ at Faridabad-2 for winter season

	µg/m3																	
	$PM_{2.5}$ Mass	OC	EC	Al	Si	Ca	Fe	Ti	K	S	Pb	Zn	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}
Mean	169	39.29	22.45	1.06	0.19	5.33	0.45	0.15	2.01	2.77	0.30	0.86	12.57	18.98	17.10	0.95	17.41	1.38	3.79
SD	37	9.41	6.56	0.43	0.06	1.43	0.20	0.07	0.61	0.84	0.13	0.38	3.49	4.07	3.70	0.15	4.73	0.44	1.33
Min	117	26.87	11.96	0.34	0.09	3.15	0.16	0.01	1.15	1.62	0.15	0.31	7.56	13.21	12.37	0.71	11.32	0.74	1.99
Max	217	58.78	32.97	1.87	0.28	7.28	0.81	0.27	2.74	4.42	0.55	1.57	18.14	24.59	22.16	1.18	23.26	1.93	5.78
C.V.	0.22	0.24	0.29	0.40	0.29	0.27	0.44	0.49	0.30	0.30	0.42	0.45	0.28	0.21	0.22	0.16	0.27	0.31	0.35
N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
95 %ile	214	53.33	31.55	1.63	0.27	7.18	0.75	0.24	2.65	4.10	0.49	1.42	16.99	24.09	22.09	1.15	22.76	1.90	5.36
50 %ile	170	40.61	22.27	1.11	0.20	5.19	0.45	0.15	2.32	2.76	0.31	0.88	12.55	20.06	16.34	0.95	18.12	1.35	4.06
5 %ile	120	27.11	14.18	0.45	0.11	3.44	0.20	0.04	1.16	1.79	0.15	0.39	8.09	13.44	13.00	0.75	11.46	0.80	2.05

Table 3.155: correlation matrix for PM_{10} and its composition for winter season at Faridabad-2

	PM_{10}	OC	EC	TC	Cl^-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.92																			
	0.00																			
EC	0.78	0.80																		
	0.01	*0.01*																		
TC	0.90	0.96	0.94																	
	0.00	*0.00*	*0.00*																	
Cl^-	0.54	0.32	0.42	0.38																
	0.11	*0.37*	*0.23*	*0.28*																
NO_3^-	0.57	0.25	0.42	0.34	0.50															
	0.09	*0.49*	*0.23*	*0.34*	*0.14*															
SO_4^{--}	0.71	0.45	0.48	0.49	0.58	0.89														
	0.02	*0.19*	*0.16*	*0.15*	*0.08*	*0.00*														
Na^+	0.52	0.68	0.67	0.71	0.26	-0.02	0.11													
	0.12	*0.03*	*0.03*	*0.02*	*0.46*	*0.96*	*0.77*													
NH_4^+	0.77	0.52	0.59	0.58	0.49	0.90	0.90	0.04												
	0.01	*0.12*	*0.08*	*0.08*	*0.15*	*0.00*	*0.00*	*0.91*												
K^+	0.68	0.59	0.46	0.56	0.46	0.58	0.56	0.33	0.57											
	0.03	*0.07*	*0.19*	*0.09*	*0.19*	*0.08*	*0.09*	*0.36*	*0.09*											
Ca^{++}	0.71	0.71	0.49	0.64	0.29	0.30	0.32	0.44	0.47	0.76										
	0.02	*0.02*	*0.16*	*0.05*	*0.41*	*0.41*	*0.36*	*0.21*	*0.17*	*0.01*										
Si	0.76	0.80	0.50	0.70	0.09	0.39	0.42	0.34	0.60	0.76	0.78									
	0.01	*0.01*	*0.14*	*0.02*	*0.80*	*0.27*	*0.23*	*0.34*	*0.07*	*0.01*	*0.01*									
Al	0.76	0.81	0.54	0.72	0.25	0.27	0.38	0.48	0.49	0.75	0.97	0.85								
	0.01	*0.00*	*0.11*	*0.02*	*0.49*	*0.45*	*0.28*	*0.17*	*0.15*	*0.01*	*0.00*	*0.00*								
Ca	0.76	0.81	0.60	0.76	0.22	0.26	0.30	0.62	0.43	0.75	0.96	0.83	0.96							
	0.01	*0.00*	*0.07*	*0.01*	*0.54*	*0.46*	*0.40*	*0.06*	*0.22*	*0.01*	*0.00*	*0.00*	*0.00*							
Fe	0.81	0.79	0.78	0.83	0.40	0.33	0.37	0.69	0.46	0.58	0.75	0.54	0.72	0.82						
	0.01	*0.01*	*0.01*	*0.00*	*0.25*	*0.35*	*0.29*	*0.03*	*0.19*	*0.08*	*0.01*	*0.11*	*0.02*	*0.00*						
Ti	0.54	0.60	0.65	0.66	0.11	0.33	0.27	0.50	0.42	0.71	0.84	0.64	0.81	0.85	0.72					
	0.11	*0.07*	*0.04*	*0.04*	*0.76*	*0.35*	*0.45*	*0.14*	*0.23*	*0.02*	*0.00*	*0.05*	*0.01*	*0.00*	*0.02*					
K	0.58	0.56	0.64	0.63	0.26	0.48	0.36	0.44	0.48	0.85	0.80	0.66	0.75	0.81	0.72	0.95				
	0.08	*0.09*	*0.05*	*0.05*	*0.48*	*0.16*	*0.31*	*0.20*	*0.16*	*0.00*	*0.01*	*0.04*	*0.01*	*0.00*	*0.02*	*0.00*				
S	0.60	0.49	0.76	0.64	0.32	0.66	0.70	0.18	0.79	0.40	0.43	0.39	0.47	0.40	0.50	0.63	0.58			
	0.07	*0.15*	*0.01*	*0.05*	*0.37*	*0.04*	*0.03*	*0.63*	*0.01*	*0.25*	*0.22*	*0.27*	*0.17*	*0.25*	*0.15*	*0.05*	*0.08*			
Ni	0.71	0.82	0.59	0.76	0.13	0.09	0.22	0.52	0.38	0.54	0.91	0.75	0.95	0.92	0.74	0.79	0.66	0.49		
	0.02	*0.00*	*0.07*	*0.01*	*0.72*	*0.81*	*0.55*	*0.13*	*0.28*	*0.11*	*0.00*	*0.01*	*0.00*	*0.00*	*0.01*	*0.01*	*0.04*	*0.16*		
Pb	0.77	0.74	0.68	0.75	0.25	0.44	0.51	0.45	0.54	0.68	0.74	0.59	0.75	0.78	0.89	0.77	0.77	0.62	0.73	
	0.01	*0.02*	*0.03*	*0.01*	*0.49*	*0.21*	*0.13*	*0.19*	*0.11*	*0.03*	*0.01*	*0.07*	*0.01*	*0.01*	*0.00*	*0.01*	*0.01*	*0.06*	*0.02*	
Zn	0.53	0.54	0.68	0.63	0.36	0.26	0.20	0.60	0.28	0.63	0.73	0.38	0.65	0.76	0.86	0.87	0.87	0.50	0.65	0.80
	0.12	*0.11*	*0.03*	*0.05*	*0.31*	*0.46*	*0.58*	*0.07*	*0.43*	*0.05*	*0.02*	*0.28*	*0.04*	*0.01*	*0.00*	*0.00*	*0.00*	*0.14*	*0.04*	*0.01*

Note: **Bold** values represents "Correlation Coefficient"and *Italic* represents "*P-value*

Table 3.156: Correlation matrix for $PM_{2.5}$ and its composition for winter season at Faridabad-2

	$PM_{2.5}$	OC	EC	TC	Cl-	NO_3^-	SO_4^{--}	Na^+	NH_4^+	K^+	Ca^{++}	Si	Al	Ca	Fe	Ti	K	S	Ni	Pb
OC	0.72																			
	0.02																			
EC	0.83	0.89																		
	0.00	*0.00*																		
TC	0.79	0.98	0.96																	
	0.01	*0.00*	*0.00*																	
Cl^-	0.71	0.20	0.46	0.31																
	0.02	*0.59*	*0.18*	*0.38*																
NO_3^-	0.76	0.58	0.66	0.63	0.46															
	0.01	*0.08*	*0.04*	*0.05*	*0.18*															
SO_4^{--}	0.93	0.64	0.78	0.72	0.61	0.92														
	0.00	*0.05*	*0.01*	*0.02*	*0.06*	*0.00*														
Na^+	0.45	0.23	0.60	0.39	0.39	0.45	0.52													
	0.19	*0.52*	*0.07*	*0.27*	*0.26*	*0.19*	*0.12*													
NH_4^+	0.85	0.60	0.70	0.66	0.51	0.81	0.87	0.48												
	0.00	*0.07*	*0.03*	*0.04*	*0.13*	*0.00*	*0.00*	*0.16*												
K^+	0.88	0.66	0.69	0.69	0.43	0.85	0.95	0.33	0.86											
	0.00	*0.04*	*0.03*	*0.03*	*0.22*	*0.00*	*0.00*	*0.35*	*0.00*											
Ca^{++}	0.47	0.13	0.02	0.09	0.19	0.37	0.43	-0.13	0.42	0.59										
	0.17	*0.72*	*0.96*	*0.82*	*0.60*	*0.29*	*0.21*	*0.73*	*0.23*	*0.08*										
Si	0.86	0.82	0.76	0.82	0.51	0.47	0.66	0.12	0.66	0.67	0.42									
	0.00	*0.00*	*0.01*	*0.00*	*0.14*	*0.17*	*0.04*	*0.75*	*0.04*	*0.03*	*0.23*									
Al	0.78	0.87	0.71	0.82	0.23	0.59	0.71	-0.02	0.63	0.82	0.47	0.87								
	0.01	*0.00*	*0.02*	*0.00*	*0.52*	*0.08*	*0.02*	*0.95*	*0.05*	*0.00*	*0.17*	*0.00*								
Ca	0.60	0.48	0.31	0.42	0.20	0.57	0.53	-0.07	0.59	0.62	0.83	0.65	0.63							
	0.07	*0.16*	*0.39*	*0.23*	*0.58*	*0.09*	*0.12*	*0.86*	*0.07*	*0.06*	*0.00*	*0.04*	*0.05*							
Fe	0.63	0.21	0.36	0.28	0.57	0.37	0.60	0.07	0.40	0.58	0.28	0.47	0.51	0.16						
	0.05	*0.55*	*0.31*	*0.44*	*0.09*	*0.29*	*0.07*	*0.85*	*0.26*	*0.08*	*0.43*	*0.18*	*0.14*	*0.65*						
Ti	0.80	0.84	0.69	0.80	0.27	0.59	0.69	0.03	0.65	0.75	0.54	0.91	0.94	0.79	0.45					
	0.01	*0.00*	*0.03*	*0.01*	*0.44*	*0.07*	*0.03*	*0.94*	*0.04*	*0.01*	*0.11*	*0.00*	*0.00*	*0.01*	*0.19*					
K	0.85	0.56	0.54	0.56	0.44	0.61	0.80	0.12	0.72	0.90	0.78	0.77	0.83	0.72	0.66	0.80				
	0.00	*0.09*	*0.11*	*0.09*	*0.20*	*0.06*	*0.01*	*0.75*	*0.02*	*0.00*	*0.01*	*0.01*	*0.00*	*0.02*	*0.04*	*0.01*				
S	0.83	0.66	0.77	0.72	0.45	0.75	0.89	0.39	0.68	0.87	0.25	0.61	0.76	0.32	0.78	0.68	0.74			
	0.00	*0.04*	*0.01*	*0.02*	*0.19*	*0.01*	*0.00*	*0.27*	*0.03*	*0.00*	*0.49*	*0.06*	*0.01*	*0.37*	*0.01*	*0.03*	*0.01*			
Ni	0.70	0.85	0.63	0.78	0.11	0.54	0.63	-0.08	0.61	0.75	0.50	0.86	0.97	0.72	0.37	0.96	0.78	0.64		
	0.02	*0.00*	*0.05*	*0.01*	*0.76*	*0.11*	*0.05*	*0.82*	*0.06*	*0.01*	*0.14*	*0.00*	*0.00*	*0.02*	*0.29*	*0.00*	*0.01*	*0.05*		
Pb	0.74	0.32	0.51	0.41	0.70	0.56	0.73	0.25	0.66	0.69	0.21	0.51	0.49	0.20	0.90	0.44	0.65	0.81	0.36	
	0.01	*0.38*	*0.13*	*0.25*	*0.03*	*0.09*	*0.02*	*0.48*	*0.04*	*0.03*	*0.56*	*0.14*	*0.15*	*0.58*	*0.00*	*0.20*	*0.04*	*0.01*	*0.31*	
Zn	0.67	0.25	0.40	0.32	0.59	0.43	0.64	0.11	0.44	0.62	0.28	0.49	0.53	0.19	1.00	0.48	0.68	0.82	0.39	0.92
	0.04	*0.48*	*0.25*	*0.37*	*0.07*	*0.22*	*0.05*	*0.76*	*0.20*	*0.06*	*0.43*	*0.16*	*0.12*	*0.61*	*0.00*	*0.16*	*0.03*	*0.00*	*0.27*	*0.00*

Note: Bold values represents “Correlation Coefficient”and *Italic* represents “*P-value*

For winter season, statistical evaluation of PM_{10} and $PM_{2.5}$, in terms of mean, range, coefficient of variation, 5%le, 50%le and 95 %le is presented in Table 3.153 and Table 3.154 for PM mass and major species, respectively. Both PM_{10} Mass and $PM_{2.5}$ mass showed a similar C.V. Crustal elements showed similar variations in both PM_{10} and $PM_{2.5}$. The secondary particulates showed a similar variation in both PM_{10} and $PM_{2.5}$.

The correlation matrix for PM_{10} and $PM_{2.5}$ is tabulated in Table 3.155 and Table 3.156 along with the PM mass and its major species. OC, EC, and TC show a better correlation with PM_{10} mass as compared to $PM_{2.5}$ mass. The crustal elements (Al, Si, Ca, Fe, and Ti) show a similar correlation with PM_{10} mass and $PM_{2.5}$ mass. The secondary particulates show a better correlation with each other in $PM_{2.5}$ and with $PM_{2.5}$ mass as well.

3.2 PM_{10} and $PM_{2.5}$ mass concentration

Results of air quality monitoring carried out for PM_{10} and $PM_{2.5}$ in summer and winter seasons in terms of mass concentrations and subsequent chemical analysis of samples collected for identification of concentrations of chemical species such as carbon fractions, ions, and elements that are presented for all the sites

In summer season, average of PM_{10} concentrations at all 20 sites in Delhi- NCR was found to be 188 μg/m^3 and was found to vary between 131 and 262 μg/m^3. Whereas variation in $PM_{2.5}$ mass concentration was found to be ranging from 65 to 130 μg/m^3 with an average of 90 μg/m^3. The lowest concentration was observed at Sonipat site, which can be attributed to the weather conditions. The monitoring at Sonipat site was conducted in July first week (this was postponed due to some public protests that were going on in that part). In the winter season, the overall average concentration of all the sites was 314 μg/m^3 (201- 441 μg/m^3) and 168 μg/m^3 (92-254 μg/m^3) for PM_{10} and $PM_{2.5}$, respectively.

3.2.1 Chemical speciation

3.2.2.1 Carbon fractions:

Carbon fractions in the particulate matter collected at a site can be mainly attributed to the combustion sources around the sites. The average of all 20 sites in Delhi-NCR for carbon fractions were found to be 52 μg/m^3 for PM_{10} in summer season with values ranging from 34 to 89 μg/m^3.

In case of $PM_{2.5}$, average carbon fractions was 27 μg/m^3 (from 16 to 50 μg/m^3), thus signifying variation in concentration amongst the sites depending upon the activities around the sites. In winter season, overall average of carbon fractions was found to be 98 μg/m^3 (54-162 μg/m^3) and 59 μg/m^3 (32-96 μg/m^3) for PM_{10} and $PM_{2.5}$, respectively.

3.2.2.2 Elements

Concentration of crustal elements (Al, Si, Ca, Mg, and Ti) in the particulate matter suggests contribution from soil dust. The average of all the 20 locations in PM_{10} in summer was 18 μg/m^3 (8–29 μg/m^3) and 4.21 μg/m^3 (2.09-6.39 μg/m^3) in case of $PM_{2.5}$. In terms of % of contribution of the crustal elements to PM_{10} and $PM_{2.5}$, the average of 20 sites was 10% and 5%, respectively. In the winter season, crustal elements were found to be 21 μg/m^3 (9-33 μg/m^3) and 4.2 (1- 10μg/m^3) for PM_{10} and $PM_{2.5}$, respectively. The average contribution of crustal elements in winter season, in terms of % of the share of PM_{10} and $PM_{2.5}$ was 7% and 2%, respectively. As can be seen, contribution of crustal elements were quite low in the case of $PM_{2.5}$, which may be explained through the fact that crustal elements are present in the coarse part of the particulate matter and, thus as very low contribution in the finer size, that is, $PM_{2.5}$ fraction.

3.2.2.3 Ions

The ionic species were found to be one of the major constituents of PM_{10} and $PM_{2.5}$ at all the sites. Average concentration of all sites in summer season for total ions was 42 μg/m^3 (24-61 μg/m^3) and 25 μg/m^3 (15-34 μg/m^3) in PM_{10} and $PM_{2.5}$, respectively. A higher contribution of ionic species was observed in $PM_{2.5}$ than in PM_{10}. In the summer season, the average contribution for all 20 sites in PM_{10} was 23% (16-30%) and in $PM_{2.5}$ it was 28% (22-38). The ionic species involved in secondary particulate formation (SO4, NO3, and NH4) are found to be predominant in both the PM_{10} and $PM_{2.5}$.

The Average concentration of secondary particulates for all 20 sites in PM_{10} was 22 $\mu g/m^3$ (15-34 $\mu g/m^3$) and in $PM_{2.5}$, it was 16 $\mu g/m^3$ (12-22 $\mu g/m^3$). The average contribution of the secondary particulates was 12% (8% - 16%) and 18% (14% - 25%) in PM_{10} and $PM_{2.5}$, respectively. Since the secondary particulates are finer in size, their contribution in terms of percentage is higher in $PM_{2.5}$ fraction as compared to PM_{10} fraction. In winter season, the total ions were found to be 101 $\mu g/m^3$ (55-150 $\mu g/m^3$) and 59 $\mu g/m^3$ (26-105 $\mu g/m^3$) in PM_{10} and $PM_{2.5}$, respectively. In the winter season, the average contribution of total ions was 32% (23-40%) and in $PM_{2.5}$, it was 36% (17-45). Average concentration of secondary particulates was 68 $\mu g/m^3$ (37-112 $\mu g/m^3$) and in $PM_{2.5}$, it was 43 $\mu g/m^3$ (22-77 $\mu g/m^3$). The average contribution of secondary particulates was 22% (14%–34%) and 26% (12%–45%) in PM_{10} and $PM_{2.5}$, respectively.

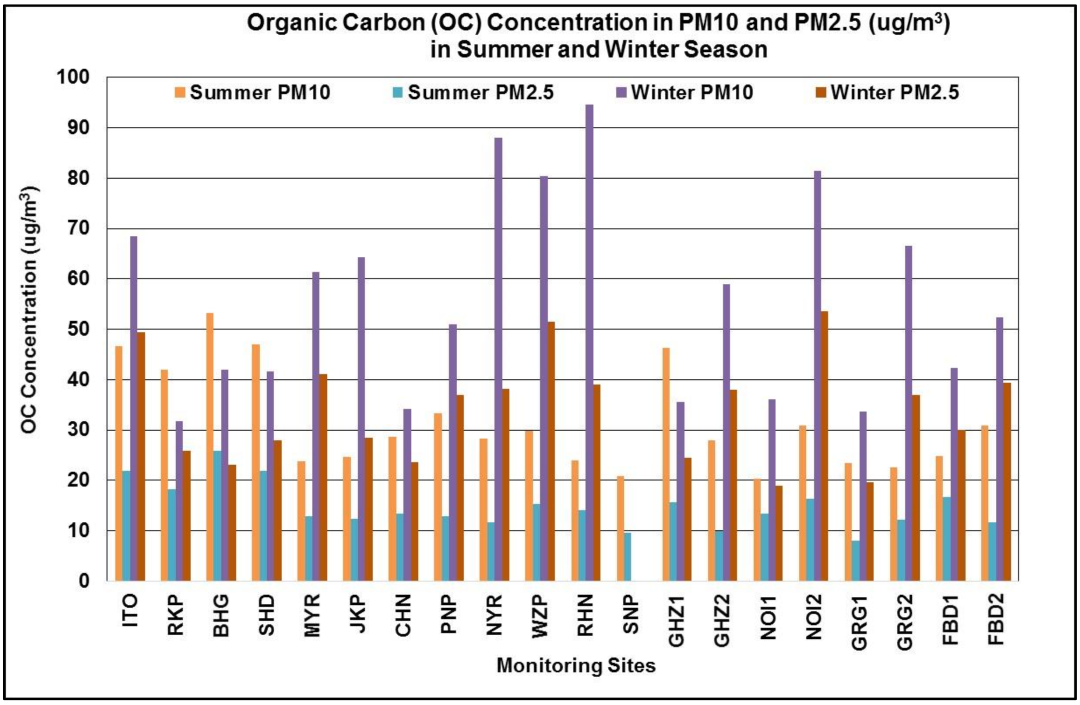


Figure 3.196: mass concentration of PM_{10} and $PM_{2.5}$ (µg/m3) in summer and winter seasons

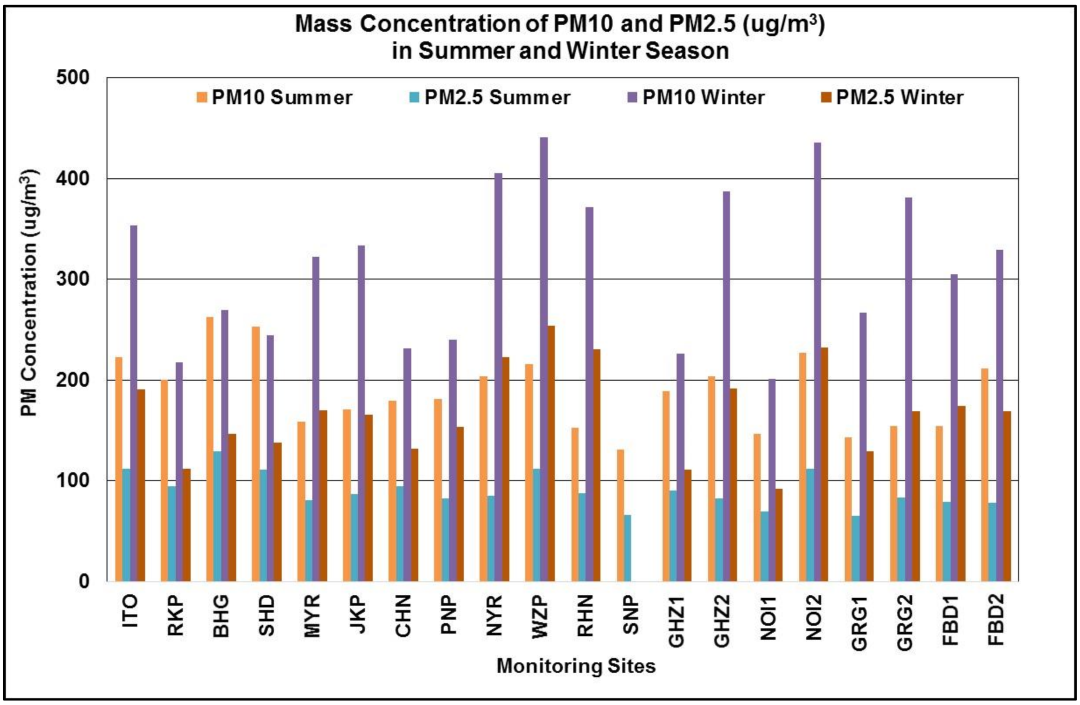


Figure 3.197: Organic carbon (OC) concentration in PM_{10} and $PM_{2.5}$ (µg/m3) in summer and winter seasons

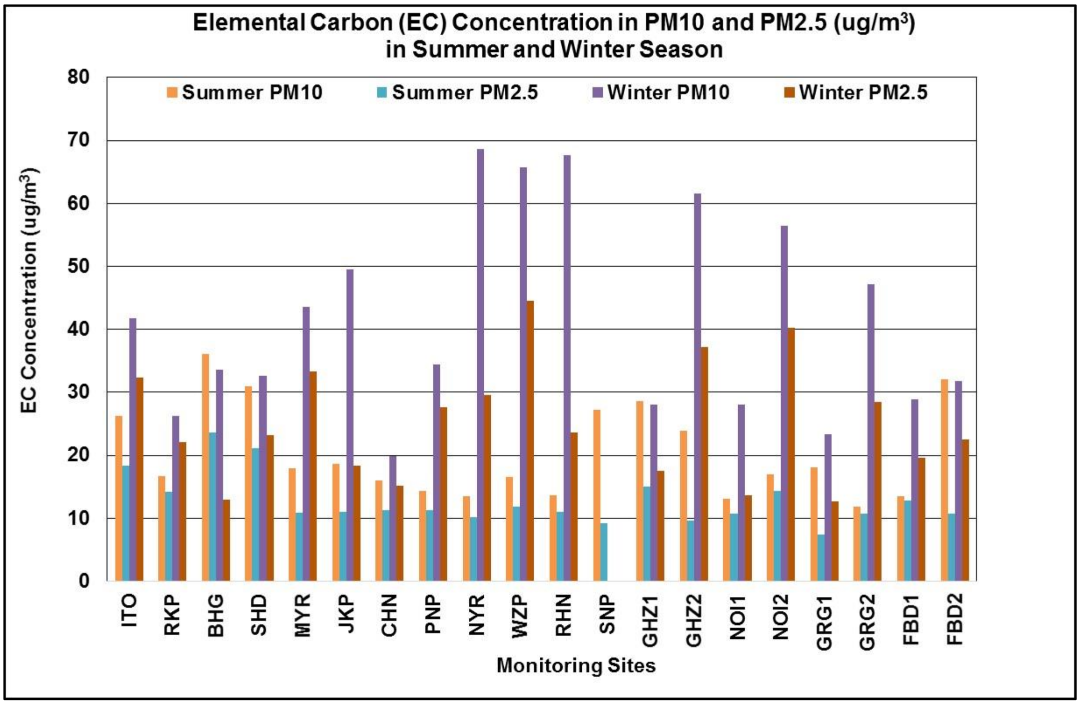


Figure 3.198: Elemental carbon (EC) concentration in PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) in summer and winter seasons

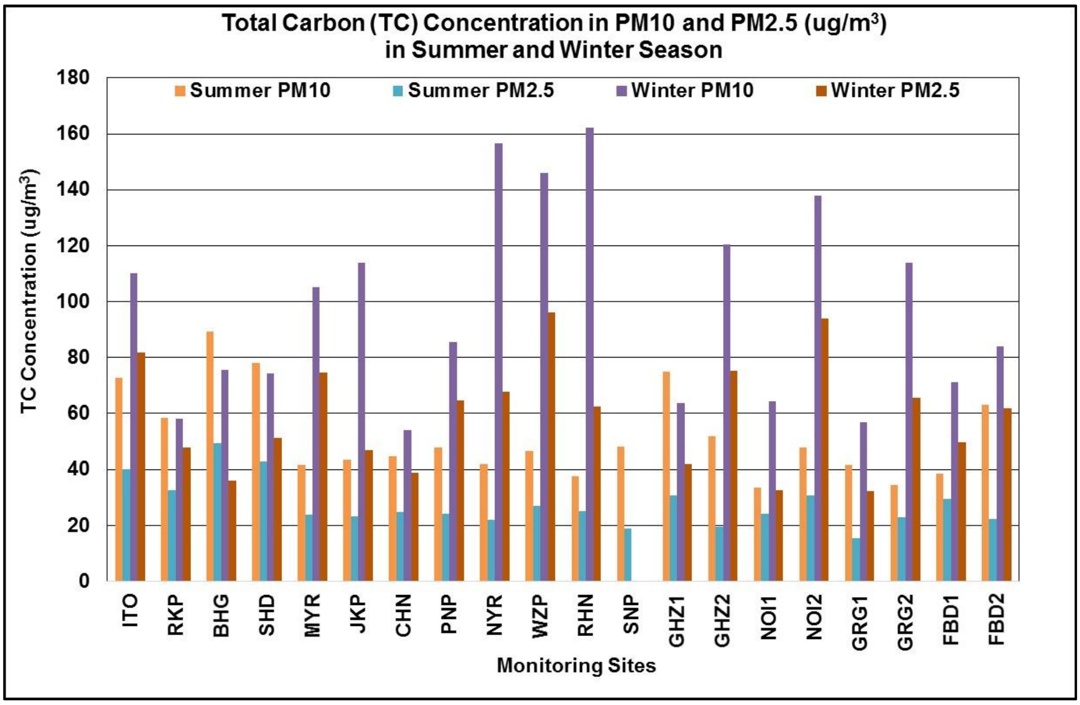


Figure 3.199: Total carbon (TC) concentration in PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) in summer and winter seasons

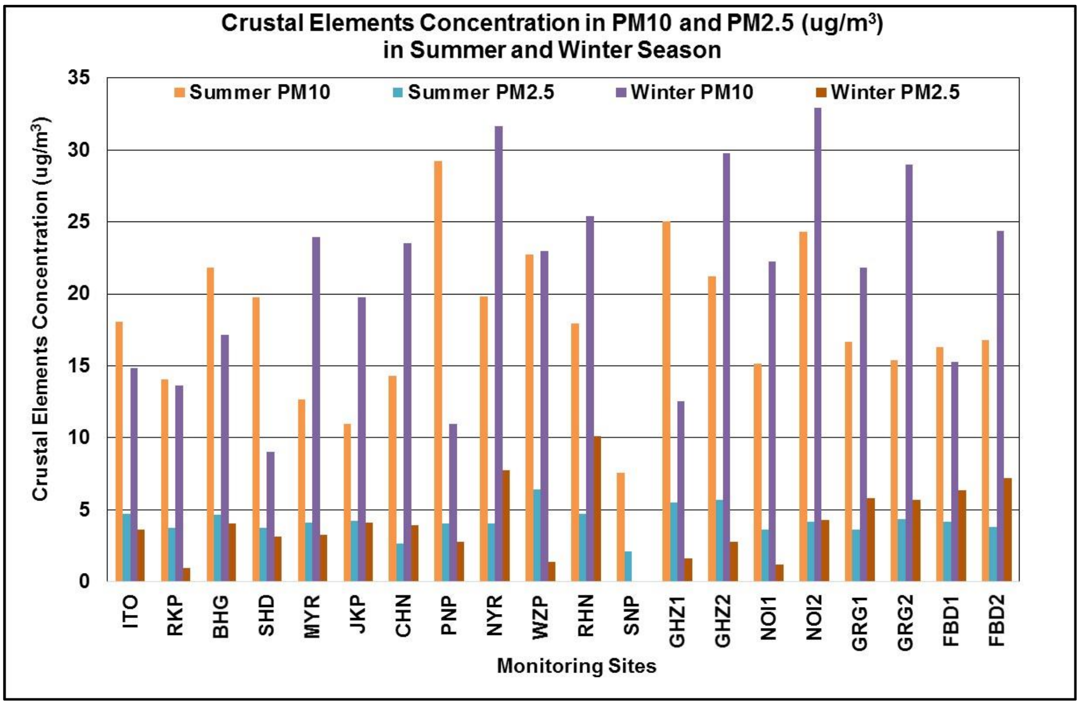


Figure 3.200: Crustal elements concentration in PM_{10} and $PM_{2.5}$ (µg/m³) in summer and winter seasons

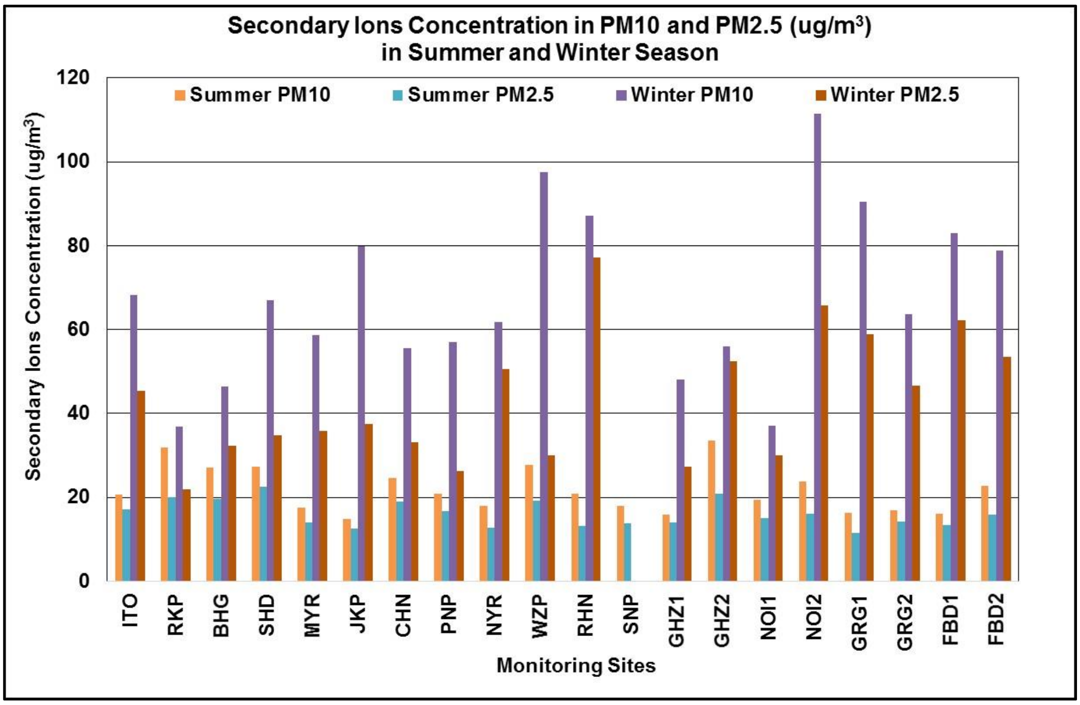


Figure 3.201: Secondary particulates concentration in PM_{10} and $PM_{2.5}$ (µg/m³) in summer and winter seasons

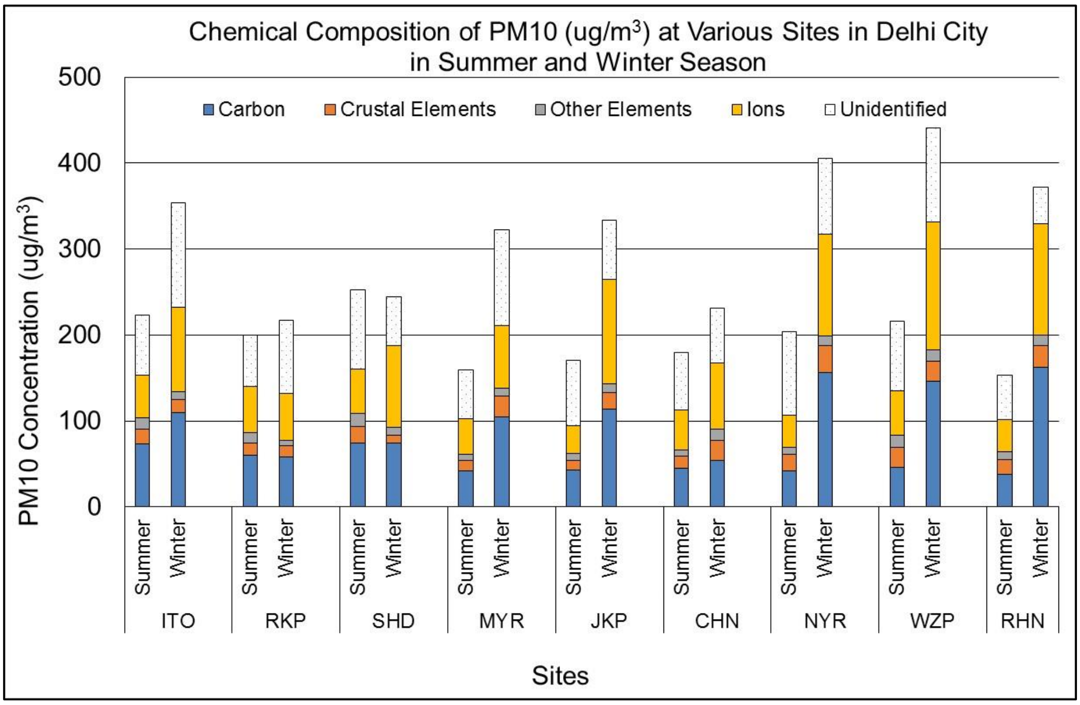


Figure 3.202: chemical composition of PM_{10} (µg/m^3) at various sites in Delhi city during the summer and winter seasons

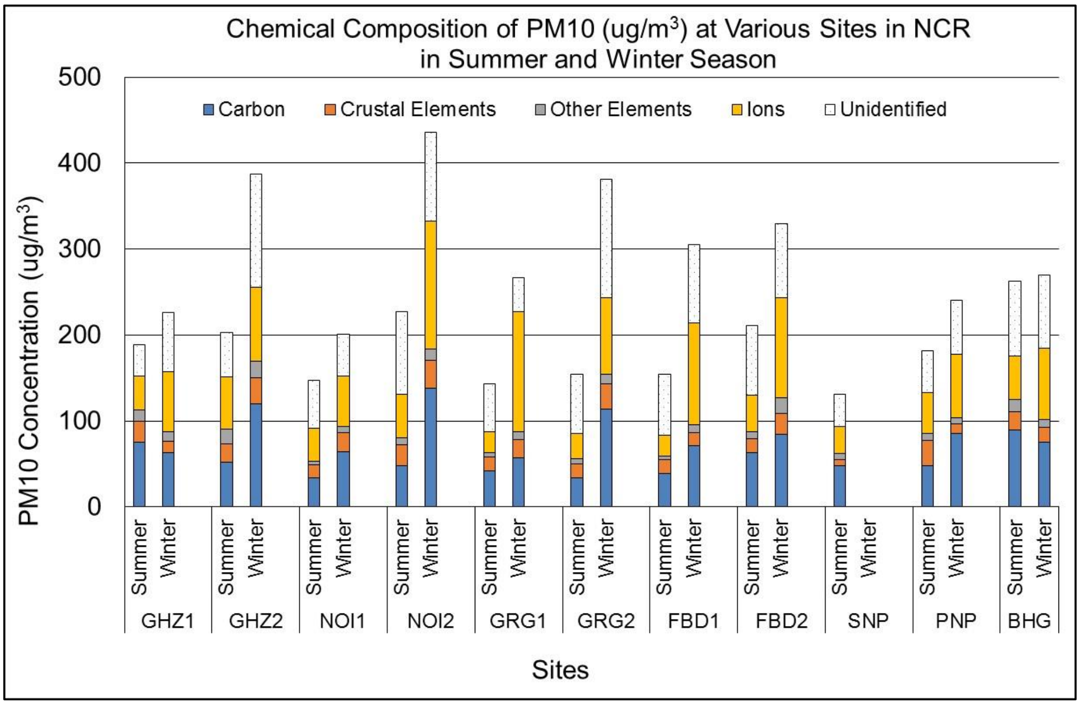


Figure 3.203: chemical composition of PM_{10} (µg/m^3) at various sites in NCR towns in summer and winter seasons

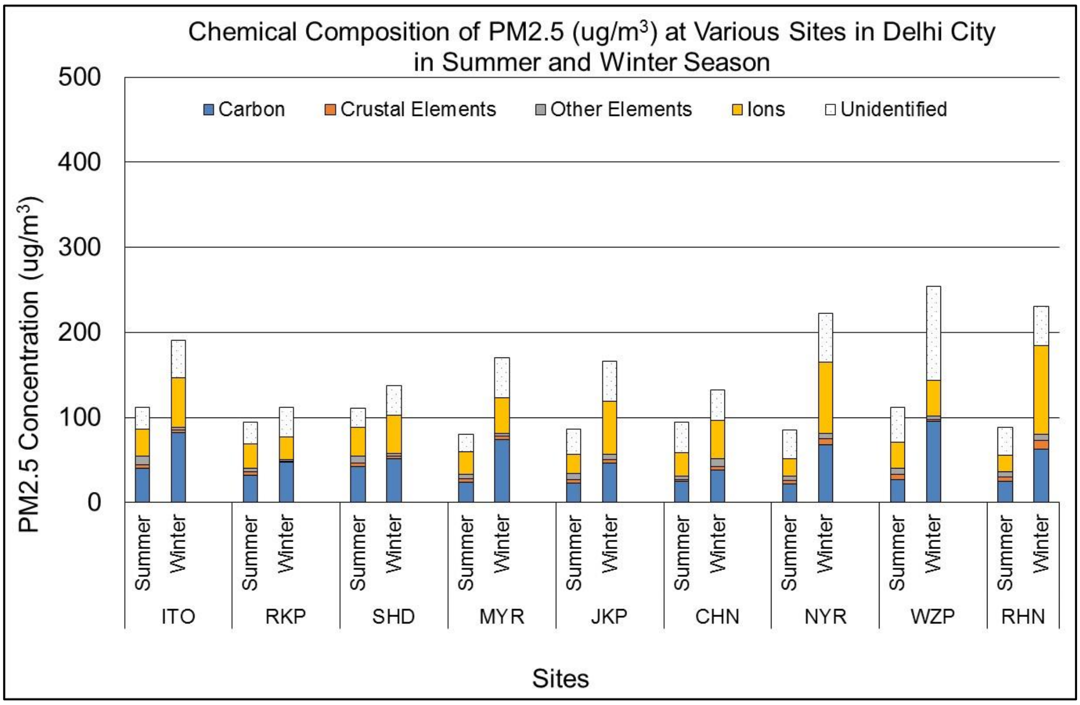


Figure 3.204: chemical composition of PM$_{2.5}$ (µg/m^3) at various sites in Delhi city in summer and winter seasons

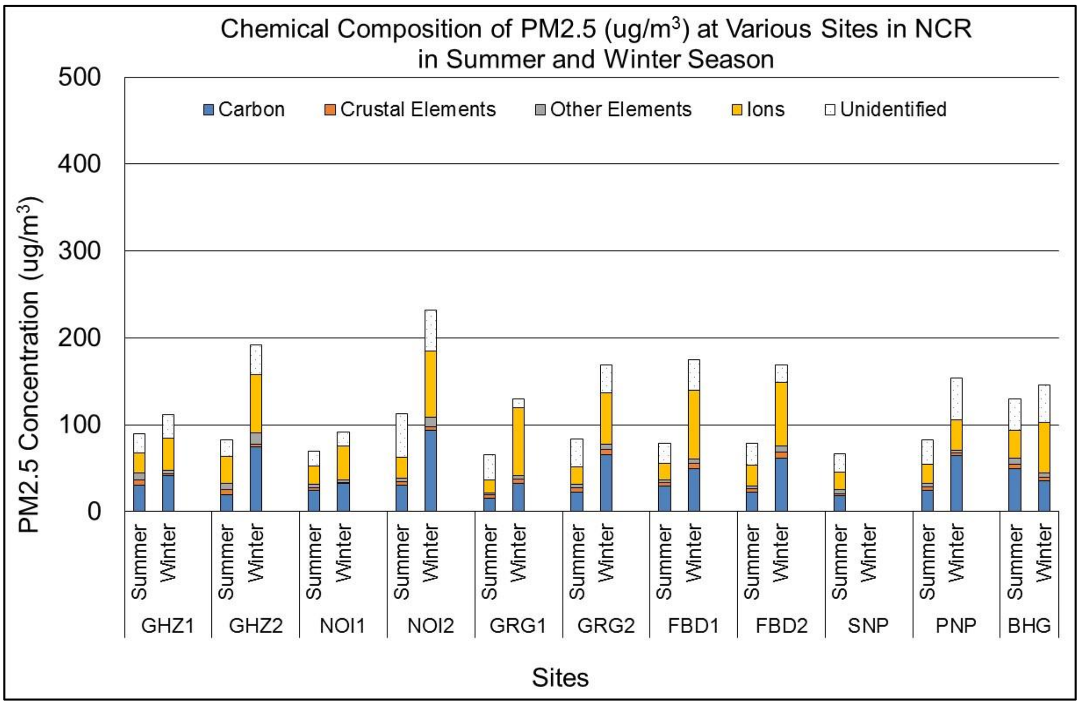


Figure 3.205: chemical composition of PM$_{2.5}$ (µg/m^3) at various sites in NCR Towns in summer and winter seasons

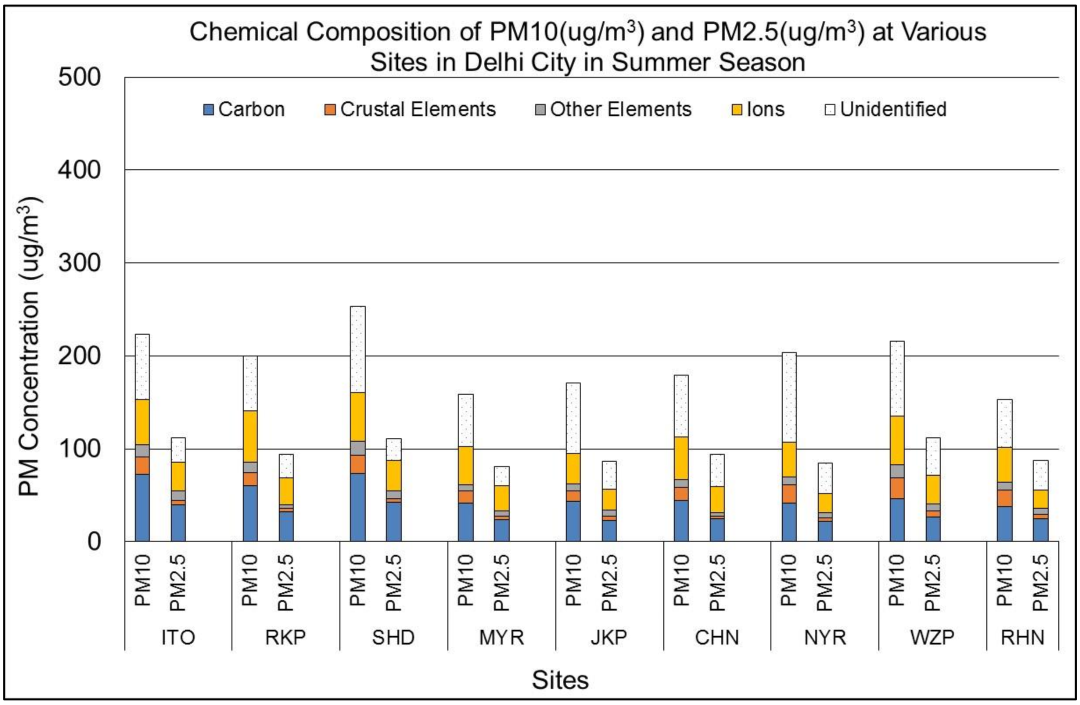


Figure 3.206: chemical composition of PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) at various sites in Delhi-city in summer season

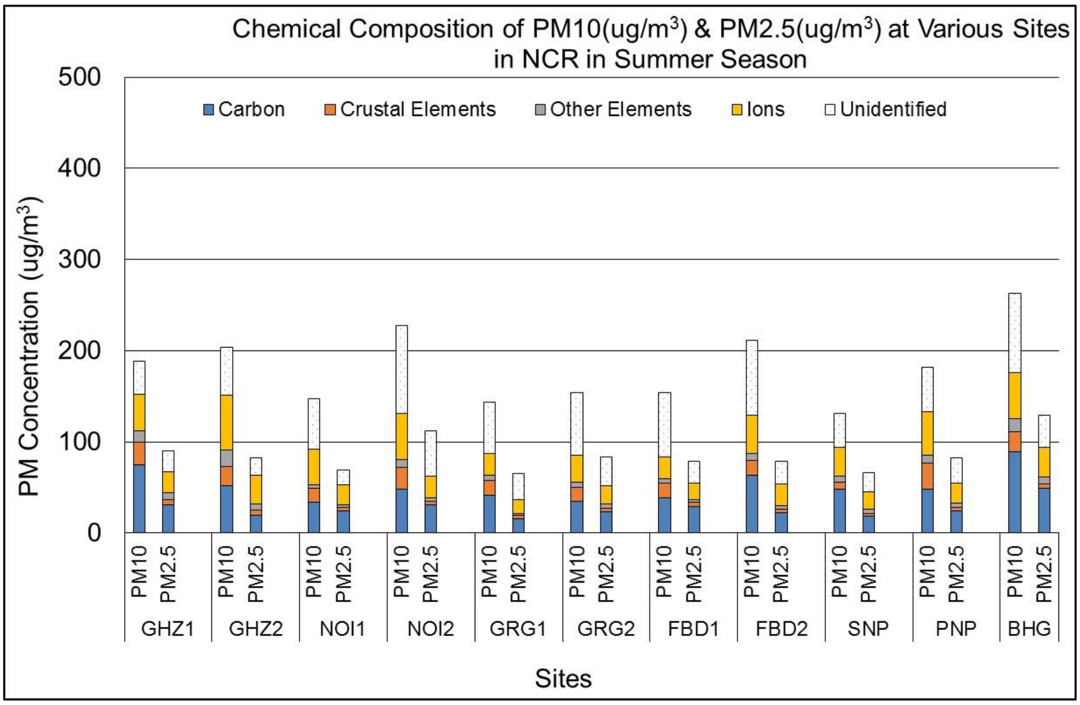


Figure.3.207: chemical composition of PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) at various sites in NCR Towns in summer season

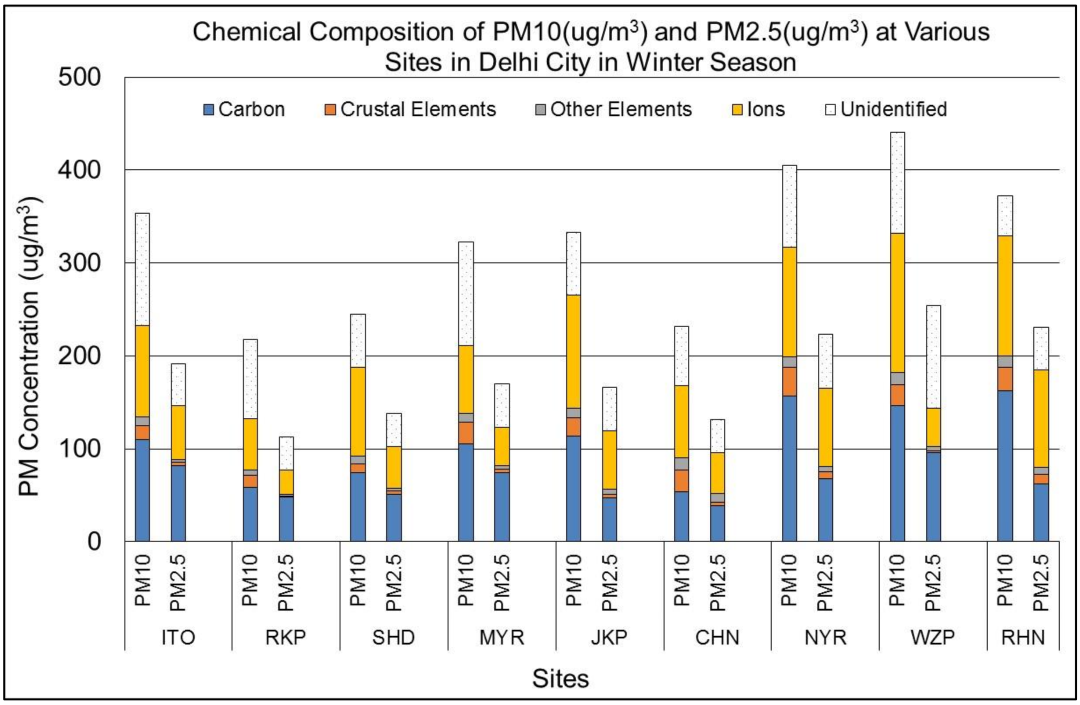


Figure.3.208: Chemical composition of PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) at various sites in Delhi-city in winter season

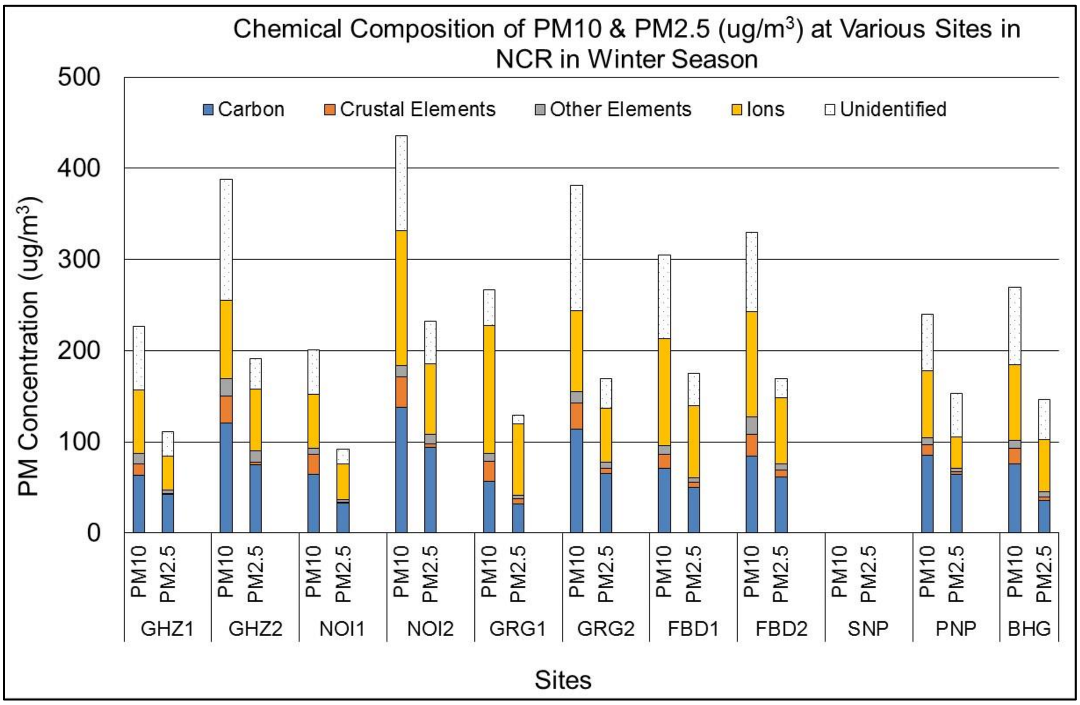


Figure.3.209: Chemical composition of PM_{10} and $PM_{2.5}$ ($\mu g/m^3$) at various sites in NCR Towns in winter season

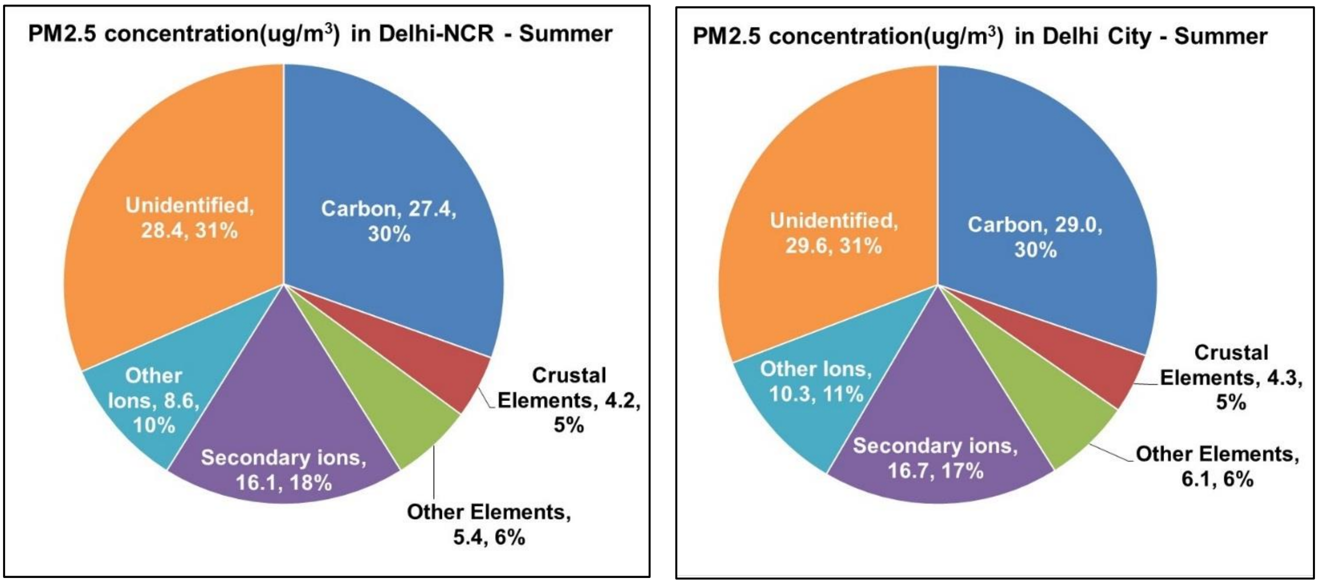


Figure.3.210: Average chemical composition of $PM_{2.5}$ (µg/m^3) Delhi-NCR (Excluding Delhi city) and Delhi city in summer season

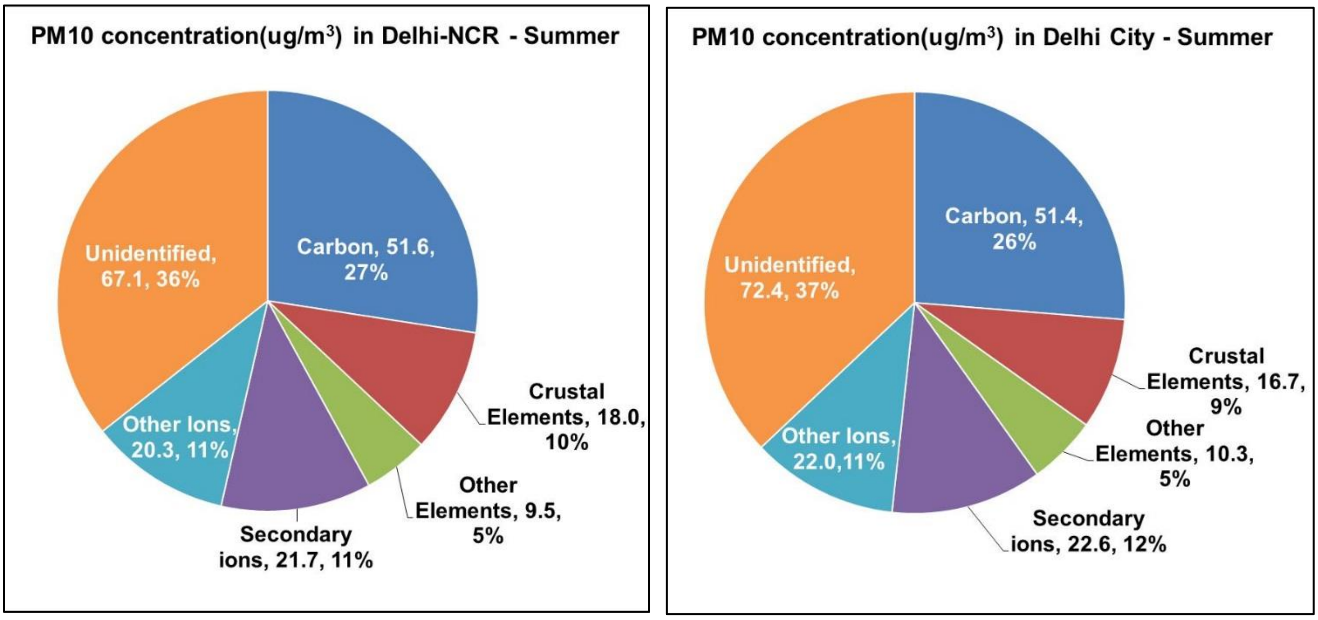


Figure.3.211: Average chemical composition of PM_{10} (µg/m^3) Delhi-NCR (Excluding Delhi city) and Delhi city in summer season

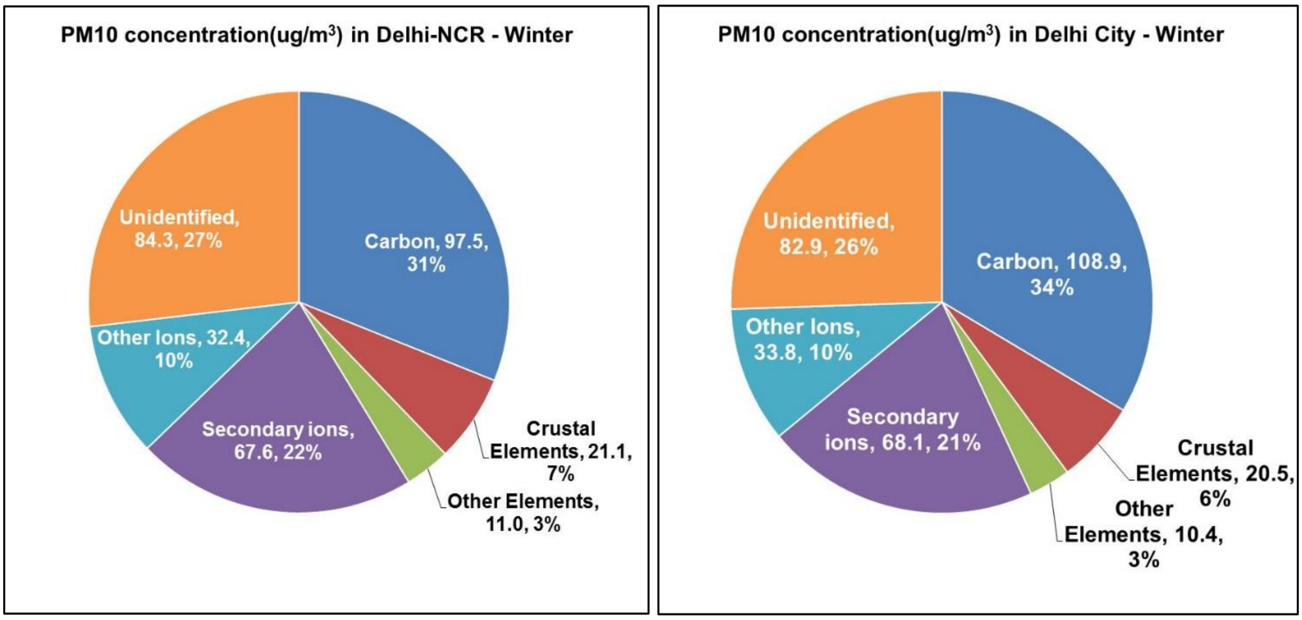


Figure.3.212: Average chemical composition of PM_{10} ($\mu g/m^3$) Delhi-NCR (Excluding Delhi city) and Delhi city in winter season

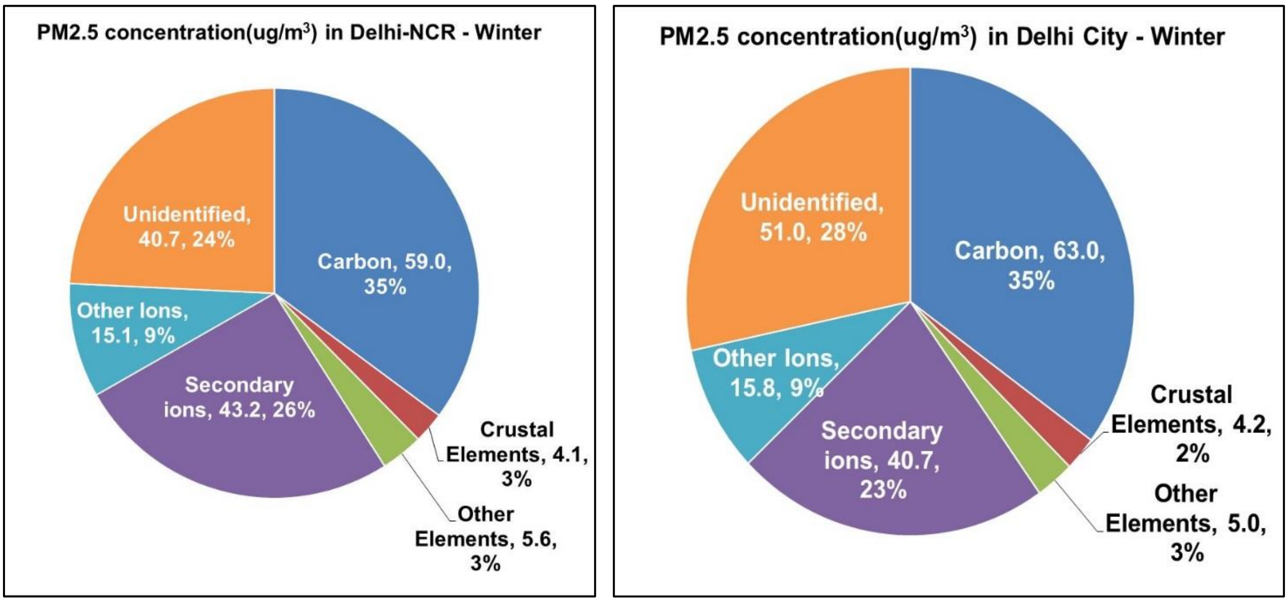


Figure.3.213: average chemical composition of $PM_{2.5}$ ($\mu g/m^3$) Delhi-NCR (Excluding Delhi city) and Delhi-city in winter season

Table 3.157: PM10 mass, total carbon (TC), crustal element, and secondary particulates (µg/m^3) in summer season

Site ID	PM$_{10}$	TC	TC/PM10	Crustal Elements	Crustal Elements / PM$_{10}$	Secondary particulates	Secondary particulates /PM$_{10}$
ITO	223.06	72.87	0.33	18.04	0.08	20.55	0.09
RKP	200.36	58.55	0.29	14.03	0.07	31.93	0.16
BHG	262.49	89.31	0.34	21.83	0.08	27.00	0.10
SHD	252.88	77.90	0.31	19.75	0.08	27.36	0.11
MYR	159.12	41.72	0.26	12.68	0.08	17.58	0.11
JKP	170.54	43.35	0.25	10.99	0.06	14.79	0.09
CHN	179.72	44.64	0.25	14.28	0.08	24.51	0.14
PNP	181.42	47.72	0.26	29.25	0.16	20.96	0.12
NYR	203.89	41.78	0.20	19.84	0.10	17.91	0.09
WZP	216.32	46.46	0.21	22.55	0.10	27.66	0.13
RHN	153.11	37.59	0.25	17.95	0.12	20.81	0.14
SNP	131.32	48.07	0.37	7.55	0.06	18.05	0.14
GHZ1	188.65	74.94	0.40	24.78	0.13	15.96	0.08
GHZ2	203.46	51.92	0.26	21.21	0.10	33.55	0.16
NOI1	147.03	33.52	0.23	15.15	0.10	19.39	0.13
NOI2	227.52	47.81	0.21	24.15	0.11	23.78	0.10
GRG1	143.61	41.49	0.29	16.51	0.11	16.39	0.11
GRG2	154.43	34.33	0.22	15.38	0.10	16.89	0.11
FBD1	154.21	38.42	0.25	16.30	0.11	16.16	0.10
FBD2	211.17	62.98	0.30	16.81	0.08	22.67	0.11
Mean	*188.22*	*51.77*	*0.27*	*17.99*	*0.10*	*21.69*	*0.12*
S.D.	*37.09*	*15.84*	*0.05*	*5.16*	*0.02*	*5.47*	*0.02*
Max	*262.49*	*89.31*	*0.40*	*29.25*	*0.16*	*33.55*	*0.16*
Min	*131.32*	*33.52*	*0.20*	*7.55*	*0.06*	*14.79*	*0.08*
CV	*0.20*	*0.31*	*0.19*	*0.29*	*0.26*	*0.25*	*0.20*

Table 3.158: $PM_{2.5}$ mass, total carbon (TC), crustal element, and secondary particulates ($\mu g/m^3$) in summer season

Site ID	$PM_{2.5}$	TC	TC/PM_{10}	Crustal Elements	Crustal Elements / PM_{10}	Secondary particulates	Secondary particulates / PM_{10}
ITO	112.04	40.13	0.36	4.70	0.04	17.16	0.15
RKP	94.37	32.50	0.34	3.77	0.04	19.93	0.21
BHG	129.59	49.46	0.38	4.64	0.04	19.52	0.15
SHD	110.82	42.89	0.39	3.72	0.03	22.48	0.20
MYR	80.59	23.70	0.29	4.12	0.05	14.06	0.17
JKP	86.84	23.29	0.27	4.23	0.05	12.57	0.14
CHN	94.38	24.68	0.26	2.63	0.03	19.01	0.20
PNP	82.23	24.24	0.29	4.04	0.05	16.66	0.20
NYR	84.98	21.86	0.26	4.07	0.05	12.86	0.15
WZP	111.78	27.06	0.24	6.39	0.06	19.17	0.17
RHN	87.94	25.04	0.28	4.71	0.05	13.17	0.15
SNP	66.48	18.83	0.28	2.09	0.03	13.82	0.21
GHZ1	90.12	30.69	0.34	5.53	0.06	13.91	0.15
GHZ2	82.32	19.53	0.24	5.69	0.07	20.78	0.25
NOI1	69.52	24.05	0.35	3.64	0.05	15.02	0.22
NOI2	112.45	30.65	0.27	4.15	0.04	15.99	0.14
GRG1	65.11	15.49	0.24	3.63	0.06	11.60	0.18
GRG2	83.31	22.85	0.27	4.37	0.05	14.18	0.17
FBD1	79.12	29.48	0.37	4.20	0.05	13.47	0.17
FBD2	78.53	22.37	0.28	3.78	0.05	15.94	0.20
Mean	*90.13*	*27.44*	*0.30*	*4.21*	*0.05*	*16.06*	*0.18*
S.D.	*17.22*	*8.46*	*0.05*	*0.97*	*0.01*	*3.13*	*0.03*
Max	*129.59*	*49.46*	*0.39*	*6.39*	*0.07*	*22.48*	*0.25*
Min	*65.11*	*15.49*	*0.24*	*2.09*	*0.03*	*11.60*	*0.14*
CV	*0.19*	*0.31*	*0.16*	*0.23*	*0.22*	*0.19*	*0.17*

Table 3.159: PM_{10} mass, total carbon (TC), crustal element, and secondary particulates (μg/m^3) in winter season

Site ID	PM_{10}	TC	TC/PM_{10}	Crustal Elements	Crustal Elements / PM_{10}	Secondary particulates	Secondary particulates / PM_{10}
ITO	353.54	110.19	0.31	14.84	0.04	68.26	0.19
RKP	217.42	58.03	0.27	13.61	0.06	36.85	0.17
BHG	269.99	75.44	0.28	17.14	0.06	46.37	0.17
SHD	244.80	74.34	0.30	9.01	0.04	66.96	0.27
MYR	322.62	105.00	0.33	23.95	0.07	58.63	0.18
JKP	333.41	113.81	0.34	19.79	0.06	79.96	0.24
CHN	231.73	54.02	0.23	23.51	0.10	55.55	0.24
PNP	240.08	85.42	0.36	10.96	0.05	57.03	0.24
NYR	405.25	156.59	0.39	31.62	0.08	61.80	0.15
WZP	440.77	146.08	0.33	23.00	0.05	97.55	0.22
RHN	372.11	162.29	0.44	25.43	0.07	87.22	0.23
GHZ1	226.54	63.62	0.28	12.53	0.06	48.00	0.21
GHZ2	387.56	120.36	0.31	29.75	0.08	55.90	0.14
NOI1	201.29	64.21	0.32	22.23	0.11	37.17	0.18
NOI2	435.58	137.90	0.32	32.94	0.08	111.53	0.26
GRG1	266.87	56.94	0.21	21.82	0.08	90.44	0.34
GRG2	381.05	113.73	0.30	28.99	0.08	63.60	0.17
FBD1	305.29	71.28	0.23	15.25	0.05	82.92	0.27
FBD2	329.55	84.02	0.25	24.38	0.07	78.87	0.24
Mean	*313.97*	*97.54*	*0.31*	*21.09*	*0.07*	*67.61*	*0.22*
S.D.	*76.61*	*35.23*	*0.05*	*7.10*	*0.02*	*20.38*	*0.05*
Max	*440.77*	*162.29*	*0.44*	*32.94*	*0.11*	*111.53*	*0.34*
Min	*201.29*	*54.02*	*0.21*	*9.01*	*0.04*	*36.85*	*0.14*
CV	*0.24*	*0.36*	*0.18*	*0.34*	*0.28*	*0.30*	*0.23*

Table 3.160: $PM_{2.5}$ mass, total carbon (TC), crustal element, and secondary particulates ($\mu g/m^3$) in winter season

Site ID	$PM_{2.5}$	TC	TC/PM_{10}	Crustal Elements	Crustal Elements / PM_{10}	Secondary particulates	Secondary particulates / PM_{10}
ITO	191.17	81.80	0.43	3.63	0.02	45.45	0.24
RKP	112.40	47.92	0.43	0.98	0.01	21.81	0.19
BHG	146.28	35.91	0.25	4.07	0.03	32.25	0.22
SHD	137.94	51.11	0.37	3.16	0.02	34.79	0.25
MYR	169.93	74.48	0.44	3.27	0.02	35.78	0.21
JKP	165.88	46.78	0.28	4.13	0.02	37.42	0.23
CHN	131.91	38.75	0.29	3.92	0.03	33.08	0.25
PNP	153.56	64.62	0.42	2.79	0.02	26.36	0.17
NYR	222.56	67.73	0.30	7.73	0.03	50.56	0.23
WZP	254.33	96.01	0.38	1.38	0.01	30.08	0.12
RHN	230.53	62.55	0.27	10.11	0.04	77.12	0.33
GHZ1	111.27	41.99	0.38	1.65	0.01	27.21	0.24
GHZ2	191.71	75.08	0.39	2.79	0.01	52.51	0.27
NOI1	92.03	32.68	0.36	1.21	0.01	30.02	0.33
NOI2	231.97	93.82	0.40	4.28	0.02	65.70	0.28
GRG1	129.57	32.33	0.25	5.81	0.04	58.79	0.45
GRG2	169.20	65.43	0.39	5.71	0.03	46.68	0.28
FBD1	174.78	49.60	0.28	6.38	0.04	62.30	0.36
FBD2	168.97	61.74	0.37	7.18	0.04	53.49	0.32
Mean	167.68	58.97	0.35	4.22	0.02	43.23	0.26
S.D.	44.74	19.48	0.06	2.43	0.01	15.37	0.07
Max	254.33	96.01	0.44	10.11	0.04	77.12	0.45
Min	92.03	32.33	0.25	0.98	0.01	21.81	0.12
CV	0.27	0.33	0.18	0.58	0.48	0.36	0.29

3.3 Summary of observations

- Mass concentration of PM10 across Delhi NCR for summer season at 20 locations varied from 131 to 262 μg/m³ with an average concentration of 188 ± 37 μg/m³. Similarly, overall average mass concentration of PM_{10} in winter season was found to be 314 ± 77 μg/m³ (201 – 441 μg/m³).

- Average concentration of $PM_{2.5}$ at 20 locations varied from 65 to 130 μg/m³ with overall average of 90 ± 17 μg/m³ in summer season. In winter season, $PM_{2.5}$ concentrations at various sites varied from 92 to 254 μg/m³ with 168 ± 45 μg/m³ as the overall average concentration.

- Average chemical composition of PM_{10} samples
  - Summer: Carbon fraction was found to be major component (~26%) followed by secondary particulates (~12%), other ions (11%) and crustal elements (~9%).
  - Winter: Carbon fraction is major component (~34%), followed by secondary particulates (~21%), other ions (10%), and crustal elements (~7%).

- Average chemical composition of $PM_{2.5}$ samples-
  - Summer: Carbon fraction is major component (~30%), followed by secondary particulates (~18%), other ions (9%), and crustal elements (~3%).
  - Winter: Carbon fraction is major component (~35%), followed by secondary particulates (~24%), other ions (9%), and crustal elements (~3%).

- The chemical composition of monitoring locations in Delhi and NCR towns was found to be similar for PM_{10} as well as $PM_{2.5}$ in respective seasons.

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Chapter 4. Receptor Modelling

4.1 Introduction

The fundamental principle of receptor models is that mass conservation can be assumed and a mass balance analysis can be used to identify and apportion sources of airborne particulate matter in the atmosphere. The approach of obtaining a data set for receptor modelling is to determine a large number of chemical constituents such as elemental concentrations in a number of samples. Receptor models use monitored pollutant concentration and some information about the chemical composition of local air pollution sources (profiles) to estimate the relative influence of these sources on pollutant concentrations at any single monitoring location. Receptor models are retrospective, that is, they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored.

4.2 CMB Model 8.2: Methodology and results

4.2.1 A mass balance equation can be written to account for all m chemical species in the n samples as contributions from p independent sources:

$$C_i = \sum_j m_j x_{ij} a_{ij}$$

Where, C_i is Concentration of species i measured at a receptor site, x_{ij} is the i^{th} elemental concentration measured in the j^{th} sample, and m_j is the airborne mass concentration of material from the j^{th} source contributing to the j^{th} sample. The term a_{ij} is included as an adjustment for any gain or loss of species i between the source and receptor. The term is assumed to be unity for most of the chemical species. (EPA Website: https://www3.epa.gov/scram001/receptor_cmb.htm)

CMB model assumptions are:

- Compositions of source emissions are constant over the period of ambient and source sampling;
- Chemical species do not react with each other (i.e., they add linearly);
- All sources with a potential for contributing to the receptor have been identified and have had their emissions characterized;
- The number of sources or source categories is less than or equal to the number of species;
- The source profiles are linearly independent of each other; and
- Measurement uncertainties are random, uncorrelated, and normally distributed.

Following approach was used for CMB modelling:

- Identification of the contributing sources to the monitoring sites.
- Selection of chemical species to be included in the calculation. Following species were analysed from the PM_{10} and $PM_{2.5}$ samples collected at respective sites in summer and winter seasons.
  - Carbon fractions based on temperature (Organic Carbon and Elemental Carbon) using Thermal Optical Reflectance (TOR) Carbon Analyzer,
  - Ions (Anions- fluoride, chloride, bromide, sulphate, nitrate and Cations sodium, ammonium, potassium, magnesium and calcium) using Ion Chromatography
  - Elements (Al, Si, K, Ca, Ti, V, Fe, Co, Ni, Cu, Zn, As, Se, Zr, Mo, Pd, Cd, Ce and Pb) using Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF)
- Selection of representative source profiles, based on the source activities around the sites and considering sources that will impact the receptor locations based on wind direction, with the fraction of each of the chemical species and uncertainty. Wind direction trajectories site specific during monitoring period were taken from

website of Air Resource Laboratory, HYSPLIT, Fire data is collected during monitoring period from NASA, Earthdata, Fire Information for Resource Management Systems (FIRMS. This data was collected to assess magnitude and spread of fire activity at the upwind direction.

- A few study-specific profiles were developed under this project and used. Details of source profiles selected are as follows:
  - Non-vehicular sources:

    A) Site specific profiles developed under this study are presented in Annexure-F: Non-Vehicular Source Profiles]:
    - Refuse burning
    - Agri-waste (sugarcane) combustion
    - Agri-waste (rice) combustion
    - Agri-waste (wheat) combustion
    - Road and soil dust (composite of Delhi and NCR).

    B) Profiles developed by IIT-Bombay (CPCB, 2009, Stationary Source Profiling report)
-
  - Vehicular sources:

    A) New composite profiles of different fuel types developed for newer technology vehicles (post 2005) under this study Annexure-G: Source Profile.

    B) Earlier profiles of pre-2005 vehicle technology. (CPCB, 2009, Vehicle Source Profiling report)

- Estimation of the both ambient concentrations and uncertainty of selected chemical species from the particulate matter collected at respective sites.
- Solution of the chemical mass balance equations was obtained through CMB-8.2 receptor model by using the chemical composition results of 24 hour daily samples collected at all sites and source profiles of applicable sources at respective sites as an input.
- Contributing sources were identified by averaging the contribution from sources observed based on daily samples across the monitoring period.

4.2.2 Source contribution estimates (SCE) are the main output of the CMB model. The sum of these concentrations approximates the total mass concentrations. When the SCE is less than its standard error, the source contribution is undetectable. The reduced chi square (χ^2), R^2, and percent mass are goodness of fit measures for the least-squares calculation. The χ^2 is the weighted sum of squares of the differences between calculated and measured fitting species concentrations divided by the effective variance and the degrees of freedom. A value of less than one indicates a very good fit to the data. Values greater than 4 indicate that one or more of the fitting species concentrations are not well-explained by the source contribution estimates. χ^2 values less than 4 were considered acceptable. R^2 is determined by the linear regression of the measured versus model-calculated values for the fitting species. R^2 ranges from 0 to 1. The closer the value is to 1.0, the better the SCEs explain the measured concentrations. When R^2 is less than 0.8, the SCEs do not explain the observations very well with the given source profiles. Value of R^2 greater than 0.8 was considered acceptable. Percent mass is the percent ratio of the sum of model-calculated SCEs to the measured mass concentration. Values ranging from 80 to 120% were considered acceptable.

4.3 Results of receptor modelling for summer and winter seasons:

Daily average concentrations of different species at sites and source profiles were used as an input to the receptor model. Results obtained in terms of source contribution estimates for individual daily samples for a site in a season were averaged to calculate source contribution to that site for that season.

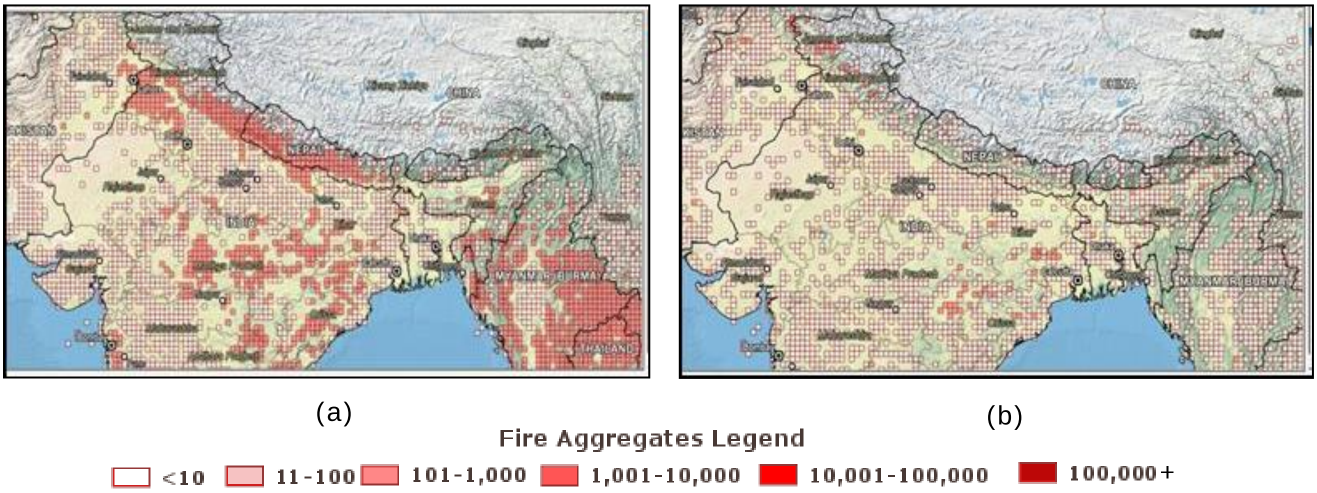
Site-wise wind direction trajectories and fire data for the monitoring period at respective sites for two seasons were utilized to assess magnitude and spread of fire activity at the upwind direction. The receptor modelling results for the sites are presented in following sections:

4.3.1 Site 1:- ITO Square

Season	Monitoring Period
Summer	13 April to 26 April 2016
Winter	24-Dec-16 to 06-Jan-17

(a) (b)

Figure 4.1: Wind direction trajectories during monitoring period (a) summer season and (b) winter season



(a) (b)

Figure 4.2: Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at ITO Square is presented in Figure 4.1 (a) and (b) for summer and winter seasons, respectively. As can be seen, wind is predominantly flowing from north-west direction and on some days from west in summer and winter seasons. In winters, there was a reversal of direction on a few days. The incoming air will carry pollutants from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Figure 4.2 (a) and (b) for summer and winter seasons, respectively. A large number of live fires were observed during summer season, especially in the directions of north-west and west. Winter season also show live fires in north-west and west direction. Thus the in-coming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

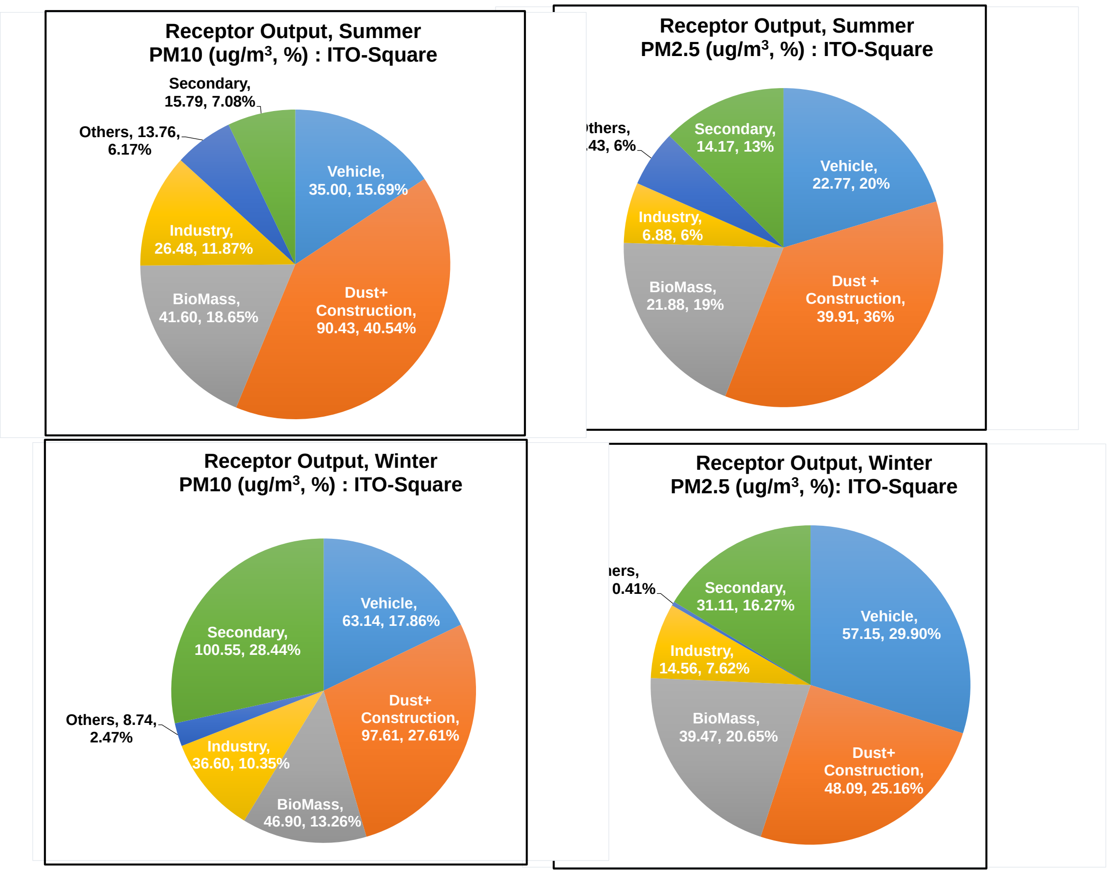


Figure 4.3: Receptor Output Summer and Winter: PM10 and PM2.5 at ITO Square

At ITO Square, which is the monitoring location alongside a major road and traffic junction in the city, contribution from dust and construction was found to be highest in both PM_{10} (41%) and $PM_{2.5}$ (36%) in summer and winter and the contribution was on lower side with 28% and 25% in PM_{10} and $PM_{2.5}$, respectively. This may be attributed to the heavy traffic flow and subsequent entrainment of road dust in the proximity of the site. Average concentration from dust and construction source was 90±22 μg/m³ with a variation in the range from 66 μg/m³ to 125 μg/m³ in summer PM_{10}. Variation in dust and construction in winter PM_{10} was higher with the average concentration 98±67 μg/m³.

Vehicular contribution was 16% (35±18 μg/m³) of PM_{10} and 20% (22±12 μg/m³) of $PM_{2.5}$ in summer and in winter contribution from $PM_{2.5}$ was found to be on higher side 30% (57±26 μg/m³), whereas it was 18% (63±34 μg/m³) in PM_{10}.

Biomass burning contributed to 19% (41±26 μg/m³) and 13% (47±11 μg/m³) of PM_{10} in summer and winter seasons, respectively, whereas, 20% (22±9 μg/m³) and 21% (39±26 μg/m³) of $PM_{2.5}$ was contributed by biomass burning in summer and winter seasons, respectively. Variation in daily contribution of biomass burning to $PM_{2.5}$ was higher in winter season, which can be attributed to variability in contribution of local sources.

contribution from industry was found to be 12% (26±19 μg/m³) of PM_{10} and 6% (7±3 μg/m³) of $PM_{2.5}$ in summer, while 10% (37±26 μg/m³) of PM_{10} and 8% (15±2 μg/m³) of $PM_{2.5}$ in winter.

The secondary pollutants, contribution was found to be more in winter with 28% (101±18 µg/m^3) of PM_{10} and 16% (31±4 µg/m^3) of $PM_{2.5}$, while in summer it was 13% (14± 4 µg/m^3) in $PM_{2.5}$ and 7% (16±4 µg/m^3) in PM10.

The contribution from other sources (refuse burning, DG sets, and so on) was found to be similar in summer, that is, 6% of both PM_{10} and $PM_{2.5}$. Other sources contributed 3% of PM_{10} and in case of $PM_{2.5}$, it was found to be less than 1% in winters.

4.3.2 Site 2:-R K Puram

Season	Monitoring Period
Summer	13-Apr-16 to 24-Apr-16 & 01-Jul-16 to 10-Jul-16
Winter	22-Nov-16 to 07-Dec-16 & 28-Feb-17 to 07-Mar-17

Figure 4.4: Wind direction trajectories during monitoring period (a) summer season and (b) winter season

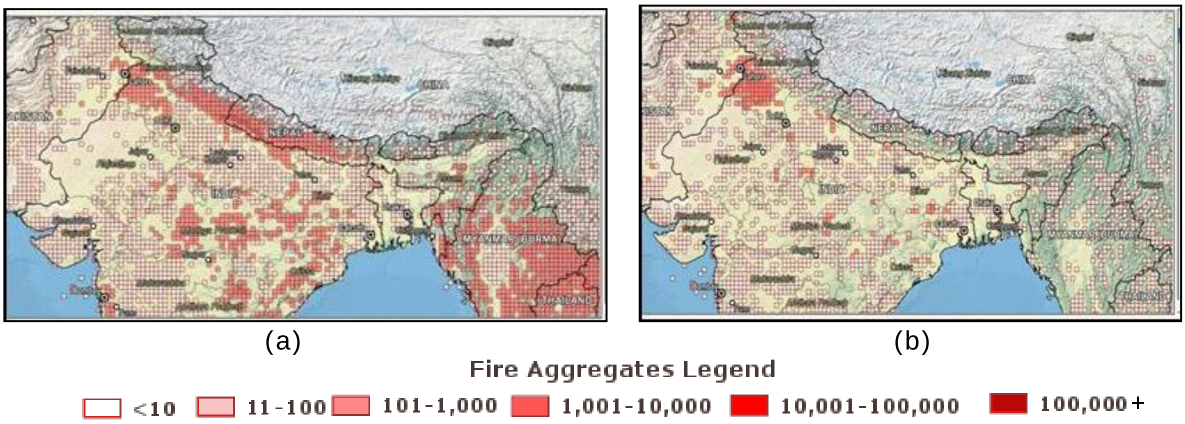


Figure 4.5: Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at R K Puram is presented in Fig. 4.4 (a) and (b) for summer and winter, respectively. Wind is predominantly flowing from north-west and west in summer and winter. During winter, there was reversal of direction on a few days. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.5 (a) and (b) for the summer and winter, respectively. A large number of live fires were observed during summer and winter season, especially in north-west direction. Thus the in-coming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

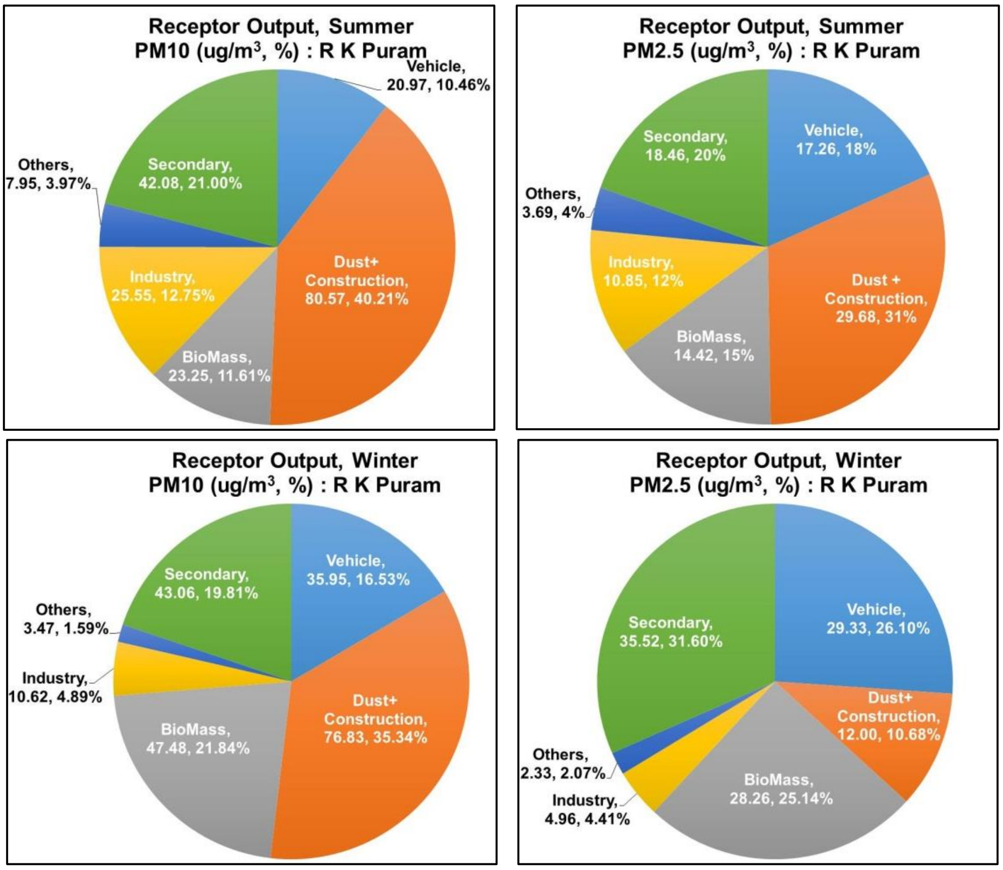


Figure 4.6: Receptor Output Summer and winter: PM10 and PM2.5 at R K Puram

R K Puram is a residential site at southern part of Delhi, which was contributed from dust and construction majorly at 40% in PM$_{10}$ and 31% in PM$_{2.5}$ in summer while in winter, the contribution was on slightly lower side with 35% in PM$_{10}$ and 11% in PM$_{2.5}$, respectively. Average concentration from dust and construction source was $81\pm25\ \mu g/m^3$ with a variation in the range from $66\ \mu g/m^3$ to $125\ \mu g/m^3$ in summer PM$_{10}$. Variation in dust and construction in winter PM$_{10}$ was higher with the average concentration $98\pm67\ \mu g/m^3$.

Vehicles contribution was 16% ($35\pm18\ \mu g/m^3$) of PM$_{10}$ and 20% ($22\pm12\ \mu g/m^3$) of PM$_{2.5}$ in summer and in winter contribution from PM$_{2.5}$ was found to be on higher side 30% ($57\pm26\ \mu g/m^3$), whereas it was 18% ($63\pm34\ \mu g/m^3$) in PM$_{10}$.

Biomass burning contributed to 12% ($23\pm10\ \mu g/m^3$) and 22% ($47\pm13\ \mu g/m^3$) of PM$_{10}$ in summer and winter respectively, whereas, 15% ($14\pm9\ \mu g/m^3$) and 25% ($28\pm9\ \mu g/m^3$) of PM$_{2.5}$ was contributed by biomass burning in summer and winter, respectively. Variation in daily contribution of biomass burning to PM$_{2.5}$ was higher in winter season, which can be attributed to variability in contribution of local sources.

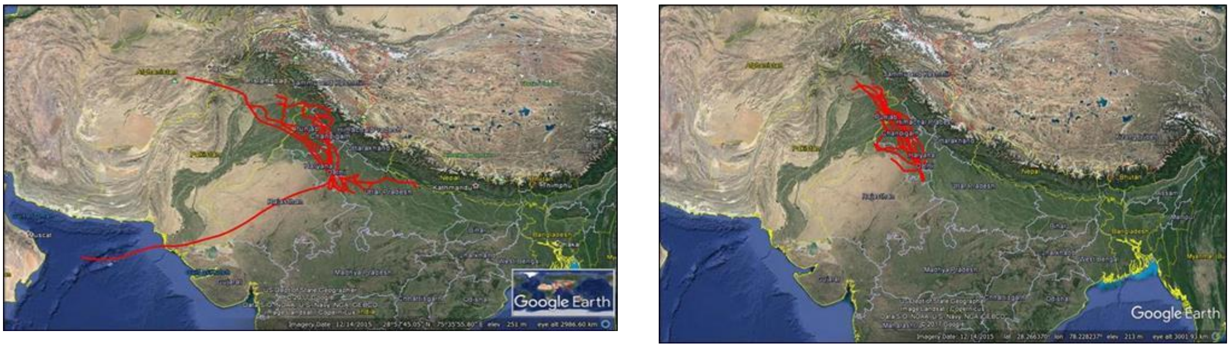
contribution from industry was found to be 12% ($26\pm19\ \mu g/m^3$) of PM$_{10}$ and 6% ($7\pm3\ \mu g/m^3$) of PM$_{2.5}$ in summer while 10% ($37\pm26\ \mu g/m^3$) of PM$_{10}$ and 8% ($15\pm1\ \mu g/m^3$) of PM$_{2.5}$ in winter.

The secondary pollutants contribution was found to be more in winter with 28% ($101\pm26\ \mu g/m^3$) of PM$_{10}$ and 16% ($31\pm26\ \mu g/m^3$) of PM$_{2.5}$ while in summer it was 13% ($14\pm26\ \mu g/m^3$) in PM$_{2.5}$ and 7% ($16\pm26\ \mu g/m^3$) in PM$_{10}$.

The contribution from other sources (refuse burning, DG sets, etc.) was found to be similar in summer, that is, 6% of both PM$_{10}$ and PM$_{2.5}$. Other sources contributed 3% of PM$_{10}$ and in case of PM$_{2.5}$ it was found to be less than 1% in winter.

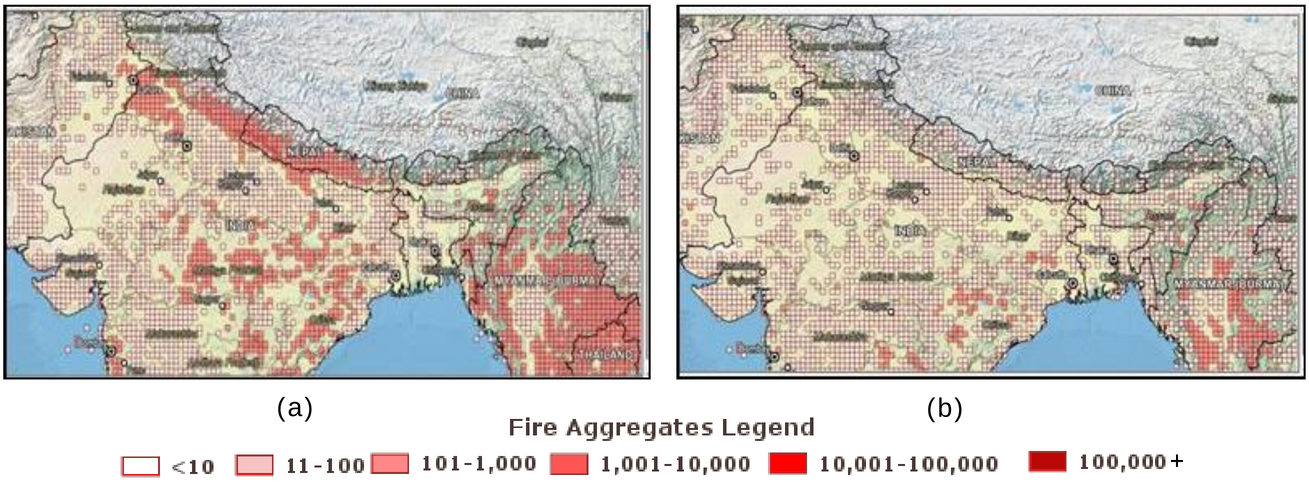
4.3.3 Site 3:- Bahadurgarh

Season	Monitoring Period
Summer	13-Apr-16 to 07-May-16
Winter	09-Feb-17 to 20-Feb-17



(a) (b)

Figure 4.7: Wind direction trajectories during monitoring period (a) summer season and (b) winter season



(a) (b)

Figure 4.8: Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Bahadurgarh is presented in Fig. 4.7 (a) and (b) for summer and winter months, respectively. Wind is predominantly flowing from north-west direction in summer and winter. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.8 (a) and (b) for summer and winter, respectively. A large number of live fires were observed during summer season, especially in the north-west direction and in winter number of fire aggregates were lesser as compared to summer monitoring period. Thus the in-coming wind to Delhi NCR is expected to carry pollutants from biomass burning, dust and tall stacks.

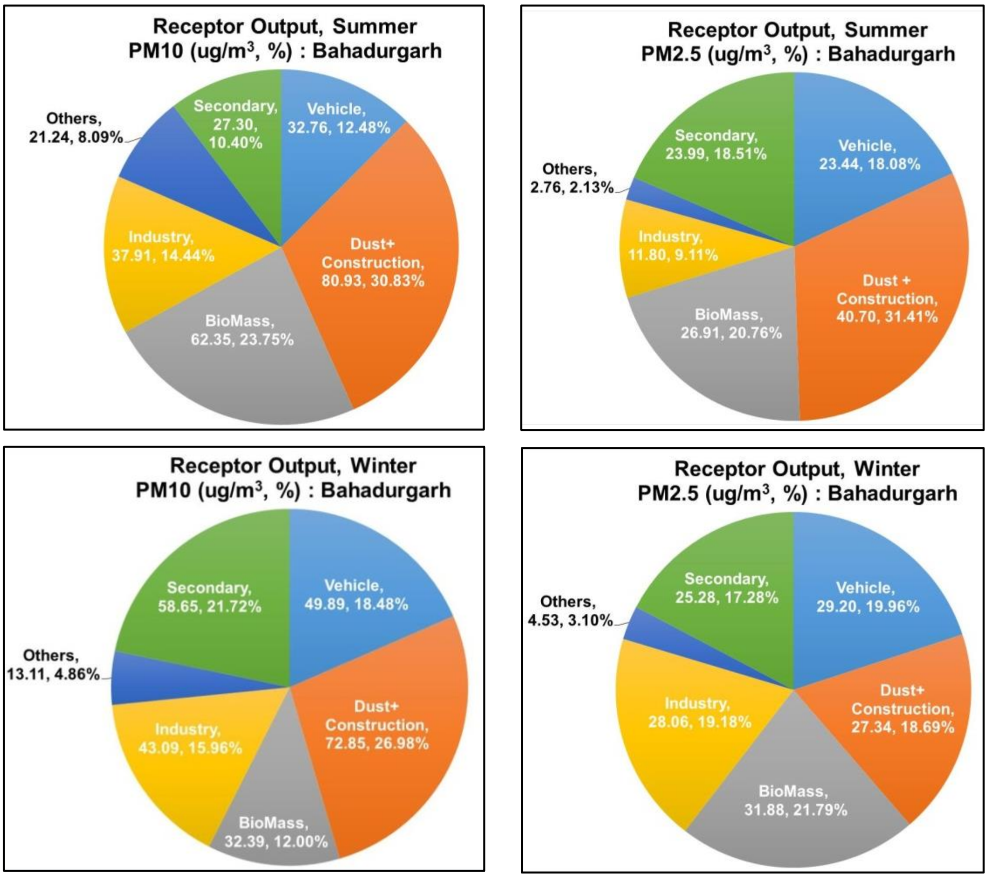


Figure 4.9: Receptor output summer and winter: PM_{10} and $PM_{2.5}$ at Bahadurgarh

Bahadurgarh is located in the Jhajjar district in the state of Haryana and is situated in the eastern part of the state, and towards the northern part of Delhi. Bahadurgarh Industrial Area in NCR is a large Industrial areas . Being a village location, a lot of agricultural activities can be seen along with instances of garbage burning can be easily noted.

In summer season in Bahadurgarh, dust and construction source showed highest percentage of contribution (31%), followed by biomass burning in both PM_{10} and $PM_{2.5}$. It showed similar a contribution, that is, 31% of both PM_{10} and $PM_{2.5}$. This can be attributed to some extent to the construction activities going on around the monitoring site. Biomass burning contributed 24% of PM_{10} and 21% of $PM_{2.5}$. Contribution from industry was somewhat higher in PM_{10} (14%) of PM_{10} and 9% of $PM_{2.5}$. The secondary pollutant contributed 10% and 19% of PM_{10} and $PM_{2.5}$, respectively. The vehicle contributed 13% of PM_{10} and 18% of $PM_{2.5}$. The other sources contributed 8% of PM_{10} and less in$PM_{2.5}$, that is, 2%.

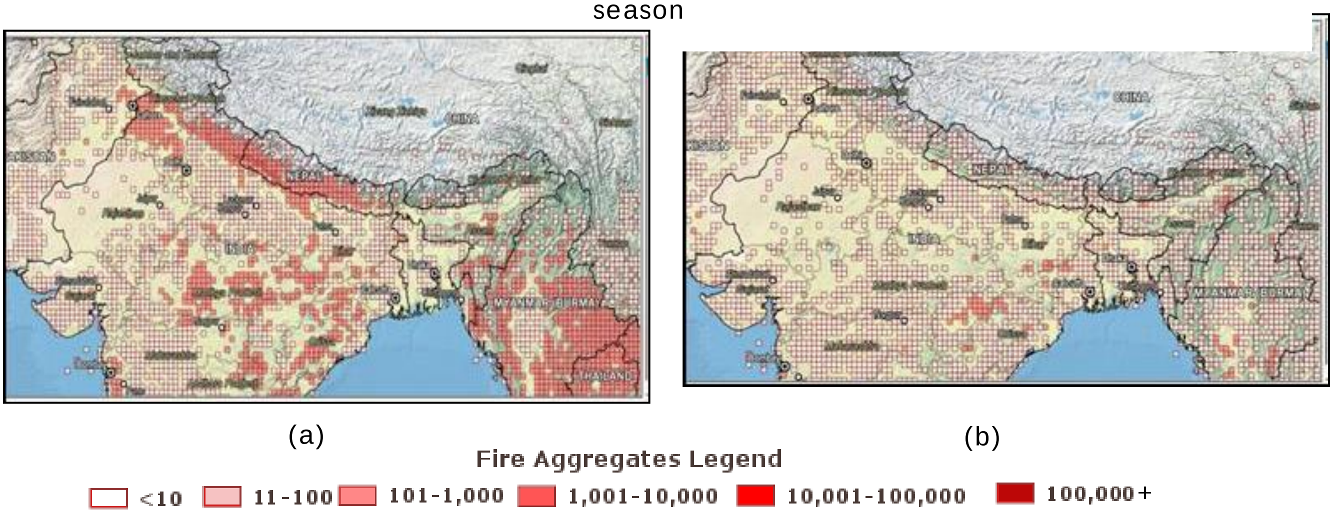
In winter season, Biomass burning was found to be significant contributor in $PM_{2.5}$ and in case of $PM_{10,}$ dust and construction was found to be highest contributor. Biomass burning contributed 12% of PM_{10} and 22% of $PM_{2.5}$. This may be due to residential as well as agricultural activities around the monitoring site. Dust and construction showed 27% of PM_{10} and 19 % of $PM_{2.5}$. Higher contribution of dust may be attributed to the open space around the site. Vehicles contributed 19% of PM_{10} and 20% of $PM_{2.5}$. Contribution from industry was found to be 16% and 19% of PM_{10} and $PM_{2.5}$, respectively. The contribution from others sources, including refuse burning and DG sets was found to be 5% and 3% of PM_{10} and $PM_{2.5}$, respectively. The secondary pollutant contributed to 22% of PM_{10} and 17% of $PM_{2.5}$.

4.3.4 Site 4:- Shahdara

Season	Monitoring Period
Summer	22-Apr-16 to 04-May-16
Winter	14-Jan-17 to 05-Feb-17

(a) (b)

Figure 4.10: Wind direction trajectories during monitoring period (a) summer Season and (b) winter season



(a) (b)

Figure 4.11: Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Shahdara is presented in Fig. 4.10 (a) and (b) for summer and winter seasons, respectively. Wind was predominantly flowing from north-west direction in summer and in winter, there were a few days when the wind was flowing from south-east. The incoming air will carry pollutants from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.11 (a) and (b) for summer and winter respectively. Large number of live fires were observed during summer season especially in North-west direction and in winter number of fire aggregates were lesser as compared to summer monitoring period. Thus the in-coming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

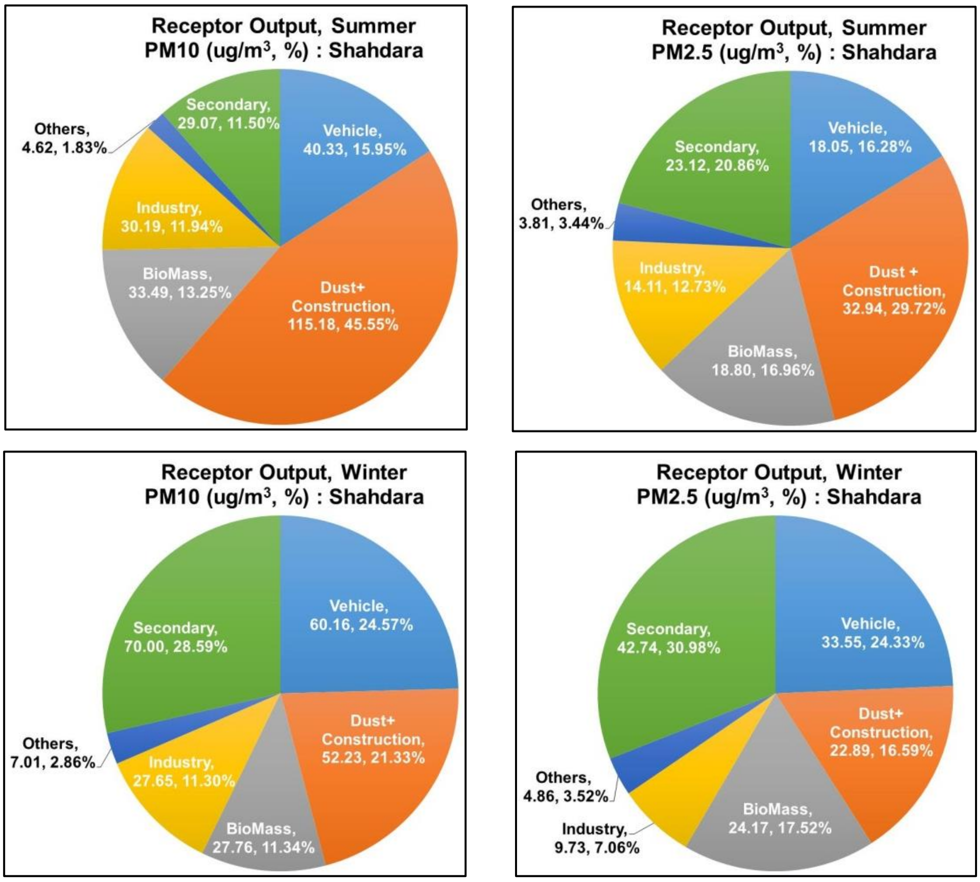


Figure 4.12: Receptor output summer and winter: PM_{10} and $PM_{2.5}$ at Shahdara

Shahdara is situated at the northeastern part of Delhi. Shahdara is mainly a residential area which is part of old Delhi. Being in old Delhi, there are many minor roads which leads to traffic congestion.

In summer season at Shahdara, dust and construction activities was highest contributor to both PM_{10} and $PM_{2.5}$. Dust and construction was found to be 46% (115 ± 31 μg/m^3) and 30% (33 ± 15 μg/m^3), which may be attributed to construction activities of Metro and over bridge going on during monitoring period near the site and also from the dust coming from upwind direction. Also, there were a number of shops related to tiles and ceramic which activities of ceramic & tiles cutting adds to dust. In winter season, Dust and construction contributed 21% (52 ± 13 μg/m^3) of PM_{10} and 17% (23 ± 18 μg/m^3) of $PM_{2.5}$.

Being part of old Delhi, the site is located in a densely populated area and features vehicle movement on nearby roads. Also, the ISBT state transport center was near site location. As a result, in summer season, vehicular contribution was found to be 16% (40 ± 16 μg/m^3) and 17% (18 ±11 μg/m^3) in PM_{10} and $PM_{2.5}$, respectively, whereas in the winter season, vehicular contribution was 25% (60 ± 18 μg/m^3) of PM_{10} and 24% (34 ± 10 μg/m^3) of $PM_{2.5}$.

In Summer season, secondary source contributed 12% (29 ± 3 μg/m^3) of PM_{10} and 21% (23 ± 7 μg/m^3) of $PM_{2.5}$, whereas during winter season, it was found to be highest, that is, 29% (70 ± 8 μg/m^3) of PM_{10} and 31% (43 ± 10 μg/m^3) of $PM_{2.5}$.

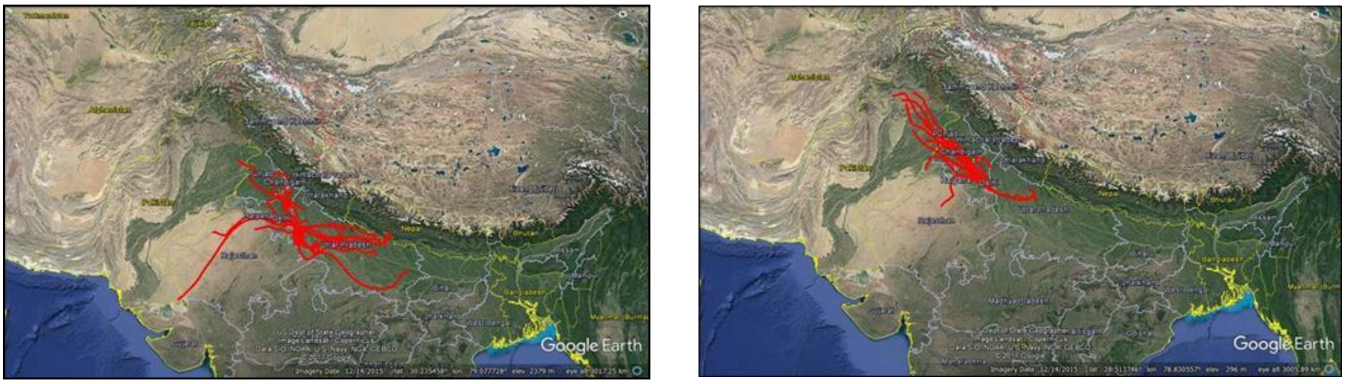
Biomass burning combustion contribution was 17% in $PM_{2.5}$ and 13% of PM_{10}, whereas it was 11% of PM_{10} and 18% of $PM_{2.5}$ in winter season.

In summer season, industries were found to be contributing 12% of PM_{10} and 13% of $PM_{2.5}$, whereas in winter season, industries contributed to 11% (28 ± 13 $\mu g/m^3$) of PM_{10} and 7% (10 ± 8 $\mu g/m^3$) of $PM_{2.5}$.

In summer season, other sources contributed 2% in PM_{10} and 3% in $PM_{2.5}$ and in winter season, other sources were contributing 3% and 4% to PM_{10} and $PM_{2.5}$, respectively.

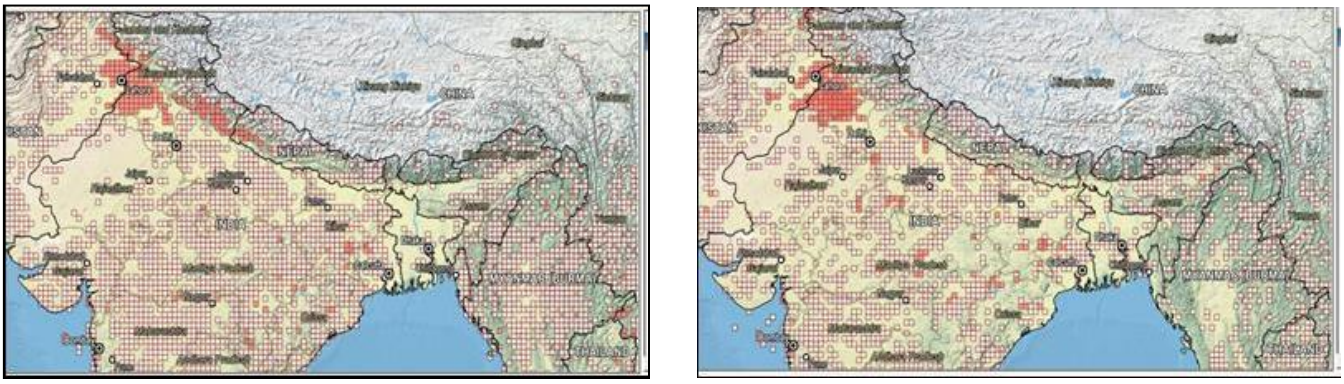
4.3.5 Site 5:- Mayur Vihar

Season	Monitoring Period
Summer	30-Apr-16 to 13-May-16 & 03-Jul-16 to 09-Jul-16
Winter	22-Nov-16 to 05-Dec-16



(a) (b)

Figure 4.13: Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Fire Aggregates Legend

☐ <10 ▨ 11-100 ▨ 101-1,000 ▨ 1,001-10,000 🟥 10,001-100,000 🟥 100,000+

Figure 4.14: Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Mayur Vihar is presented in Fig. 4.13 (a) and (b) for summer and winter respectively. Wind is predominantly flowing from north-west and south-east direction in summer and in winter from north-west direction. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.14 (a) and (b) for summer and winter, respectively. A large number of live fires were observed during summer and winter seasons, especially in the north-west direction. Thus the incoming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

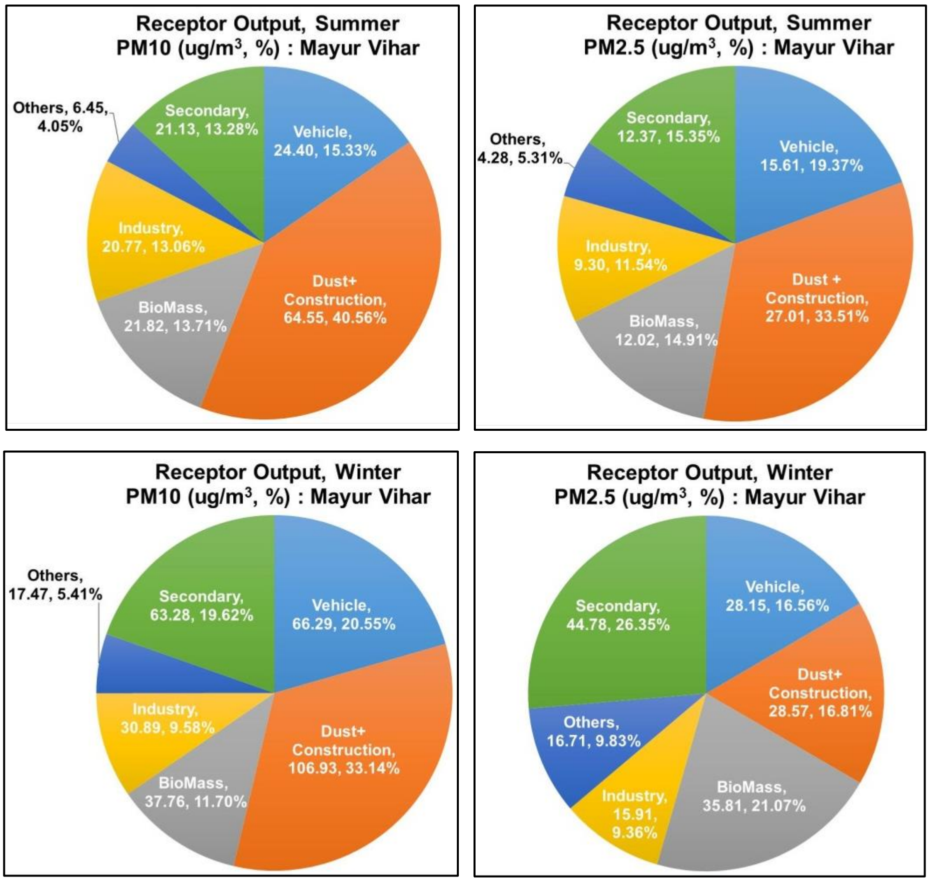


Figure 4.15: Receptor output summer and winter: PM$_{10}$ and PM$_{2.5}$ at Mayur Vihar

Mayur Vihar is a residential area in East Delhi, close to the Noida–Delhi border and is situated just across the Yamuna River.

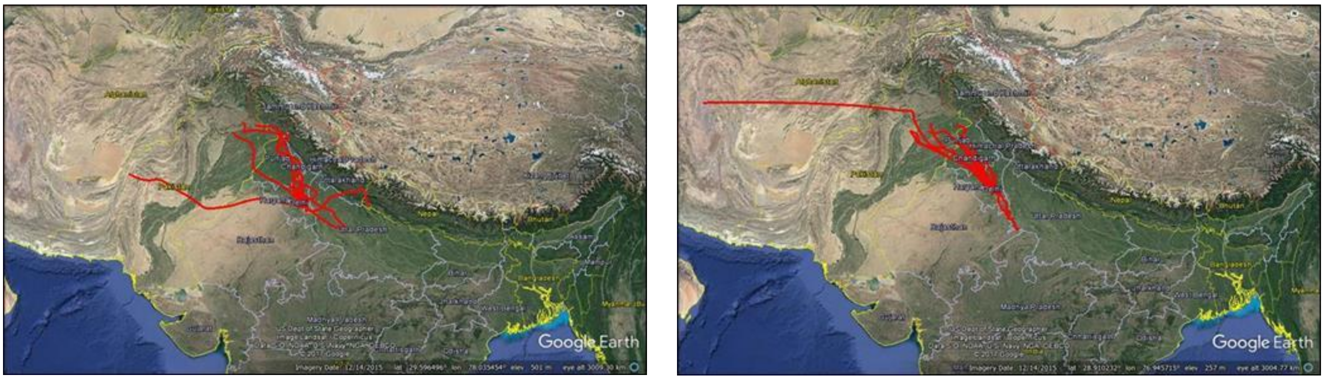
In summer season, dust and construction showed highest contribution, that is, 41% (65 ± 16 $\mu g/m^3$) of PM$_{10}$ and 34% (27 ± 9 $\mu g/m^3$) of PM$_{2.5}$. Dust and construction were highest contributor in PM$_{10}$, that is, 33% (107 ± 53 $\mu g/m^3$). This may be attributed to ongoing Metro work near site.
Vehicles contributed 15% (24 ± 2 $\mu g/m^3$) of PM$_{10}$ and 19% (16 ± 8 $\mu g/m^3$) of PM$_{2.5}$ In summer season. Whereas, in winter season, vehicles contributed 21% (66 ± 22 $\mu g/m^3$) of PM$_{10}$ and 17% (29 ± 17 $\mu g/m^3$) of PM$_{2.5}$.
The contribution from biomass burning combustion in summer season was 14% (22 ± 14 $\mu g/m^3$) of PM10 and 15% (12 ± 5 $\mu g/m^3$) of PM2.5. Similarly, in winter it was found to be PM2.5 i.e. 21% (36 ± 16 $\mu g/m^3$) while PM10 was found to be 12% (38 ± 12 $\mu g/m^3$).

Being a residential area, concentration from the industries was very less. Industries contributed 13% (21 ± 11 $\mu g/m^3$) of PM$_{10}$ and 12% (9 ± 3 $\mu g/m^3$) of PM$_{2.5}$ in summer. In winter, contribution from industries was 10% (31 ± 20 $\mu g/m^3$) of PM$_{10}$ and 9% (17 ± 15 $\mu g/m^3$).

Other sources contributed 4% of PM$_{10}$ and 5% of PM$_{2.5}$.The secondary pollutant contributed 13% of PM$_{10}$ and 15% of PM$_{2.5}$.

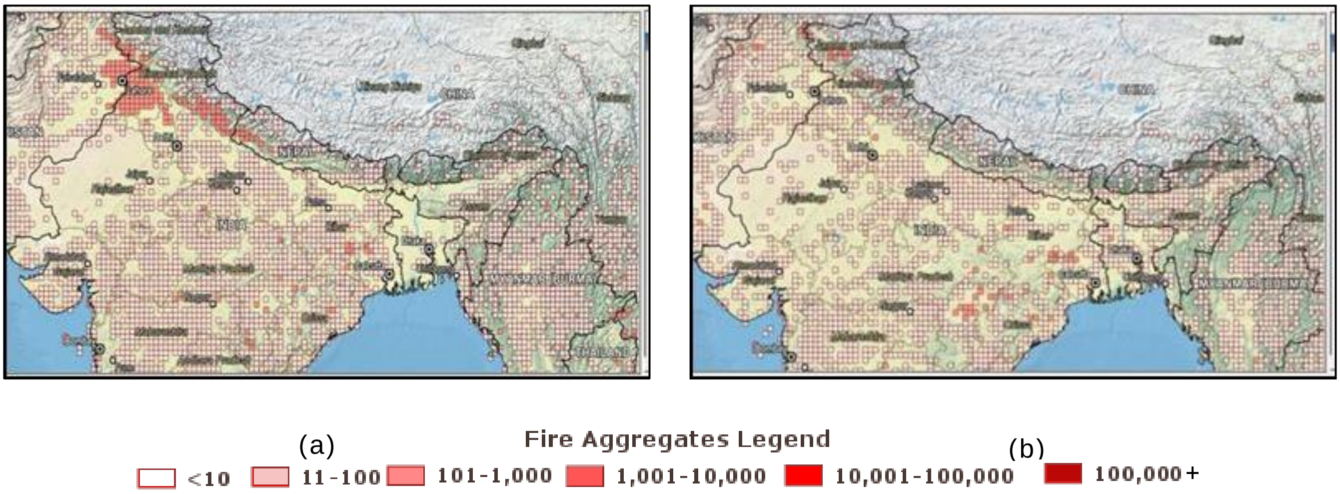
4.3.6 Site 6 : Janakpuri

Season	Monitoring Period
Summer	11-May-16 to 19-May-16
Winter	08-Dec-16 to 22-Dec-16



(a) (b)

Figure 4.16: Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.17 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Janakpuri is presented in Fig. 4.16 (a) and (b) for summer and winter Seasons, respectively. Wind was predominantly flowing from north-west direction in summer and winter Seasons. The incoming air will carry pollutants from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.17 (a) and (b) for summer and winter respectively. A large number of live fires were observed during summer season, especially in north-west direction and in winter number of fire aggregates were lesser as compared to summer monitoring period. Thus the incoming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

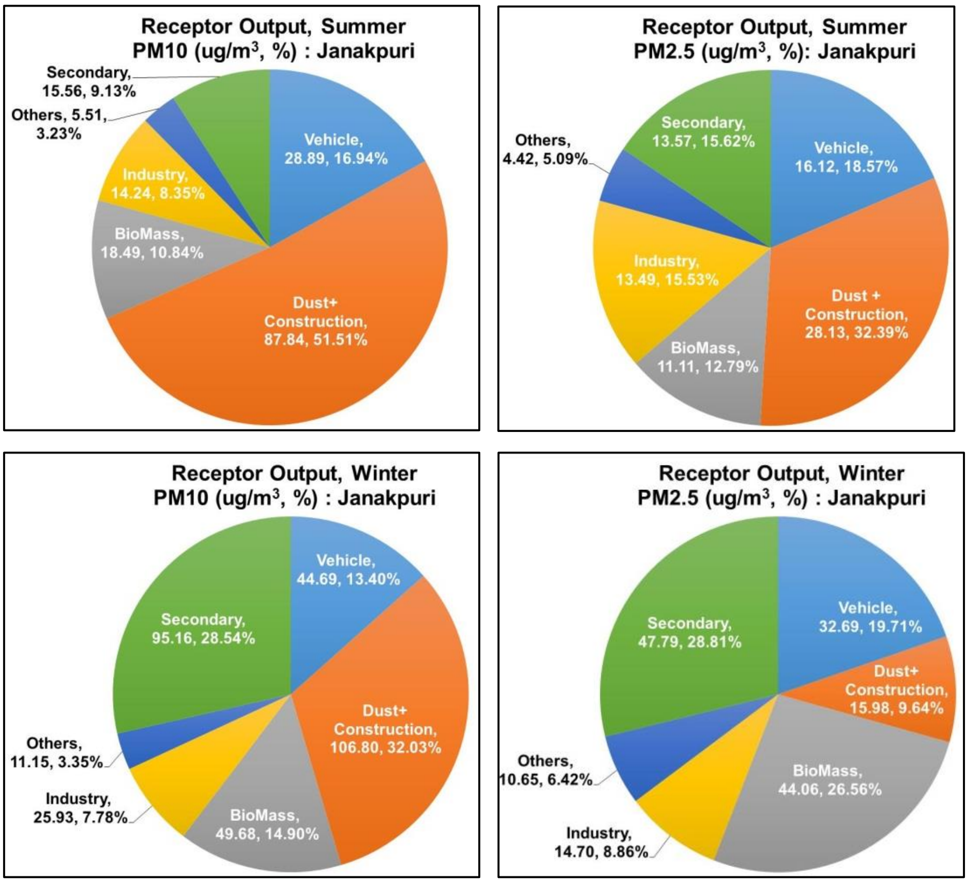


Figure 4.18 : Receptor output summer and winter: PM$_{10}$ and PM$_{2.5}$ at Janakpuri

Janakpuri is a residential neighborhood in the West Delhi district of National Capital Territory of Delhi. It is located near the Delhi Cantonment area.

In summer season, the dust and construction was found to be the highest contributor of both PM$_{10}$ and PM$_{2.5}$. It showed 52% (88 ± 18 μg/m^3) of PM$_{10}$ and 32% (28 ± 14 μg/m^3) of PM$_{2.5}$. In winter season, dust and construction was 32% (107 ± 86 μg/m^3) in PM $_{10}$, while it was 10% (16 ± 8 μg/m^3) in PM$_{2.5}$.

Vehicles contributed 17% (29 ± 8 μg/m^3) of PM$_{10}$ and 19% (16 ± 6 μg/m^3) of PM$_{2.5}$ in summer season, whereas in in winters it showed 13% (45 ± 11 μg/m^3) of PM$_{10}$ and 20% (33 ± 10 μg/m^3) of PM$_{2.5}$.

Biomass burning contributed 11% in PM$_{10}$ concentration of 19 ± 7 μg/m3 in PM$_{10}$ and 13% (11 ± 7 μg/m3) in PM$_{2.5}$. In winter season, it increased to 27% (44 ± 19 μg/m3) of PM$_{2.5}$ and 15% (50 ± 19 μg/m3) of PM$_{10}$.

In summer season, industry contribution was found to be 8% in PM$_{10}$, while, in PM$_{2.5}$, it was 16%. In winter season, industry contribution was found to be 8% of PM$_{10}$ and 9% of PM$_{2.5}$. Other sources contributed 3% of PM$_{10}$ and 5% of PM$_{2.5}$ in summer and in winter seasons, contribution was found to be similar i.e. 3% in PM$_{10}$ and 6% in PM$_{2.5}$.

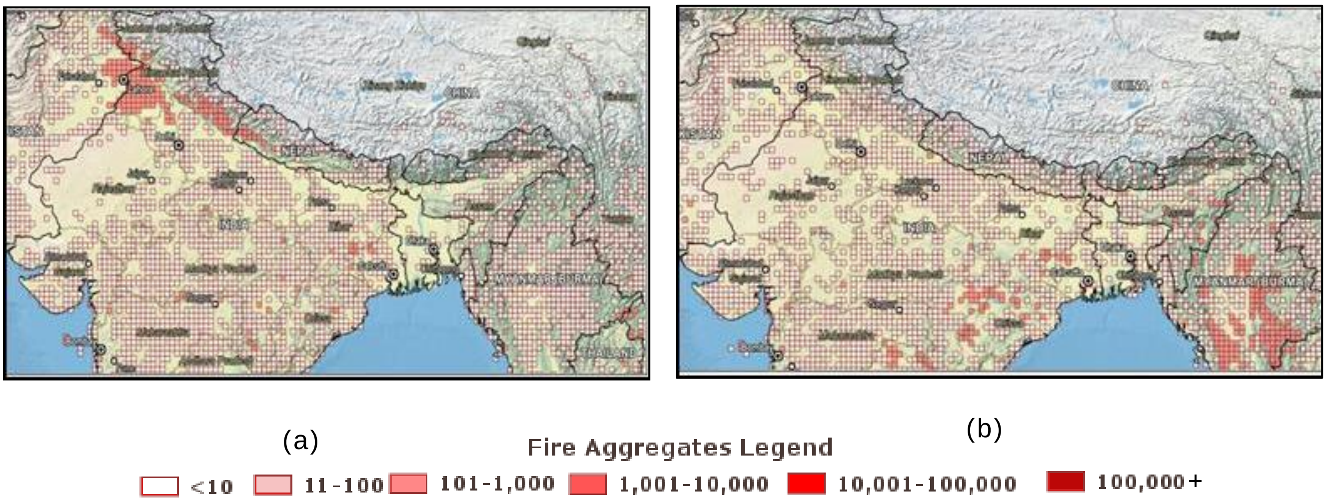
Secondary particulates contributed 9% of PM$_{10}$ and 16% PM2$_{.5}$. The secondary pollutant in both PM$_{10}$ and PM$_{2.5}$ was found to be similar, that is, 29%, but concentration was 95 ± 34 μg/m^3 in PM$_{10}$ and 48 ± 6 μg/m^3 in PM$_{2.5}$.

4.3.7 Site 7: Chandani Chowk

Season	Monitoring Period
Summer	13-May-16 to 22-May-16
Winter	27-Jan-17 to 08-Feb-17

(a) (b)

Figure 4.19 : Wind direction trajectories during monitoring period (a) summer season and (b) winter season



(a) (b)

Figure 4.20 : Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Chandani Chowk is presented in Fig. 4.19 (a) and (b) for summer and winter months, respectively. Wind is predominantly flowing from north-west and southeast direction during summer and in winter it is flowing from northeast direction. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.20 (a) and (b) for summer and winter months, respectively. A large number of live fires were observed during summer season, especially in north-west direction and in winter, number of fire aggregates were lesser as compared to summer monitoring period. Thus the incoming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

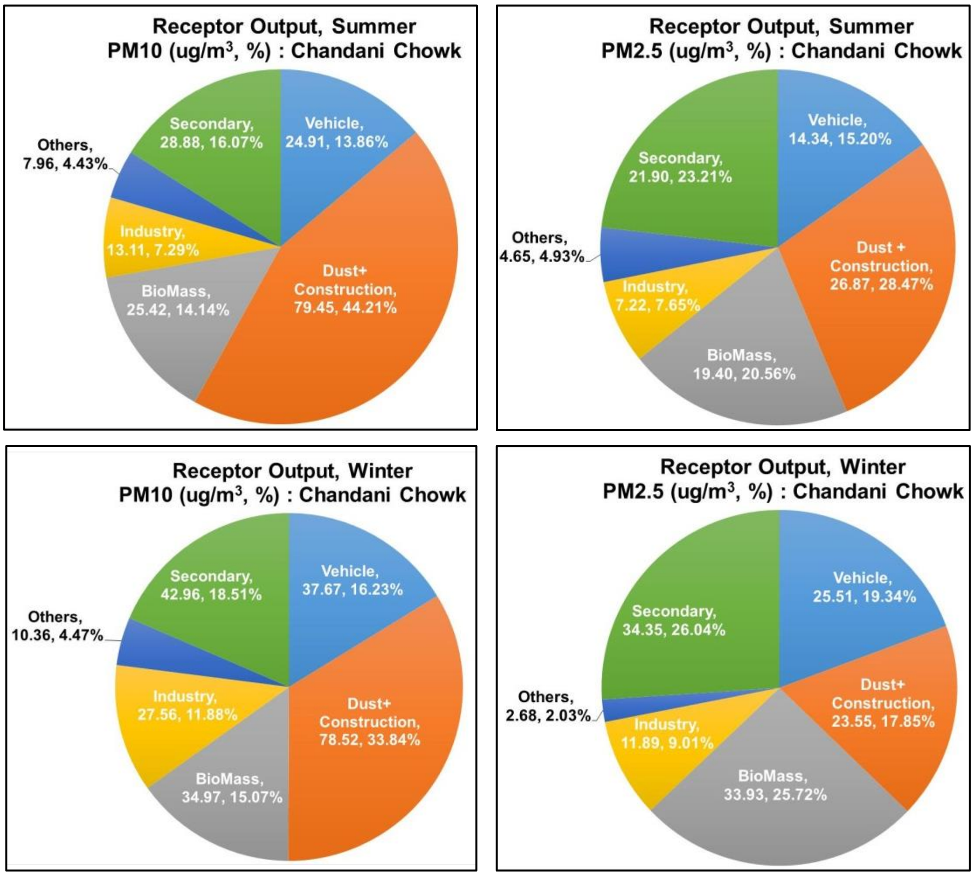


Figure 4.21 : Receptor output summer and winter PM_{10} and $PM_{2.5}$ at Chandani Chowk

Chandni Chowk is one of the oldest and busiest markets in Old Delhi. Chandni Chowk is located close to Old Delhi Railway Station. Therefore, there are many activities related to transportation. In addition, there were various activities in and around busy roads, these include congested traffic areas, street vendors, bakeries, hotels, *dhabas*, diesel locomotives, etc.

During the summer season in Chandani Chowk, the dust and construction was found to be contributing highest in both PM_{10} and $PM_{2.5}$. It contributed 44% (79 ± 39 $\mu g/m^3$) of PM_{10} and 29% (27 ± 14 $\mu g/m^3$) of $PM_{2.5}$. In winter season, dust and construction was 34% (79 ± 47 $\mu g/m^3$) in PM_{10} while it was 18% (24 ± 10 $\mu g/m^3$).

In summer season, Vehicles showed 14% (25 ± 6 $\mu g/m^3$) of PM10 and 15% (14 ± 6 $\mu g/m^3$) of PM2.5. In winter, contribution from Vehicles was 16% (38 ± 10 $\mu g/m^3$) of PM10 and 19% (26 ± 9 $\mu g/m^3$) of PM2.5.

Biomass burning was found to be higher in both summer and winter seasons. This is mainly due to activities from hotels, bakeries, *chullahs*, etc. In summer season, biomass burning contributed 14% (25 ± 13 $\mu g/m^3$) PM_{10} and 21% (19 ± 11 $\mu g/m^3$) $PM_{2.5}$ while in winter season, biomass burning contributed 15% (35 ± 23 μg/m3) of PM10 and 26% (23 ± 12 μg/m3)of PM2.5.

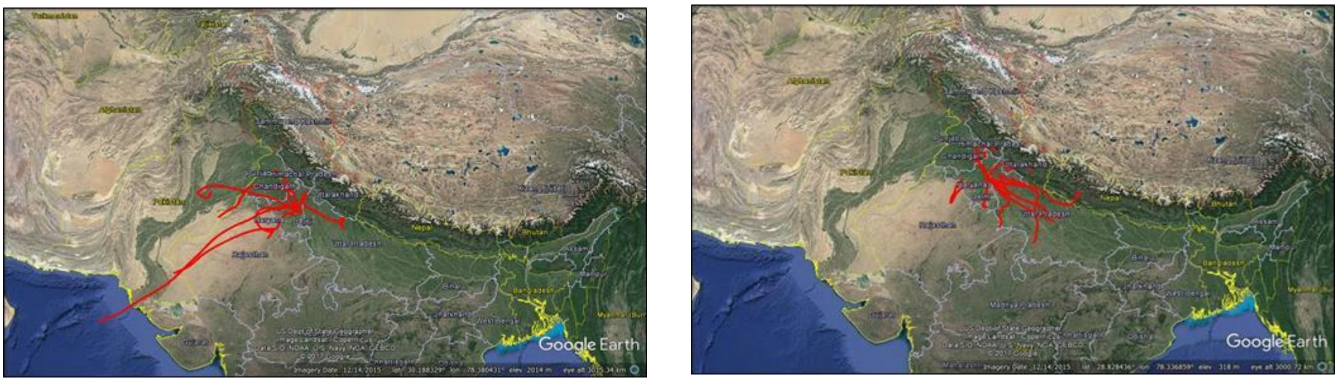
As there are no major industries in Chandani Chowk, contribution from industries was very less in both summer and winter seasons. Industries contribution was 7% of PM10 and 8% of PM2.5 in summer season while in winter season contribution was 12% of PM10 and 9% in PM2.5.

In summer season, contribution from secondary particulates was 16% (29 ± 6 µg/m3) PM10 and 23% (22 ± 3 µg/m3) in PM2.5, whereas in the winter season, secondary particulates showed 26% (34 ± 26 µg/m3) of PM2.5 and 19% (43 ± 24 µg/m3) of PM10.

Contribution from other sources was very less with 4% of PM_{10} and 5% of $PM_{2.5}$ in summer season. While in winter season, it was found to be 5% of PM_{10} and 2% of $PM_{2.5}$.

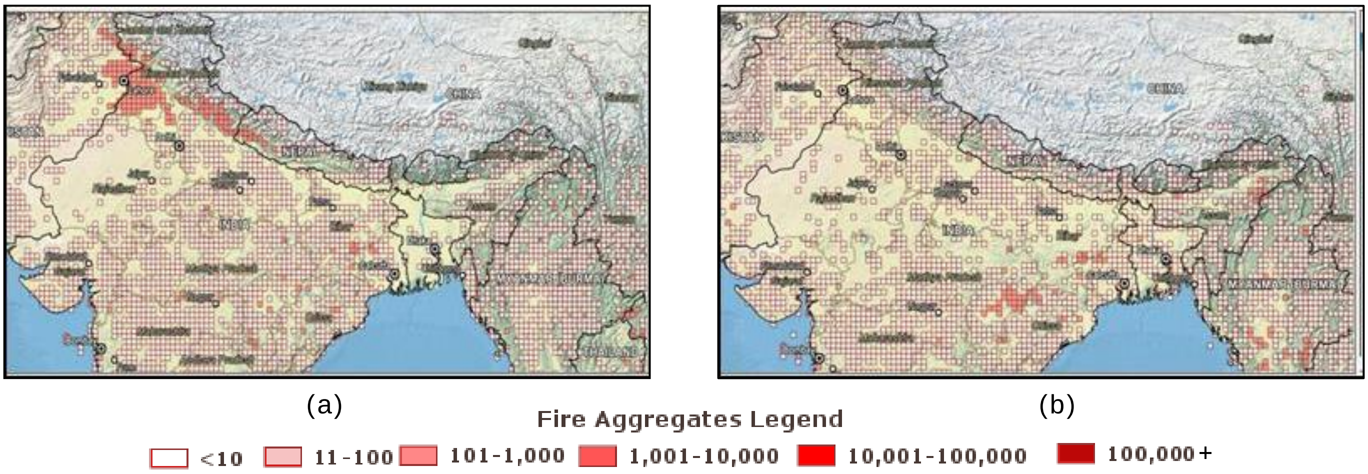
4.3.8 Site 8: Panipat

Season	Monitoring Period
Summer	25-May-16 to 02-Jun-16
Winter	30-Dec-16 to 09-Jan-17



(a) (b)

Figure 4.22 : Wind direction trajectories during monitoring period (a) summer season and (b) winter season



(a) (b)

Figure 4.23 : Fire data collected during monitoring period in (a) summer season and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring day at Panipat is presented in Fig. 4.22 (a) and (b) for summer and winter seasons, respectively. Wind was predominantly flowing from west direction in summer and in winter season it was flowing from east direction. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.23 (a) and (b) for summer and winter months, respectively. A large number of live fires were observed during summer, season especially in north-west direction and in winter, number of fire aggregates were lesser as compared to summer monitoring period. Thus, the incoming wind to Delhi-NCR is expected to carry pollutants from biomass burning, dust, and tall stacks.

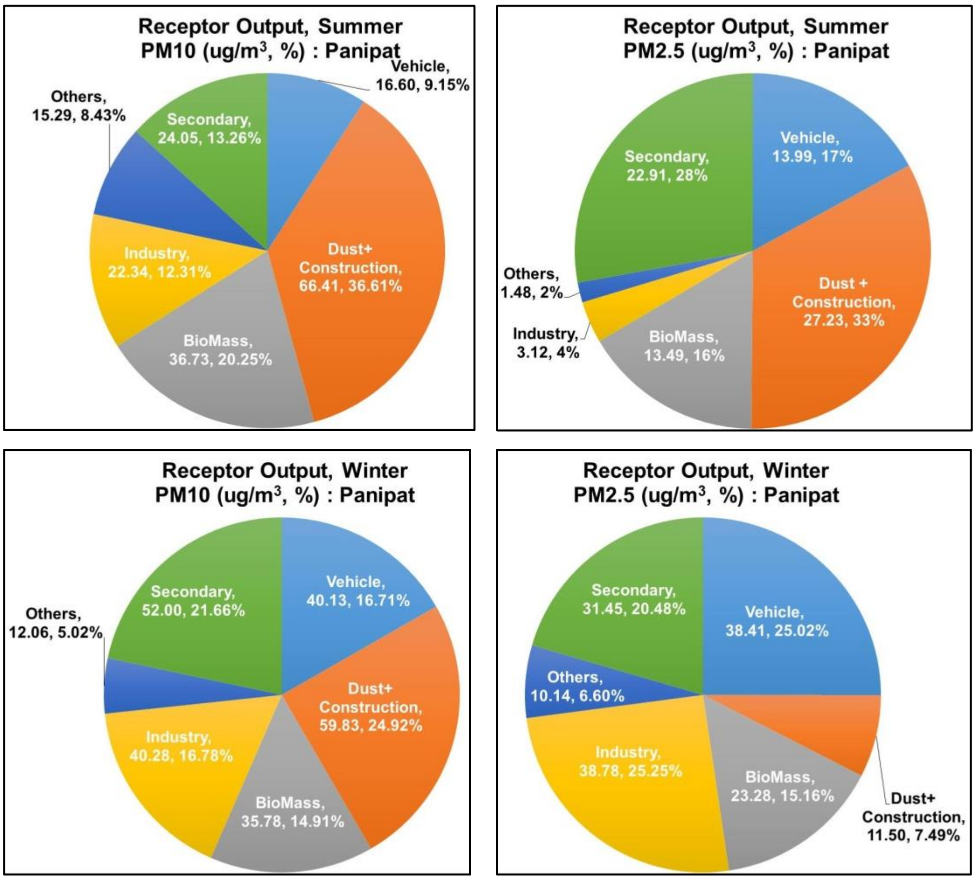


Figure 4.24: Receptor Output Summer and Winter : PM$_{10}$ and PM$_{2.5}$ at Panipat

Panipat is located at about 90 km from Delhi. It is towards the north direction from Delhi and is a site with mainly residential area around it.

Due to open spaces and some construction activities found near the site, contribution from dust and construction was found to be highest in both the summer and winter seasons for both PM$_{10}$ and PM$_{2.5}$. In summer season, dust and construction was found to 37% (66 ± 10 µg/m^3) in PM$_{10}$ and 33% (27 ± 15 µg/m^3) in PM$_{2.5}$, while it was 25% (60 ± 22 µg/m^3) to PM$_{10}$ and was 8% (12 ± 3 µg/m^3) in PM$_{2.5}$.

Vehicular contribution was found to be 9% (17 ± 8 µg/m^3) of PM$_{10}$ while PM$_{2.5}$ showed 17% (14 ± 3 µg/m^3) in summer season. Whereas in winter season, it was17% (40 ± 18 µg/m^3) and 25% (38 ± 19 µg/m^3) in PM$_{10}$ & PM$_{2.5}$ respectively.

In summer season, contribution of secondary particulates was 13% (24 ± 3 µg/m^3) in PM$_{10}$ and 28% (23 ± 2 µg/m^3) in PM$_{2.5}$, whereas in winter season, it was 22% (52 ± 33 µg/m^3) and 20% (31 ± 6 µg/m^3) in PM$_{10}$ and PM$_{2.5}$, respectively.

Industry contribution was found to be lesser, namely, in summer season, contribution was found to be 12% in PM$_{10}$ and 4% in PM$_{2.5}$, whereas in winter season, contribution to PM$_{10}$ was found to be 17% (40 ± 19 µg/m^3) and was 26% (37 ± 18 µg/m^3).

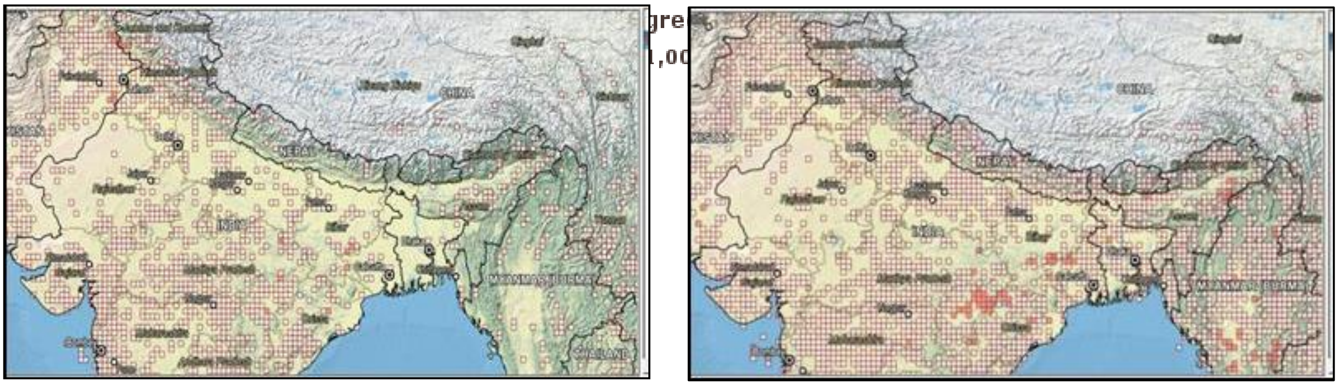
In summer season, other sources contributed 8% in PM$_{10}$ and 2% in PM$_{2.5}$ and in winter season, it was 5% in PM$_{10}$ and 7% in PM$_{2.5}$.

4.3.9 Site 9: Naraina

Season	Monitoring Period
Summer	06-Jun-16 to 12-Jun-16
Winter	09-Jan-17 to 19-Jan-17

(a) (b)

Figure 4.25 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.26 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Naraina is presented in Fig. 4.25 (a) and (b) for summer and winter respectively. Wind is predominantly flowing from east direction and from west direction on a few days in during summer and in winter from north-west direction. The incoming air will carry large pollutant from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented in Fig. 4.26 (a) and (b) for summer and winter seasons, respectively. The number of live fires observed during monitoring duration in summer and winter seasons were found to be lesser as the crop residue-burning activity diminishes during this period. Thus the incoming wind to Delhi-NCR is expected to carry dust.

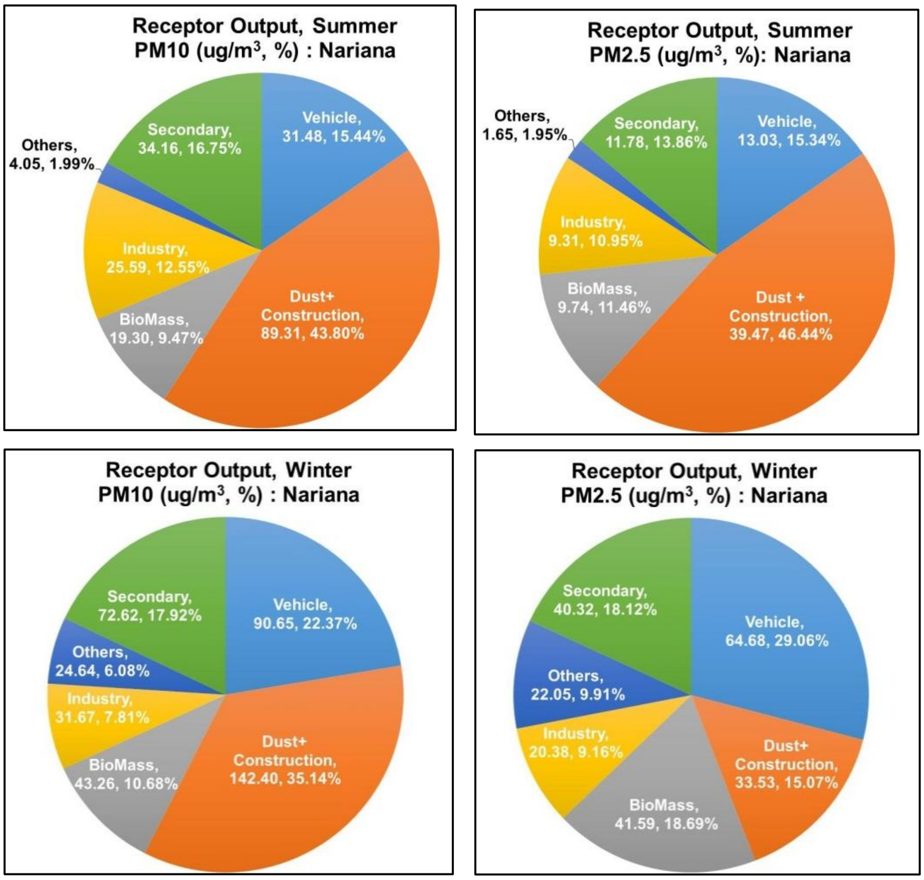


Figure 4.27 : Receptor Output Summer and Winter : PM10 and PM2.5 at Nariana

Naraina area is located in south-west of Delhi. It is a mix of industrial, residential, and rural areas. The industrial area has a large conglomerate of steel and electronics. The residential comprises of residential flats built by and individually built houses. It also has a rural area called *Naraina Gaanv*. Naraina is adjacent to the western segment of the Ring Road, between Dhaula Kuan and Rajouri Garden.

Dust and construction was found to be contributing highest percentage in both PM_{10} and $PM_{2.5}$ in both summer and winter seasons. In summer season, it contributed to 44% (89 ± 16 μg/m^3) in PM_{10} and 46% (39 ± 20 μg/m^3) of $PM_{2.5}$, whereas in winter season, contribution was 35% (142 ± 72 μg/m^3) in PM_{10} and 15 % (34 ± 23 μg/m^3) of $PM_{2.5}$.

Contribution from vehicles was found to be significant as there is a ring road in the vicinity of the site. In summer season, vehicles contributed to 15% in both PM_{10} and $PM_{2.5}$ with a concentration levels from vehicles as 32 ± 9 μg/m^3 in PM_{10} and 13± 4 μg/m^3 in $PM_{2.5}$. In winter season, vehicular contribution was 22% (91 ± 25 μg/m^3) in PM_{10} and 29% (65 ± 32 μg/m^3) in $PM_{2.5}$.

In summer season, biomass burning was found to be 12% (10 ± 5 μg/m^3) in $PM_{2.5}$ and 10% (19 ± 5 μg/m^3) in PM_{10}, whereas in winter season, biomass burning was found to increase to 19% (42 ± 31 μg/m^3) in $PM_{2.5}$ and 11% (43 ± 22 μg/m^3) in PM_{10}.

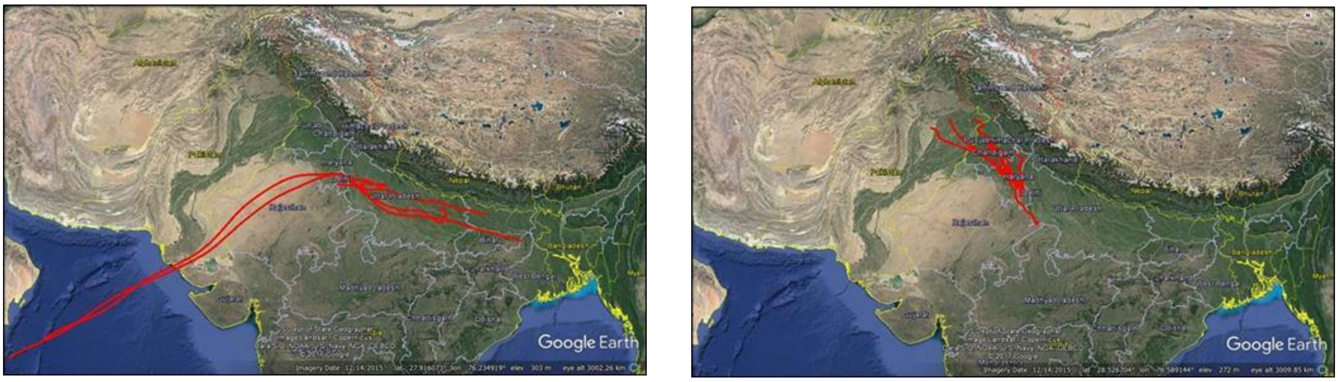
In summer season, secondary particulates contributed about 17% (34 ± 5 μg/m^3) in PM_{10} and 14% (12 ± 2 μg/m^3) in $PM_{2.5}$. In winter season, contribution from secondary particulates was found to be 18% in both PM_{10} and $PM_{2.5}$ with concentration level of 73 ± 28 $\mu g/m^3$ and 40 ± 25 $\mu g/m^3$ in PM_{10} and $PM_{2.5}$, respectively.

In summer season, contribution from industry was 13% of PM_{10} and 11% of $PM_{2.5}$, whereas in winter season, it was about 8% and 9% of PM_{10} and $PM_{2.5}$, respectively.

contribution from other sources were found to be similar, i.e. about 2% in both PM_{10} and $PM_{2.5}$ in summer season, while in winter season, it showed 6% in PM_{10} and 10% in $PM_{2.5}$.

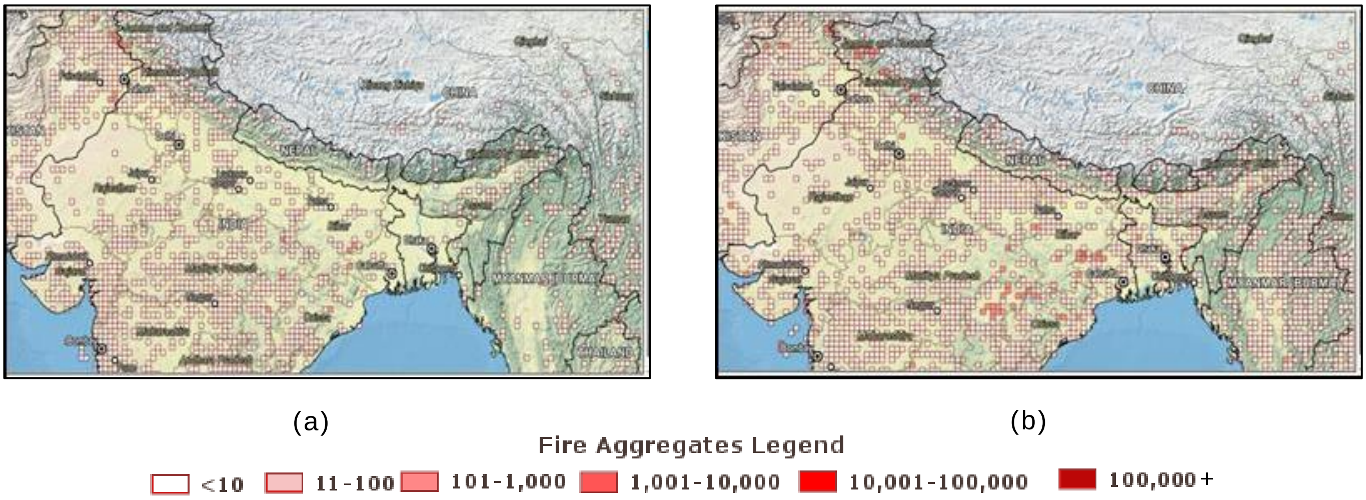
4.3.10 Site 10: Wazirpur

Season	Monitoring Period
Summer	14-Jun-16 to 20-Jun-16
Winter	07-Dec-16 to 18-Dec-16



(a) (b)

Figure 4.28 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.29 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Wazirpur is presented in Fig. 4.28 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east direction and from west direction on a few days in summer and in winter from north-west direction. The incoming air will carry from large pollutants from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.29 (a) and (b) for summer and winter seasons, respectively. The number of live fires observed during monitoring duration in summer and winter seasons were found to be lesser as the crop residue-burning activity diminishes during this period. Thus, the incoming wind to Delhi-NCR is expected to carry s like dust and pollutants from tall stacks.

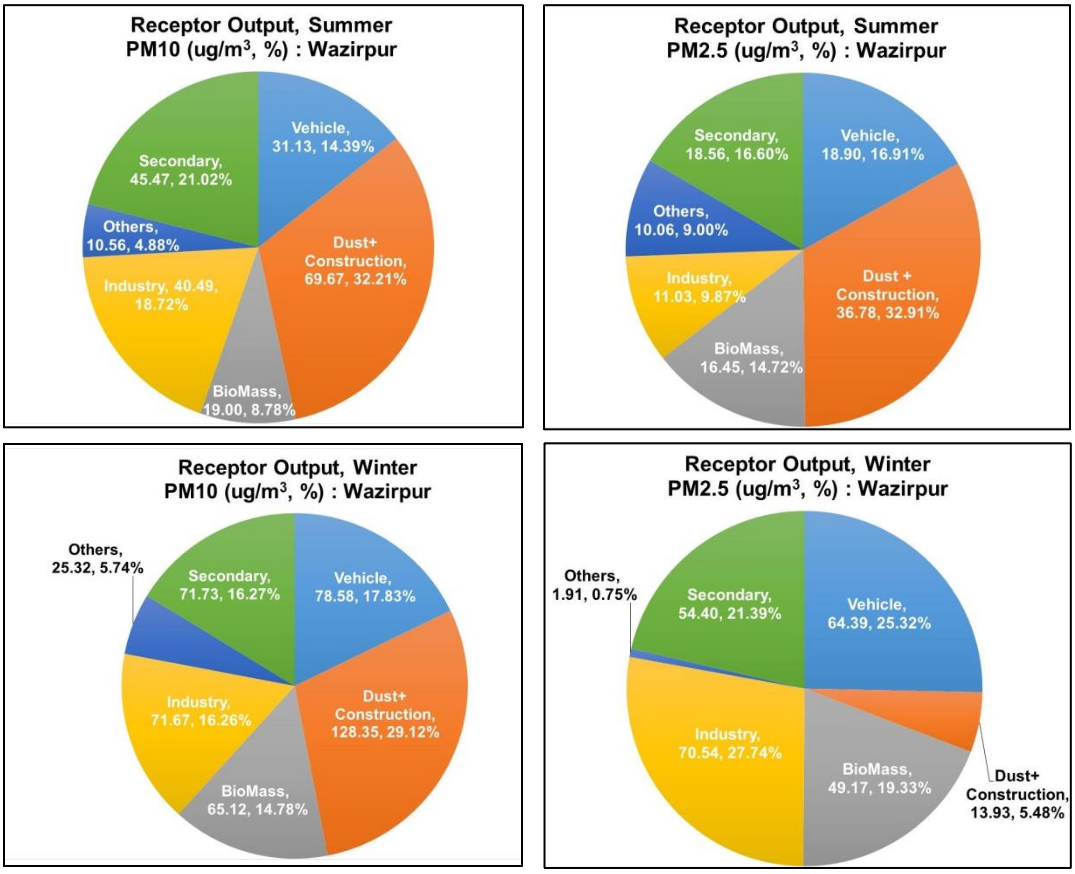


Figure 4.30 : Receptor Output Summer and Winter : PM10 and PM2.5 at Wazirpur

Wazirpur is located in North Delhi and is an industrial area. It is known mainly for its utensils industry. In Wazirpur during summer season, both in PM$_{10}$ and PM$_{2.5}$, dust, and construction was highest contributor with nearly same contribution, that is, 32% (70 ± 18 µg/m^3) in PM$_{10}$ and 33% (37 ± 9 µg/m^3) in PM$_{2.5}$. Dust and construction was found to be 29% (128 ± 48 µg/m^3) in PM$_{10}$, whereas it was 5% (14 ± 4 µg/m^3) in PM$_{2.5}$. This is due to the over-bridge construction activities taking place near take site. In addition, there were unpaved roads found near site, which may lead to resuspension of road-dust.

In summer season, vehicular contribution was about 14% (31 ± 5 µg/m^3) in PM$_{10}$ and 17% (19 ± 7 µg/m^3) of PM$_{2.5}$, whereas in winter season vehicles contributed 25% (64 ± 37 µg/m^3) of PM$_{2.5}$ and 18% (79 ± 38 µg/m^3) of PM$_{10}$.

Due to the presence of the industrial area around the site, industry contribution in summer season was, 19% (41 ± 10 µg/m^3) and 10% (11 ± 5 µg/m^3) of PM$_{10}$ and PM$_{2.5}$, respectively, whereas industry contributed 16% (72 ± 40 µg/m^3) and 28% (71 ± 28 µg/m^3) in winter season.

In summer season, secondary particulates contributed 21% (45 ± 6 µg/m^3) of PM$_{10}$ and 17% (19 ± 5 µg/m^3) of PM$_{2.5}$, whereas in winter season, 16% (72 ± 41 µg/m^3) and 24% (54 ± 13 µg/m^3) in PM$_{10}$ and PM$_{2.5}$, respectively.

Biomass burning was found to be 15% (16 ± 5 µg/m^3) of PM$_{2.5}$ and 19% (41 ± 11 µg/m^3) of PM$_{10}$ in summer season. Whereas in winter season, biomass burning contributed to about 15% (65 ± 29 µg/m^3) of PM$_{10}$ and19% (49 ± 19 µg/m^3) of PM$_{2.5}$. This may be attributed to biomass burning happening in the nearby slum area.

In the summer season, other sources contributed 5% of PM$_{10}$ and 9% in PM$_{2.5}$, whereas in winter season, it contributed to about 6% of PM$_{10}$ and 1% in PM$_{2.5}$.

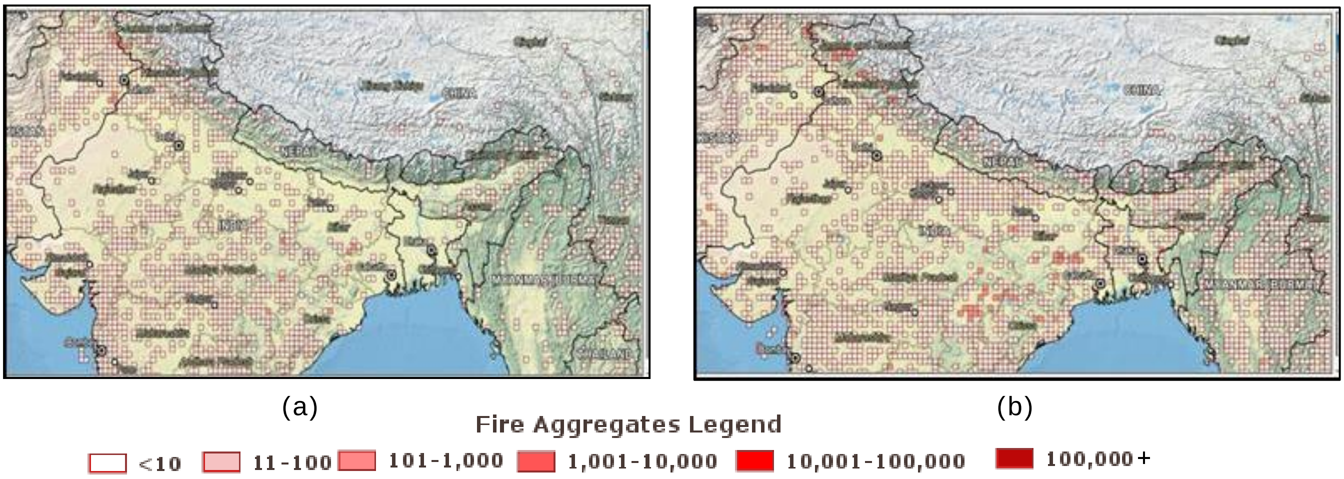
4.3.11 Site 11: Rohini

Season	Monitoring Period
Summer	21-Jun-16 to 01-Jul-16
Winter	23-Dec-16 to 08-Jan-17

(a)

(b)

Figure 4.31 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a)

(b)

Figure 4.32 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Rohini is presented in Fig. 4.31 (a) and (b) for summer and winter season, respectively. Wind is predominantly flowing from east and west direction on a few days in summer and in winter from north-west and southeast direction. The incoming air will carry large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.32 (a) and (b) for summer and winter seasons, respectively. The number of live fires observed during monitoring duration in summer and winter seasons were found to be lesser as the crop residue-burning activity diminishes during this period. Thus the incoming wind to Delhi-NCR is expected to carry s like dust and pollutants from tall stacks.

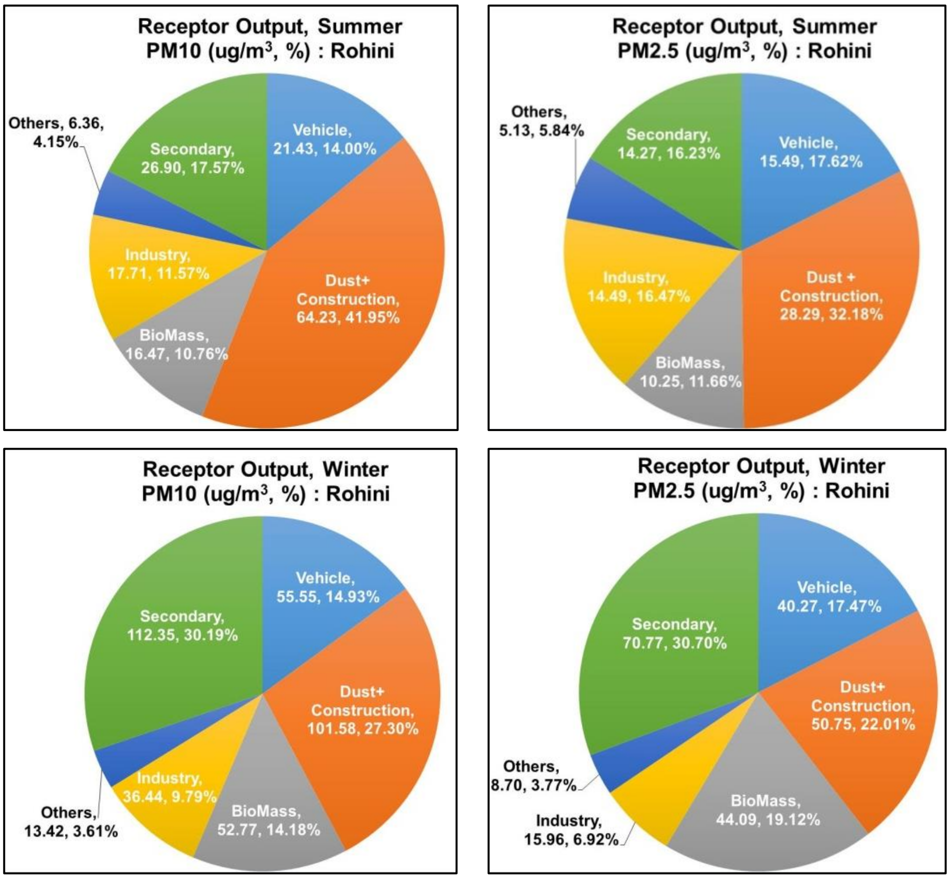


Figure 4.33 : Receptor Output Summer and Winter : PM10 and PM2.5 at Rohini

Rohini is situated in North-west part of the city. Rohini is a densely populated residential site with a large number of inhabitants. Heavy vehicular traffic features at Madhuban Chowk, which is very close to monitoring site.

During summer season at Rohini, contribution from dust and construction was found to be highest in both PM$_{10}$ and PM$_{2.5}$. It contributed about 42% (64 ± 25 µg/m^3) of PM$_{10}$ and 32% (28 ± 9 µg/m^3) of PM$_{2.5.}$ In winter, dust and construction was observed to contribute to about 27% (102 ± 74 µg/m^3) of PM$_{10}$ and about 22% (51±13 µg/m^3) of PM$_{2.5}$.

In summer season, vehicles contributed 14% (21 ± 2 µg/m^3) to PM$_{10}$ and 18% (16 ± 6 µg/m^3) of PM$_{2.5}$, whereas it contributed 15% (56 ± 35 µg/m^3) of PM$_{10}$ and 18% (40 ± 12 µg/m^3) of PM$_{2.5}$. Vehicular contribution is due to small busy roads and heavy traffic on the Ring road, especially at Madhuban Chowk, which is very close to monitoring site.

The contribution from industries was less as there were few industries in close vicinity to monitoring site. It contributed about 12% (18 ± 8 µg/m^3) of PM$_{10}$ and 17% (15± 2 µg/m^3) of PM$_{2.5}$ in summer season, whereas, in winter industry contributed 10 % of PM$_{10}$ and 7% of PM$_{2.5}$.

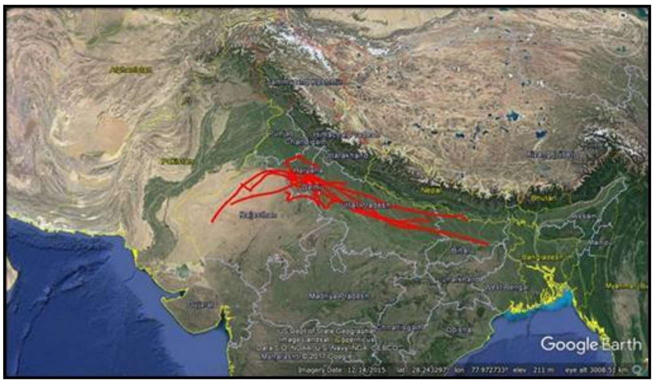
Biomass burning was observed in nearby restaurants and bakeries t and in residential areas, which resulted in contribution in summer as 11% of PM$_{10}$ and 12% of PM$_{2.5}$. In winter season, contribution from biomass burning was higher to about 14% of PM$_{10}$ and 19% of PM$_{2.5}$.

Secondary particulates contributed to about 18% (27 ± 5 μg/m^3) of PM_{10} and 16% (14 ± 4 μg/m^3) of $PM_{2.5}$ in summer. Secondary particulates were major contributor to PM_{10} at 30% (112 ± 54 μg/m^3) and about 31% in $PM_{2.5}$ (71 ± 42 μg/m^3) in winter.

Other sources contributed 4% of PM_{10} and 6% of $PM_{2.5}$ in summer and about 4% in both PM_{10} and $PM_{2.5}$ in winter.

4.3.12 Site 12: Sonipat

Season	Monitoring Period
Summer	27-Jun-16 to 08-Jul-16
Winter	Air quality monitoring could not be conducted



(a)

Figure 4.34 : Wind Direction Trajectories during monitoring period (a) Summer Season

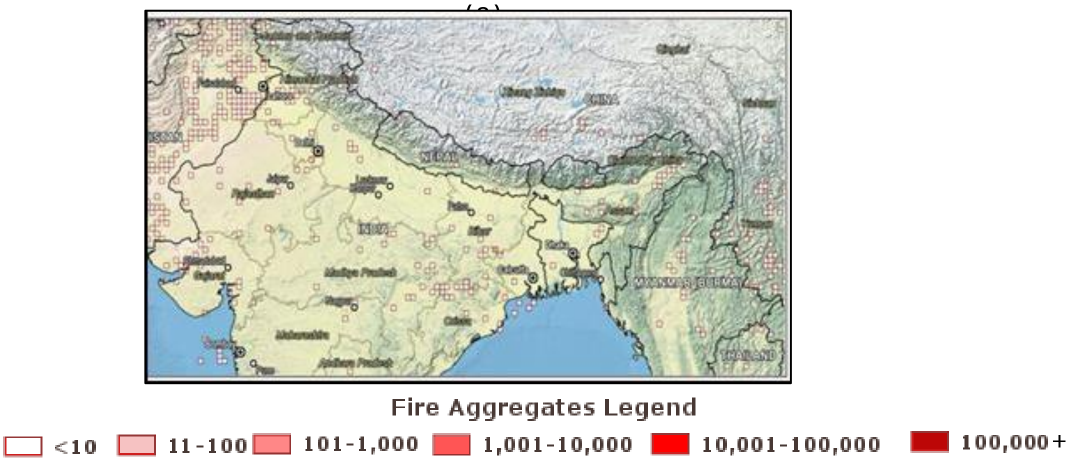


Figure 4.35 : Fire data collected during monitoring period in (a) Summer Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Sonipat is presented in Fig. 4.34 (a) for summer season. During monitoring at this site, frequent rains were observed and, therefore, valid samples could not be conducted in winter season. Incoming air will carry s from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.35 (a) for summer season. The number of live fires were observed during monitoring duration in summer and were found to be lesser as the crop residue burning-activity diminishes during this period. Thus, the incoming wind to Delhi-NCR is expected to carry s like dust and pollutants from tall stacks.

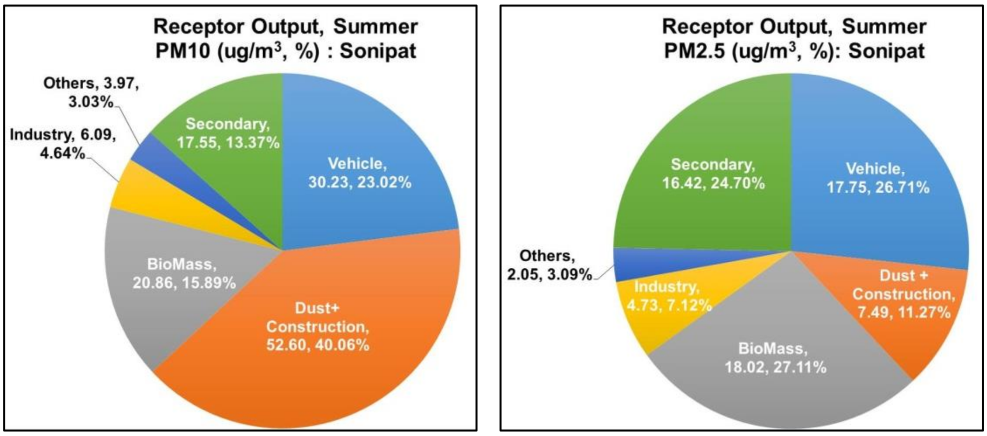


Figure 4.36 : Receptor Output Summer : PM10 and PM2.5 at Sonipat

Sonipat is 43 km from Delhi and is in the state of Hariyana. It is predominantly a residential site. During summer season at Sonipat, dust and construction contributed the highest percentage of PM_{10} while biomass burning contributed higher percentage of $PM_{2.5}$. Dust and construction contributed 40% (53 ± 17 $\mu g/m^3$) of PM_{10} and 11 %(8±1 $\mu g/m^3$) of $PM_{2.5}$ in summer. Monitoring in the summer season was carried out in the month of July, during which there was rainfall and this has resulted in the lowering down of the overall mass concentration levels. Biomass burning has contributed 16% of PM_{10} and 27% of $PM_{2.5}$. As Sonipat is a residential site, contribution from industries was less. Industry contributes to about 5% of PM_{10} and 7% of $PM_{2.5}$. Secondary particulates contributed to 13% of PM_{10} and about 25% in $PM_{2.5}$. Other sources contributed about 3% to PM_{10} and 4% to $PM_{2.5}$.

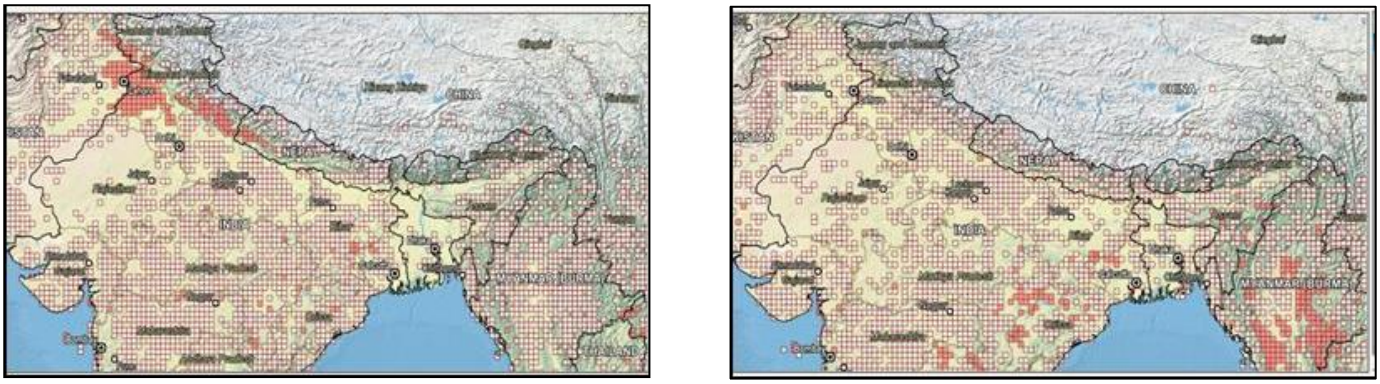
Air quality monitoring could not be conducted in winter season, hence only summer season results are reported.

4.3.13 Site 13: Ghaziabad 1

Season	Monitoring Period
Summer	24-May-16 to 30-May-16
Winter	06-Feb-17 to 16-Feb-17

(a) (b)

Figure 4.37 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Fire Aggregates Legend

☐ <10 🟥 11-100 🟥 101-1,000 🟥 1,001-10,000 🟥 10,001-100,000 🟥 100,000+

Figure 4.38 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Ghaziabad-1 is presented in Fig. 4.37 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from north-west and west direction in summer season and in winter from north-west and on a few days from southeast direction. The incoming air will carry s from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.38 (a) and (b) for summer and winter seasons, respectively. A large number of live fires were observed during monitoring duration in summer and winter seasons, and it was lesser as compared to the summer as the crop residue-burning activity diminishes during the winter months. Thus the incoming wind to Delhi-NCR is expected to carry pollutants for sources like biomass burning, dust, and tall stacks.

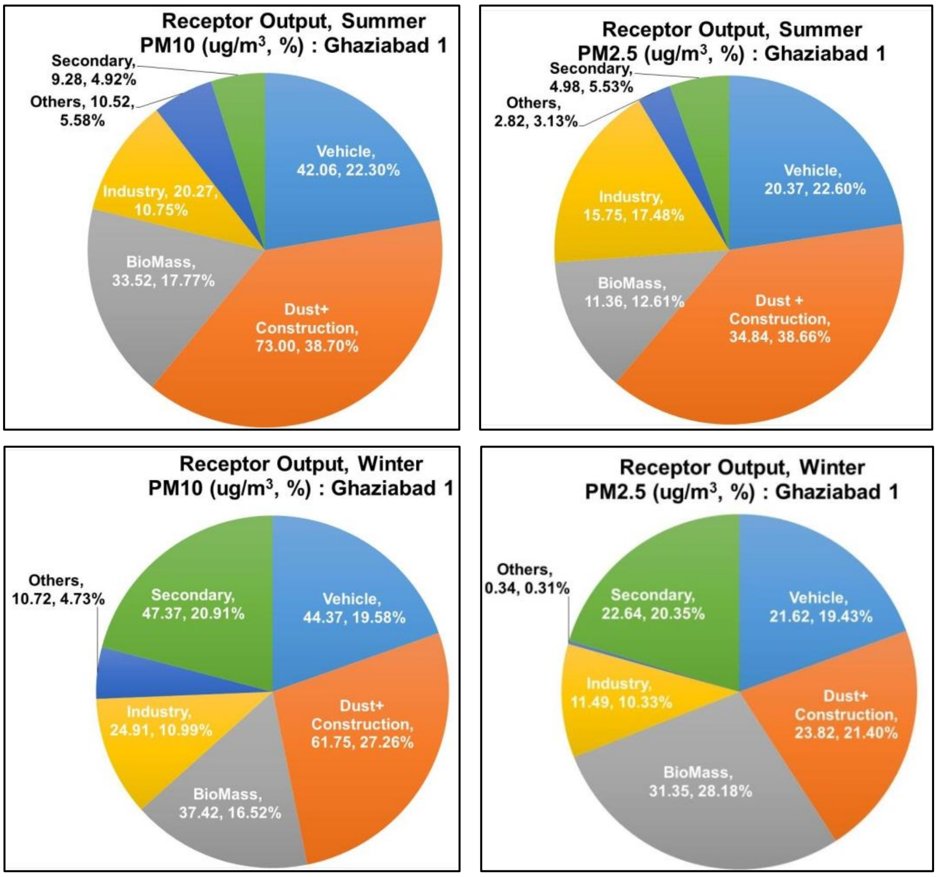


Figure 4.39 : Receptor Output Summer and Winter : PM_{10} and $PM_{2.5}$ at Ghaziabad 1

Ghaziabad-1 is a site in the town in NCR region at the southeast side of Delhi. This site is located in the densely populated area and activities around the site include vehicle traffic, construction activities, slum area, unpaved road, occasional garbage burning, DG sets, and building construction.

In summer season at Ghaziabad-1, dust and construction was found to be highest and contribution in terms of percentage was similar, about 39%, in both PM_{10} and $PM_{2.5}$. Average concentration was found to be 73 ± 13 $\mu g/m^3$ in PM_{10} and 35 ± 14 $\mu g/m^3$ in $PM_{2.5}$. In winter season, dust and construction contributed 27% (62 ± 37 $\mu g/m^3$) in PM_{10} and 21% (24 ± 3 $\mu g/m^3$) in $PM_{2.5}$.

In summer season, contribution from vehicles was 22% (42 ± 21 $\mu g/m^3$) of PM_{10} and 23% (20 ± 11 $\mu g/m^3$) of $PM_{2.5}$ and in winter season, vehicles contributed to about 20% (44 ± 8 $\mu g/m^3$) of PM_{10} and about 19% (22 ± 9 $\mu g/m^3$) of $PM_{2.5}$.

Secondary particulates contributed 5% of PM10 and 6% of PM2.5 in summer season. In winter season, its contribution increased and was about 21% of PM_{10} and 20% of $PM_{2.5}$.

Biomass burning contributed to 18% (34 ± 24 $\mu g/m^3$) of PM_{10} and 13% (11 ± 7 $\mu g/m^3$) of $PM_{2.5}$. Biomass burning contributed 17% (37 ± 9 $\mu g/m^3$) of PM_{10} and significantly higher to about 28% (31 ± 12 $\mu g/m^3$) of $PM_{2.5}$.

As small- to medium-scale industries are present in Ghaziabad 1, industry contribution was significant. In summer, industries contributed to about 11% of PM_{10} and about 18% of $PM_{2.5}$.

Similarly, in winter, Industries contributed to 11% (25 ± 5 $\mu g/m^3$) of PM_{10} and 10% (11 ± 8 $\mu g/m^3$) of $PM_{2.5}$.

In summer season, other sources contributed 5% of PM_{10} and 3% of $PM_{2.5}$, whereas in winter season, other sources contributed to about 5% of PM_{10} and in case of $PM_{2.5}$, it was less than 1%.

4.3.14 Site 14: Ghaziabad 2

Season	Monitoring Period
Summer	12-Jun-16 to 18-Jun-16
Winter	21-Nov-16 to 30-Nov-16


(a) (b)

Figure 4.40 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season

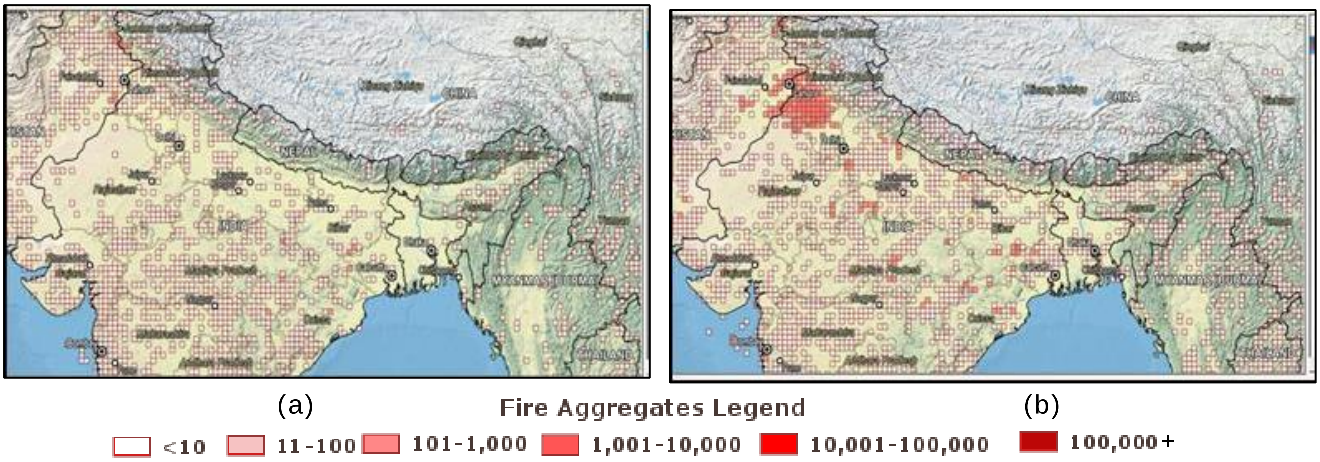

(a) (b)

Figure 4.41: Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Ghaziabad-2 is presented in Fig. 4.40 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east and west direction in summer season and in winter season from north-west and on a few days from southeast direction. The incoming air will carry pollutants from large sources with it from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.41 (a) and (b) for summer and winter seasons, respectively. The numbers of live fires observed during monitoring duration in summer season were fewer as the crop residue-burning activity diminishes during this period and in winter season; it was lesser as compared to the summer in winter. Thus, the incoming wind to Delhi-NCR is expected to carry s for sources, such as biomass burning, dust, and tall stacks.

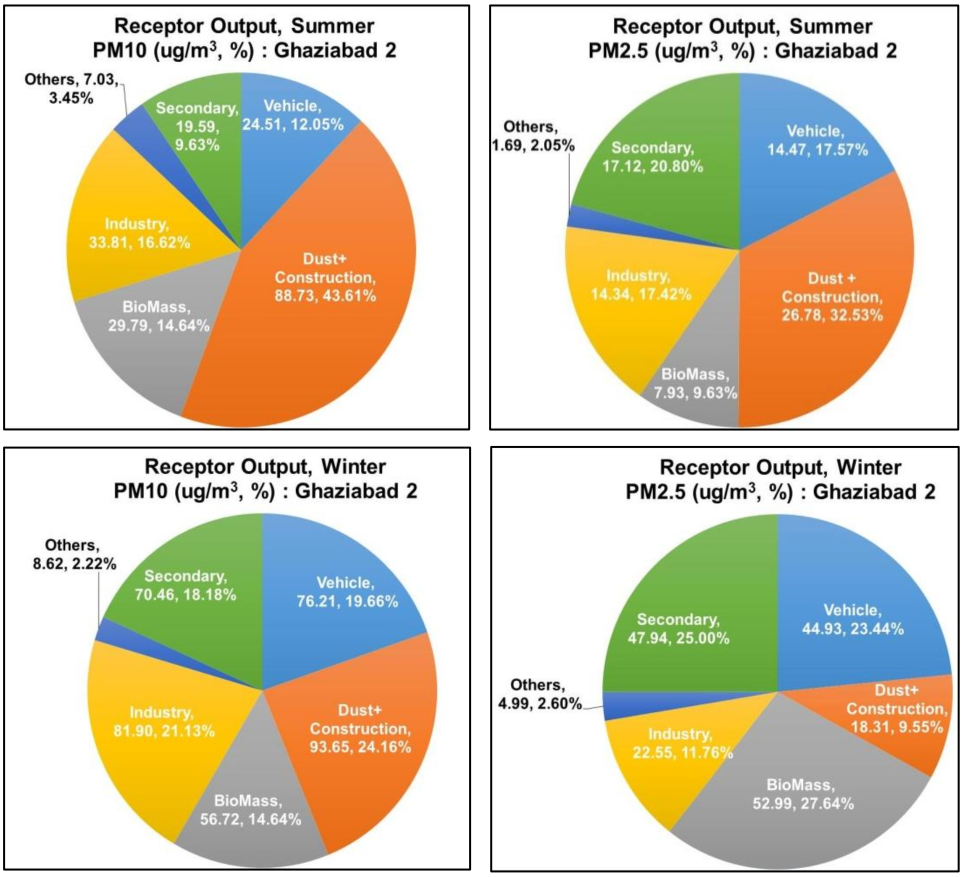


Figure 4.42 : Receptor Output Summer and Winter : PM10 and PM2.5 at Ghaziabad 2

Ghaziabad-2 site was mainly an industrial site with Kavinagar industrial area nearby. Activities around site include unpaved road, diesel locomotive, chemical and dyes industries, and construction activities. The site was situated at south-east direction of Delhi.

During summer season at Ghaziabad 2, dust and construction were major contributors to both PM_{10} and $PM_{2.5}$, with 44% (89 ± 17 $\mu g/m^3$) contribution in PM_{10} and 33% (27 ± 6 $\mu g/m^3$) in $PM_{2.5}$. Whereas in winter season, dust and construction contributed 24% (94 ± 19 $\mu g/m^3$) of PM_{10} and in case of $PM_{2.5}$ it was found to be 10% (18 ± 11 $\mu g/m^3$). This may be attributed to the unpaved roads and construction sites going on around the monitoring site.

contribution from vehicles was about 12% (25 ± 10 $\mu g/m^3$) in PM_{10} and 18% (15± 5 $\mu g/m^3$) in $PM_{2.5}$ in summer season and contributed 20% (76 ± 19 $\mu g/m^3$) in PM_{10} and 23% (45 ± 10 $\mu g/m^3$) in $PM_{2.5}$ in winter season. This may be due to the heavy traffic and vehicle movement on national highway (NH-24), which is near to the monitoring site.

Contribution from industries was significant in summer season with 17% (34 ± 17 $\mu g/m^3$) contribution to PM_{10} and about 17% (14 ± 5 $\mu g/m^3$) in $PM_{2.5}$. In winter season, industries contributed 21% (82 ± 56 $\mu g/m^3$) of PM_{10} and 12% (23 ± 13 $\mu g/m^3$) of $PM_{2.5}$.

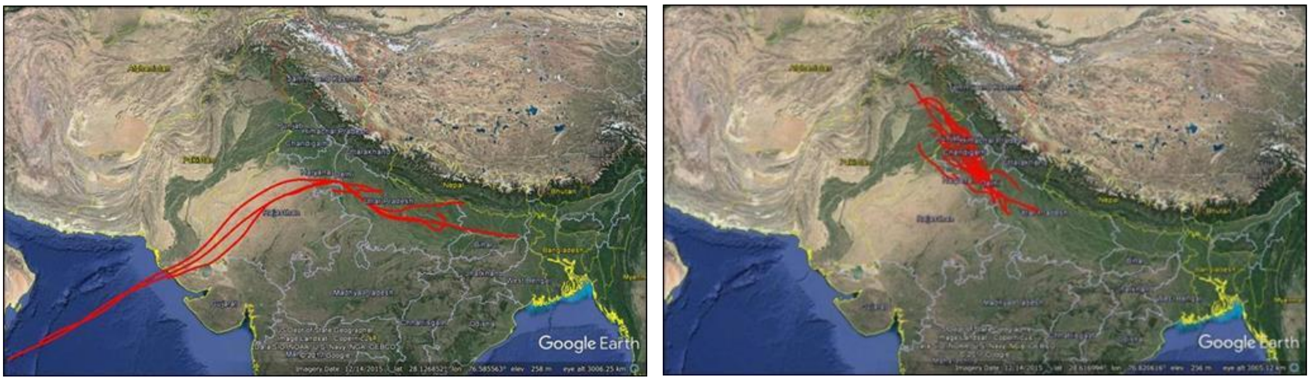
Secondary particulates contribution in summer season was almost 21% (17 ± 5 $\mu g/m^3$) in $PM_{2.5}$ and 10% (20 ± 2 $\mu g/m^3$) in PM_{10}. Secondary particulates contribution was higher in winter, with about 25% (48 ± 12 $\mu g/m^3$) in $PM_{2.5}$ and 18% (70 ± 8 $\mu g/m^3$) in PM_{10}.

In summer season, biomass burning contributed to about 15% of PM_{10} and about 10% of $PM_{2.5}$. In winter season, $PM_{2.5}$ concentration was majorly due to biomass burning with 28% (53 ± 17 $\mu g/m^3$), whereas it was 15% (57 ± 16 $\mu g/m^3$) in PM_{10}. Higher biomass burning contribution in winter season was may be due to the burning of wood, chullahs found near the site.

Other sources contributed 4% of PM_{10} and 3% of $PM_{2.5}$ in summer season and it was about 2% and 3% in winter for PM_{10} and $PM_{2.5}$, respectively.

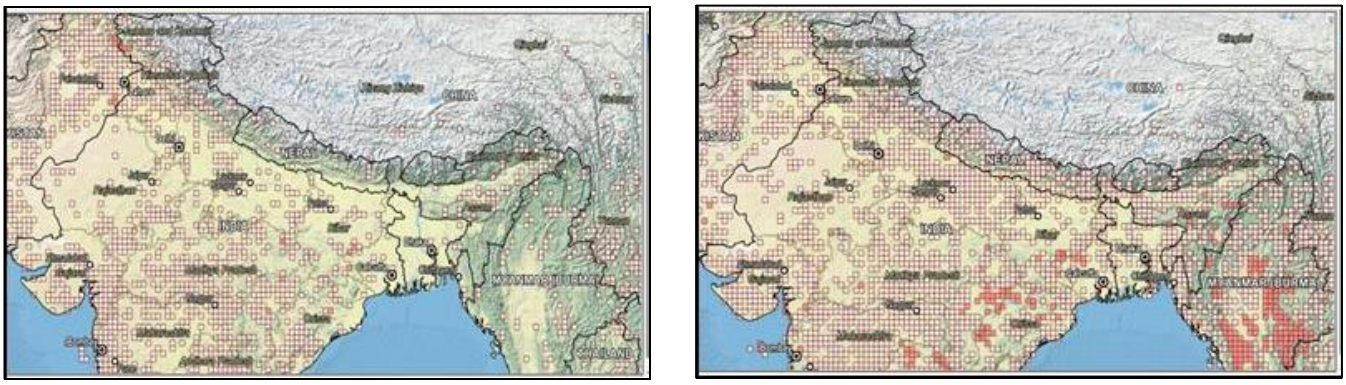
4.3.15 Site 15: Noida 1

Season	Monitoring Period
Summer	13-Jun-16 to 19-Jun-16
Winter	04-Feb-17 to 27-Feb-17



(a) (b)

Figure 4.43 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Fire Aggregates Legend

☐ <10 ▨ 11-100 ▨ 101-1,000 ▨ 1,001-10,000 🟥 10,001-100,000 🟥 100,000+

Figure 4.44 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Noida-1 site is presented in Fig. 4.43 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from south-west and east direction in summer in winter from the north-west and, on a few days, from southeast direction. The incoming air will carry large sources from the area over which it is flowing. Data on the number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.44 (a) and (b) for summer and winter seasons, respectively. The number of live fires observed during monitoring duration in summer and winter were fewer as the crop residue burning-activity diminishes during this period. Thus, the incoming wind to Delhi-NCR is expected to carry s for sources like dust and tall stacks.

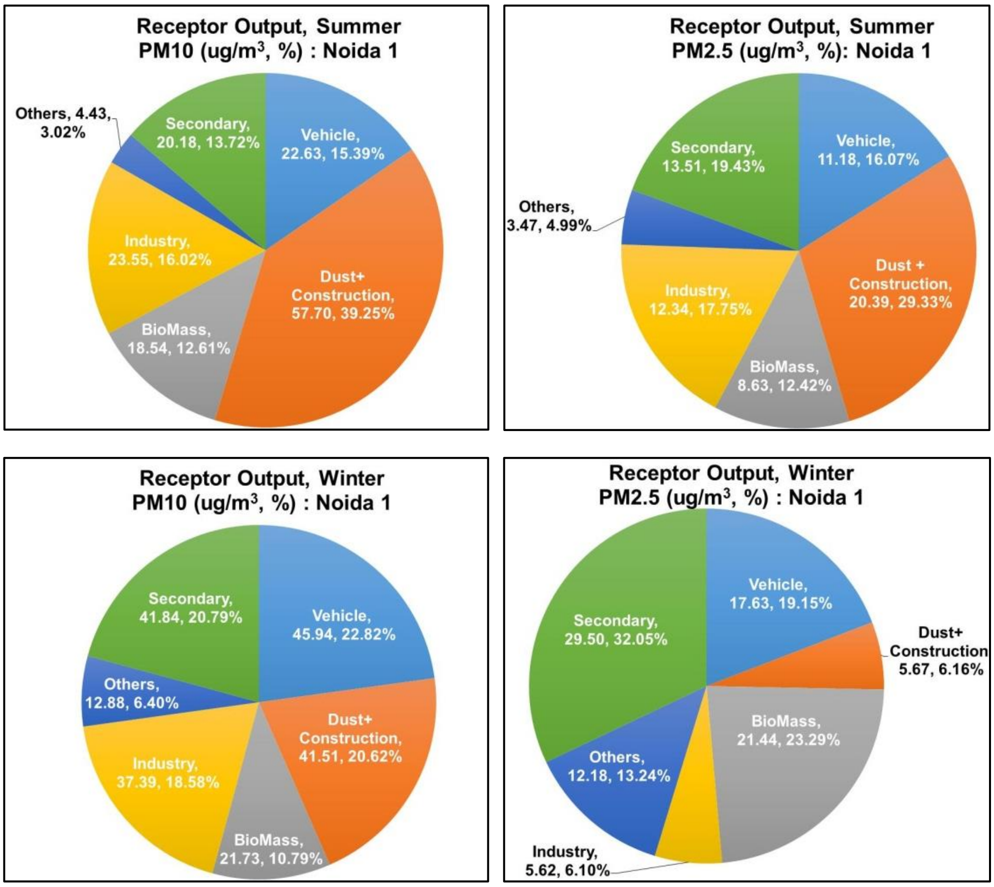


Figure 4.45 : Receptor Output Summer and Winter : PM_{10} and $PM_{2.5}$ at Noida 1

Noida-1 is situated in the NCR region at the southwest side of Delhi. This site is located in an industrial area and activities around the site include vehicular traffic on the Delhi–Noida highway, construction activities, slum area, occasional garbage burning, and use of DG sets.

During summer season in Noida-1, dust and construction were highest contributor at 39% (58 ± 20 μg/m^3) in PM_{10} and 29% (20 ± 4 μg/m^3) in $PM_{2.5}$, whereas in winter season, dust and construction was 21% (42 ± 20 μg/m^3) in PM_{10} and 6% (6 ± 3 μg/m^3) in $PM_{2.5}$.

Vehicles contributed 15% (23 ± 4 μg/m^3) of PM_{10} and 16% (11 ± 5 μg/m^3) of $PM_{2.5}$ in summer season. Whereas in winter season, it was major source in PM_{10}, with contribution to about 23% (46 ± 17 μg/m^3) in PM_{10} and 19% (18 ± 7 μg/m^3) in $PM_{2.5}$.

In summer season, secondary particulates contributed to about 14% (20 ± 3 μg/m^3) of PM_{10} and about 19% (14 ± 2 μg/m^3) of $PM_{2.5}$. In winter season, secondary particulates contributed was found to higher. It contributed to about 21% (42 ± 13 μg/m^3) in PM_{10} and 32% (26 ± 2 μg/m^3) in $PM_{2.5}$.

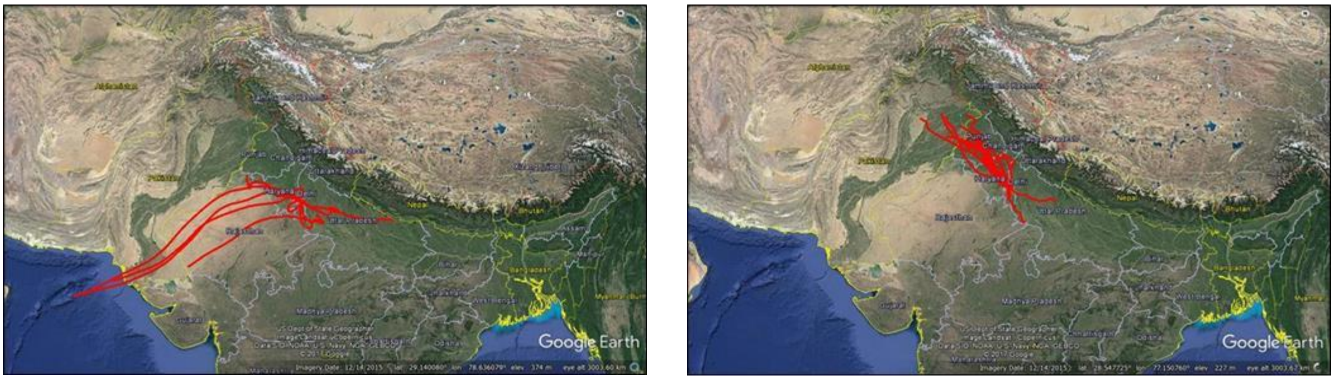
In summer season, biomass burning contributed to 13% of PM_{10} and 12% of $PM_{2.5}$. In winter season, biomass-burning activity increased with contribution to $PM_{2.5}$ as 24% (21 ± 13 μg/m^3) and about 11% (22 ± 13 μg/m^3) in PM_{10}.

In summer season, industries contributed 16% (24 ± 11 μg/m^3) of PM_{10} and 18% (12 ± 8 μg/m^3) of $PM_{2.5}$, whereas industry contributed 19% (37 ± 24 μg/m^3) of PM_{10} and 6% (7 ± 4 μg/m^3) of $PM_{2.5}$ in winter season.

In summer season, other sources contributed 3% of PM_{10} and 5% of $PM_{2.5}$, whereas it contributed to about 6% of PM_{10} and about 13% of $PM_{2.5}$ in winter season.

4.3.16 Site 16: Noida 2

Season	Monitoring Period
Summer	23-May-16 to 01-Jun-16
Winter	01-Dec-16 to 24-Dec-16



(a) (b)

Figure 4.46 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter

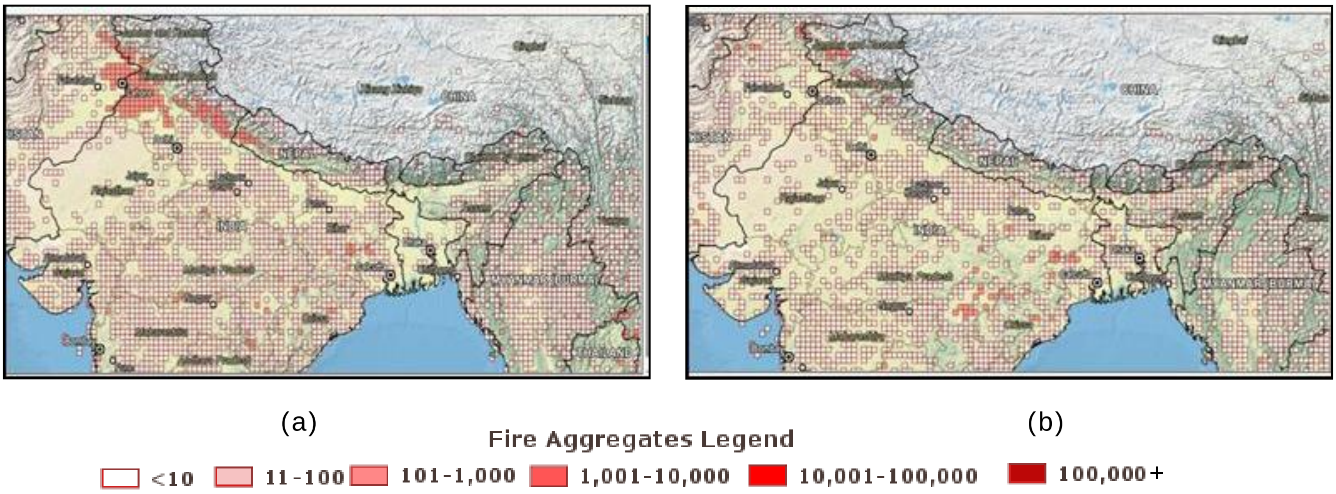


Figure 4.47 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Noida-2 site is presented in Fig. 4.46 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from west and east directions in summer season and in winter from north-west and, on a few days, from southeast direction. The incoming air will carry pollutants with it from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.47 (a) and (b) for the summer and winter seasons, respectively. A large number of live fires were observed in north-west direction and fewer in west direction, which is the predominant wind direction during the monitoring duration in the summer and winter seasons. Fewer numbers of live fires were observed in north-west direction as the crop residue-burning activity diminishes during this period. Thus, the incoming wind to Delhi NCR is expected to carry pollutants for sources like dust and tall stacks in summer and crop residue burning, dust, and tall stacks in winter.

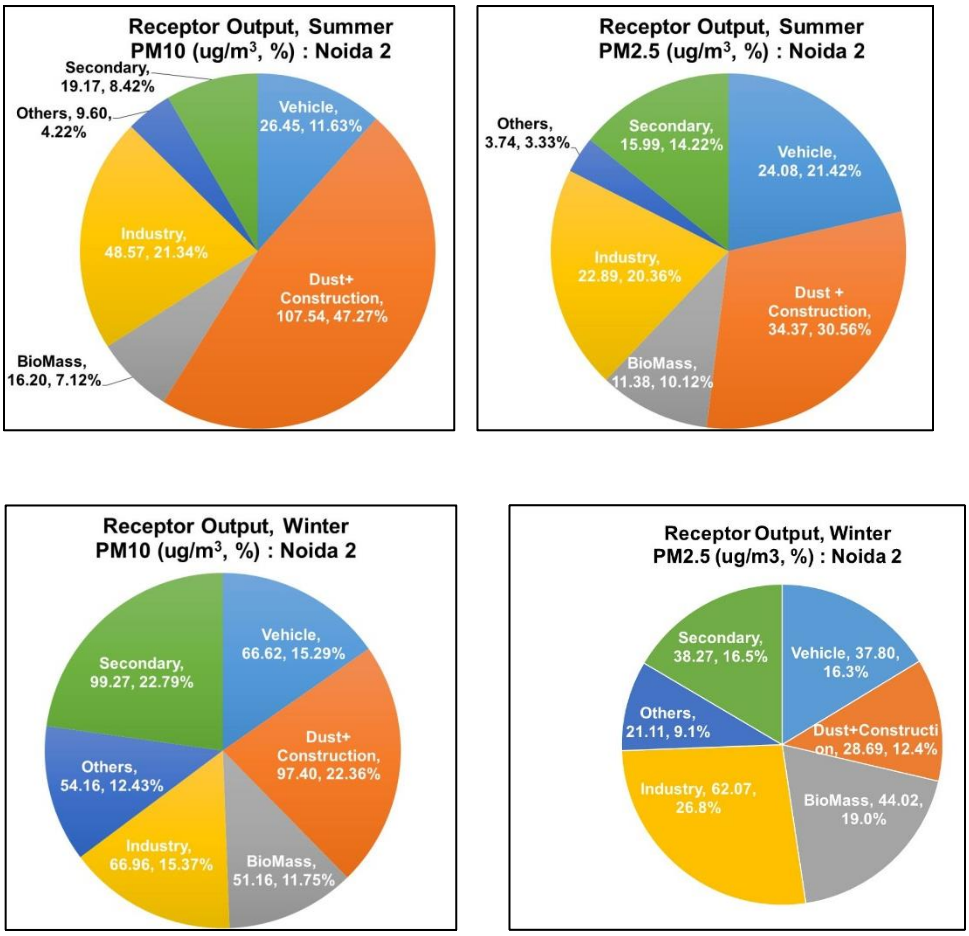


Figure 4.48 : Receptor Output Summer and Winter : PM10 and PM2.5 at Noida 2

In summer season at Noida-2, contribution from dust and construction was found to be higher in both PM_{10} (47%) with a concentration of 108 ± 25 $\mu g/m^3$ and $PM_{2.5}$ (31%) with concentration 34 ± 20 $\mu g/m^3$, which may be attributed to the ongoing construction site near the site. contribution of construction and dust decreased in winter season to 22% (97 ± 28 $\mu g/m^3$) and 12% (29 ± 12 $\mu g/m^3$) towards PM_{10} and $PM_{2.5}$, respectively. This may be due to lower wind velocity affecting transport of dust particles from the upwind direction.

The monitoring site was located in an industrial area and contribution from industries in summer was found to be 21% to PM_{10} (49 ± 21 $\mu g/m^3$) and 20% to $PM_{2.5}$ (23 ± 10 $\mu g/m^3$). Contribution in terms of percentage was increased to 27% in winter for $PM_{2.5}$ with concentration levels of 62 ± 38 $\mu g/m^3$ while industries contributed 15% (67 ± 32 $\mu g/m^3$) to PM_{10} in summer.

The site is surrounded by a densely populated area with significant vehicular movement. Contribution from vehicles in summer season was 12% of PM_{10} with an average concentration from vehicles of 26 ± 2 $\mu g/m^3$ and 21% of $PM_{2.5}$ (24 ± 7 $\mu g/m^3$). In winter, contribution was 15% (67 ± 28 $\mu g/m^3$) and 16% (38 ± 42 $\mu g/m^3$) to PM_{10} and $PM_{2.5}$, respectively.

The site has a slum area in the vicinity and wood is used for combustion for cooking. In addition, open burning was observed during the monitoring period. Contribution from biomass burning at this site in summer was 7% of PM_{10} (16 ± 3 $\mu g/m^3$) and 10% of $PM_{2.5}$ (11 ± 3 $\mu g/m^3$). While in winter, the contribution increased significantly to 19% for $PM_{2.5}$ with an average concentration of 44 ± 16 μg/m³. Similarly, there was an increased (12%) in contribution to PM_{10} with average concentration of 51 ± 18 μg/m³ from biomass burning.

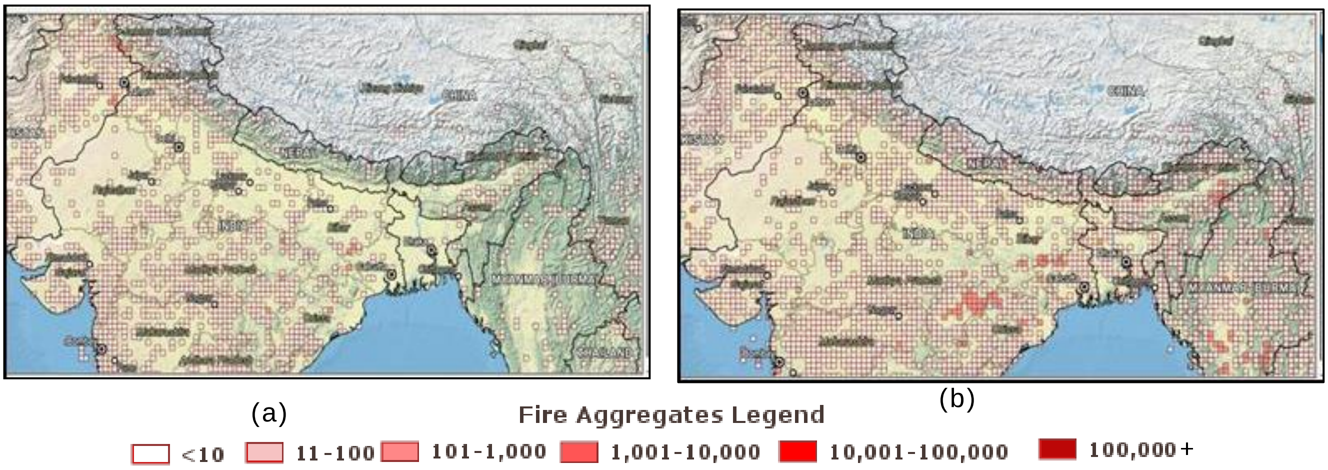
Contribution from other sources was 4% of PM_{10} and 3% of $PM_{2.5}$. The surrounding area of site shows a presence of open drainage and the contribution from secondary pollutant was 8% of PM_{10} (19 ± 8 μg/m³) and 14% of $PM_{2.5}$ (14 ± 3 μg/m³) in summer. In winter, contribution from secondary particles was found to be increased to 23% and 17% to PM_{10} and $PM_{2.5}$, respectively. Large variation was observed in secondary particles concentrations (99 ± 49 μg/m³) in case of PM_{10} in winter season.

4.3.17 Site 17: Gurgaon 1

Season	Monitoring Period
Summer	19-Jun-16 to 25-Jun-16
Winter	30-Jan-17 to 17-Feb-17

(a) (b)

Figure 4.49 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.50 : Fire data collected during monitoring period in (a) summer and (b) winter season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Gurgaon-1 site is presented in Fig.4.49 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east direction in summer and in winter from north-west and, on a few days, from southeast direction. The incoming air will carry with it pollutants from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.50 (a) and (b) for summer and winter seasons, respectively. Lesser number of live fires were observed in east direction, which is the predominant wind direction during monitoring duration in summer and in winter seasons, fewer number of live fires were observed in north-west direction as the crop residue-burning activity diminishes during this period. Thus the incoming wind to Delhi-NCR is expected to carry pollutants for sources like dust and tall stacks in summer and crop residue burning, dust, and tall stacks in winter.

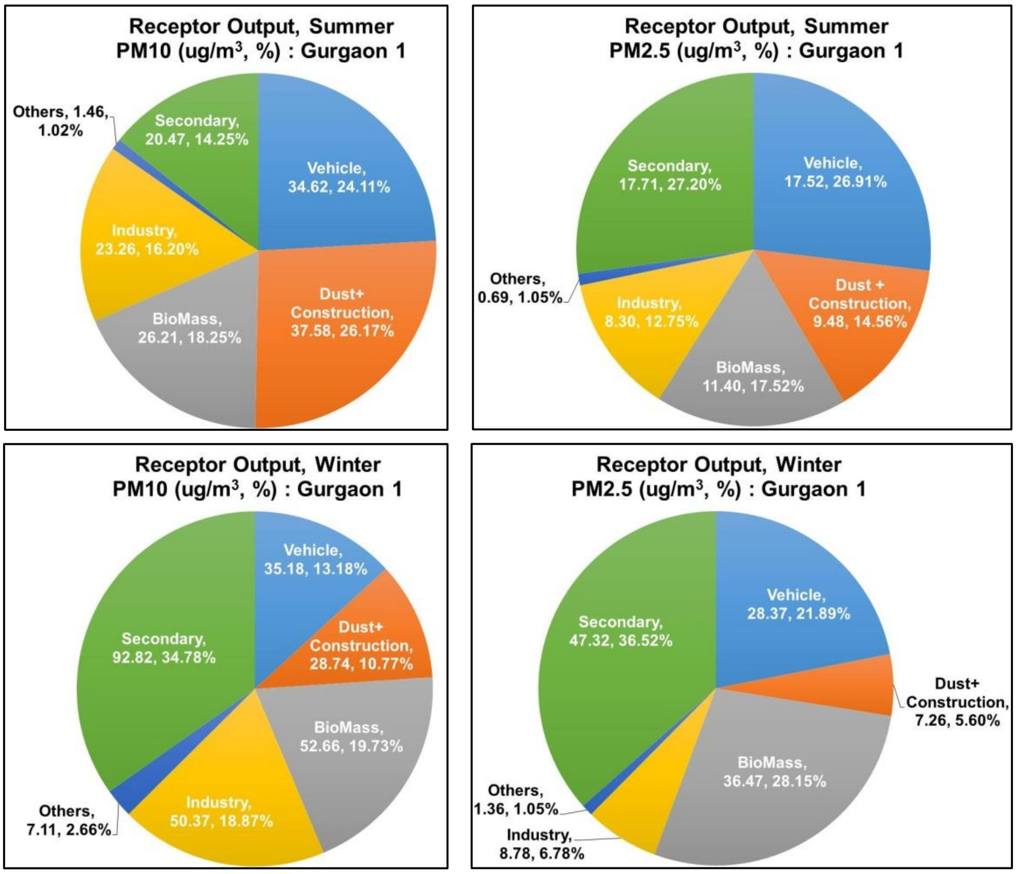


Figure 4.51 : Receptor Output Summer and Winter : PM10 and PM2.5 at Gurgaon 1

Gurgaon-1 is a site in the NCR region situated at the south side of Delhi city. This site is located in a residential area. Activities around the site include vehicles plying on the nearby highway, a few construction sites, and has some open space and unpaved roads in near vicinity.

In summer season at Gurgaon-1, contribution from dust and construction was found to be higher in PM_{10} (26%) with concentration of 36 ± 15 µg/m^3 while its contribution to $PM_{2.5}$ was 15% with concentration 9 ± 2 µg/m^3, which may be attributed to the re-suspension of dust from the open space and unpaved roads near the site. contribution of construction and dust decreased in winter season to 11% (29 ± 10 µg/m^3) and 6% (7 ± 3 µg/m^3) towards PM_{10} and $PM_{2.5}$, respectively. This may be due to a lower wind velocity affecting transport of dust particles from the upwind direction.

Though Gurgaon in NCR is an industrial area, the site is located in a purely residential area and the industries are situated at a distance from the site. This has reflected in seasonal variation in contribution of industries. Contribution from the industries in summer season was found to be 16% to PM_{10} (23 ± 14 µg/m^3) and 13% to $PM_{2.5}$ (8 ± 3 µg/m^3). Contribution in terms of percentage was 7% in winter for PM $_{2.5}$ with concentration levels of 9 ± 3 µg/m^3 while industries contributed 19% (50 ± 17 µg/m^3) to PM_{10} in winter. A somewhat higher contribution in PM_{10} in winter may be due to the trade-off between industries and dust and construction, which seem to be underestimated.

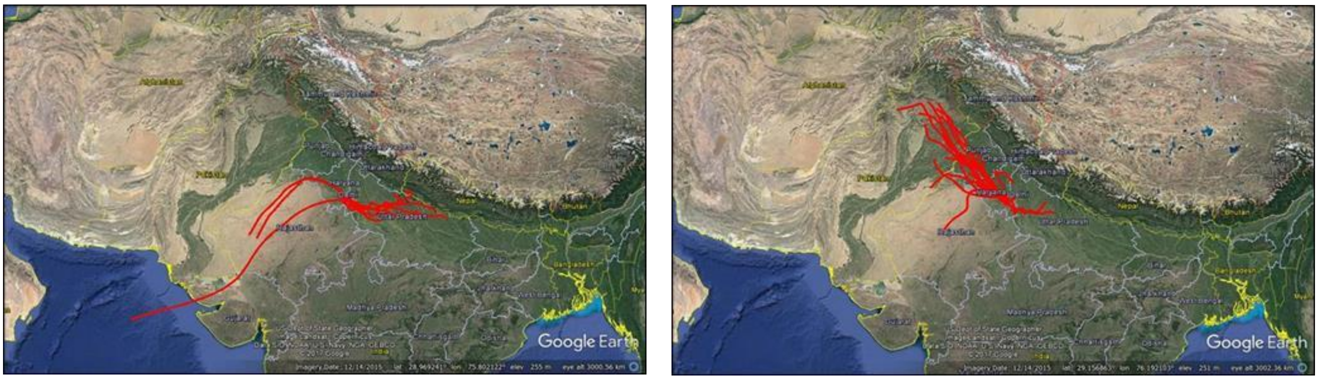
The site is located in a populated area and features vehicular movement on the nearby highway. contribution from vehicles in summer season was 24% of PM_{10} with an average concentration from vehicles of 35 ± 14 µg/m³ and 27% of $PM_{2.5}$ (18 ± 2 µg/m³). In the winter season, contribution was 13% and 22% to PM_{10} and $PM_{2.5}$, respectively. Contribution in terms of concentration in PM_{10} has remained similar, however, in $PM_{2.5}$, it increased significantly to 28 µg/m³. This may be attributed to the lower wind velocities in winter and thus predominant contribution from local sources.

Contribution from biomass burning at this site in summer was 18% of PM_{10} (26 ±19 µg/m³) and 18% of $PM_{2.5}$ (11 ± 3 µg/m³). While in winter, the contribution increased significantly to 28% for $PM_{2.5}$ with an average concentration of 37 µg/m³ and in case of PM_{10}, it was 20% with an average concentration of 53 µg/m³ from biomass burning. This may be attributed to the open burning of dry leaves observed during the monitoring period.

Contribution from secondary particulates was 14% of PM_{10} and 27% of $PM_{2.5}$ in summer season. In winter season, the secondary particles were found to be highest in both PM_{10} and $PM_{2.5}$ and contribution was found to be increased to 35% and 37% for PM_{10} and $PM_{2.5}$.

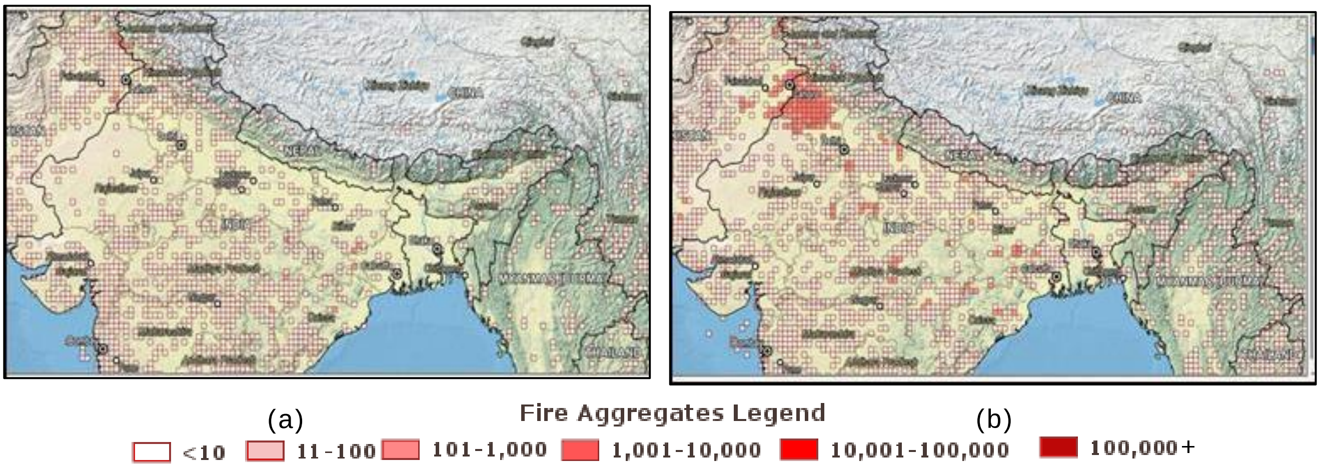
4.3.18 Site 18: Gurgaon 2

Season	Monitoring Period
Summer	03-Jun-16 to 11-Jun-16
Winter	21-Nov-16 to 06-Dec-16



(a) (b)

Figure 4.52 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.53 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Gurgaon-2 site is presented in Fig. 4.52 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east and west direction in summer and in winter from north-west and, on a few days, from southeast direction. The incoming air will carry with it pollutants from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.53 (a) and (b) for summer and winter seasons, respectively. Fewer number of live fires were observed in east and direction as the crop residue burning-activity diminishes during this period, which is the predominant wind direction during monitoring duration in summer and in winter a large number of live fires were observed in north-west direction. Thus the incoming wind to Delhi-NCR is expected to carry pollutants for sources like dust and tall stacks in summer and crop residue burning, dust, and tall stacks in winter.

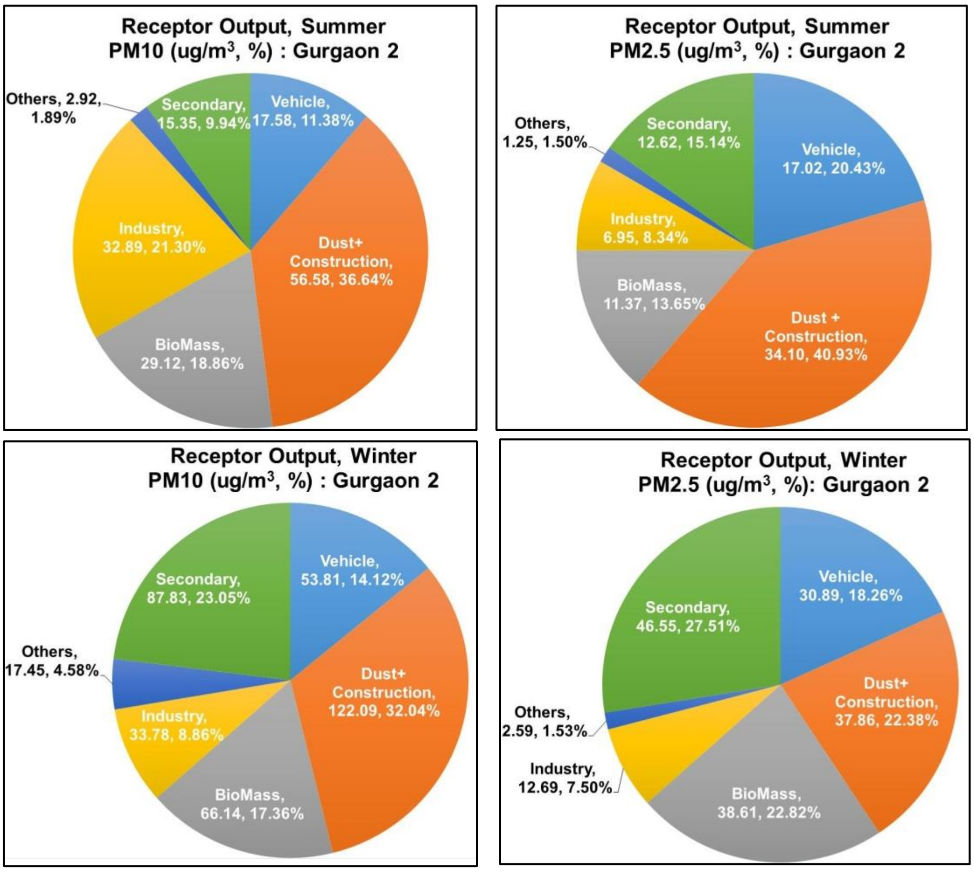


Figure 4.54 : Receptor Output Summer and Winter : PM10 and PM2.5 at Gurgaon 2

Gurgaon-2 is situated in the NCR region at the southern side of city. This site is located in the densely populated area and activities around the site, including light vehicular traffic, construction activities, and the site in near vicinity has railway lines and open land.

In summer season at Gurgaon-2, contribution from dust and construction was found to be higher in PM_{10} (37%) with a concentration of 57 $\pm$ 14 $\mu g/m^3$, while its contribution to $PM_{2.5}$ was 41% with a concentration 34 $\pm$ 13 $\mu g/m^3$, which may be attributed to the re-suspension of dust from the open spaces and unpaved roads near the site. contribution of construction and dust decreased, in terms of percentage, in winter season to 32% (122 $\pm$ 75 $\mu g/m^3$) and 22% (39 $\pm$ 25 $\mu g/m^3$) towards PM_{10} and $PM_{2.5}$, respectively. However, in terms of concentration, it was significantly higher. The concentration in case of $PM_{2.5}$ remained lower and PM_{10} was found to be higher. This may be due to lower wind velocity and thus lesser transport of fine dust particles from the upwind direction.

The site is located in a purely residential area and the industries are at a distance from the site. The contribution from industries in summer was found to be 21% to PM_{10} (33 $\pm$ 7 $\mu g/m^3$) and 8% to $PM_{2.5}$ (7 $\pm$ 5 $\mu g/m^3$). Contribution in terms of percentage was 8% in winter for $PM_{2.5}$ with concentration levels of 13 $\pm$ 7$\mu g/m^3$, while industries contributed 9% (34 $\pm$ 8 $\mu g/m^3$) to

PM_{10} in the winter. Contribution of industries in concentration was higher in winter for $PM_{2.5}$ but remained similar to PM_{10}.

The site is located in a densely populated area and features vehicle movement on nearby roads. The contribution from vehicles in summer was 11% of PM_{10} with an average concentration from vehicles of 18 ± 4 $\mu g/m^3$ and 20% of $PM_{2.5}$ (17 ± 4 $\mu g/m^3$). In the winter, contribution was 14% and 18% to PM_{10} and $PM_{2.5}$ respectively. Contribution in terms of concentration in PM_{10} and $PM_{2.5}$ increased significantly to 54 $\mu g/m^3$ and 31$\mu g/m^3$. This may be attributed to the lower wind velocities in winter and thus predominant contribution from local sources.

Contribution from biomass burning in the summer was 19% of PM_{10} (29 ±11 $\mu g/m^3$) and 14% of $PM_{2.5}$ (11 ± 9 $\mu g/m^3$). While in the winter, the contribution increased and was 23% for $PM_{2.5}$ with an average concentration of 39 $\mu g/m^3$ and in case of PM_{10}, it was 17% with an average concentration of 66 $\mu g/m^3$ from biomass burning. This increased concentration level in the winter may be attributed to the local sources during the monitoring period.

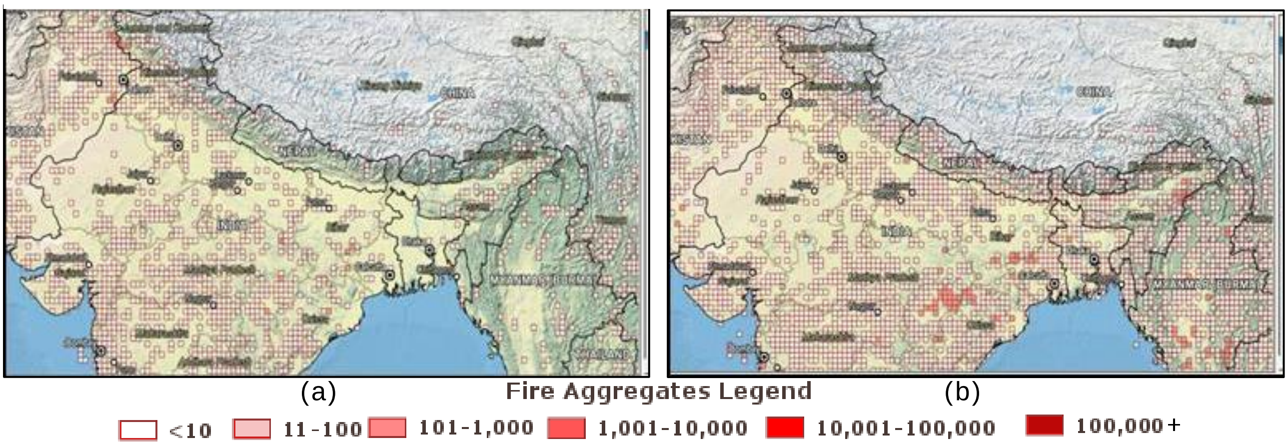
Contribution from secondary particulates was 10% of PM_{10} and 15% of $PM_{2.5}$ in summer. In winter season, the secondary particles were found to be highest in $PM_{2.5}$ and contribution was found to have increased to 23% and 28% for PM_{10} and $PM_{2.5}$.

4.3.19 Site 19: Faridabad 1

Season	Monitoring Period
Summer	21-Jun-16 to 29-Jun-16
Winter	11-Jan-17 to 21-Jan-17

(a) (b)

Figure 4.55 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Figure 4.56 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Faridabad-1 site is presented in Fig. 4.55 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east direction in summer and in winter from north-west direction. The incoming air will carry with it pollutants from large sources from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.56 (a) and (b) for summer and winter seasons, respectively. Fewer number of live fires were observed in east direction, which is the predominant wind direction during monitoring duration in summer and in winter fewer number of live fires were observed in north-west direction as the crop residue-burning activity diminishes during this period. Thus the incoming wind to Delhi-NCR is expected to carry pollutants for sources like dust and tall stacks in summer and crop residue burning, dust, and tall stacks in winter.

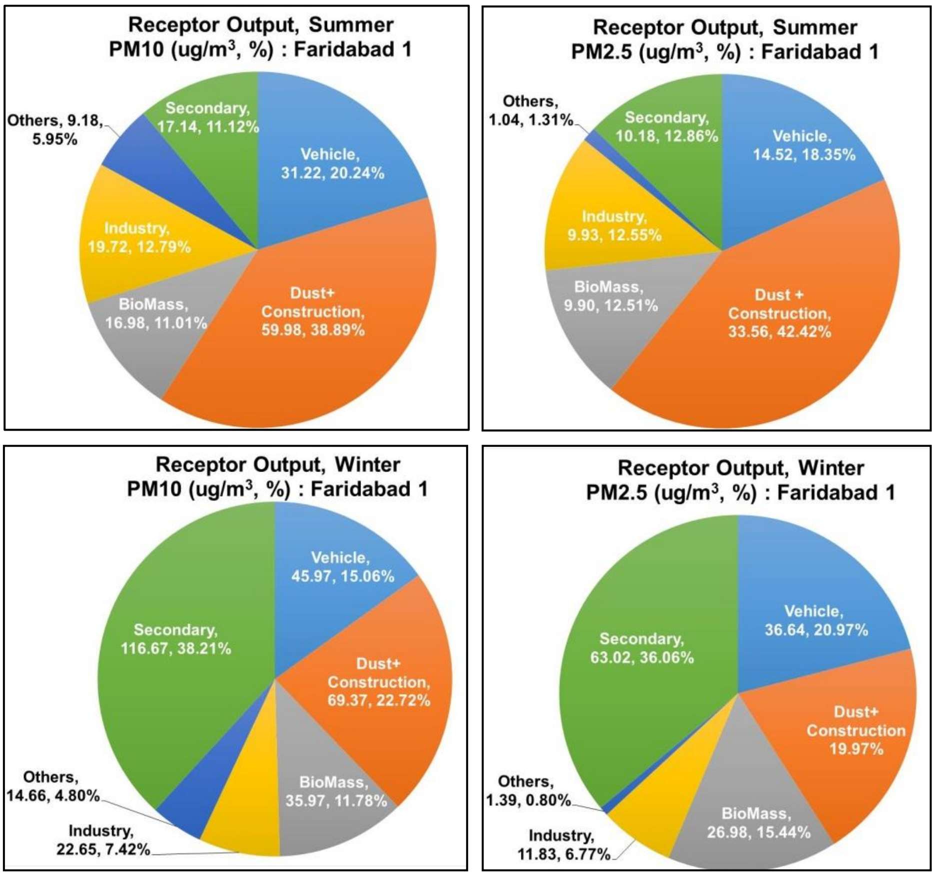


Figure 4.57 : Receptor Output Summer and Winter : PM10 and PM2.5 at Faridabad 1

Faridabad-1 is situated in the NCR region at the southern side of Delhi city. This site is located in a densely populated area and activities around the site include light vehicle traffic, construction activities, unpaved road, occasional garbage burning, and open land.

In summer season at Faridabad-1, contribution from dust and construction was found to be higher in PM_{10} (39%) with a concentration of 60 ± 4 µg/m^3, while its contribution to $PM_{2.5}$ was 42% with concentration 34 ± 7 µg/m^3. This may be attributed to the re-suspension of dust from the open space and unpaved roads near the site and also from the dust coming from upwind direction. Contribution of construction and dust decreased, in terms of percentage, in winter season to 23% (69 ± 13 µg/m^3) and 20% (35 ± 17 µg/m^3) towards PM_{10} and $PM_{2.5}$, respectively. However, in terms of concentration, it was significantly higher. In winter, concentration in case of $PM_{2.5}$ remained similar to that of summer and PM_{10} was found to be higher. This may be due to a lower wind velocity and thus resulted in the less transport of fine dust particles from the upwind direction.

Contribution from industries in summer was found to be 13% to PM_{10} (20 ± 13 µg/m^3) and 13% to $PM_{2.5}$ (10 ± 4 µg/m^3). Contribution in terms of percentage was 7% in the winter for $PM_{2.5}$ and PM_{10} with concentration levels of 23 ± 17 µg/m^3 12 ± 7 µg/m^3 of PM_{10} and $PM_{2.5}$ in the winter.

The site is located in a densely populated area and features vehicular movement on nearby roads. Contribution from vehicles in summer was 20% of PM$_{10}$ with an average concentration from vehicles of 31 ± 11 $\mu g/m^3$ and 18% of PM$_{2.5}$ (15 ± 5 $\mu g/m^3$). In winter, contribution was 15% and 21% to PM$_{10}$ and PM$_{2.5}$, respectively. Contribution in terms of concentration in PM$_{10}$ and PM$_{2.5}$ increased significantly in winter to 46 $\mu g/m^3$ and 37$\mu g/m^3$. This may be attributed to the lower wind velocities in winter and thus predominant contribution from local sources.

Contribution from biomass burning at this site in summer was 11% of PM$_{10}$ (17 ± 9 $\mu g/m^3$) and 13% of PM$_{2.5}$ (10 ± 6 $\mu g/m^3$). While in winter, the contribution was 16% for PM$_{2.5}$ with an average concentration of 27 $\mu g/m^3$ and in case of PM10, it was 12% with average concentration of 36 $\mu g/m^3$ from biomass burning. This increased concentration level in winter may be attributed to the local sources during the monitoring period.

Contribution from secondary particulates was 11% (17 ± 2 $\mu g/m^3$) of PM$_{10}$ and 13% (10 ±4 □g/m^3) of PM$_{2.5}$ in summer. In winter season, the secondary particles was found to be highest in PM$_{2.5}$ and PM$_{10}$ and contribution was found to be increased to 39% (117 ± 43 $\mu g/m^3$) and 36% (63 ± 13 $\mu g/m^3$) for PM$_{10}$ and PM$_{2.5}$.

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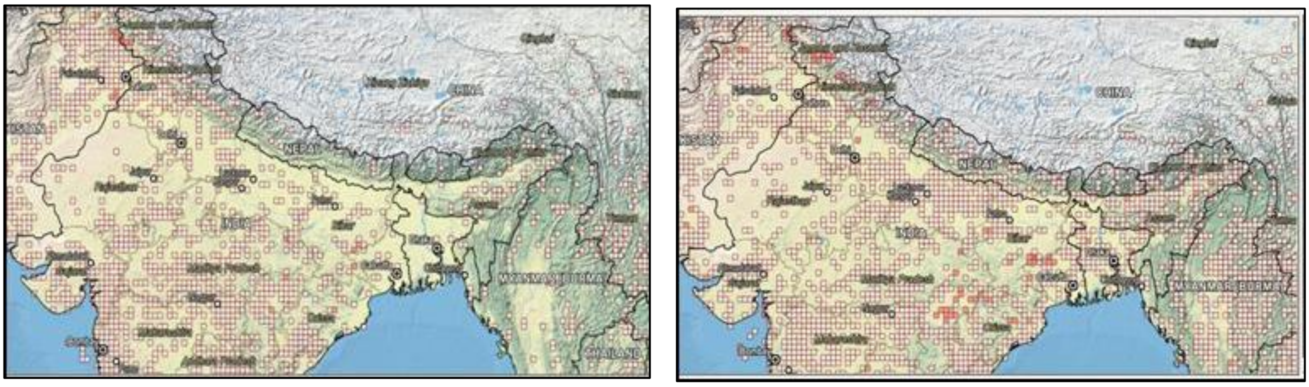
4.3.20 Site 20: Faridabad 2

Season	Monitoring Period
Summer	04-Jun-16 to 10-Jun-16
Winter	28-Dec-16 to 08-Jan-17

(a) (b)

Figure 4.58 : Wind Direction Trajectories during monitoring period (a) Summer Season and (b) Winter Season



(a) (b)

Fire Aggregates Legend

☐ <10 ▨ 11-100 ▨ 101-1,000 ▨ 1,001-10,000 🟥 10,001-100,000 🟥 100,000+

Figure 4.59 : Fire data collected during monitoring period in (a) Summer Season and (b) Winter Season

Wind back-trajectories HYSPLIT for 48 hours for the monitoring days at Faridabad-2 site is presented in Fig. 4.58 (a) and (b) for summer and winter seasons, respectively. Wind is predominantly flowing from east direction in summer and in winter from the north-west direction. The incoming air will carry pollutants with it large sources t from the area over which it is flowing. Data on number of live fire aggregates observed from Fire Information for Resource Management Systems (FIRMS) during the monitoring period is presented Fig. 4.59 (a) and (b) for summer and winter seasons, respectively. Fewer number of live fires were observed in east direction, which is the predominant wind direction during monitoring duration in summer and in winter less number of live fires were observed in north-west direction as the crop residue-burning activity diminishes during this period. Thus the incoming wind to Delhi-NCR is expected to carry pollutants for sources such as dust and tall stacks in summer and crop residue-burning, dust, and tall stacks in winter.

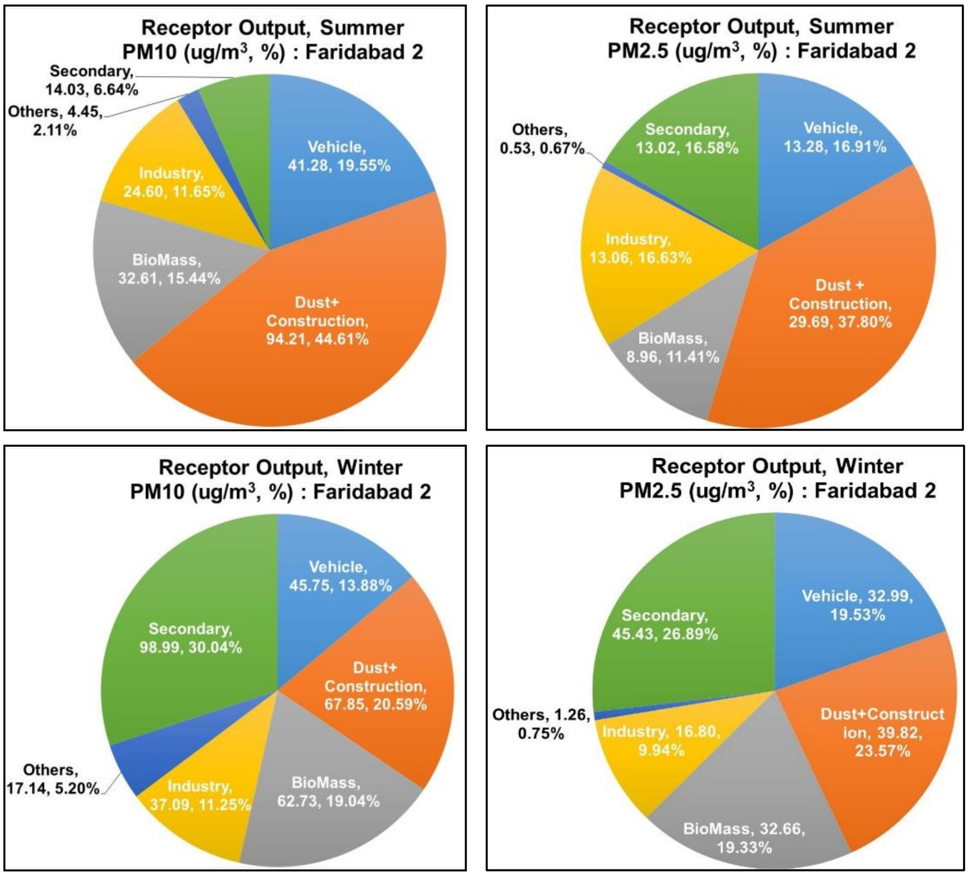


Figure 4.60 : Receptor Output Summer and Winter : PM10 and PM2.5 at Faridabad 2

Faridabad-2 site is situated in the NCR region at the southern side of Delhi city. This site is located in the densely populated area and activities around the site include vehicular traffic, construction activities, slum area, unpaved road, hotels nearby, and occasional garbage burning.

In summer season at Faridabad-2, contribution from dust and construction was found to be higher in PM_{10} (45%) with a concentration of 94 ± 8 $\mu g/m^3$ while its contribution to $PM_{2.5}$ was 38% with a concentration 30 ± 13 $\mu g/m^3$. This may be attributed to the re-suspension of dust from the open space, unpaved roads near the site and from the dust coming from upwind direction. Contribution of construction and dust decreased, in terms of percentage, in winter season to 21% (68 ± 13 $\mu g/m^3$) and 24% (42 ± 33 $\mu g/m^3$) towards PM_{10} and $PM_{2.5}$, respectively. However, in terms of concentration, it was significantly higher for $PM_{2.5}$.

Contribution from industries in summer season was found to be 12% to PM_{10} (25 ± 6 $\mu g/m^3$) and 17% to $PM_{2.5}$ (13 ± 5 $\mu g/m^3$). The contribution in terms of percentage was 10% and 11% in winter season for $PM_{2.5}$ and PM_{10}, respectively. The concentration levels were observed to be 37 ± 15 $\mu g/m^3$ and 17 ± 10 $\mu g/m^3$ for PM_{10} and $PM_{2.5}$ in winter season. Contribution of industries in concentration level was higher in winter for $PM_{2.5}$ and PM_{10}.

The site is located in a densely populated area and features vehicular movement on nearby roads. Contribution from vehicles in summer was 20% of PM_{10} with an average concentration from vehicles of 41 ± 8 $\mu g/m^3$ and 18% of $PM_{2.5}$ (13 ± 6 $\mu g/m^3$). In winter, contribution was 14% and 20% to PM_{10} and $PM_{2.5}$, respectively. Contribution in terms of concentration in PM_{10} and $PM_{2.5}$ increased significantly in winter to 45 $\mu g/m^3$ and 33 $\mu g/m^3$, respectively. This may be attributed to the lower wind velocities in winter and thus predominant contribution from local sources.

Contribution from biomass burning at this site in summer was 15% of PM_{10} (33 ±19 μg/m^3) and 11% of $PM_{2.5}$ (9 ± 5 μg/m^3). While in winter, its contribution was 19% for both $PM_{2.5}$ and PM_{10} with an average concentration of 33 μg/m^3 and 63 μg/m^3, respectively to $PM_{2.5}$ and PM_{10} from biomass burning. This increased concentration level in winter may be attributed local sources during the monitoring period.

The contribution from secondary particulates was 7% (14 ± 7 μg/m^3) of PM_{10} 11and 17% (13 ± 2 μg/m^3) of $PM_{2.5}$ in summer. In winter season, the secondary particles were found to be highest in $PM_{2.5}$ and PM_{10} and contribution was found to be increased to 30% (99 ± 35 μg/m^3) and 27% (45 ± 12 μg/m^3) for PM_{10} and $PM_{2.5}$, respectively.

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The results of source apportionment by receptor modelling of $PM_{2.5}$ and PM_{10} in summer and winter seasons at the monitoring sites are presented in Figures 4.61 to 4.64.

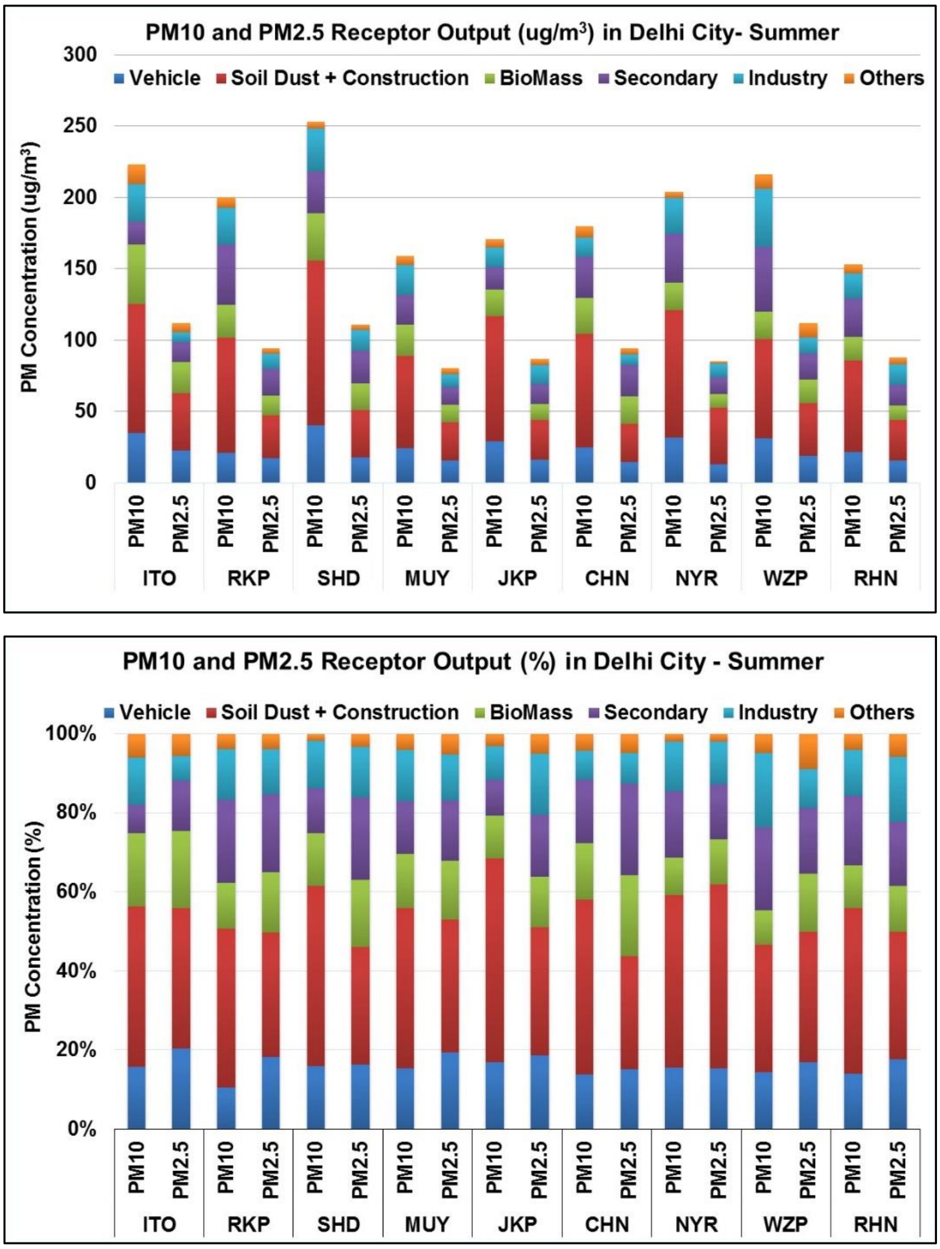
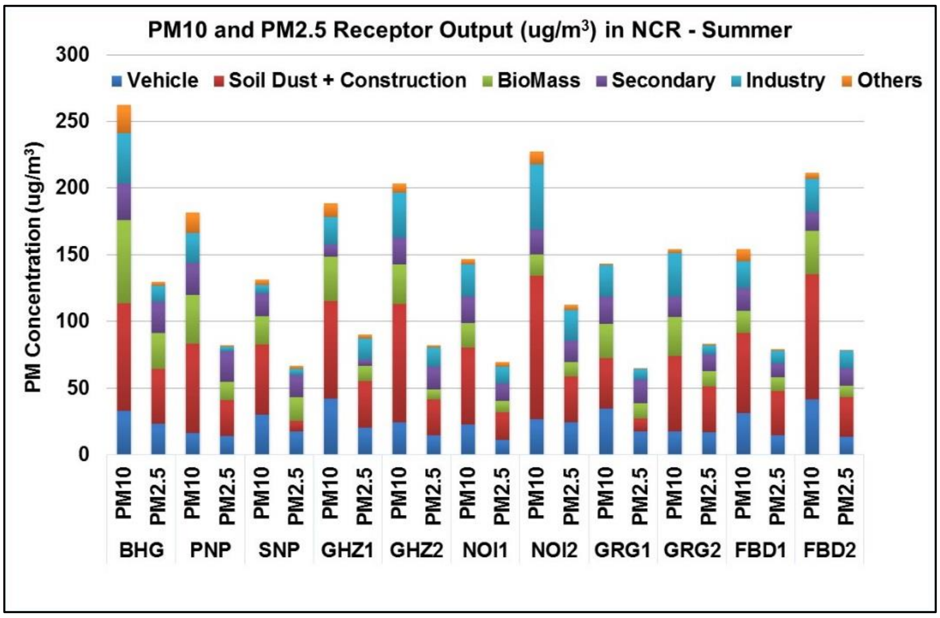


Figure 4.61: Receptor modelling output (µg/m³ and %) of PM_{10} and $PM_{2.5}$ in summer season at respective monitoring site in Delhi city



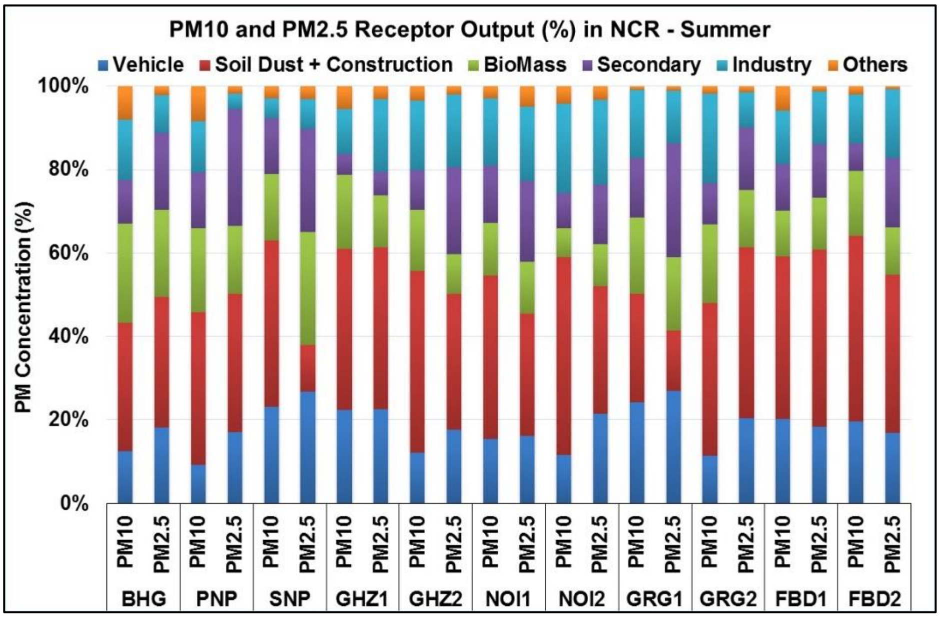
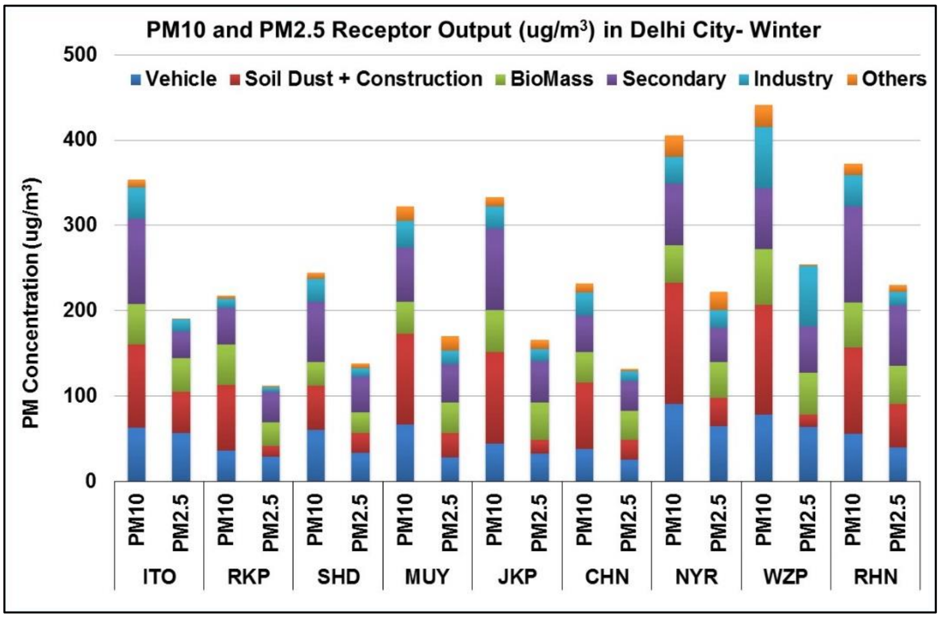


Figure *4.62*: Receptor modelling output (µg/m³ and %) of PM_{10} and $PM_{2.5}$ in summer season at respective monitoring site in NCR Towns



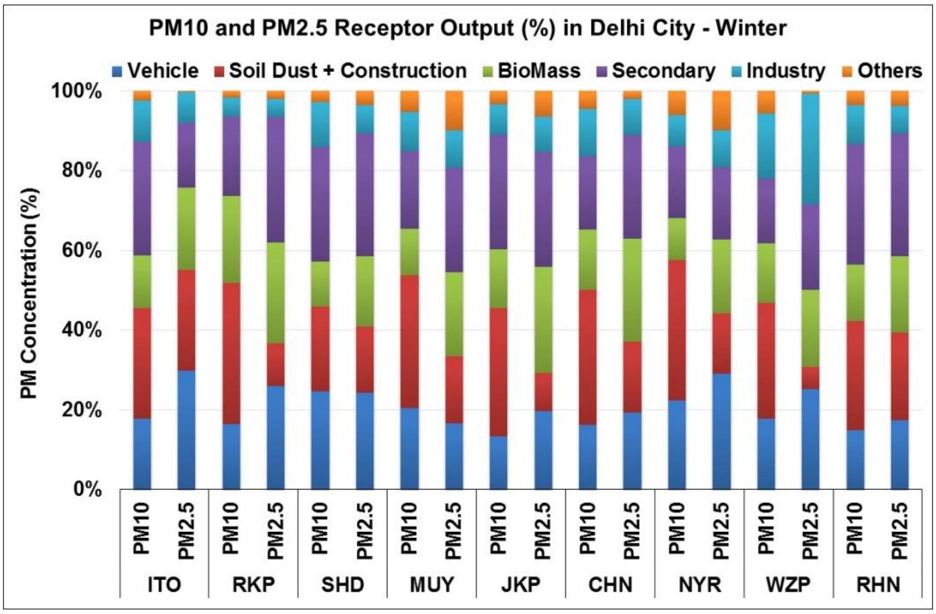


Figure 4.63: Receptor modelling output (µg/m³ and %) of PM_{10} and $PM_{2.5}$ in Winter Season at respective monitoring site in Delhi City

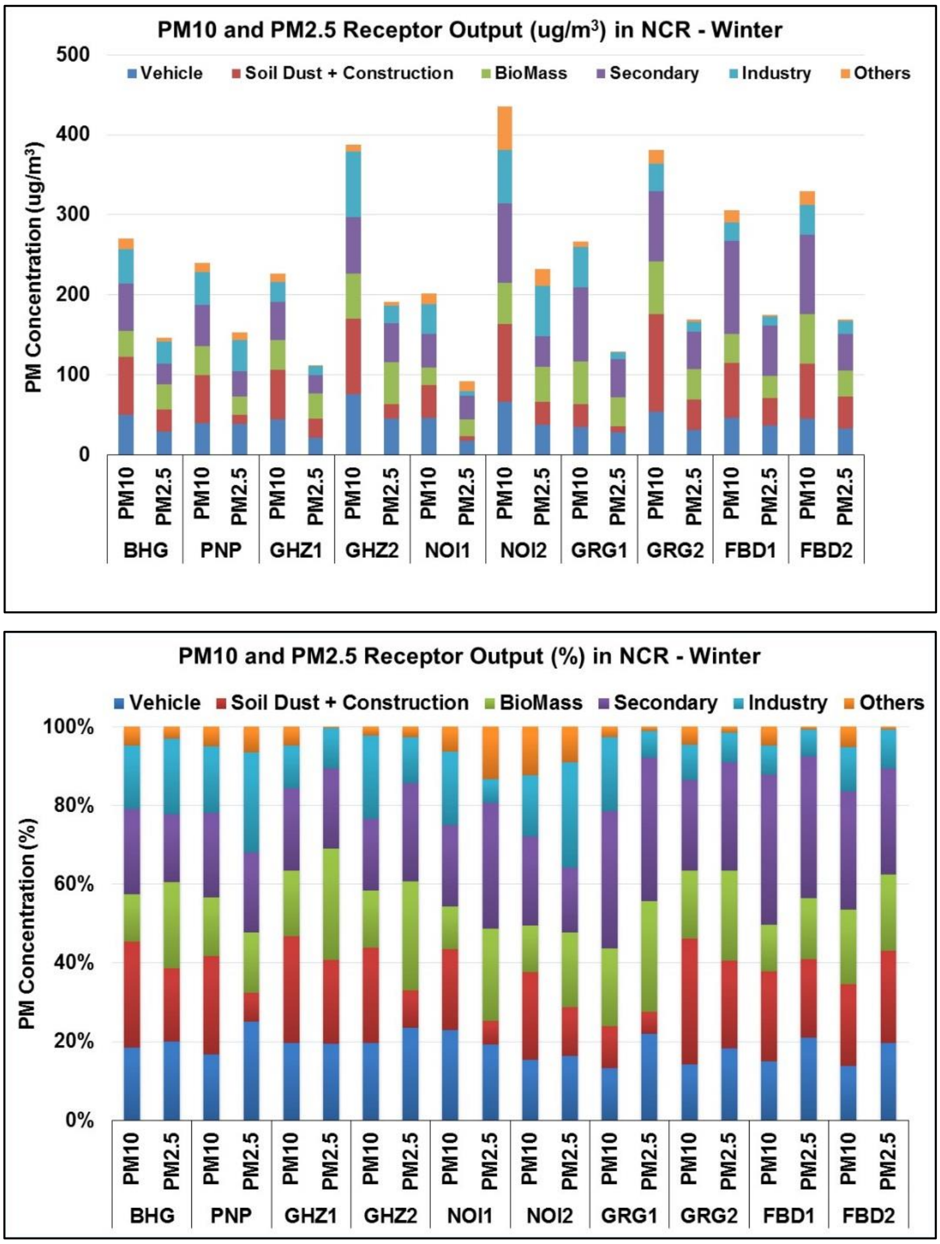


Figure 4.64: Receptor modelling output (µg/m³ and %) of PM_{10} and $PM_{2.5}$ in Winter Season at respective monitoring site in NCR Towns

Average contribution of different sources towards PM_{10} and $PM_{2.5}$ in summer and winter seasons for sites in Delhi city and NCR is presented in Figures 288 to 295.

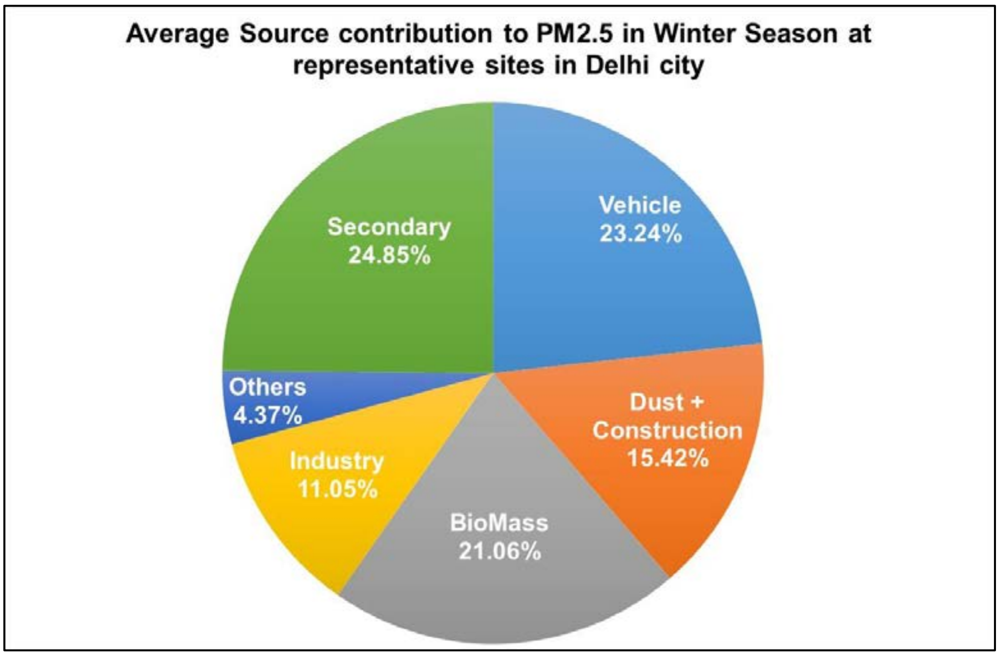


Figure 4.65: Average source contribution to $PM_{2.5}$ samples at representative sites in winter season in Delhi City

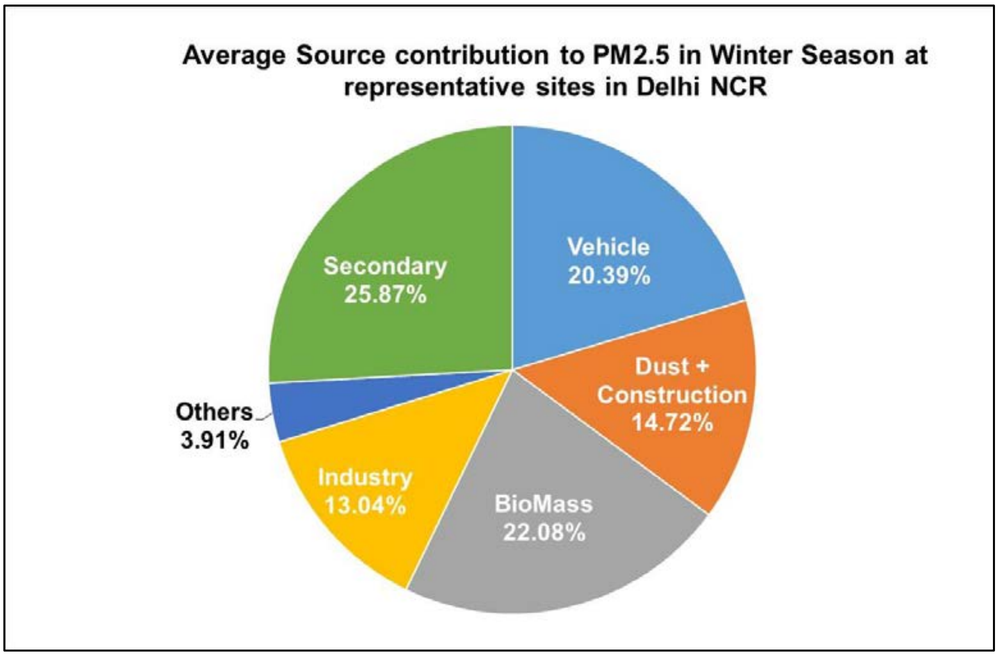


Figure 4.66: Average source contribution to $PM_{2.5}$ samples at representative sites in winter season in NCR (Excluding Delhi City)

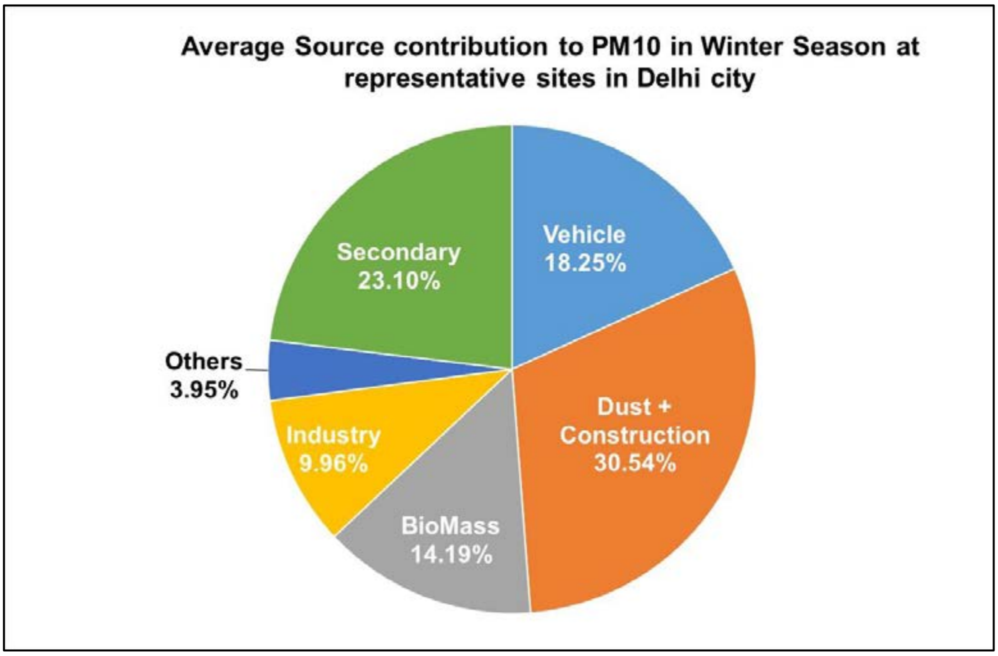


Figure 4.67: Average source contribution to PM_{10} samples at representative sites in winter season in Delhi City

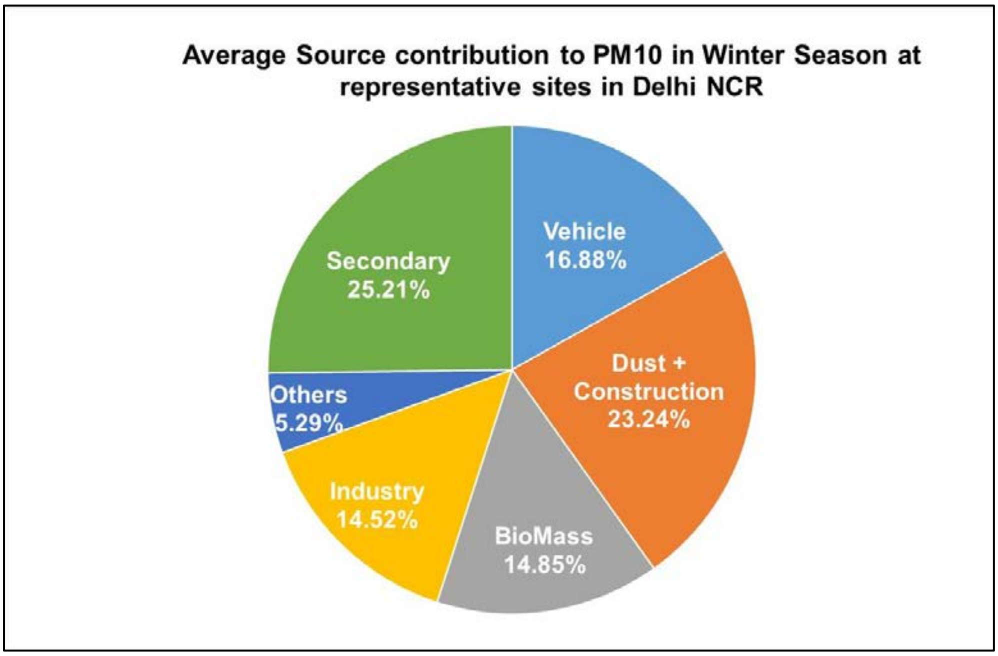


Figure 4.68: Average source contribution to PM_{10} samples at representative sites in winter season in NCR (Excluding Delhi City)

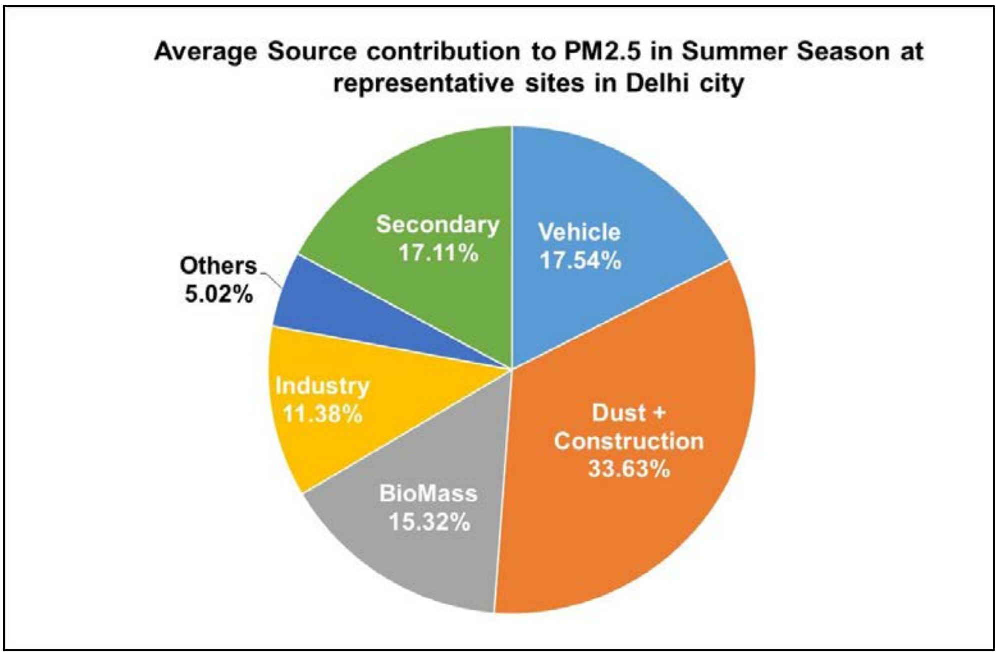


Figure 4.69: Average source contribution to $PM_{2.5}$ samples at representative sites in Summer season in Delhi City

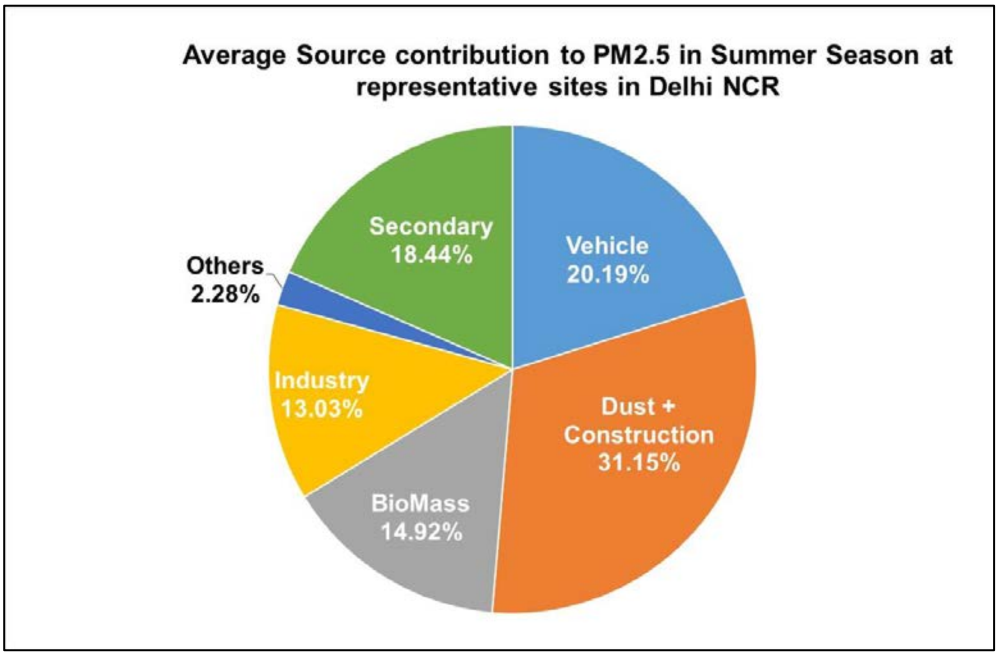


Figure 4.70: Average source contribution to $PM_{2.5}$ samples at representative sites in Summer season in NCR (Excluding Delhi City)

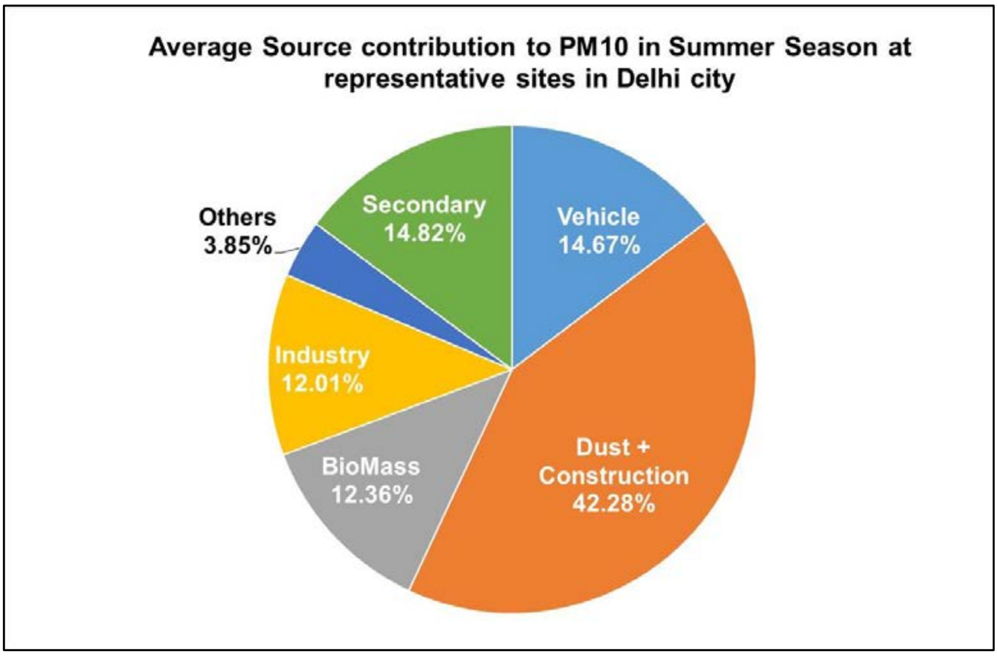


Figure 4.71: Average source contribution to PM_{10} samples at representative sites in Summer season in Delhi City

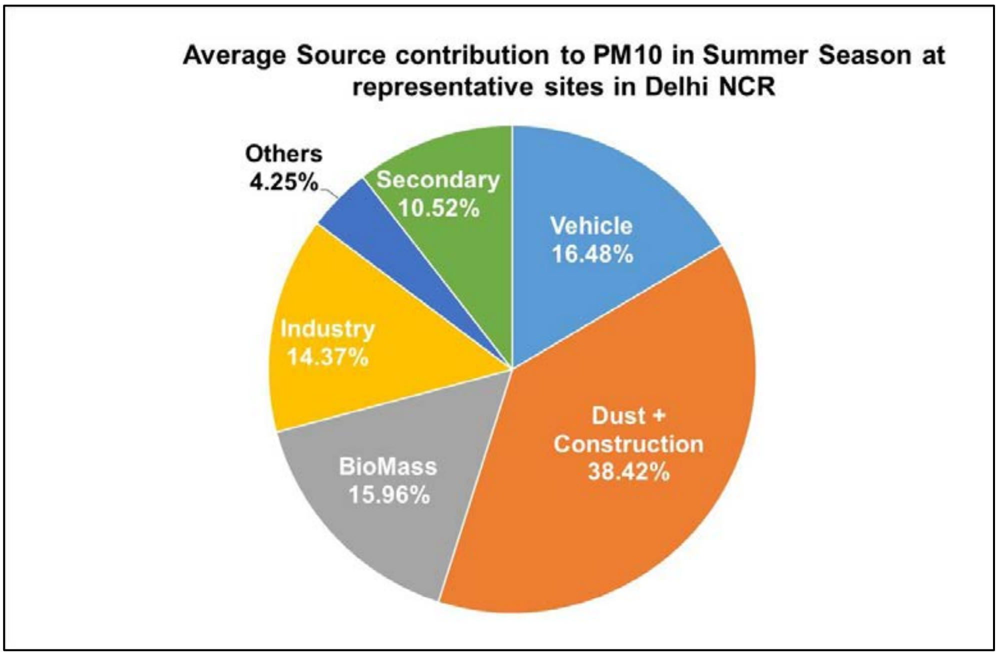


Figure 4.72: Average source contribution to PM_{10} samples at representative sites in Summer season in NCR (Excluding Delhi City)

4.4 Results and Discussion:

Variation in contribution of sources, such as vehicles, biomass burning, and dust, at various sites may be attributed to the variation in activities at the local level. Contribution from sources outside Delhi, such as agricultural waste burning and dust particles may be expected.

4.4.1 $PM_{2.5}$

Average of estimated contribution from vehicles towards $PM_{2.5}$ in winter season was found to be 22% ± 4% (35±15 µg/m^3). Similarly, contribution of dust and construction was 15% ± 7% (24 ± 14 µg/m^3), biomass burning 22% ± 4% (34 ± 12 µg/m^3), industry 12% ± 7% (20 ± 18 µg/m^3), secondary particulates 26% ± 7% (40 ± 15 µg/m^3), and others 4% ± 4% (7 ± 7 µg/m^3).

Overall average of estimated contribution towards $PM_{2.5}$ in summer season based on all sites in Delhi NCR, from dust and construction was 32% ± 8% (30 ± 9 µg/m^3). Average contribution form vehicles was found to be 19% ± 3% (17 ± 4 µg/m^3), biomass burning 15% ± 4% (14 ± 5 µg/m^3), industry 12% ± 5% (11 ± 4 µg/m3), secondary particulates 18% ± 5% (16 ± 5 µg/m^3), and others 4% ± 2% (3 ± 2 µg/m^3).

4.4.2 PM_{10}

Average of estimated contribution from vehicles towards PM_{10} in winter season was found to be about 18% ± 5% (52 ± 20 µg/m^3). Similarly, contribution of dust and construction was 27% ± 5% (80 ± 35 µg/m^3), biomass burning 15% ± 3% (43 ± 16 µg/m^3), industry 12% ± 4% (37 ± 19 µg/m^3), secondary particulates 24% ± 6% (72 ± 29 µg/m^3), and others 5% ± 2% (15 ± 11 µg/m^3).

Overall average of estimated contribution towards PM_{10} in summer season shows considerable contribution from dust and construction of 41% ± 6% (76 ± 19 µg/m^3). contribution from vehicles was about 16% ± 4% (29 ± 7 µg/m^3) followed by biomass burning 14% ± 4% (27 ± 11 µg/m^3), Industry 13% ± 4% (25 ± 10 µg/m^3), secondary particulates 13% ± 5% (23 ± 9 µg/m^3) and other 4% ± 2% (8 ± 5 µg/m^3).

Significantly, higher contribution of dust in PM_{10} and in $PM_{2.5}$, particularly in summer season, may be attributed to the transboundary contribution, which can be observed from wind trajectories.

Chapter 5: Emission Inventory, Dispersion Modelling and Source Apportionment

5.1 Study domain

The National Capital Region (NCR), the largest urban agglomeration in India known for its deteriorated air quality, is the domain chosen for this study. The region accommodated a population of over 47 million in 2011 (RGCC, 2011). Other than Delhi, there are districts from 3 other states (Haryana, Uttar Pradesh, and Rajasthan) which fall under the NCR. Figure 5.1 shows the overall study domain with key locations as the constituent districts. For the purpose of emissions inventorization and air quality modelling, the domain is divided into grids of 4x4 km^2 using Geographical Information System (GIS). Overall there are 73 grids in x-direction (292 km) and 91 grids in y-direction (364 km). Delhi being the capital city accommodates a huge population base of about 16.8 million. The registered vehicle population in the city has grown from about 3 million in 1998 to more than 10 million in 2017. Along with its own vehicles, there is a large movement of vehicles from surrounding towns, such as Gurugram, Faridabad, Sonepat, Ghaziabad, and Gautam Budh Nagar.

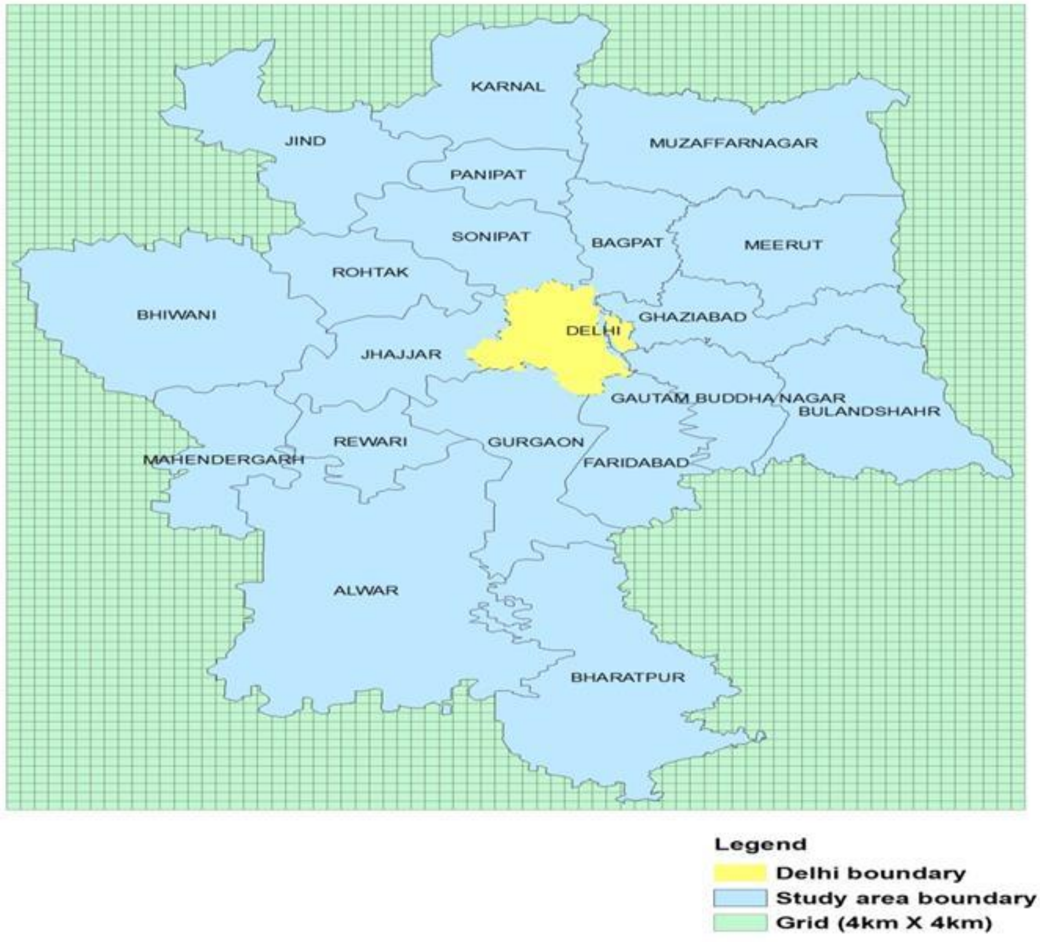


Figure 5.1: Study domain covering the NCR

The NCR hosts a number of power plants based on coal and gaseous fuels. Though, less common in Delhi, there are frequent power cuts in other parts of NCR, which lead to use of standby power sources like diesel generators. There are not many polluting industries in Delhi as most have been shifted from Delhi to the outside regions. However, the data on industries shows significant fuel consumption in districts neighbouring Delhi. More importantly, while there are standards for control of particulate matter (PM), there are no standards for control of gaseous pollutants like oxides of nitrogen (NOx), sulphur dioxide (SO_2), etc., from industrial stacks, which are important precursors for secondary particulate formation. Other than these, there are rural regions in NCR were biomass is burnt in rural kitchens for cooking and in fields as agricultural residues.

5.2 Approach

The study aimed at preparing an air quality management plan for Delhi based on simulation of air quality in present and future scenarios. While the Automotive Research Association of India (ARAI) carried out the detailed measurements followed by chemical characterisation and receptor modelling, The Energy and Resources Institute (TERI) prepared source-wise multi-pollutants inventories of air pollutants and ran dispersion models for air quality prediction and source apportionment. The modelled pollutant concentrations were validated with actual observations, and the validated model was used for future projections and other sensitivity analysis. The results of source apportionment from both approaches are compared to arrive at meaningful conclusions. The overall approach of the study is presented in Figure5.2.

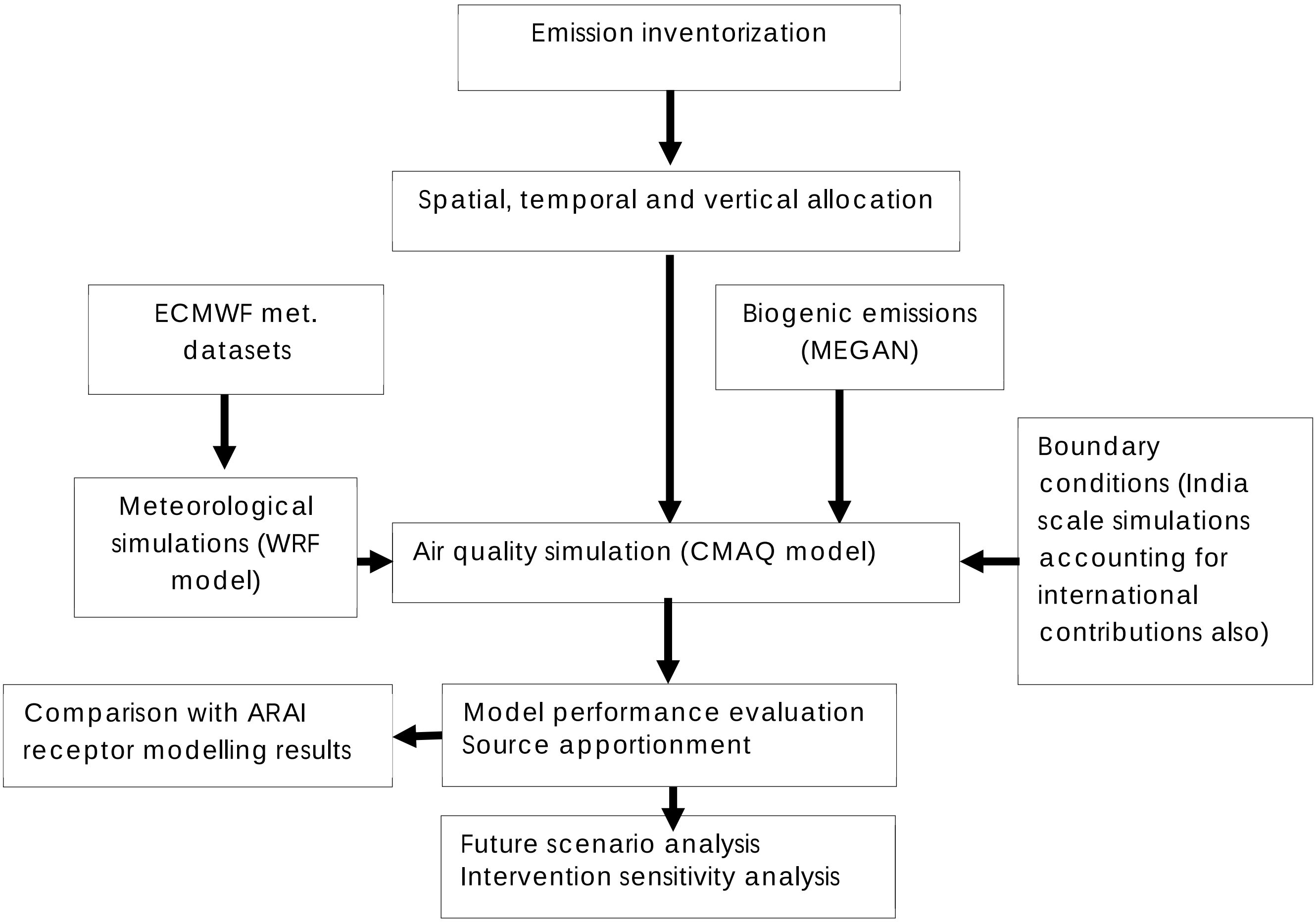


Figure 5.2: Overall approach of the study

5.3 Project activities

The activities envisaged to accomplish the desired objectives are as follows:

5.3.1 Understanding pollution in NCR

Data from different air quality monitoring stations in NCR have been collected from Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC), ARAI, and other pollution control boards in the region. The data has been used to assess prevailing levels of PM and gaseous concentrations in different parts of the NCR. As part of the objective, a detailed literature review has been carried out to compile the results of previous studies on modelling in the region. The latest report by IITK (2015) has been reviewed to understand source contributions.

5.3.2 Developing emission inventory for NCR

A list of all significant possible sources of air pollution in NCR was prepared. A high resolution (4x4 km^2) emission inventory for different pollutants was developed based on the emission factors approach. A literature review has been carried to compile a database of emission factors for different emissions sources. Indigenously generated emission factors have been used as far as possible. Along with PM, inventories of SO_2, NOx, carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs) have also been prepared to account for secondary particulates formation. Emissions inventories have been prepared for the base year 2016 and are allocated spatially over the study domain divided into the grids of 4x4 km^2.

Information was sought for the seasonal and diurnal variations of emissions for different sectors and have been accounted for. The major sectors which have been covered in the analysis are : 1)Residential, 2)Open agricultural residue burning, 3)Transport – tailpipe, 4)Construction, 5)Industries (including bricks), 6)Power plants- stacks and fly ash ponds, 7)Road dust, 8)Diesel generators, 9)Refuse burning, 10)Crematoria, 11)Restaurants-hotels, 12)Airport, 13)Landfills, 14)Waste incinerators, 15)Solvents, and 16)Ammonia emissions, etc.

The basic approach used for emission inventorisation is presented below

$$Ek = \sum_{l} \sum_{m} A_{k,l}\, ef_{k,l}(1 - \eta_{l,m.}).X_{k,l,m} \qquad \text{----------------(1)}$$

Where, ***k***, ***l***, ***m*** are regions, activity type, abatement technology, respectively; ***E*** denotes emissions; A the activity rate or energy consumption; *ef* the unabated emission factor; ***η*** is the efficiency of control; and ***X*** the actual application rate of control technology i.e. advanced fuel quality and emission norms in this case.

Activity data was collected for different sectors from various government and other reliable sources for the year 2016. Moreover, activity data was also collected from primary surveys through traffic counts and parking lots for vehicle usage patterns, DG set types and usages, silt loadings on roads, agricultural wastes, etc. A newly developed database of vehicular emissions factors developed by ARAI has been used for vehicular sources.

ARAI has developed new emissions factors for several new categories of vehicles introduced after 2008. Emissions factors for road dust have been derived from actual measurements of silt on the roads in the NCR. For industrial sources, the emissions factors developed in earlier studies have been used. Sectoral methodologies are discussed below for emissions estimation.

Population and per capita fuel use are the two major aspects which define activity data in the residential sector. The dataset of district wise rural and urban population in NCR was collected from the census data for the year 2011 (www.censusindia.gov.in) and projected for the year 2016 using the prevailing population growth rate of each district (DES, 2015; NCRPD, 2015a).Per capita consumption of different types of fuel for residential use in the rural and urban areas of different states of India was collected from the National Sample Survey Organization (NSSO 2012) to estimate energy consumption in the residential sector during 2016. Latest estimates of LPG penetration in the region under the Ujjwala scheme have also been accounted. A review of emissions factors for residential fuel burning has been provided in Datta and Sharma (2016). The review suggested a wide range of reported emission factors, and hence, a median value has been adopted.

Open agricultural burning is prevalent in the NCR and other regions of north India. To estimate emissions from this sector, activity data was derived using crop production, crop to waste ratios, and burning fractions. The primary crops considered for inventory preparation were wheat, rice, soya bean, jute, maize, and sugarcane. District-wise production data of different crops was collected from DAC&FW (2016). *Waste to crop ratios, dry fractions, and* burning fraction of different crop residues were obtained from published literature (Jain et al., 2014) and through a primary survey conducted in different agricultural districts of NCR. A review of emission factors for open agricultural burning has been provided in Datta and Sharma (2016). The review suggested a wide range of reported emissions factors, and hence, a median value has been adopted.

Transport sector emissions in Delhi and NCR have been estimated using the data for category wise vehicle-kilometres travelled (i.e. VKT) estimated from primary traffic count surveys at 72 locations in Delhi and surroundings. Primary surveys have been carried out at 20 grids in the study domain representing different land use. In each grid, 3 roads (arterial, sub-arterial, and minor) have been surveyed for 24-hour traffic counts. The traffic count data was substantiated by parking lot surveys to distribute the vehicles in categories of engine size, vintage, and fuel. The categorised vehicular traffic counts were multiplied with the road length to estimate VKT. Based on estimated VKTs, and standard fuel consumption rates of different categories of vehicles, total fuel consumed in Delhi and NCR was estimated and compared with the actual fuel consumption data collected from the oil companies for the purpose of validation. Emissions factors were adopted from the recently developed dataset of ARAI, which are based on different technologies and vintages of the various categories of vehicles. The vehicular intensities in the grids, where primary surveys have been carried out, were extrapolated for the remaining regions in the study domain based on similarities in land use and population densities. For some of the districts in NCR region (Baghpat, Meerut, Muzzafarnagar, Bhiwani, Jind, Karnal, Mahendragarh, Rohtak, and Rewari) VKT were estimated based on registered vehicles adjusted for on-road vehicles. In this study, we have additionally accounted for high-emitting vehicles which do not get accounted in the emissions factors developed on normally representative vehicles in the fleet. In order to account for high-emitters which remain unnoticed in the normal emissions factor approach, we assumed an increase of estimated emissions by 25%. A similar increase in emissions have been found in the literature review on account of high emitters (Park et al., 2011).

Emissions of the construction sector depend heavily on the area of construction activity. The data on areas on active construction sites in Delhi and surroundings has been collected from various sources like Delhi Metro Rail Corporation (DMRC), Public Works Department (PWD), Delhi Development Authority (DDA), etc. High-resolution images were used for the study from Google Earth imagery (sourced from Digital globe) to create polygons and then ArcGIS software was used to estimate the area under construction. The four main construction types taken into account for identification of construction sites were big housing complexes, flyovers, roads, and the

Delhi Metro construction in phase III. The emissions from construction activities were estimated using PM emission factor, adopted from AP42 emission factor database. Chow and Watson (1998) have suggested PM_{10} to PM and $PM_{2.5}$ to PM ratios from construction activity and the same has been adopted to estimate PM_{10} and $PM_{2.5}$ emissions. Based on the marked regions/area of construction and emission factors, total emissions from the construction sector were estimated for NCR.

There are a number of manufacturing industries (including bricks, sugar, paper, dyeing, rubber, chemical ceramics, iron & steel, textile, fertilizer, stone crushers, and casting & forging etc) within the study domain. Emissions from these industries are due to burning of different types of fossil fuels in boilers, furnaces, etc. Although, most polluting industries are banned in the Delhi region, they are still operational in other parts of NCR. We have considered only red and orange categories of industries falling under the study area for estimation of industrial emissions. Estimation of emissions from the industrial sector was based on the activity data (production and fuel consumption) and stack emissions monitoring data collected from district offices of the respective state pollution control boards. Industries report their fuel consumption and emissions details to their respective state pollution control boards through consent to operate, consent to establish and annual environmental statements. The data for different industries have been collected from various regional offices of state pollution control boards (i.e. Haryana SPCB, UP PCB, Rajasthan SPCB), and CPCB. Other than fuel consumption, specific information on the air pollution control systems adopted by the industries was also collected. Finally, emissions from various industries were estimated, either based on actual stack monitoring reports or by using the reported fuel consumption data. Standard efficiencies of control have been assumed for the air pollution equipments stated by the industries. Consumption of pet-coke has been taken from the latest assessment conducted by NEERI (2017) for CPCB. The emissions factors for industries using various types of fuels (rice husk, wood , coal, diesel, pet-coke, FO) have been adopted from Irfan et. al (2014), CPCB (2011), Jaygopal et al. (2017), and Mantananont et al. (2011). Other than these, emissions due to brick manufacturing activity are estimated for about 5000 brick kilns identified within the NCR using Google Earth and GIS software. Previous studies have been used to assess brick production rates and emissions factors have been adopted from GAINS India database. Data on stone crushers have also been collected; the activity was found to be dominant in the districts of Alwar and Bharatpur. The emissions factors for the stone crushing activity have been adopted from CPCB (2009a).

The data on power plants in NCR was collected from CEA (2017). While some power plants have been closed down in NCR, there are still 5 coal based and 5 gas-based functional power plants in the region. The PM emission factors for coal based power stations was customized using the ash content, bottom ash ratios, and efficiency of tail –pipe controls. Emissions factors for other pollutants were adopted from the review of factors provided in Sharma and Kumar (2016). Other than stack emissions from power stations, emissions from coal handling units and flyash ponds have also been estimated using the area covered and wind speeds in the region.

Road dust re-suspension is one of the important sources identified by previous studies within the cities, which contribute to PM emissions. The AP-42 methodology was applied to assess the road dust emissions in Delhi and surrounding NCR. The emissions factor for road dust re-suspension was customized for local conditions using the information on silt loading on the roads, and weight of vehicular fleet (from traffic counts). To estimate the silt loading, dust samples were collected as per the methods described in AP-42. The samples were obtained from various arterial, sub arterial, and local roads in various districts of Delhi and NCR. Prescribed sieve analysis was performed to estimate the silt loading on different roads. Silt load sampling was carried out in both summer and winter seasons to account for variation in silt loadings. Expectedly, winters have shown much lower silt loads than summers. The total VKT estimated for all the vehicle categories in the transport section was used for estimation of road dust suspension emissions by multiplying with the road-wise emissions factor estimated using silt loading data.

The towns and semi-urban areas of NCR are home to numerous energy-intensive industries, residential apartments, and commercial complexes; as a result, the area witnesses frequent power cuts. In order to maintain a regular supply of electricity, use of diesel generator sets is common in the area. Data for installed DG sets capacity in different districts was collected through Chief Electrical Inspectorates in various districts in NCR. A primary survey was also conducted to understand the usage pattern of DG sets, i.e. hours of usage, fuel consumption rates, etc. The data was used to estimate the fuel consumption in DG sets and emissions factors are used to assess emissions loads.

In order to estimate the emissions of pollutants on account of waste burning, the quantum of waste burnt in rural and urban areas of each district of Delhi and NCR were estimated. The waste generated in each district is estimated using per capita waste generation estimates and the population in each district. Shah et al. (2012) estimated that around 0.29 kg of waste was generated per person per day in the rural areas of India in 2011 and DPCC (2015) reported Daily municipal solid waste generated in Delhi, Haryana, Rajasthan, and Uttar Pradesh. Using these, per capita waste generated in rural and urban areas in the three states were estimated for the year 2016. An estimate of about 3% of MSW burnt in Delhi is used for estimation of refuse burning activity (Nagpure et al. 2015). For rural area estimations, 60% of total waste generated is assumed to be burnt (Wiedynmyer et al. 2014). Emissions from refuse burning were estimated using emissions factors provided in Woodall et.al (2012) and Pappu et al. (2007). Other than local refuse burning, landfill fires are a common problem in Delhi and NCR. In this study, estimates have also been made for landfill fire emissions. The area of major landfills (Gazipur, Okhla, Bhalswa) have been marked using Google Earth and NCR. The number of fire events have been estimated using the fire database of MODIS. The same emissions factors have been used for estimating emission from landfills.

There are several other smaller sources for which inventories have also been prepared. Emissions from crematoria have been estimated through surveys conducted in major crematoria of Delhi to find out the wood required for cremations. For assessment of emissions from crematoria, data on number of deaths in different districts and wood burnt estimates were used. The emissions factors from burning wood were adopted from Akagi et al. (2008). Emissions from restaurants and hotels were estimated mainly on account of fuel use in tandoors/barbeques. Primary surveys were conducted to estimate coal and LPG usage in restaurants in specific grids of Delhi and remaining NCR. Secondary data on restaurants have also been taken from the *Delhi Statistical Hand Book*, 2014. The data collected in these grids is extrapolated for other grids in the study domain based on population density. The emissions factors are adopted from CPCB (2011). Emissions from airport (Indira Gandhi International Airport) in New Delhi are estimated using the emissions factors per landing and take-off (LTO). The data on total aircraft movements at Delhi airport (LTO) was collected. The emissions factors are taken from EEA (2013) and IPCC (2000). Emissions have also been estimated for waste incinerators in Delhi. The waste processing capacity of these units and relevant emissions factors from EEA (2016) have been used for emissions estimation.

Additionally, the study has taken into account the real world emissions for sectors like transport, industries, and residential (Annexure-H), sectors. These are the sectors for which emission inventories for India have been reported to be uncertain (Saikawa et al;. 2017, Sadavarte et al. 2016) and hence the emissions are generally under reported. Finally, the estimated emissions from various sectors have been suitably allocated over the study domain as per area, line, and point source categories. ARCGIS was used for estimation of gridded emissions (4x4 km^2) for different pollutants across the NCR.

5.3.3 Simulation of air quality: dispersion modelling

Ambient PM_{10} and $PM_{2.5}$ concentrations were simulated in this study using the WRF-CMAQ modelling combination (Figure5.3). Models-3/CMAQ modelling system has been used in the study to assess chemical transport of different pollutant species under prevailing meteorological conditions (Byun and Ching, 1999). The CMAQ system is based on multi-pollutant and one atmosphere approach and is a leading air quality model used for assessment of ozone (O_3) and aerosols (Byun and Schere, 2006). CMAQ is known to have certain advantages over the traditional Gaussian-based models (ISCST3, AERMOD), which have been generally used in India in source apportionment studies. CMAQ is a Eulerian model as compared to Gaussian approach followed in AERMOD/ISCST3 and includes many more atmospheric processes than traditional models. CMAQ deals with chemical reactive species like ozone, NOx, hydrocarbons, and secondary particulates (sulphates, nitrates) and can be used on a range of spatial scales – continental to local, and accounts for long and medium range transport of pollutants. The model can deal with multiple pollutants together rather than individually and also takes into account the photo-chemistry which is not accounted for in traditional models.

A number of studies have shown satisfactory performance of the Community Multi scale Air Quality Modelling System (CMAQ) to predict urban and regional scale concentrations of a variety of pollutants (Marmur et al., 2009, Jose et al., 2013, Liu, 2013). The model has been extensively used for policy and research evaluations across the world (Paza et al., 2013 (Mediterranean Basin), Sokhi et al., 2006 (London), Chen et al., 2007 (Beijing), Khiem et al, 2010 (Japan), Lee et al, 2011 (USA). Sharma et al. (2014) have applied the CMAQ model to predict NOx concentrations for Bangalore city and ozone concentrations in India (Sharma et al., 2016). Based on the widespread applicability and requirements of multi-pollutant prediction, WRF (ver 3.1.1)-CMAQ (ver 5.0.2) combination have been chosen for carrying out the assessment in the present study.

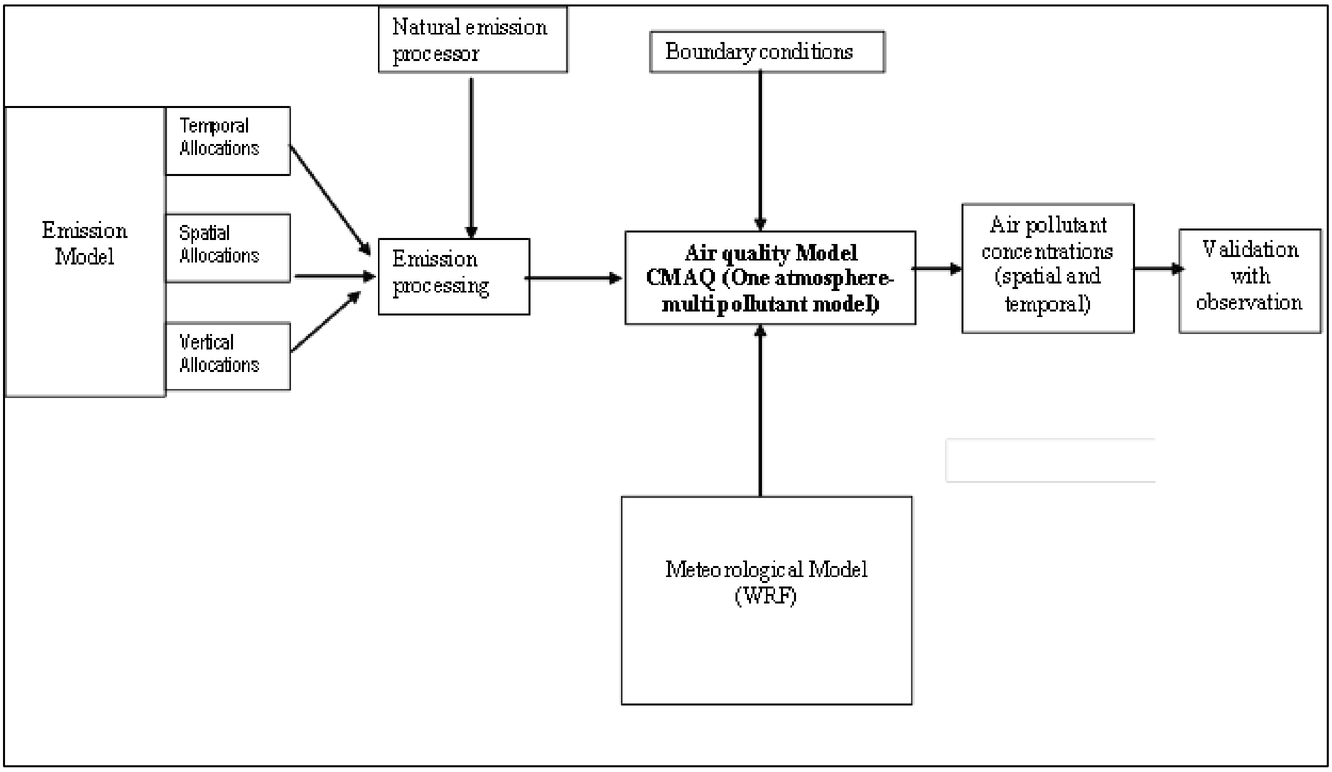


Figure 5.3: Modelling approach for the study

WRF model runs have been carried out to generate 3-dimensional meteorological fields over the study domain which acts as an input to the CMAQ model along with emissions inventories. ECMWF and USGS datasets have been used for running the WRF model, the output of which are the 3-dimensional meteorological inputs that are fed to the CMAQ model. For creating boundary conditions for the NCR region (i.e. to account for contributions from outside of NCR), India scale simulation runs have been carried out for the year 2016. India-scale emission inventory data at a resolution of 36x36 km^2 has been taken from TERI database of emissions in India. The national scale emission estimates by TERI have been extensively published in Sharma and Kumar (2016), Sharma et al. (2016), Pommier et al. (2018) etc. To account for transport of pollutants from outside India, international boundary conditions have been adopted from global air quality products of NCAR (National Centre for Atmospheric Research, U.S.). These global products are generated using the global chemical transport model MOZART. The contributions of neighbouring countries like Pakistan, Nepal, Bangladesh etc., which fall within the Indian study domain are taken from ECLIPSE database of IIASA (2014). Biogenic emissions for India scale run are adopted from the MEGAN model (WSU, 2016). Ammonia emissions for the study domain are adopted from IIASA (2014). WRF-CMAQ model runs have been performed for India and hourly boundary conditions were generated for the NCR for the year 2016.

Thereafter, WRF-CMAQ model runs have been performed for the NCR, using emissions inventories at 4x4 km^2 resolution, and also taking into account the boundary conditions generated from the India-scale runs. Daily PM concentrations have been simulated for all the grids in NCR and compared with the actual observations taken by ARAI for the period of monitoring.

Once the model is suitably validated, sensitivities of different sources have been estimated by removing 20% emissions of each source one by one from the emissions inventory in the CMAQ model. The major sectors for which sensitivities have been tested are residential, transport, industries (including power plants), road and construction dust, open agricultural burning, and others (including refuse, DG sets, ammonia, biogenic, restaurants, airport, incinerators, etc.). The sensitivities are normalised and have been used to derive source contributions at the sites, where monitoring was carried out by ARAI in NCR for summers (15 April–30 June) and winter seasons (15 November–28 February).

5.4 Results

The results of the study are presented in the sections on emissions inventory, air quality simulations, and source apportionment.

5.4.1 Emissions inventory

The emissions inventory for Delhi and entire NCR is shown below in Table 5.1. The estimates presented are the annual totals for different sectors, however, there are seasonal variations in emissions from different sectors, which have been accounted for during simulations. Vertical allocations have also been made as per the release height of emissions in different sectors. The total emissions of PM10, PM2.5, NOx, SO2, CO, and NMVOC are estimated to be 68, 32, 156, 33, 598, 427 kt/yr, respectively, for Delhi. These emissions were significantly higher in NCR i.e. 1017, 528,886, 892, 4964, 1671 kt/yr, respectively. The percentage share of sectors in overall inventory of PM_{10}, $PM_{2.5}$, NOx, and SO_2 emissions are shown in Figure 5.4, 5.5, 5.6 and 5.7, respectively.

Among the sources in Delhi, the share of the transport sector is significant (39%) in $PM_{2.5}$ emissions. This reduces to 19% in PM_{10} emissions in Delhi, due to presence of other sources like road dust and construction, which emit more particles in the coarser range of PM. Refuse burning in the open and in landfill fires are the other source which contribute significantly to the inventories and are expected to be more in summers due to higher temperatures, causing burning of waste and generation of methane in the landfills. Transport has a dominant share (81%) in the NOx emissions among the sources within Delhi. The SO_2 emissions within the city of Delhi are small and are mainly contributed by the coal-based power plant.

Sectoral shares are significantly different, when the entire NCR is considered. Industries (28%), road dust (13%), residential (20%), and agricultural burning (17%) are the main contributors in PM_{10} emissions in NCR. The sectoral shares are somewhat different in $PM_{2.5}$ emissions in NCR. Industries (24%), residential (25%), agricultural burning (19%), and transport (13%) are the major contributors to $PM_{2.5}$ emissions in NCR. The share of transport in NOx emissions reduces from 81% in Delhi to about to 60% in NCR, considering the presence of other sources in NCR. Power plants, DG sets, and industries are the other major contributors of NOx in NCR. SO_2 emissions in NCR are about 27 times higher than in Delhi. This is mainly due to presence of industrial sources and power plants. Standards for control of NOx and SO_2 in industrial setups have not yet been prescribed, and the emissions have remained uncontrolled. Use of petcoke, which is a very high sulphur fuel, is a significant source of industrial SO_2 emissions in NCR. This assessment was carried out in 2016, when the use of petcoke and fuel oil (FO) were not banned.

It is evident that the share of different sectors is significantly different in Delhi and NCR. The air quality in Delhi is impacted by both local and outside sources, and hence, a simulation exercise is a pre-requisite to understand the contributions of different sectors lying within or outside the city of Delhi. Other than emissions, meteorology also plays an important role in defining pollutant concentrations and source contributions.

Table 5.1 : Annual Emission inventory of pollutants (kt/yr) in Delhi and NCR for 2016

SECTOR	DELHI						NCR					
	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC	PM_{10}	$PM_{2.5}$	NO_x	SO_2	CO	NMVOC
TRANSPORT*	12.8	12.4	126.9	1.1	501.1	342.1	68.6	66.5	528.9	4.4	1750.9	886.5
INDUSTRIES	1.3	1.1	1.6	4.6	0.2	0.0	288.3	127.4	85.2	556.2	620.0	27.0
POWER PLANTS	6.1	3.5	11.2	23.6	3.5	0.9	73.7	41.1	132.5	297.1	13.4	9.4
RESIDENTIAL	2.9	2.0	3.7	0.2	61.1	12.7	204.3	131.5	38.0	16.8	1700.3	374.1
AGRICULTURAL BURNING	0.5	0.4	0.1	0.0	2.7	0.3	174.1	102.2	30.6	9.0	781.1	209.2
ROAD DUST	24.0	5.8	0.0	0.0	0.0	0.0	137.2	30.6	0.0	0.0	0.0	0.0
CONSTRUCTION	14.2	2.7					43.7	7.8				
DG SETS	0.1	0.0	0.7	0.0	0.2	0.1	3.7	3.2	53.0	3.5	11.4	4.3
REFUSE BURNING	1.4	1.2	0.5	0.1	4.6	2.7	17.5	14.4	5.5	0.7	56.0	33.3
CREMATORIA	0.4	0.2	0.1	0.0	2.2	1.2	1.5	0.8	0.2	0.0	7.7	4.3
RESTAURANT	1.4	0.8	0.4	1.3	2.5	0.4	1.7	1.0	0.5	1.6	2.9	0.4
AIRPORT	0.1	0.1	6.6	0.5	13.6	7.0	0.1	0.1	6.6	0.5	13.6	7.0
WASTE INCINERATORS	0.5	0.3	4.1	1.6	0.9	0.0	0.5	0.3	4.1	1.6	0.9	0.0
LANDFILL FIRES	1.8	1.5	0.6	0.1	5.8	2.2	1.9	1.6	0.6	0.1	6.1	2.3
SOLVENTS						57.3						112.8
TOTAL	68	32	156	33	598	427	1017	528	886	892	4,964	1671

Note: These are annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations. Real world emissions have also been accounted for certain sectors. Power plants include stack, flyash ponds and coal handling emissions

*Including high emitters

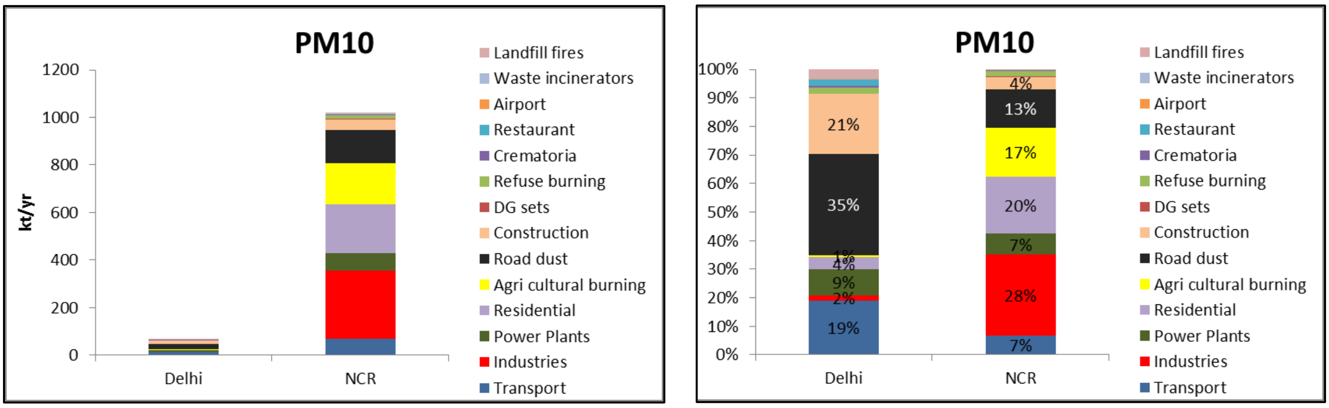


Figure 5.4: Absolute and percentage share of different sectors in overall inventory of PM$_{10}$ in NCR and Delhi

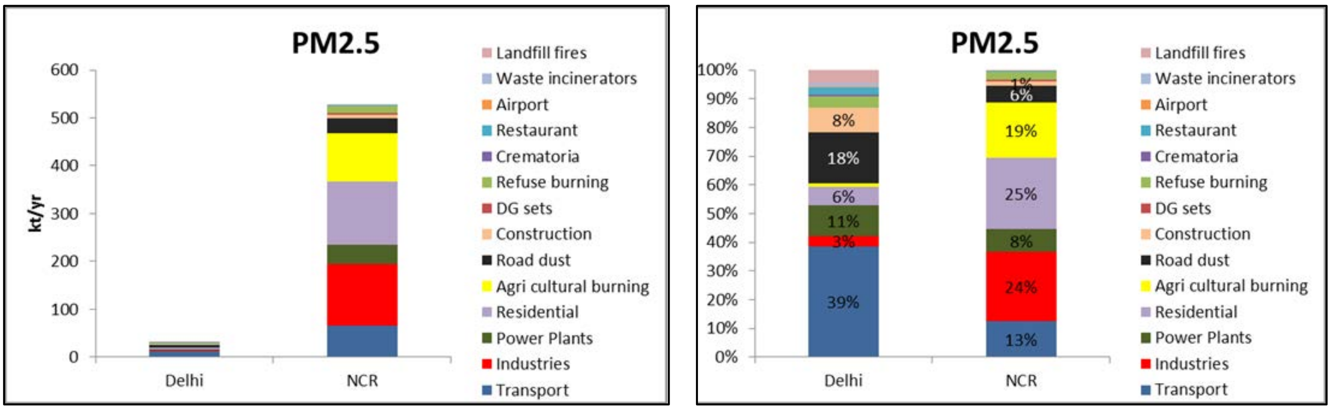


Figure 5.5 : Absolute and percentage share of different sectors in overall emission inventory of PM$_{2.5}$ in NCR and Delhi

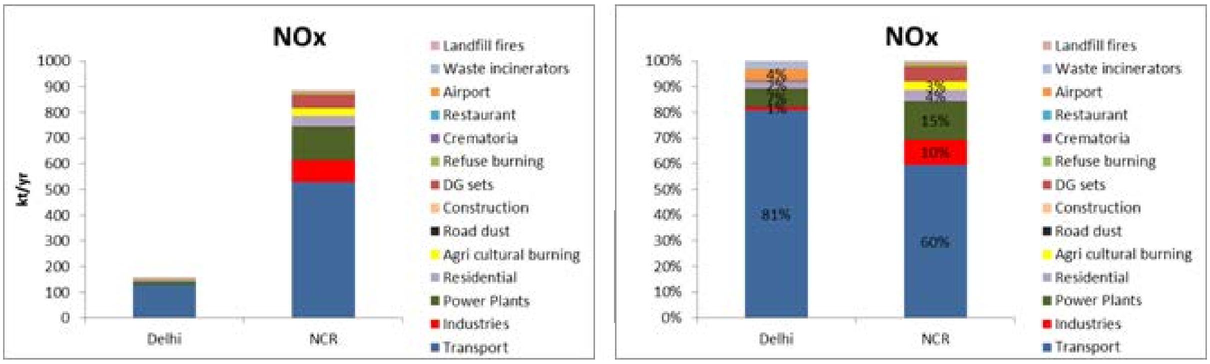


Figure 5.6: Absolute and percentage share of different sectors in overall inventory of NOx in NCR and Delhi

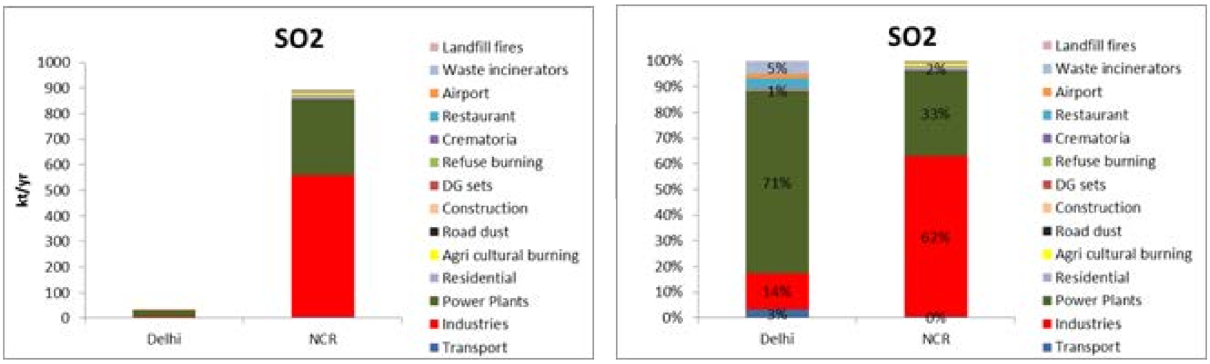


Figure 5.7 : Absolute and percentage share of different sectors in overall inventory of SO_2 in NCR and Delhi

Note: These are based on annual totals for emissions from different sectors. However, there are monthly variations in emissions from various sectors, which have been taken into account during simulations

The sub-distribution of transport, industrial and residential sector emissions is shown in Figure 5.8 and Figure5.9.

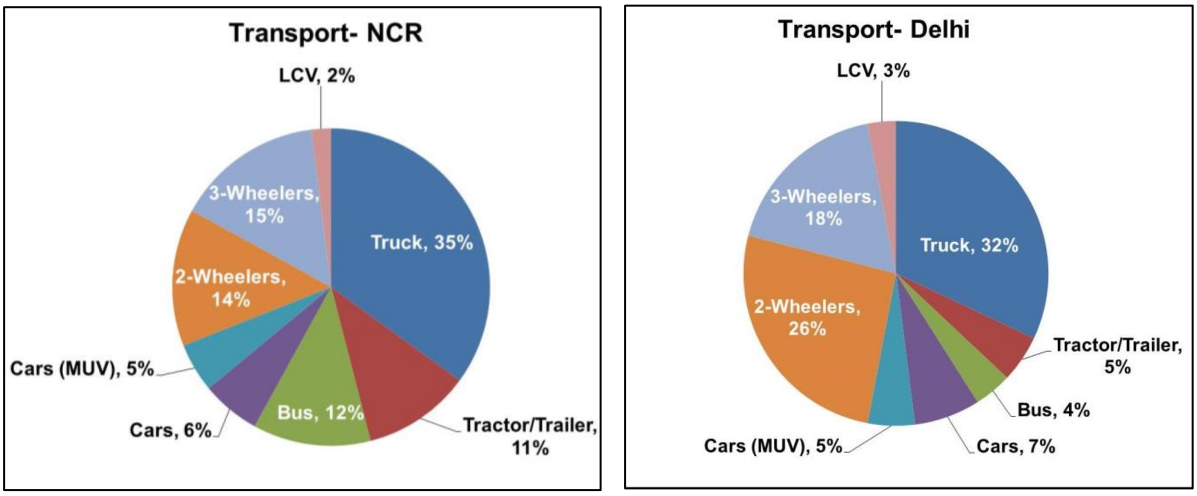


Figure 5.8 : Vehicle category-wise $PM_{2.5}$ emissions in NCR and Delhi

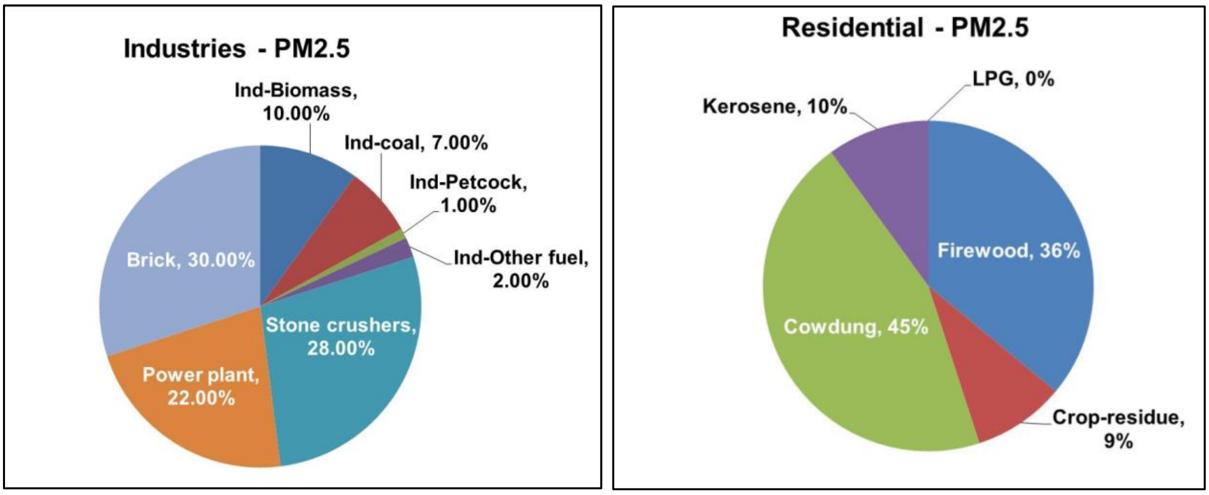


Figure 5.9 : Distribution of industrial and residential $PM_{2.5}$ emissions in NCR

The spatial distribution maps of PM_{10} emissions from different sectors are shown in Figures 5.10, 5.11 and 5.12.

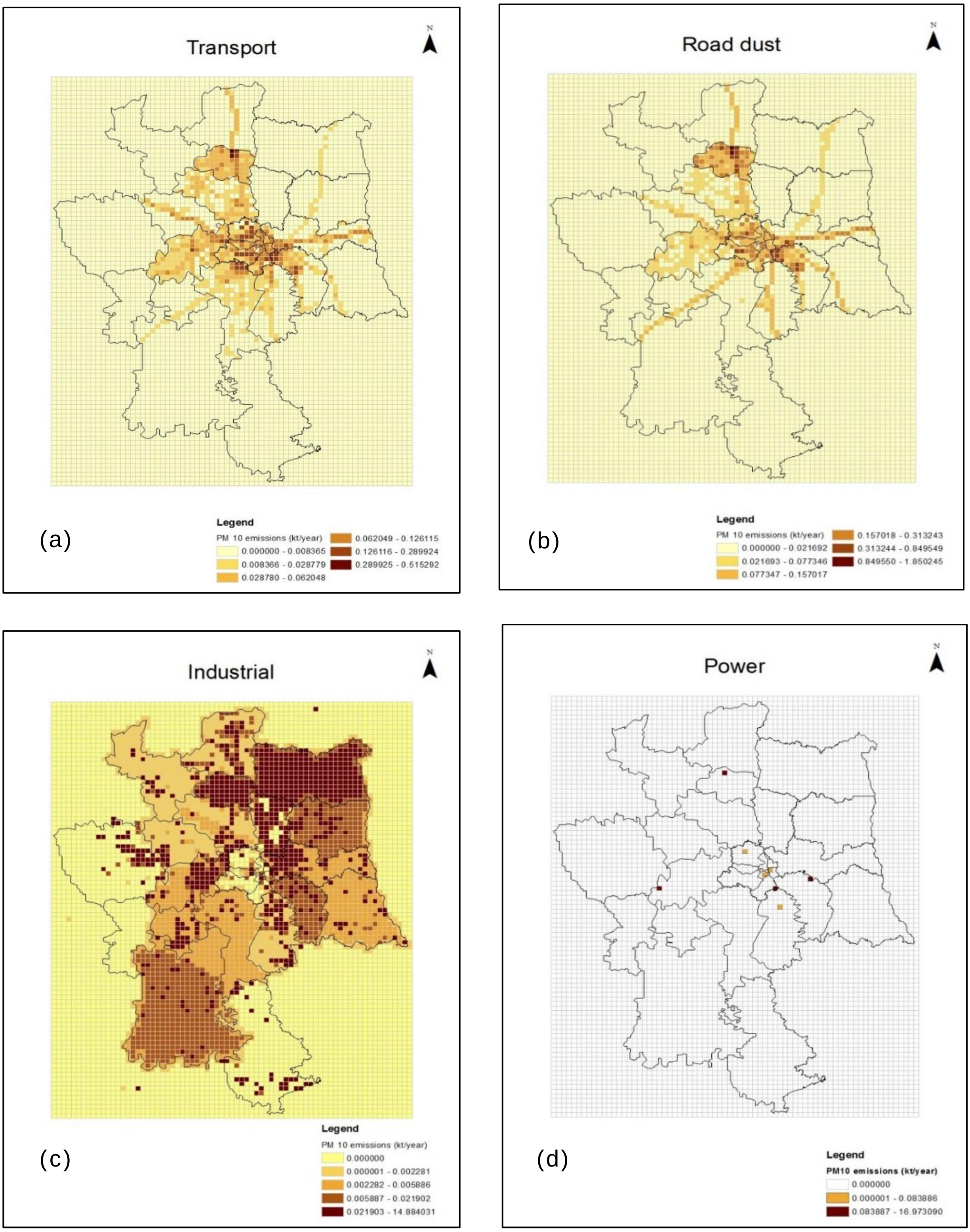


Figure 5.10: Spatial distribution maps of PM_{10} emissions from different sectors:
(a) Transport (b) Road Dust (c) Industrial (d) Power

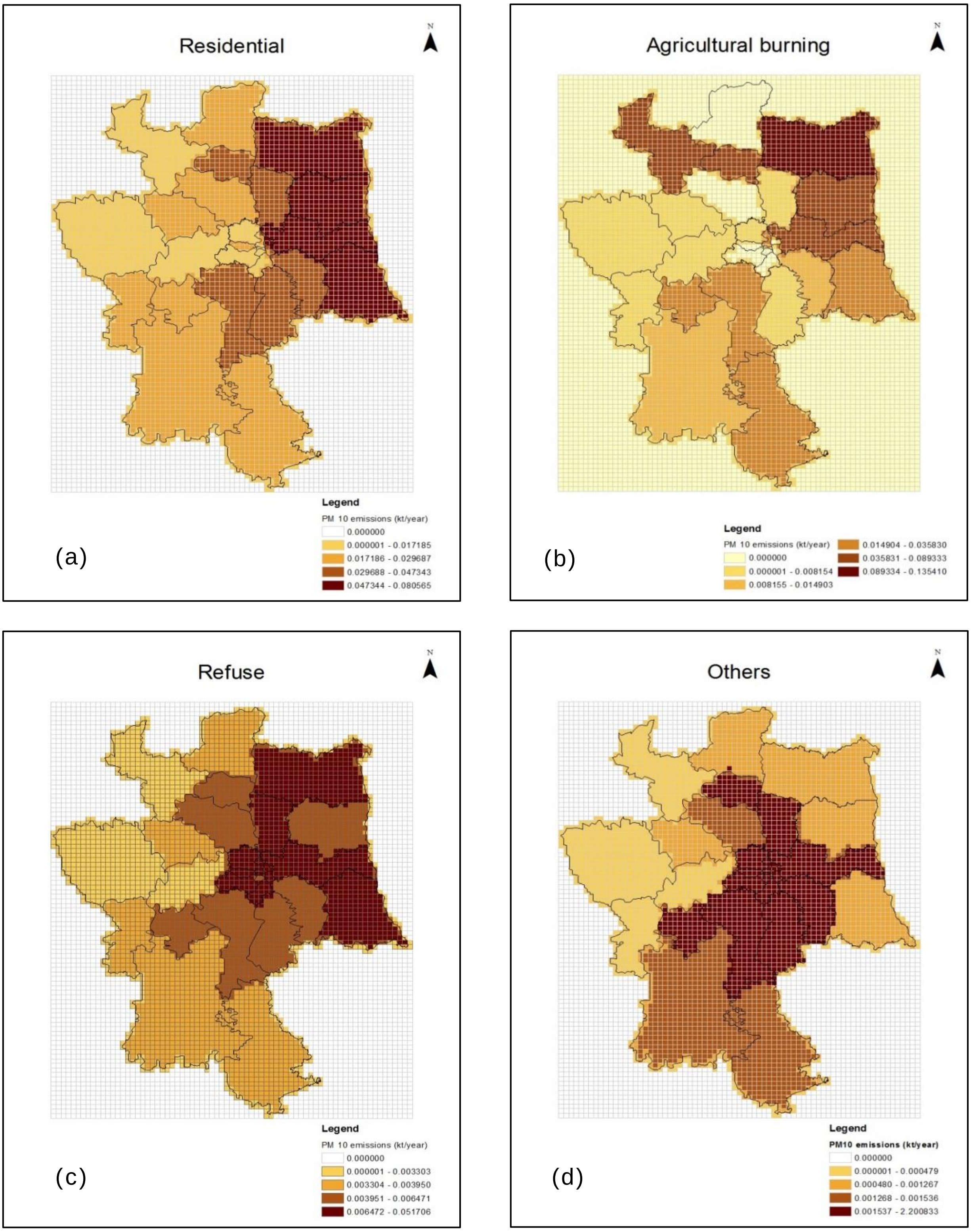


Figure 5.11: Spatial distribution maps of PM_{10} emissions from different sectors: (a) Residential (b) Agricultural Burning (c) Refuse (d) Others

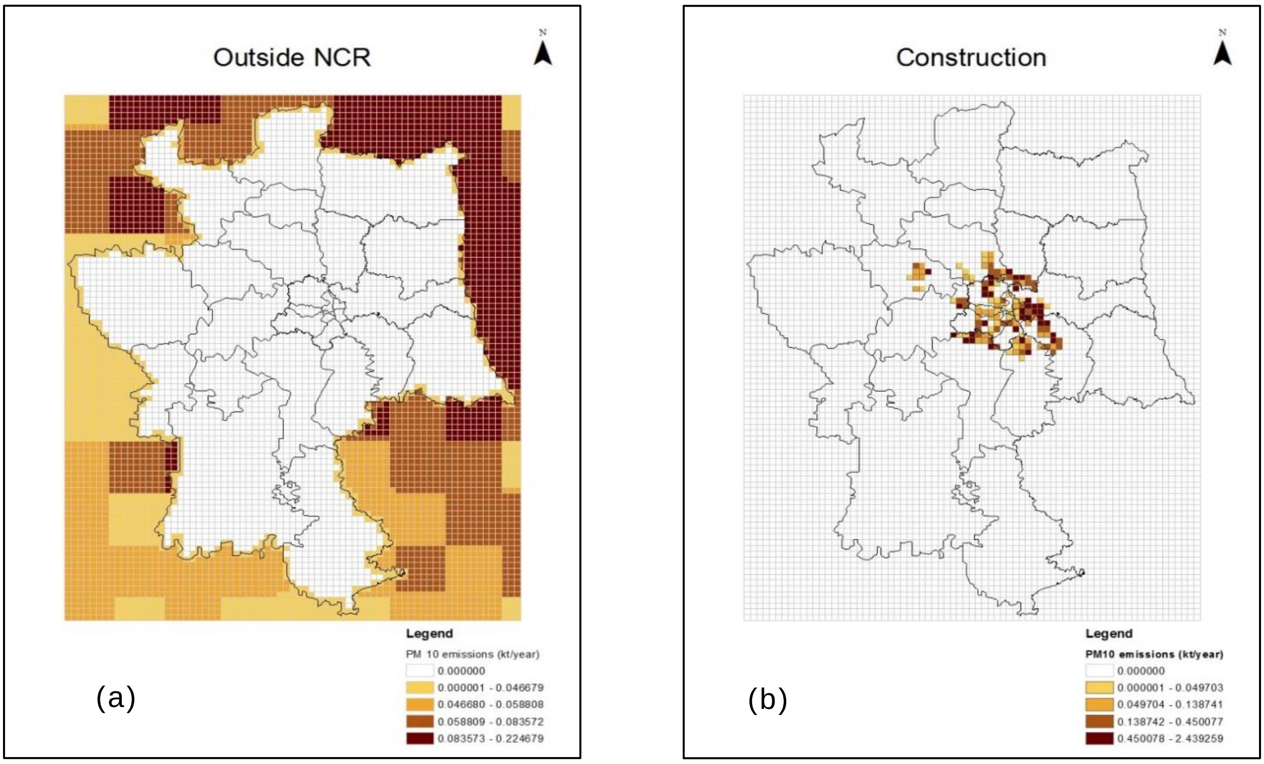


Figure 5.12: Spatial distribution maps of PM_{10} emissions from different sectors:
(a) Outside NCR (b) Construction

The total emission maps for PM_{10}, NOx, SO_2, NMVOC, and CO are shown in Figure5.13 and Figure 5.14.

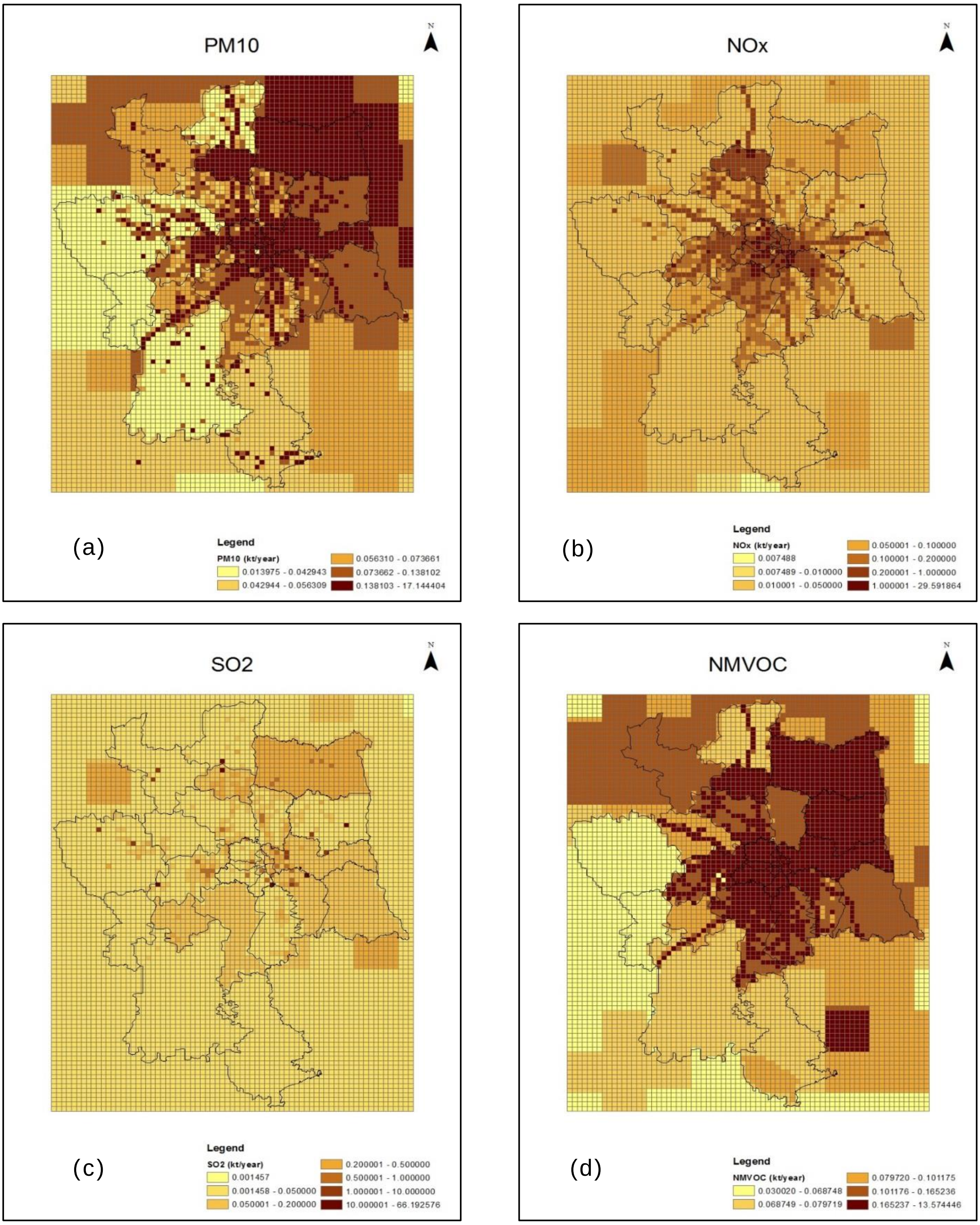


Figure 5.13: Total emission maps for (a) PM_{10} (b) NOx (c) SO_2 (d) NMVOC

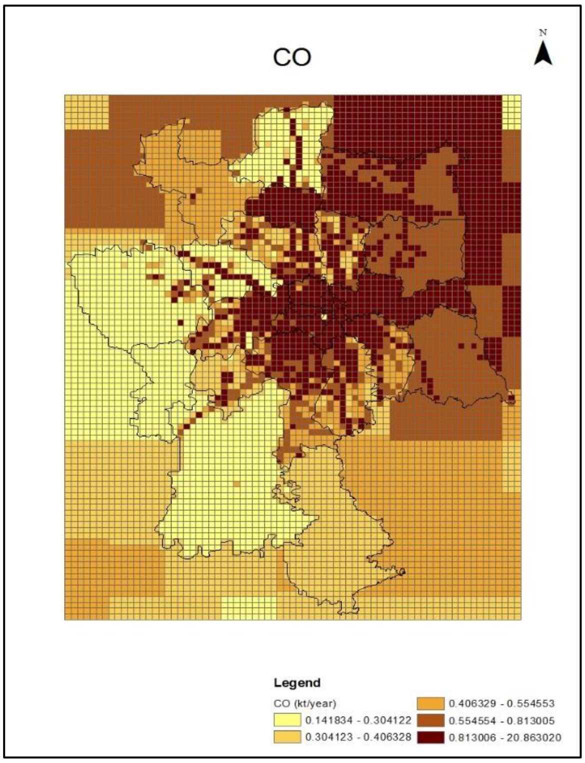


Figure 5.14: Total emission maps for CO

5.4.2 Air quality simulation

Emissions along with meteorological outputs of WRF model were fed into the CMAQ model for daily PM_{10} and $PM_{2.5}$ predictions. The simulation period were 15 Apr 2016-30 June 2016(summer) and 15-November 2016 to 28 February 2017 (winter), and were chosen in alignment with the monitoring schedule of ARAI. The average simulation results for the summer and winter seasons for PM2.5 concentrations are depicted in

Figure 5.15.

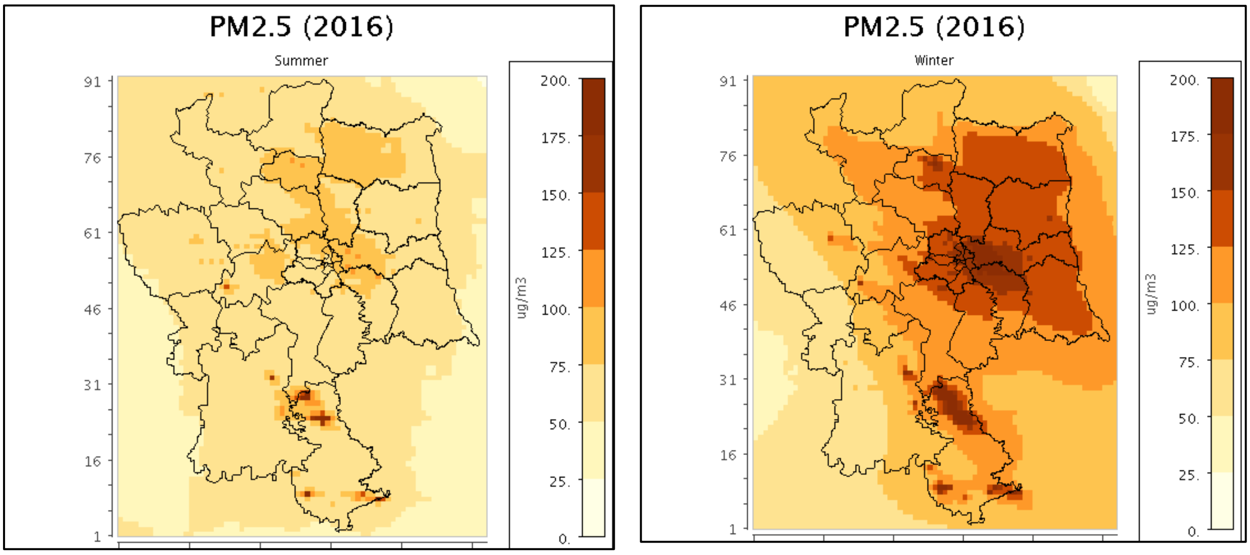


Figure 5.15: Average simulation results for the study domain for summers and winter seasons for $PM_{2.5}$ concentration ($\mu g/m^3$) in 2016

Evidently, the concentrations are significantly higher during winter than in summer, due to adverse meteorological conditions. Reduction in wind speed and boundary layer height during winter reduces the dispersive capacity of the atmosphere and leads to higher concentrations of pollutants near the ground. The levels are shown to be equally high in several other parts of NCR.

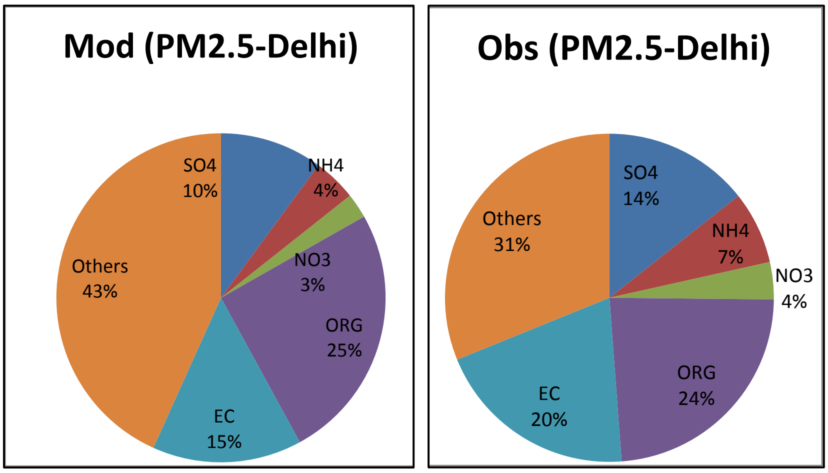


Figure 5.16 : Species wise distribution of modelled and observed $PM_{2.5}$ concentrations in Summer

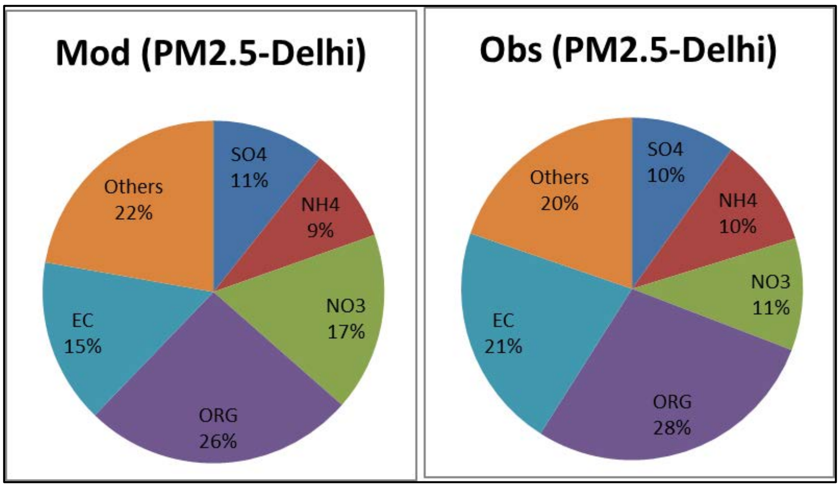


Figure 5.17 : Species wise distribution of modelled and observed $PM_{2.5}$ concentrations in Winter. (EC: Elemental Carbon; ORG: Organic carbon; SO_4: Sulphates; NH_4: Ammonium; and NO_3: Nitrates)

The average ratio of modelled to observed $PM_{2.5}$ concentrations was found to be 0.82–0.87. For PM_{10}, this was somewhat lower (0.48-0.57) indicating towards some unaccounted natural sources of dust. However, the performance of the model appears to be satisfactory, when compared with previous studies (e.g. IITK (2015)). The share of different constituent species of $PM_{2.5}$ is also satisfactorily reproduced by the CMAQ model. The species-wise distribution of modelled and observed $PM_{2.5}$ concentrations in winter and summer seasons are shown in Figure 5.16 and Figure 5.17. It can be seen that the winter season shows higher shares of carbonaceous species (EC and OC) and lower contributions from others. In summer, the share of 'other' species increases considerably, owing to contributions from dust. The share of secondary particulates is also higher in winter than in summer.

The validated model has been used to carry out source apportionment using the source-sensitivity method.

5.5 Source apportionment in Delhi

Table 5.2 shows the contributions of various sectors in $PM_{2.5}$ and PM_{10} concentrations, estimated using dispersion modelling for winter and summer seasons in Delhi-NCR. This is to be noted that contribution of agricultural burning is not fully accounted for in this study as the monitoring and modelling periods did not include the month of October, when the burning activities are generally found to be at their peak. Moreover, the sectoral contributions are averaged for the whole modelling/monitoring period, and hence, do not highlight contribution of agricultural burning, which happens during a certain number of days and cause episodically high pollutant concentrations. The results are discussed for both $PM_{2.5}$ and PM_{10} fractions.

5.5.1 $PM_{2.5}$

In $PM_{2.5}$ concentrations during winter, the share of the transport sector is 28% in Delhi. Industries contribute to 30%, while biomass burning in residences and agricultural fields contribute to 14% in Delhi. Dust (soil, road and construction) have a share of 17% in Delhi.

In $PM_{2.5}$ concentrations during summer, the share of the transport sector is17% in Delhi. Industries contribute to 22%, while biomass burning in residences and agricultural fields contribute to 15% in Delhi. Dust (soil, road and construction) have a share of 38% in Delhi . The model shows significantly high contributions from natural dust from far-off sources, during summer season. HEI (2018), a recent study conducted by Health effects Institute and IIT Mumbai, has also shown significant transboundary pollution in north-west India, where it accounts for 15%–30% of ambient $PM_{2.5}$.

5.5.2 PM_{10}

In PM_{10} concentrations during winter, the share of the transport sector is 24% in Delhi. Industries contribute to 27%, while biomass burning in residences and agricultural fields contribute 13% in Delhi. Dust has a considerably higher share in PM_{10} concentrations (25%).

During summer, share of the transport sector is 15% in Delhi. Industries contribute 22%, while biomass burning in residences and agricultural fields contribute 15% in Delhi. Road, construction and natural dust have a significantly higher share of 42% in PM_{10} fractions than in $PM_{2.5}$. The model shows significantly high contributions from international boundaries in summer, which is consistent with the findings of HEI (2018).

Table 5.2 : Sectoral contributions in $PM_{2.5}$ and PM_{10} concentrations estimated using dispersion modelling under different modelled scenarios during Winter and Summer in Delhi

$PM_{2.5}$		
Sectors	Winter	Summer
Residential	10%	8%
Agri. Burning	4%	7%
Industry	30%	22%
Dust (soil, road, const.)	17%	38%
Transport	28%	17%
Others	11%	8%
PM_{10}		
Sectors	Winter	Summer
Residential	9%	8%
Agri. Burning	4%	7%
Industry	27%	22%
Dust (soil, road, const.)	25%	42%
Transport	24%	15%
Others	10%	7%

Note: Industries include power plants, brick manufacturing, stone crushers, and other industries. Others include DG sets, refuse burning, crematoria, airport, restaurants, incinerators, landfills etc. Dust includes sources of natural and anthropogenic origin (soil, road dust re-suspension, and construction activities). Dust is also contributed through trans-boundary atmospheric transport from international boundaries.

5.6 Comparison with receptor modelling results

The comparison of sectoral contributions obtained from receptor modelling and dispersion modelling approaches is discussed in subsequent sections. The estimated sectoral contributions from the receptor modelling exercise in this study are also compared with results of IITK (2015).

5.6.1 $PM_{2.5}$

The results of this study are broadly consistent with the IITK study Figure 5.18 with slight variations in magnitude. Contribution of dust in $PM_{2.5}$ concentrations is found to be somewhat higher in this study, and share of biomass is lower. This is possibly because open agricultural burning activity could not be fully accounted for in the modelling period; also there is reduction in residential biomass use due to enhanced LPG penetration in last few years. Dust contributions are understandably more in summers due to drier conditions and higher wind speeds, leading to dust suspension. Share of secondary particulates is higher in winter due to higher nitrate formation rates, than in summer.

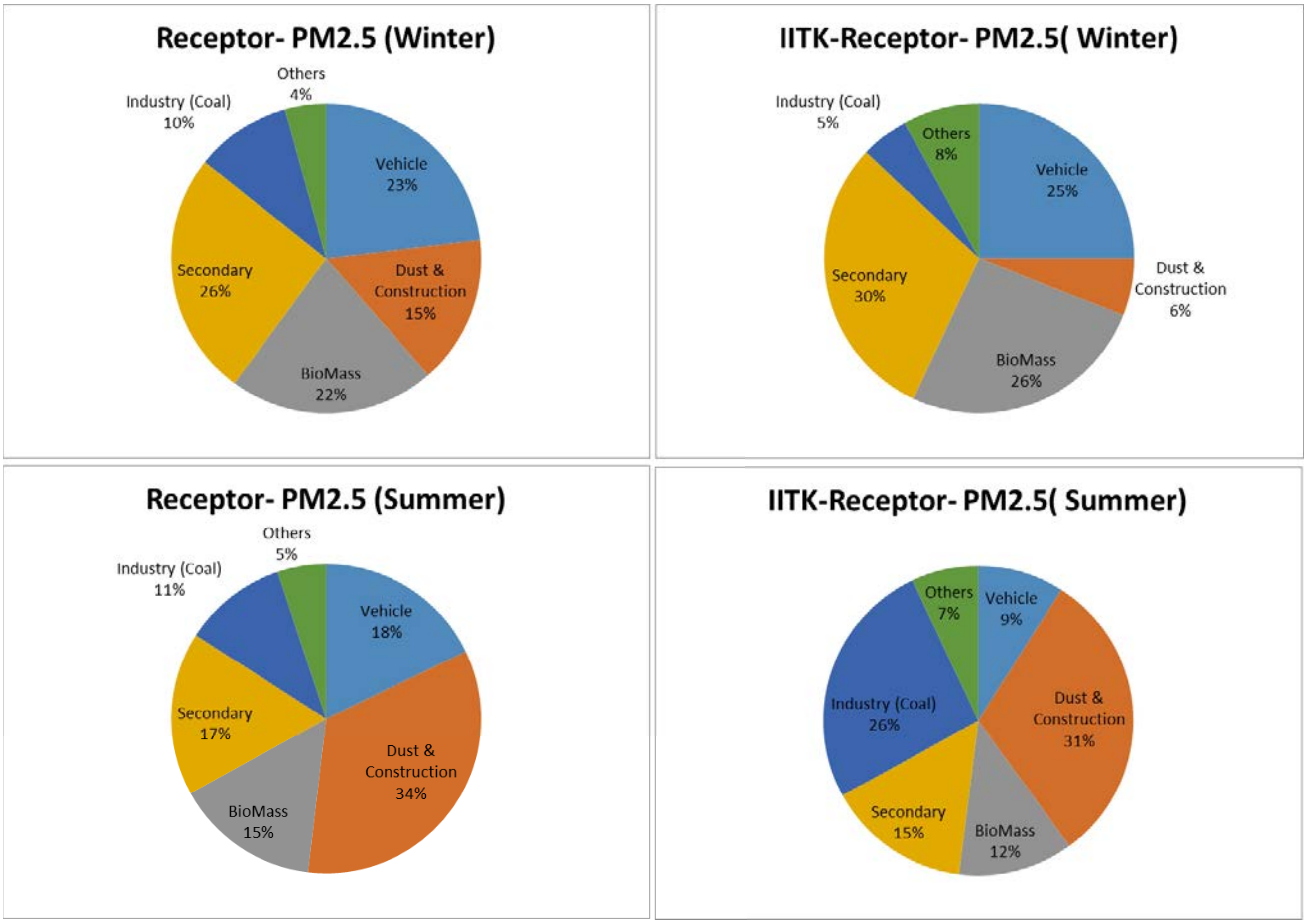
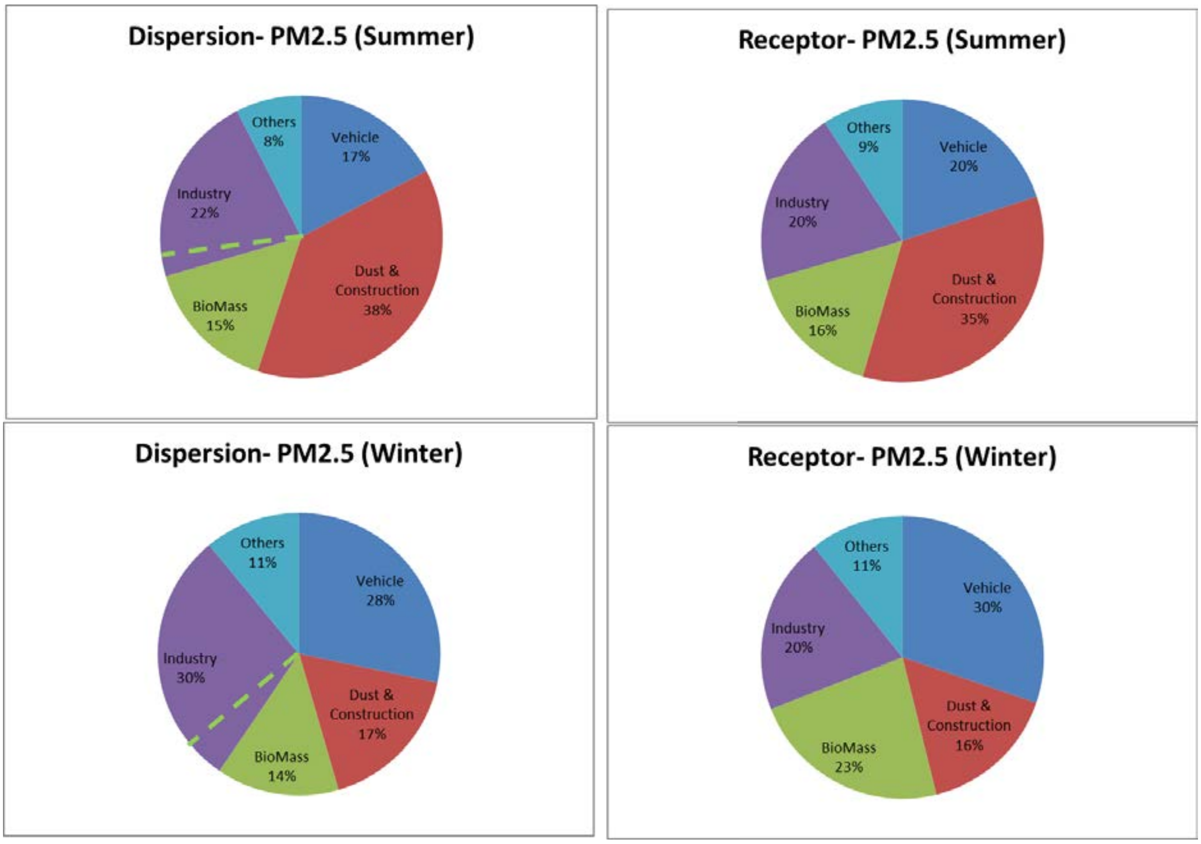


Figure 5.18 : Sectoral contributions from receptor modelling in winters and summers: this study and IITK (2015)

The results of receptor modelling are also compared with the dispersion modelling. The receptor modelling results show primary sectoral contributions, and secondary particulates separately. It is to be noted that secondary particulates are also contributed by gaseous emissions from different sectors. The dispersion model was used to assess contribution of different sectors to secondary particulates. Using this, secondary particulates in the results of receptor modelling were allocated accordingly to different sectors to assess total sectoral contributions (primary and secondary).



Dispersion- PM2.5 (Summer)

Receptor- PM2.5 (Summer)

Dispersion- PM2.5 (Winter)

Receptor- PM2.5 (Winter)

Figure 5.19 : Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ in Delhi

* Green dotted line shows that some industries in NCR, which contribute to Delhi's air quality also use biomass

Figure 5.19 shows that the results of the two approaches are close for most of the sectors. It is to be noted that in the dispersion modelling approach, the industrial sector (which seems to be overestimated) includes biomass as an industrial fuel. Dust includes contributions from road dust re-suspension, construction activities and natural dust contributions. Based on the assessment of species, it may be concluded that in summers, trans-boundary contributions are mainly composed of dust, However, in winters, there are also some contributions from sectors like biomass burning and industries as well.

Overall, the results of source apportionment seem to be consistent for most sectors in both the approaches. In the two seasons, the dispersion model shows contributions of transport sector as 17%-28%, in comparison to the receptor model estimations of 20%-30%. These findings are higher than the contributions of the transport sector reported in IITK (2015) report, because in the present study they include secondary particulates along with the primary contributions.

5.6.2 PM_{10}

Results of source apportionment of PM_{10} show that dust is a major contributor to PM_{10} concentrations. The share of dust is 31% in winter, which increases to 42% in summer. This study shows lower contribution from industrial coal use, which may attributed to closure and limited operation of some of the power plants in the vicinity. Contribution of the transport sector to PM_{10} is somewhat higher in this study (15%-18%), than the IITK (2015) study (6%-20%) (Figure5.20).

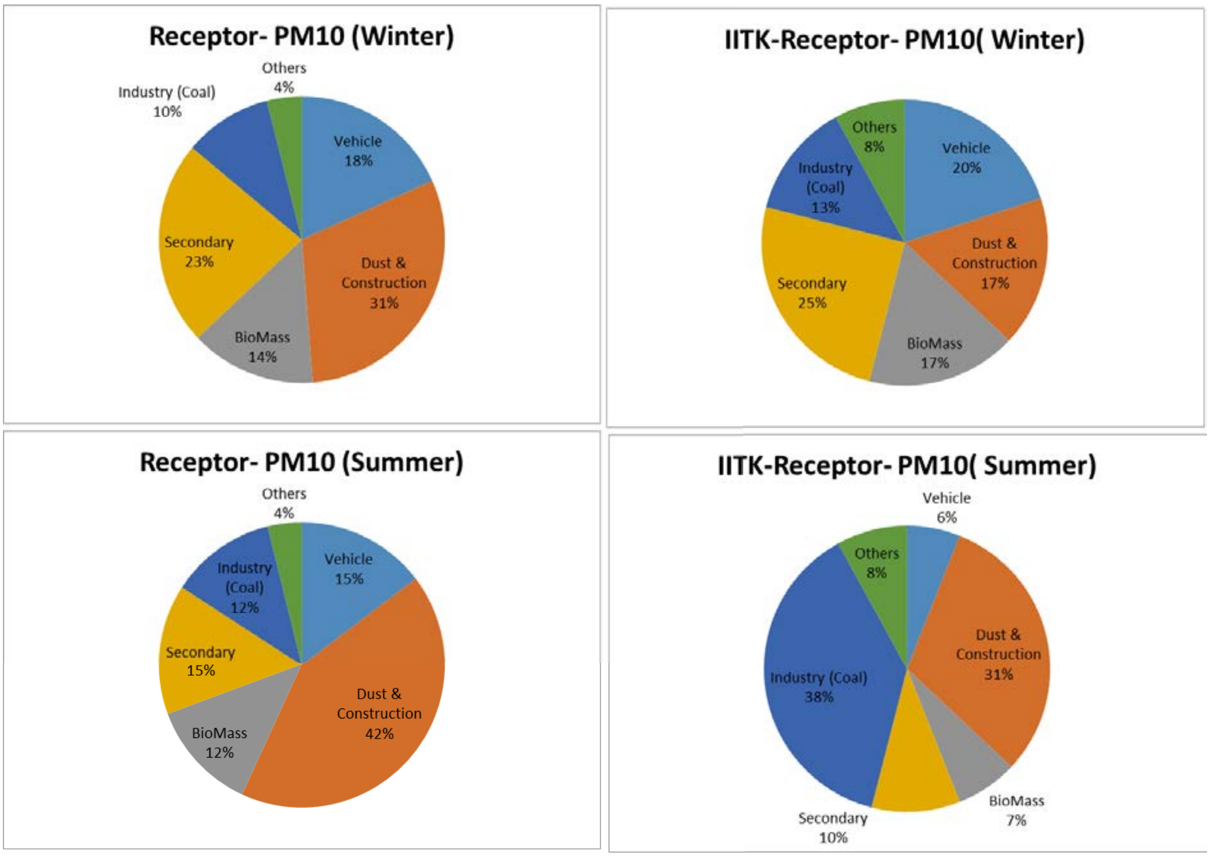


Figure 5.20 : PM10 Sectoral contributions from receptor modelling in winters and summers: this study and IITK (2015)

Comparison of results of dispersion modelling with receptor modelling for PM_{10} are shown in Figure 5.21. The results complement each other. Receptor modelling shows dust contributions of 31%-43%, which are shown to be in the range of 25%-41% by the dispersion modelling approach in the two seasons. The range of estimates for the transport sector is 15%-24% as per dispersion model runs in different seasons, while it is 17%-25% using the receptor model. Biomass burning consistently shows contributions in the range of 13%-15%. The two approaches show slight variation in industrial sector contributions, which ranges from 19%-27%.

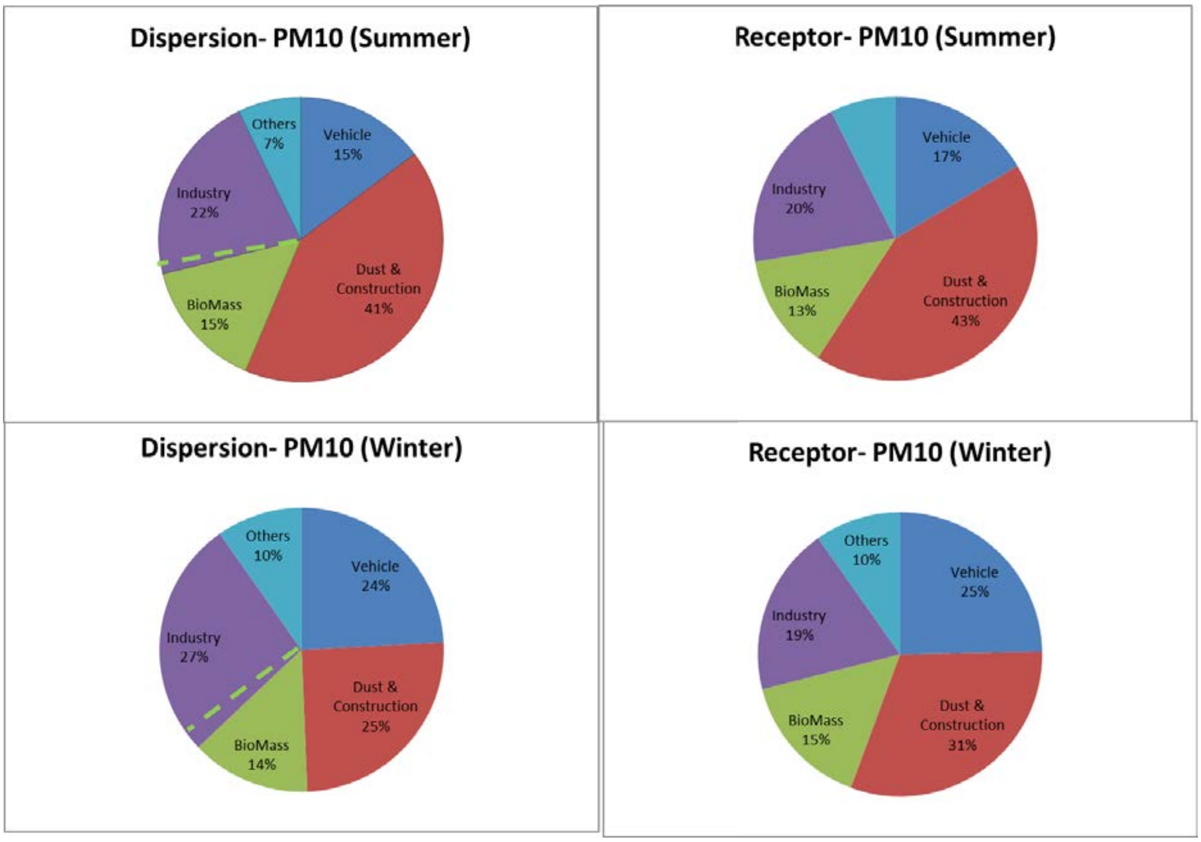


Figure 5.21 : Comparison of results of dispersion and receptor modelling assessment for PM_{10} in Delhi for the two seasons

* Green dotted line shows that some industries in NCR, (which contribute to Delhi's air quality) also use biomass

5.7 Sub-sectoral contributions to PM_{10} and $PM_{2.5}$ concentrations in Delhi

While the broad sectoral shares have been described in the previous section, this section shows contribution of different sub-sectors towards $PM_{2.5}$ and PM_{10} concentrations in Delhi.

5.7.1 Winters

Table 5.3 and 5.4 show the sub-sectoral contributions towards ambient $PM_{2.5}$ and PM_{10} concentrations in Delhi during winters, respectively. It is evident that within the residential sector, biomass fuel is the dominant factor contributing to $PM_{2.5}$ and PM_{10} concentrations. It contributes to 9% in $PM_{2.5}$ and 8% in PM_{10} concentrations in winters. Within the industrial sector, which has a contribution of about 30% in $PM_{2.5}$ concentrations, 8% is contributed by the brick kiln sector, 6% by power stations, 2% by stone crushers and other industries using coal, biomass, pet-coke, and FO contributed to about 14%. Later, in 2017, the use of pet-coke and FO were banned in the region. In the other category, (within the overall contribution of 11%), DG sets because of high PM and NOx emissions contribute significantly (5%), followed by refuse burning (3%), and the other sources contribute to less than 1% each, towards $PM_{2.5}$ concentrations. In the dust category, road dust contributes to 4%, and construction 1% to the $PM_{2.5}$ concentrations. Within the transport sector in Delhi, trucks have the highest share of 8%, followed by two-wheelers (7%), and three-wheelers (5%). This is due to their higher shares in either or both $PM_{2.5}$ and NOx emissions.

In PM_{10}, the shares for different sub-sectors almost remain the same as $PM_{2.5}$. However, the shares of dust increase considerably, with road dust and construction contributing to 8% and 6%, respectively in Delhi's PM_{10} concentrations.

Table 5.3 : Sub-sectoral contribution to $PM_{2.5}$ in Delhi in winter 2016

Sectors	Sub-sectors	Delhi
Residential		10%
	Biomass	9%
	Kerosene	1%
	LPG	0.1%
Agricultural burning	Biomass	4%
Industry		30%
	Power plant	6%
	Bricks	8%
	Stone crushers	2%
	Other industries	14%
Others		11%
	DG sets	5%
	Refuse burning	3%
	Crematoria	0.2%
	Restaurant	1%
	Airport	1%
	Waste incinerators	1%
	Landfill fires	0.4%
Dust		17%
	Road dust	4%
	Construction	1%
	Others	12%
Transport		28%
	Truck	8%
	Tractor	1%
	Bus	3%
	Cars	3%
	2 wheelers	7%
	3 wheelers	5%
	LCVs	1%

Table 5.4 : Sub-sectoral contribution to PM_{10} in Delhi in winter 2016

Sectors	Sub-sectors	Delhi
Residential		9%
	Biomass burning in kitchen	8%
	Kerosene	1%
	LPG	0%
Agricultural burning	Biomass	4%
Industry		27%
	Power plant	5%
	Bricks	7%
	Stone crushers	3%
	Other industries	12%
Others		10%
	DG sets	4%
	Refuse burning	4%
	Crematoria	0.3%
	Restaurant	0.6%
	Airport	0.4%
	Waste incinerators	0.6%
	Landfill fires	0.4%
Dust		25%
	Road dust	8%
	Construction	6%
	Others	11%
Transport		24%
	Truck	7%
	Tractor	1%
	Bus	2%
	Cars	3%
	2 wheelers	6%
	3 wheelers	4%
	LCVs	1%

5.7.2 Summers

During summers, contribution of different sectors varies due to increased wind speeds and increased natural dust contributions (Table 5.5 and Table 5.6). Within the sectors, biomass fuel use in residential sector is the dominant factor contributing to $PM_{2.5}$ and PM_{10} concentrations. It contributes to 7-8% in $PM_{2.5}$ and PM_{10} concentrations in summers. Within the industrial sector, contribution of about 22% in $PM_{2.5}$ concentrations in Delhi, 5% is contributed by the brick kiln sector, 7% by power stations, 1% by stone crushers and other industries using coal, biomass, pet-coke, and FO contributed to about 8%. In the others category, the share of DG sets falls to 2% due to reduced nitrate formation in summers. Refuse burning contributes significantly (4%), and rest other sources contribute to less than 1% each, towards $PM_{2.5}$ concentrations. In the dust category, road dusts contribute to 3%, and construction 2% to the PM2.5 concentrations. Within the transport sector in Delhi, trucks have the highest share of 5%, followed by two-wheelers (4%), and three-wheelers (3%). This is due to their higher shares in either or both $PM_{2.5}$ and NOx emissions. The share of cars remains at 2% in $PM_{2.5}$ concentrations in Delhi during summers.

In PM_{10}, the shares for different sub-sectors almost remain same as $PM_{2.5}$. However, the shares of dust increase considerably, with road dust and construction contributing to 10% and 4% in PM_{10} concentrations in Delhi.

Table 5.5 : Sub-sectoral contribution to $PM_{2.5}$ in Delhi in summers 2016

Sectors	Sub-sectors	Delhi
Residential		8%
	Biomass burning in kitchen	7%
	Kerosene	1%
	LPG	0.1%
Agricultural biomass burning	Biomass	7%
Industry		22%
	Power plant	7%
	Bricks	5%
	Stone crushers	1%
	Other industries	8%
Others		8%
	DG sets	2%
	Refuse burning	4%
	Crematoria	0.2%
	Restaurant	0.4%
	Airport	0.2%
	Waste incinerators	0.3%
	Landfill fires	0.5%
Dust		38%
	Road dust	3%
	Construction	2%
	Others	33%
Transport		17%
	Truck	5%
	Tractor	1%
	Bus	1%
	Cars	2%
	2 wheelers	4%
	3 wheelers	3%
	LCVs	1%

Table 5.6 : Sub-sectoral contribution to PM_{10} in Delhi in summers 2016

Sectors	Sub-sectors	Delhi
Residential		8%
	Biomass	8%
	Kerosene	0.5%
	LPG	0.1%
Agri. Burning	Biomass	7%
Industry		22%
	Power plant	7%
	Bricks	5%
	Stone crushers	2%
	Other industries	8%
Others		7%
	DG sets	2%
	Refuse burning	4%
	Crematoria	0.3%
	Restaurant	0.5%
	Airport	0.1%
	Waste incinerators	0.3%
	Landfill fires	0.4%
Dust		43%
	Road dust	10%
	Construction	4%
	Others	28%
Transport		15%
	Truck	5%
	Tractor	1%
	Bus	1%
	Cars	2%
	2 wheelers	4%
	3 wheelers	3%
	LCVs	0.5%

5.8 Sub-category-wise contribution of different vehicles in $PM_{2.5}$ concentrations

The share of cars in winter and summer $PM_{2.5}$ concentrations is about 3.4% and 2%, respectively (Table5.7). However, within this, the share of older cars on road is much higher than the newer ones. The table shows the category-wise distribution of the share of cars to $PM_{2.5}$ concentrations, which shows that older cars (BS-II and before) contribute about 31%-50%, while BS-III cars contribute about 19%-22%. BS-IV cars contribute to 50% and 28% in the overall car contribution to $PM_{2.5}$ in Delhi and NCR, respectively. The fuel-wise distribution shows that diesel has a major contribution of 67%-74% in the share of cars, followed by CNG (13%-20%) and petrol (13%-14%) cars. CNG cars, although contribute minimally in primary PM emissions, but have some secondary nitrate contributions through NOx. Considering the 2.0%-3.4% share of cars in $PM_{2.5}$ concentrations in two seasons, and a 19%-27% contribution of BS-IV diesel cars within this (Table), the overall share of all BS-IV diesel cars in $PM_{2.5}$ concentrations is estimated to be about 0.5%-0.9% in Delhi and 0.3%-0.5% in NCR. Similarly, the share of BS-IV MUV cars in $PM_{2.5}$ concentrations is 0.14%-0.23% in Delhi and 0.07%-0.12% in NCR.

Table 5.7: Category-wise distribution of cars share to $PM_{2.5}$ concentrations

	Delhi					NCR				
Emission norms	Petrol	Diesel (Smaller)	Diesel-MUV	CNG	All cars	Petrol	Diesel (Smaller)	Diesel-MUV	CNG	All cars
Pre BS to BS-I	0%	0%	0%	0%	0%	5%	9%	8%	0%	22%
BS-II	4%	13%	15%	0%	31%	3%	14%	11%	0%	28%
BS-III	2%	8%	5%	4%	19%	1%	10%	7%	3%	22%
BS-IV	7%	20%	7%	16%	50%	5%	11%	4%	9%	28%
Total	13%	41%	26%	20%	100%	14%	44%	30%	13%	100%

* accounting for both primary PM and secondary nitrate contributions to PM2.5 conc. in Delhi-NCR

Table 5.8 shows the vintage-wise distribution of truck and buses share to $PM_{2.5}$ concentrations. The heavy-duty vehicles (buses and trucks) registered after 2010 have a share of 30%-60% in Delhi and 30%-42% in NCR, while the older vehicles with inferior emission norms have the remaining share.

Table 5.8: Vintage category-wise distribution of truck and bus share to $PM_{2.5}$ concentrations

Vehicle	1991-2000	Post 2000	2005-10	Post 2010
Delhi				
Truck	0%	0%	69%	30%
Bus	0%	0%	40%	60%
NCR				
Truck	0%	13%	57%	30%
Bus	0%	15%	43%	42%

* accounting for both primary PM and secondary nitrate contributions to PM2.5 conc. in Delhi-NCR

Table 5.9 shows the vintage-wise distribution of 2-wheeler share to $PM_{2.5}$ concentrations. Post 2010, 2-wheelers have a share of 34%-35%, while the older vehicles with inferior emission norms have higher shares.

Table 5.9: Vintage category-wise distribution of two-wheelers to $PM_{2.5}$ concentrations

	1991-96	1996-2000	Post 2000	Post 2005	Post 2010
Delhi	0%	0%	28%	36%	35%
NCR	0%	0%	30%	35%	34%

* accounting for both primary PM and secondary nitrate contributions to $PM_{2.5}$ conc. in Delhi-NCR

It may be noted that these are the shares of vehicles in 2016, and with fleet turnovers, the share of BS-IV vehicles will increase and contribution of older vehicles will decline. Although, the absolute numbers of BS-IV vehicles will be much lower than pre BS-IV vehicles due to improved technologies.

5.9 Sectoral shares in other towns

Source apportionment was also carried out for towns in NCR other than Delhi. The results for source apportionment of $PM_{2.5}$ and PM_{10} in these towns are provided in subsequent sections. Generally, the range of source contributions predicted by the two approaches is wider in NCR town in comparison to results of Delhi. This can be attributed to more intensive emissions inventories and higher number of monitoring stations in Delhi than in NCR towns.

5.9.1 Ghaziabad

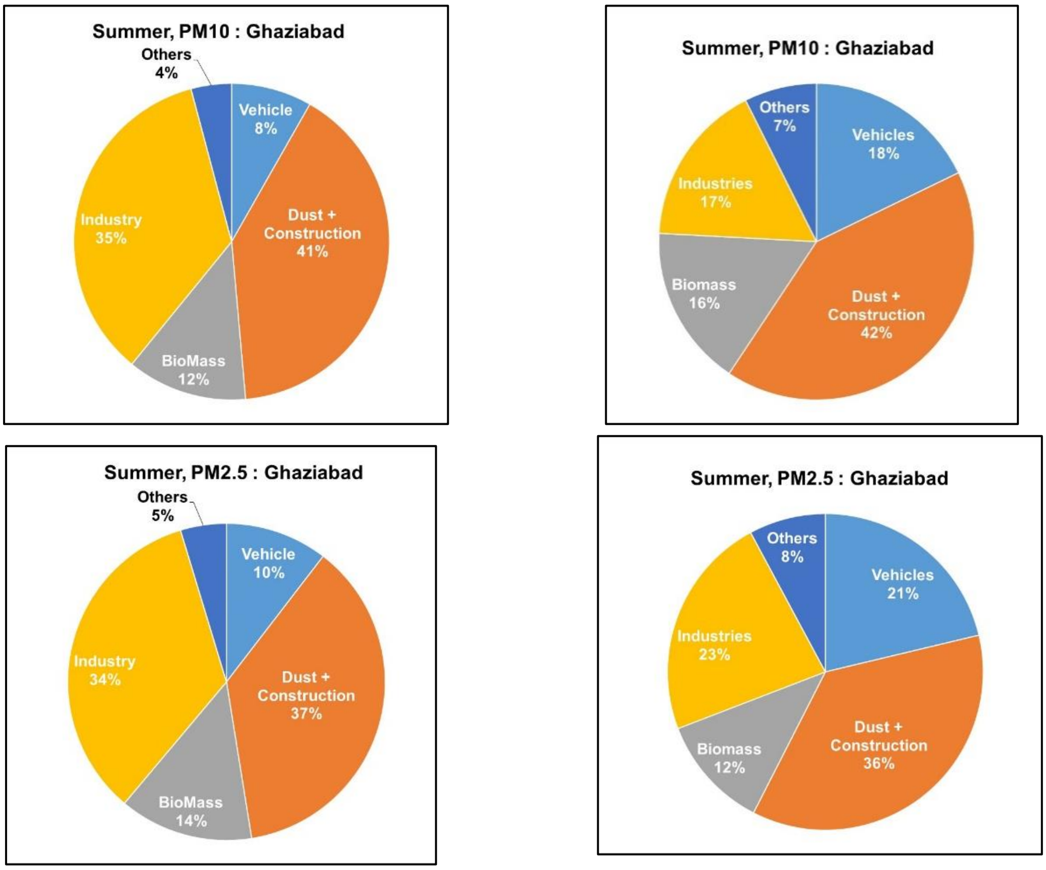
Source contributions at the two monitoring locations in Ghaziabad were estimated using both receptor and dispersion modelling techniques. The average shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Ghaziabad are presented in Figure 5.22 and Figure 5.23, respectively.

5.9.1.1 PM_{10}

The results of both the approaches show that in PM_{10} concentrations in Ghaziabad, contribution of dust (road dust, construction, and other sources) was found to be higher (41%-42%) in summer and lower (27%-31%) in winters. This is mainly due to higher wind speeds, which lead to higher contributions of dust from far off sources in summers. Contribution of vehicles was estimated to be 8%-18% in summer and 13%-22% in winter. Industries emerged as one of the important contributors in PM_{10} concentrations in Ghaziabad, with 17%-35% share in summer and 24%-35% in the winter season. Biomass burning (in rural households and agricultural fields) contributes to 12%-16% in PM_{10} concentrations. Higher biomass contributions are shown in receptor modelling approach, which also includes the biomass combustion in industries.

5.9.1.2 $PM_{2.5}$

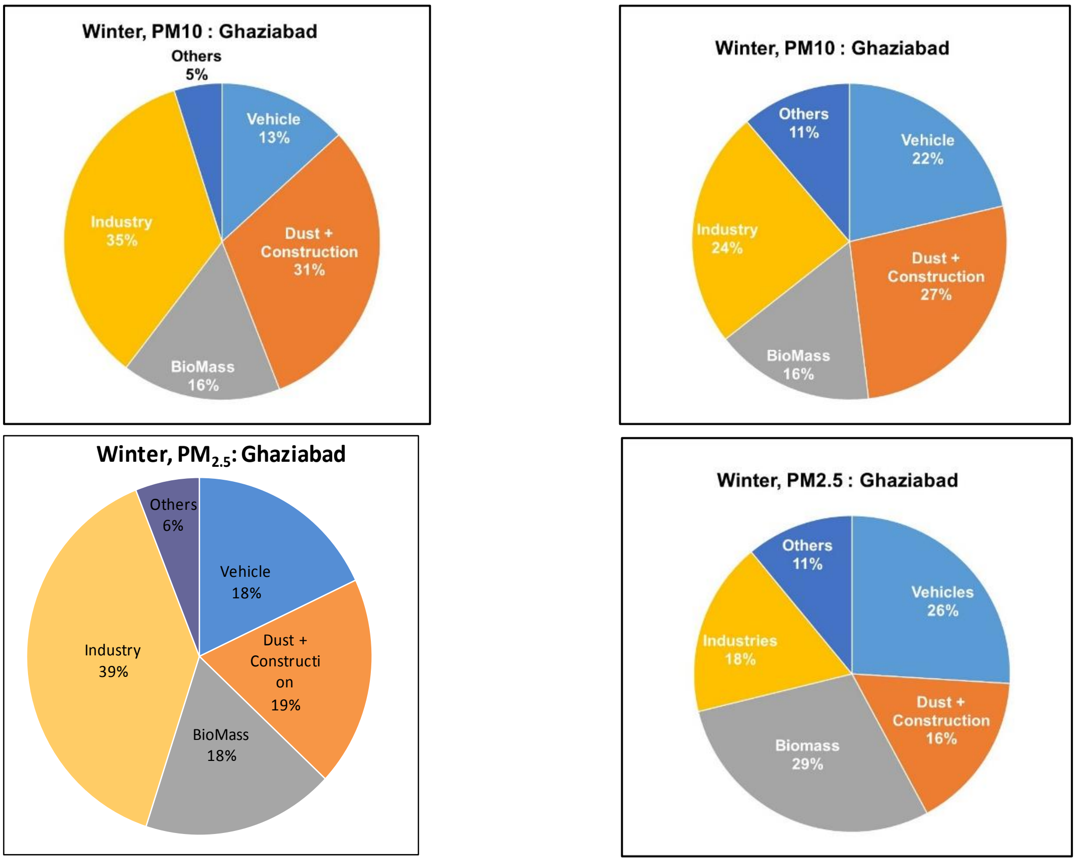
During winters in Ghaziabad, vehicles contribute in the range of 18%-26%. The city shows the significant influence of industrial emissions. However, the shares of industrial contributions appear somewhat different in the two approaches, but it may be noted that there are industries in Ghaziabad, which use biomass as fuel. The share of biomass is found to be higher in the receptor modelling approach, which is accounted in industrial shares in the dispersion modelling approach, as many industries use biomass as fuel in the region. In summers, there is a significantly high dust contribution shown by the receptor model, which is attributed to local sources (road and construction dust) and to natural sources from far-off regions.



Dispersion Modelling output

Receptor Modelling output

Figure 5.22: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Ghaziabad for summer season



Dispersion Modelling output

Receptor modelling output

Figure 5.23: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Ghaziabad for winter season

5.9.2 Gurgaon

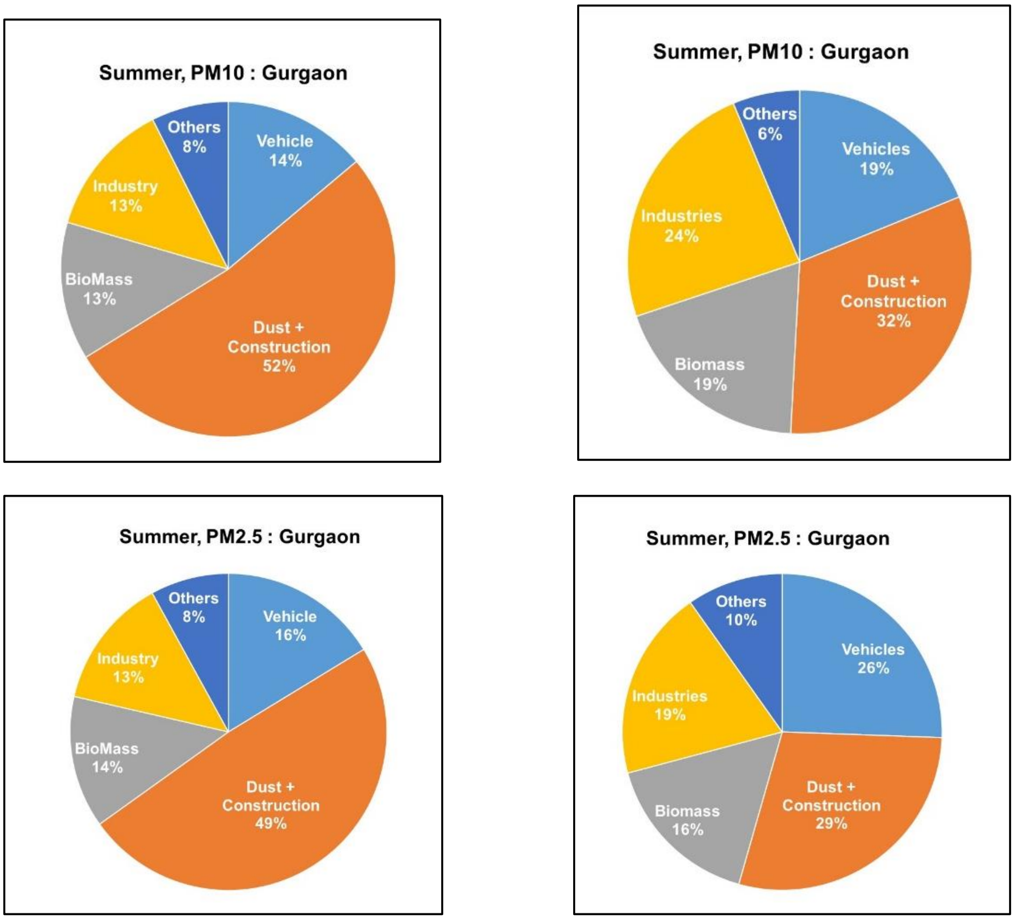
Source contributions at the two monitoring locations in Gurgaon were estimated using both receptor and dispersion modelling techniques. The average shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Gurgaon are presented in Figure 5.24 and Figure5.25, respectively.

5.9.2.1 PM_{10}

The results of both the approaches show that in PM_{10} concentrations in Gurgaon, contribution of dust (road dust, construction and other sources) was found to be higher (32%-52%) in summers and lower (23%-30%) in winters. This is mainly due to higher wind speeds, which lead to higher contributions of dust from far off sources in summers. In June there are significantly high contributions from natural dust from far-off regions which impacted the results in Gurgaon where monitoring was carried out during June for the summer season. Contribution of vehicles was estimated to be 14%-19% in summers and 16%-23% in winters. Industrial contributions (mainly from sources outside of Gurgaon) in PM_{10} concentrations in Gurgaon are 13%-26% in the two seasons. Biomass contributes to 13%-19% and 14%-20% in PM_{10} concentrations during summer and winter, respectively.

5.9.2.2 $PM_{2.5}$

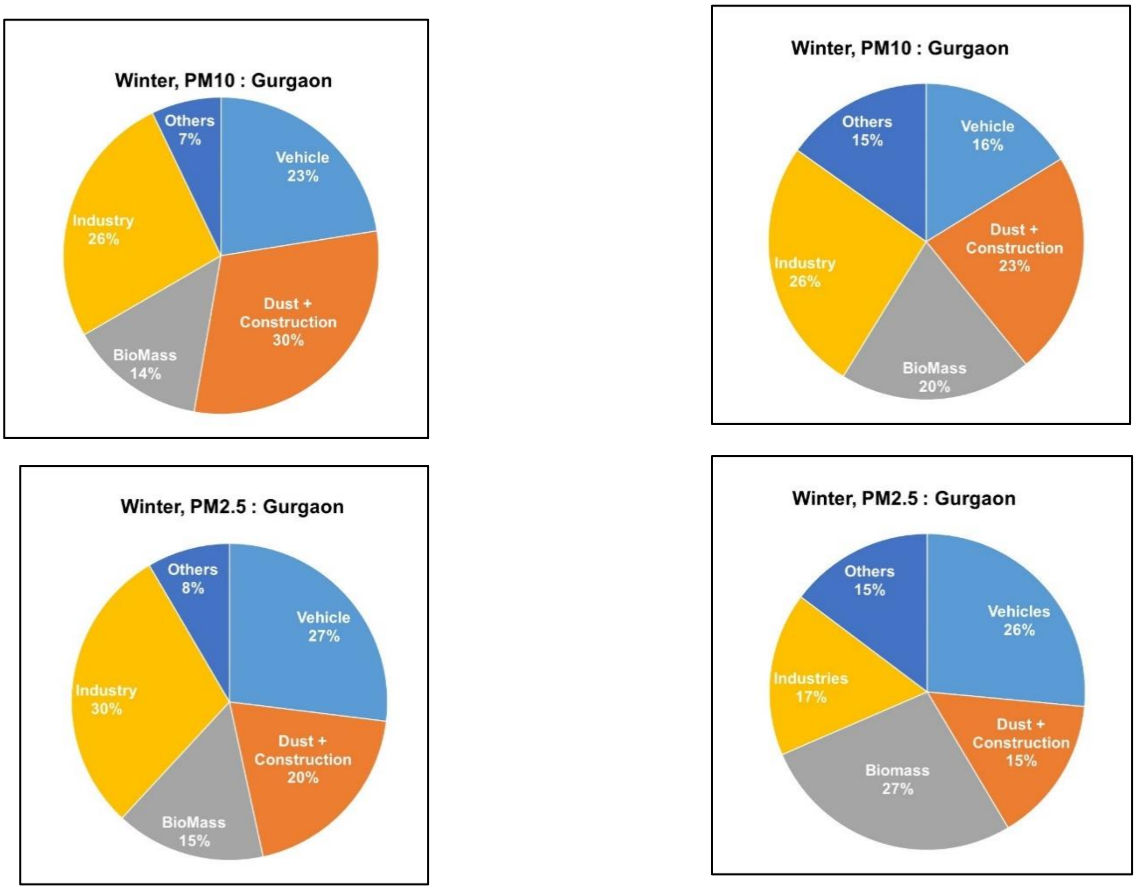
In both approaches, Gurgaon, in winters, shows significant contribution of vehicular sector (16%-26%). contribution of industries was higher in Gurgaon, often accounting for biomass use in the industrial units, which is reflected in biomass shares in the receptor modelling approach. In summers, the dispersion model predicts higher ranges (49%) of dust, in comparison to receptor model which shows 29% of dust contributions. Among the two sites in Gurgaon, the share of dust (in receptor modelling approach) varies from 16% at Site-1 to 42% at Site-2, mainly due to rain event at Site-1 during monitoring. Moreover, the monitoring locations are too few in number to account for spatial variations in emissions across the city.



Dispersion Modelling output

Receptor Modelling output

Figure 5.24: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Gurgaon for summer season



Dispersion Modelling output

Receptor modelling output

Figure 5.25: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Gurgaon for winter season

5.9.3 Faridabad

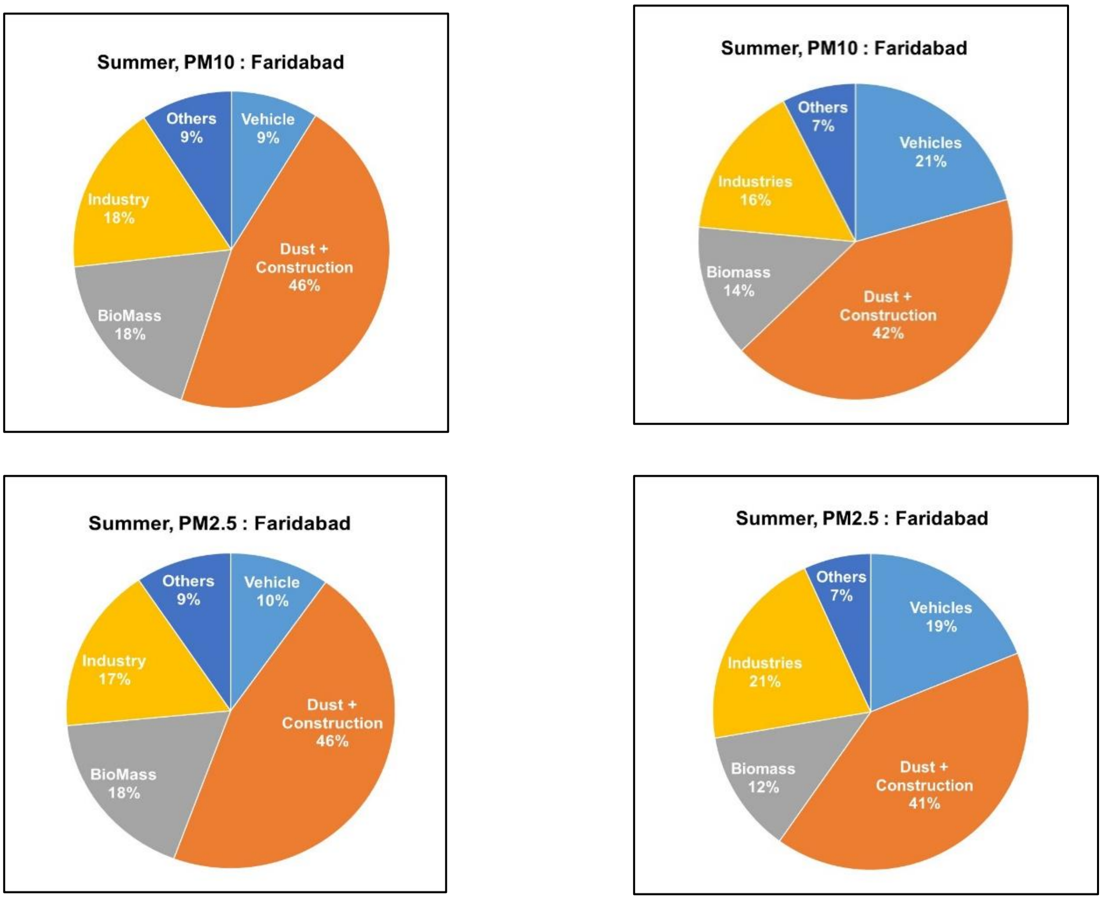
Source contributions at the two monitoring locations in Faridabad were estimated using both receptor and dispersion modelling techniques. The average shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Faridabad are presented in Figure 5.26 and Figure 5.27, respectively.

5.9.3.1 PM_{10}

The results of both the approaches show that in PM_{10} concentrations in Faridabad, contribution of dust (road dust, construction, and other sources) was found higher (42%-46%) in summer and lower (19%-23%) in winter. This is mainly due to higher wind speeds, which lead to higher contributions of dust from far off sources in summers. Contribution of vehicles was estimated to be 9%-21% in summer and 17%-21% in winter. Industries are also an important contributor in PM_{10} concentrations in Faridabad, with 16%-18% share in summer and 24%-32% in winter season. Biomass contributes within 14%-18% in PM_{10} concentrations in two seasons.

5.9.3.2 $PM_{2.5}$

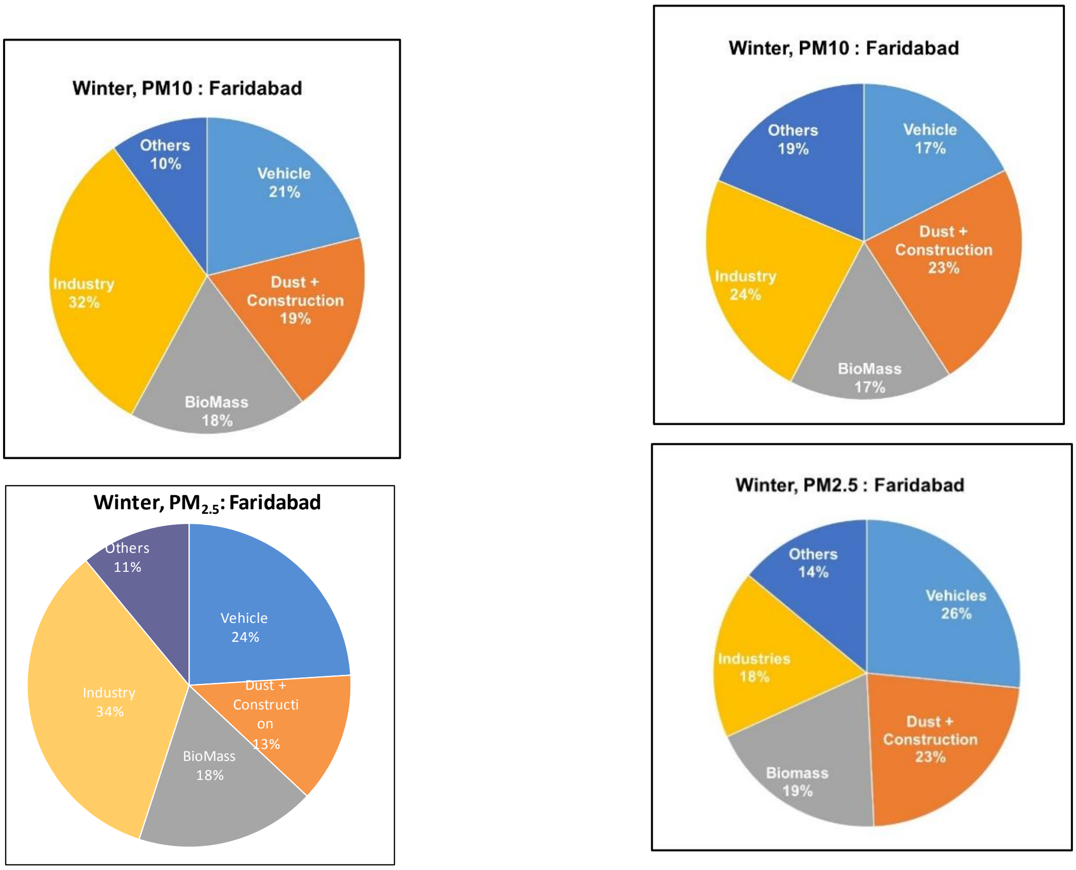
In case of $PM_{2.5}$ concentrations, the share of dust-based particles goes down, and particles emitted from combustion-based activities show higher shares. Faridabad, in winter, shows significant and consistent contribution of vehicular sector (24%-26%) in both the approaches. contribution of industries was found to be more in Faridabad, also accounting for biomass use in the industrial units, which is reflected in biomass shares in the receptor modelling approach. In summers, the higher ranges (41%-46%) of contributions have been estimated from dust, largely from international origin. Contribution of dust is slightly over-predicted from the dispersion model in comparison to the receptor model.



Dispersion Modelling output

Receptor Modelling output

Figure 5.26: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Faridabad for summer season



Dispersion Modelling output

Receptor Modelling output

Figure 5.27: Comparison of results of dispersion and receptor modelling assessment for PM$_{2.5}$ and PM$_{10}$ in Faridabad for winter season

5.9.4 Panipat

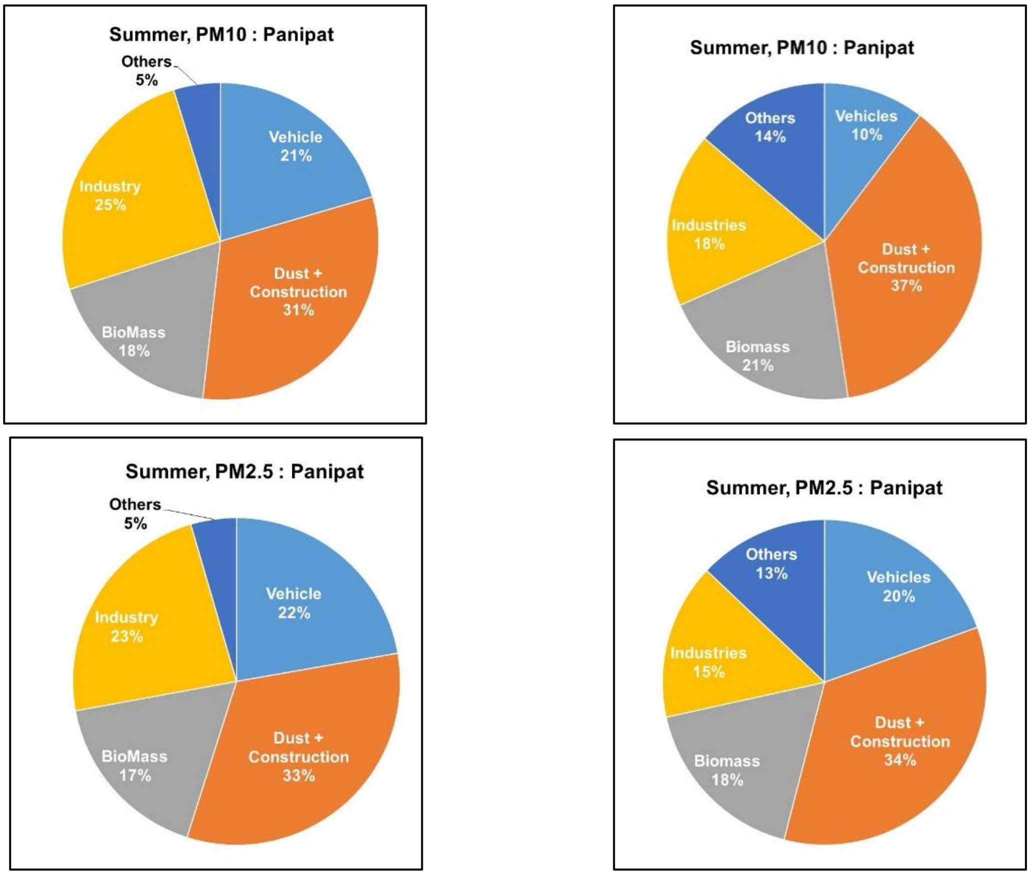
Source contributions at one monitoring location in Panipat were estimated using both receptor and dispersion modelling techniques. The shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Panipat are presented in Figure 5.28 and Figure 5.29, respectively.

5.9.4.1 PM_{10}

The results of both the approaches show that in PM_{10} concentrations in Panipat, contribution of dust (road dust, construction and other sources) was higher (31%-37%) in summer and lower (25%-26%) in winter. This is mainly due to higher wind speeds which lead to higher contributions of dust from far off sources in summer. Contribution of vehicles was estimated to be 10%-21% in summer and 18%-22% in winter. Industries emerge as one of the important contributors in PM10 concentrations in Panipat, with 18%-25% share in summers and 28%-31% in winter season. Biomass contributes to 16%-21% in PM_{10} concentrations during two seasons.

5.9.4.2 $PM_{2.5}$

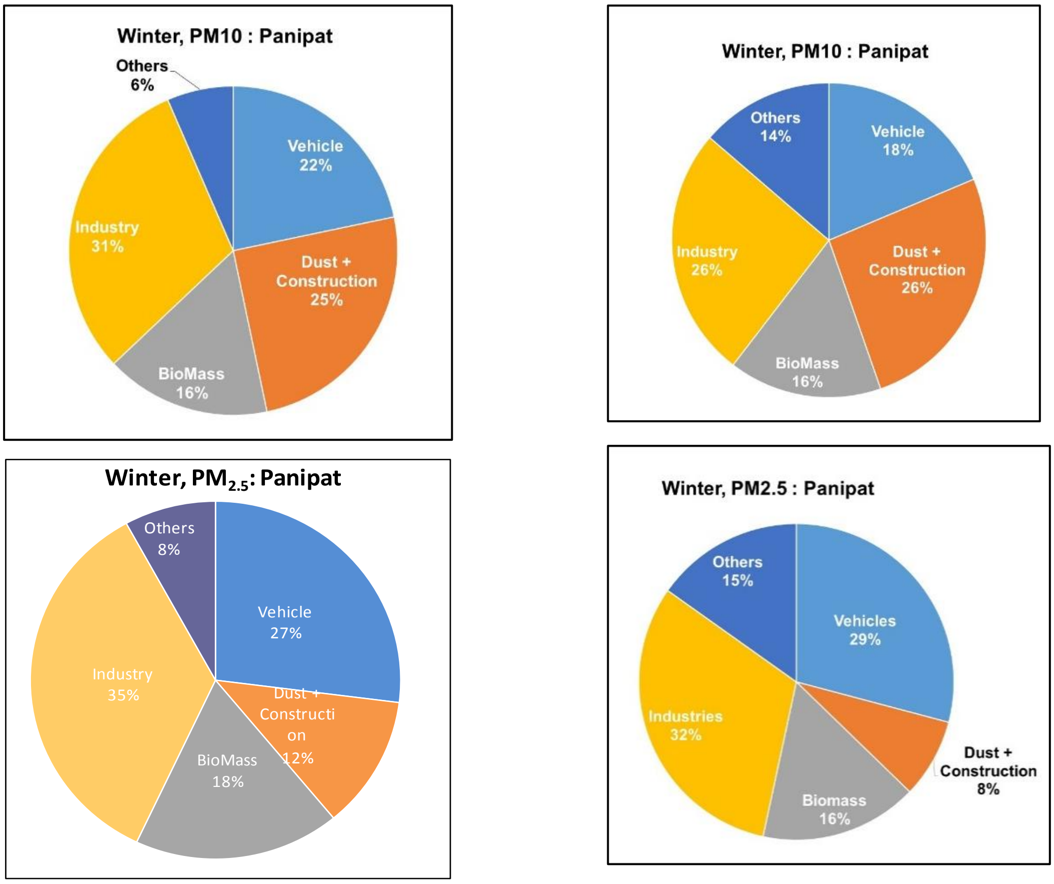
In both the seasons, Panipat shows significant and consistent contribution of vehicular sector (20%-29%). contribution of industries higher more in Panipat, also accounting for biomass use in the industrial units, which is reflected in biomass shares in the receptor modelling approach. Biomass burning also features significantly in the contributions across both the seasons (16%-18%) In summers, the higher ranges (33%-34%) of contributions have been estimated from dust.



Dispersion Modelling output

Receptor Modelling output

Figure 5.28: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Panipat for summer season



Dispersion Modelling output

Receptor modelling output

Figure 5.29: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Panipat for winter season

5.9.5 Bahadurgarh

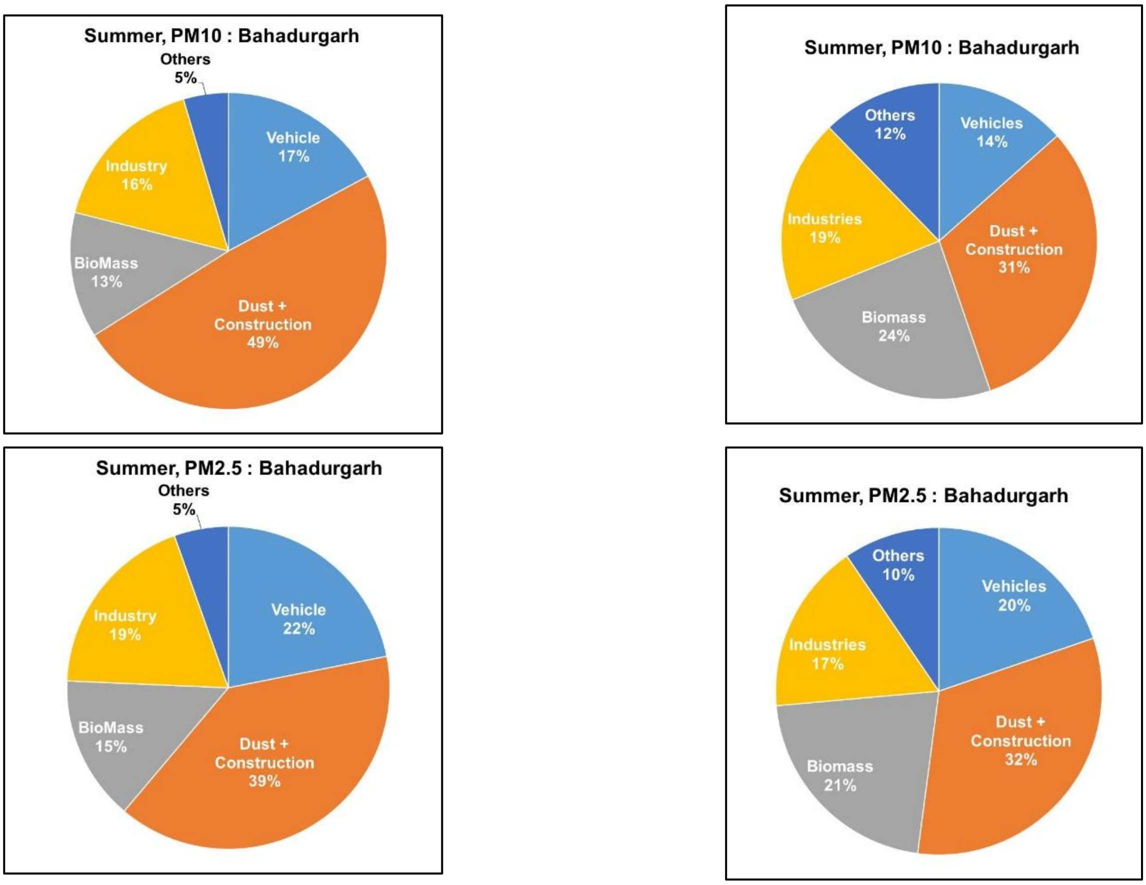
Source contributions at the one monitoring location in Bahadurgarh were estimated using both receptor and dispersion modelling techniques. The shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Bahadurgarh are presented in Figure 5.30 and Figure 5.31, respectively.

5.9.5.1 PM_{10}

In PM_{10} concentrations in Bahadurgarh, contribution of dust (road dust, construction, and other sources) was higher (31%-49%) in summer and lower (28%-40%) in winters. This is mainly due to higher wind speeds which lead to higher contributions of dust from far off sources in summer. Contribution of vehicles was estimated to be 14%-17% in summers and 20%-21% in winters. Industries are also one of the important contributors in PM_{10} concentrations in Bahadurgarh, with 16%-19% share in summer and 22%-25% in winter. Biomass contributes to 13%-24% and 11%-13% in PM_{10} concentrations during summer and winter.

5.9.5.2 $PM_{2.5}$

Bahadurgarh being close to Delhi, shows similar source contributions. Vehicles have a share of 24%-28% in winters, and 20%-22% in summers. Biomass burning (including both agricultural and kitchen) also contribute significantly in both the seasons (12%-23%) In summer, the higher ranges (32%-39%) of contributions have been estimated from dust, contributed by both road dust, construction, and particles of natural origin from far-off regions.



Dispersion Modelling output

Receptor Modelling output

Figure 5.30: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Bahadurgarh for summer season

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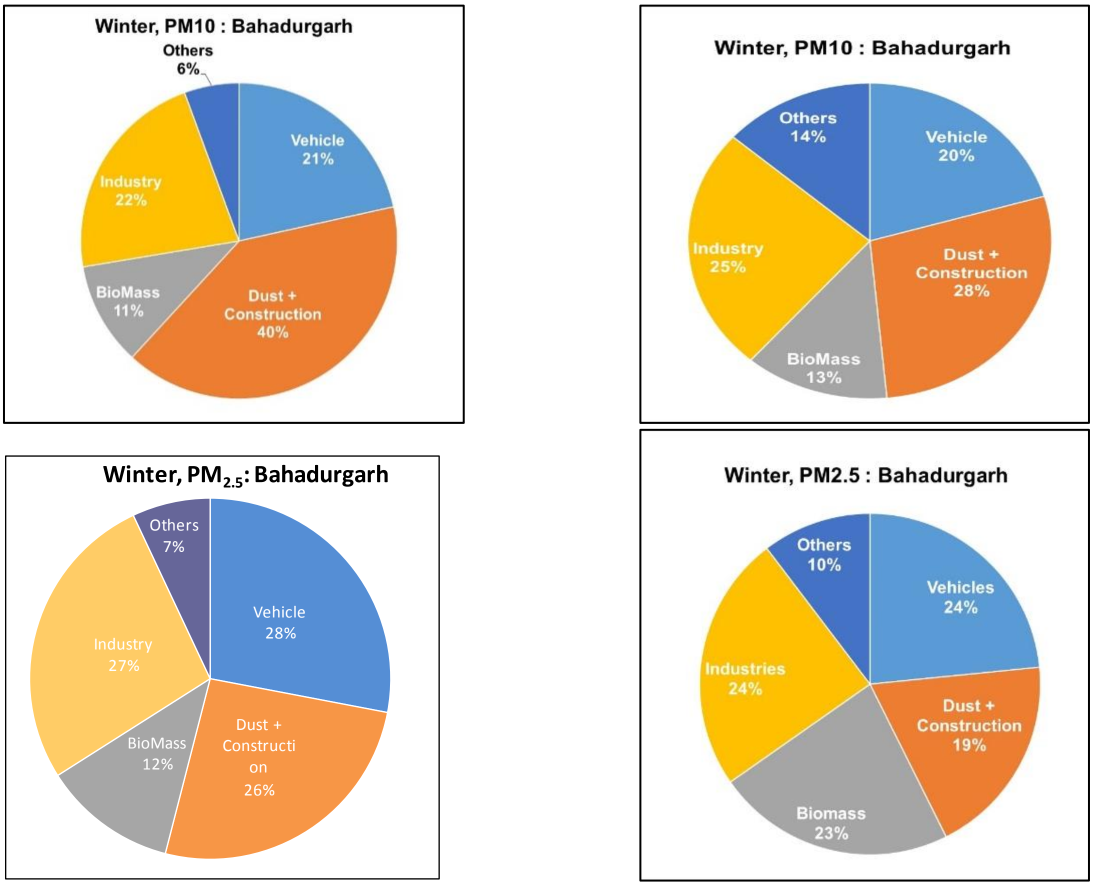


Dispersion Modelling output

Receptor Modelling output

Figure 5.31: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Bahadurgarh for winter season

5.9.6 Noida

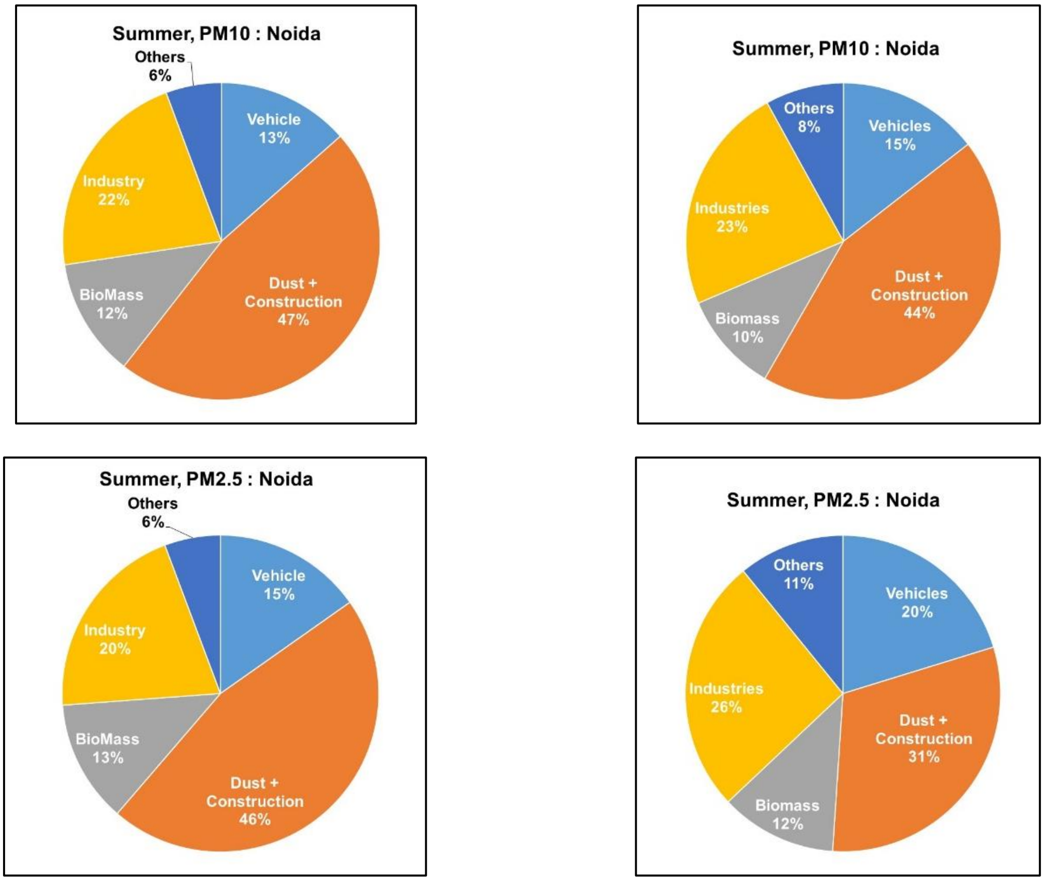
Source contributions at the two monitoring locations in Noida were estimated using both receptor and dispersion modelling techniques. The shares of different contributing sectors in PM_{10} and $PM_{2.5}$ concentrations in Noida are presented in Figure 5.32 and Figure 5.33, respectively.

5.9.6.1 PM_{10}

In PM_{10} concentrations in Noida, contribution of dust (road dust, construction and other sources) was higher (44%-47%) in summer and lower (23%-29%) in winter. This is mainly due to higher wind speeds which lead to higher contributions of dust from far off sources in summer. Contribution of vehicles was estimated to be 13%-15% in summer and 21%-25% in winter. Being in downwind of Delhi, Noida receives the effect of emissions released in Delhi. Industries emerged as one of the important contributors in PM_{10} concentrations in Noida, with 22%-26% share in the two seasons. Biomass contributes to 10%-12% in PM_{10} concentrations.

5.9.6.2 $PM_{2.5}$

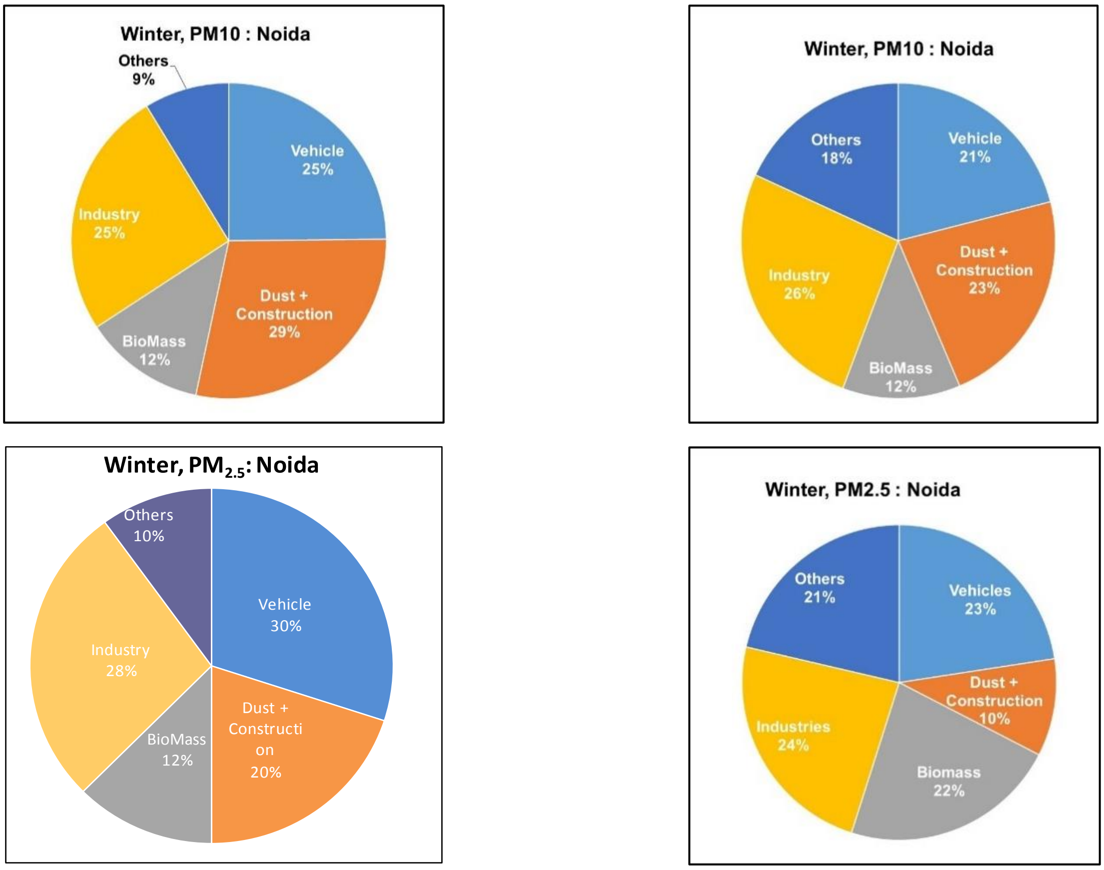
Noida located in downwind direction to Delhi, receives significant contributions from Delhi-based sources. Accordingly, in winters, vehicle contributions are found to be higher (23%-30%). Industrial contributions are in the range of 24%-28%, followed by biomass 13%-22% in winters. In summer, contribution of most sectors is found to be lower due to increase in dust of natural origin.



Dispersion Modelling output

Receptor Modelling output

Figure 5.32: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Noida for summer season



Dispersion Modelling output

Receptor Modelling output

Figure 5.33: Comparison of results of dispersion and receptor modelling assessment for $PM_{2.5}$ and PM_{10} in Noida for winter season

5.10 Geographical contributions

This study also estimated contribution of various regions towards $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR towns. The average contribution of Delhi's own emissions in Delhi $PM_{2.5}$ concentrations was 36% in winter and 26% in summer (Figure5.34). However, there are variations across different places in the city. The finding is in line with other recent studies for Delhi (Marrapu et al., 2014; IITK, 2015) regarding significant contributions from outside of the city to local Delhi pollution. The joint study by IITM and University of Iowa (Marrapu et al., 2014) showed that outside sources contributed 30%–80% to air pollution in different parts of Delhi. IITK (2015) also showed significant contributions (~56%) from secondary particulates, coal use, and biomass burning, which mainly originate from regions outside Delhi. Kiesewetter et al. (2017) recently has also shown that about 60% of $PM_{2.5}$ is contributed by sources outside the city of Delhi. In summer, contribution of outside sources is higher on account of higher wind speeds and enhanced atmospheric transport of pollutants.

In the towns of NCR, contribution of emissions from Delhi city varies as per their location with respect to Delhi and the prevailing wind direction. Noida city which is located in the downwind of Delhi receives 28%-40% of its $PM_{2.5}$ concentrations from Delhi-based sources, in summer-winter seasons, respectively. On the other hand, Panipat which is upwind of Delhi receives only 1% contribution from Delhi, and shows 56%-70% contribution from the remaining NCR regions. Ghaziabad also receives its major (61%-70%) contribution from NCR.

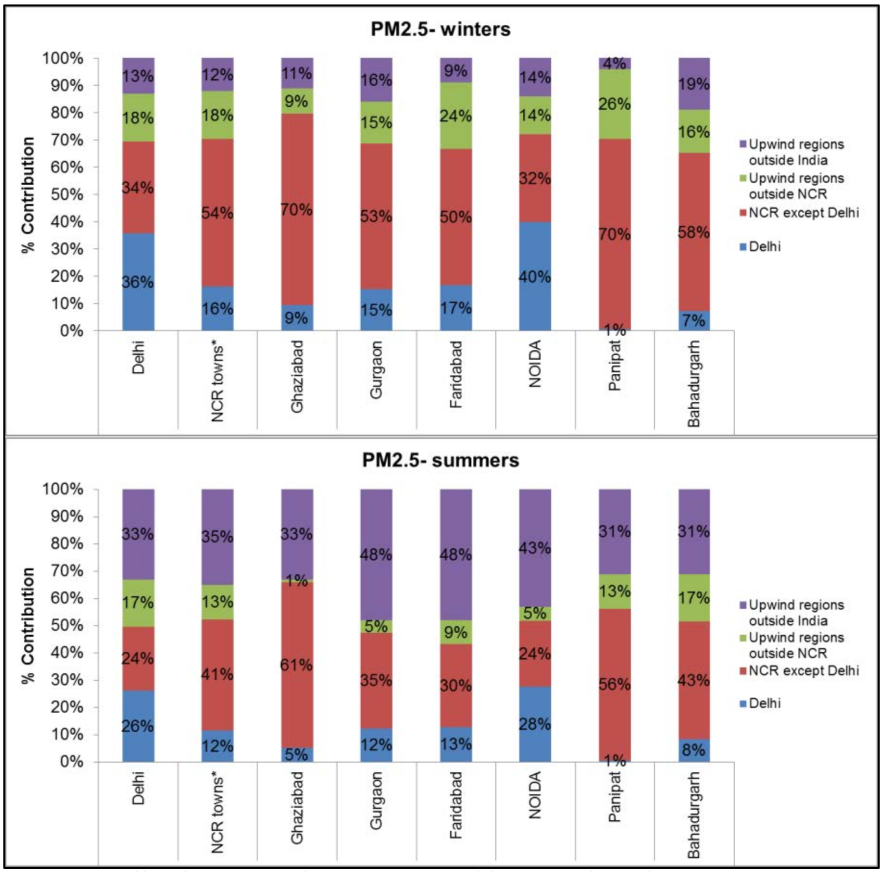


Figure 5.34: contribution of various geographical regions in $PM_{2.5}$ concentrations in different towns during summer and winter seasons

* The contribution of nearby districts like Gurgaon, Faridabad, NOIDA, Ghaziabad, Jhajjar and Sonipat in Delhi's PM2.5 concentrations was 23-24%.

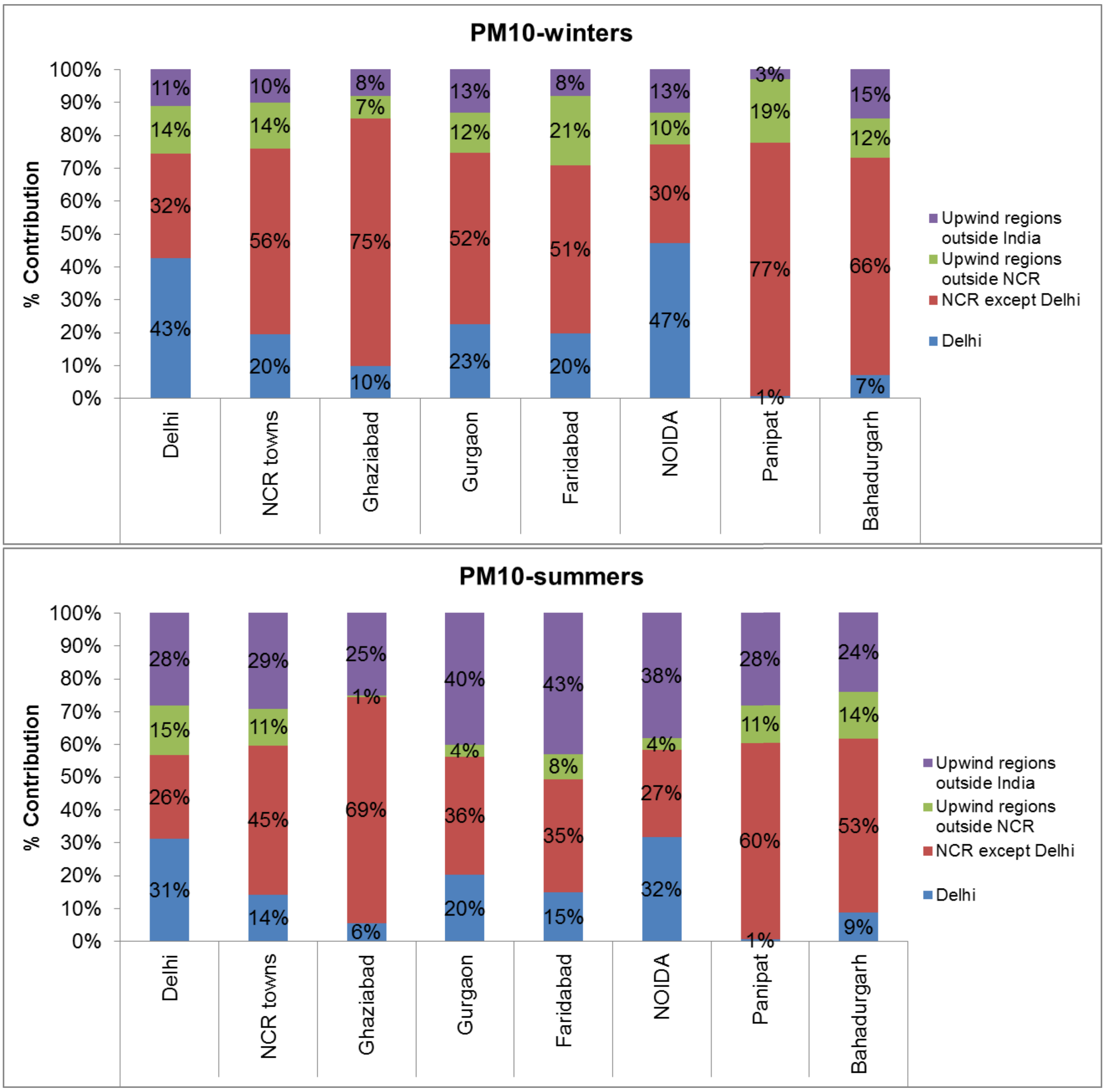


Figure 5.35: contribution of various geographical regions in PM_{10} concentrations in differ towns during summer and winter seasons

* The contribution of nearby districts like Gurgaon, Faridabad, NOIDA, Ghaziabad, Jhajjar and Sonipat in Delhi's PM_{10} concentrations was 26%.

Note: Share of different regions (Figure 5.34 and Figure 5.35) vary across different cities because of sources and also because of changing meteorology as the period monitoring varied across three months within a season

The average contribution of Delhi's own emissions in Delhi's PM_{10} concentrations was found to be 43% in winter and 31% in summer (Figure 5.35). There are variations across different places in the city. In the NCR towns, contribution of emissions from Delhi city varies as per their location with respect to Delhi and prevailing wind directions. Noida located in the downwind of Delhi receives 32%-47% of its PM_{10} concentrations from Delhi-based sources, in summer-winter seasons, respectively. On the other hand, Panipat which is upwind of Delhi receives only 1% contribution from Delhi, and shows 60%-77% contribution from remaining NCR regions (mainly from its own sources). Ghaziabad also receives it major (69%-75%) contribution from NCR only. Gurgaon gets 20%-23% of its PM_{10} concentrations from Delhi-based sources, while 36%-52% are contributed by remaining NCR sources.

5.11 Daily variations in source contributions

Other than the averaged values for the season, there are daily variations in modelled source contributions. These are mainly due to changes in meteorological parameters, such as wind speed, wind direction, planetary boundary, layer height, etc. Figure 5.36 shows Daily variations in source contributions at two typical sites – one in Delhi (Janak Puri) and another one in NCR but outside Delhi (Panipat). Evidently, the variations are stark during certain periods. During 6-10 December, due to reduced wind speeds, the concentrations were higher. During these calmer conditions, contribution of local sources (transport, road dust, others, etc.) is enhanced.

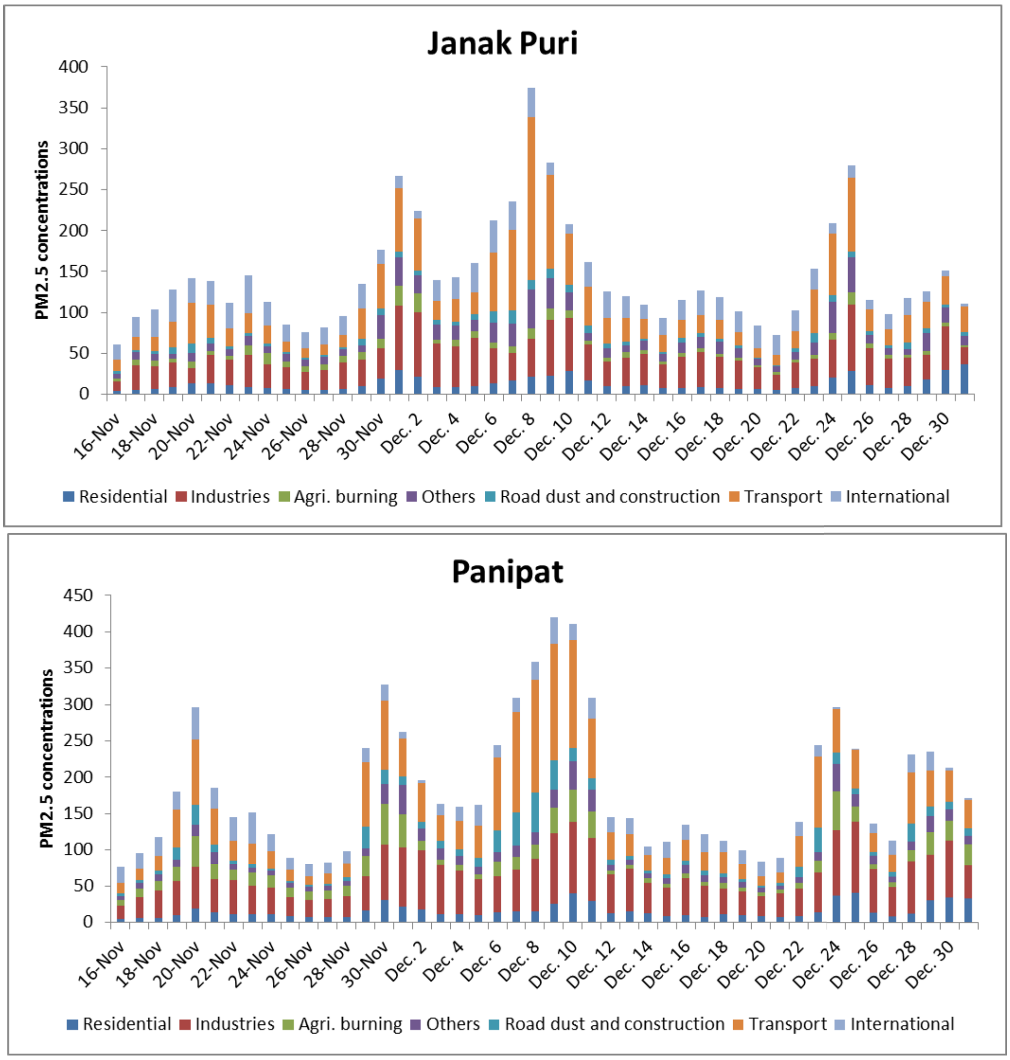


Figure 5.36: Daily modelled results of PM2.5 source apportionment using dispersion modelling at two typical locations in Delhi (Janak Puri) and NCR (Panipat)

Chapter 6: Future projections

In the last section, the CMAQ model results were validated with the actual observations and source contributions derived for the year 2016. In order to understand the growth in different sectors contributing to air pollution in the region, analysis of future scenario has also been carried out. In this regard, possible future growth scenarios have been prepared for the year 2025 (medium term) and 2030 (long term). A Business as Usual (BAU) scenario has been developed, which takes into account the growth trajectories in various sectors and also the policies and interventions, which have already been notified for control of air pollution. A No-Further-Control (NFR) scenario has been analysed in which impacts of these already planned interventions have been discounted. In order to assess the potential of various strategies for control of PM_{10} and $PM_{2.5}$ concentrations, 28 interventions in different sectors have been tested on the model. Strategies which could provide significant air quality benefits, have been identified and by combining them, an alternative scenario (ALT) has been developed with the aim to meet the prescribed ambient air quality standards..

6.1 Business as Usual Scenario

The BAU scenario depicts change in different sectors, such as transport, industries, domestic, open burning, crematoria, restaurants, etc. This scenario does not account for any additional interventions to manage air quality, in addition to the already planned policies/interventions by the government in different sectors. The growth rates of different sectors have been adopted through literature review. Growth rates of different types of vehicle registrations are obtained from NCR functional plan document for the transport sector (NCRPD, 2010). Accordingly, the vehicular sector has been assumed to grow at a rate of 7% till 2025 and by 4% thereafter. As notified, BS-VI emission norms have been assumed to be effective from 2020 and further expansion in CNG network in NCR has also been envisaged in the BAU scenario. Growth rate of industries is taken to be same as the growth rate of gross domestic product (GDP) of secondary sector in the NCR region (NCRPD, 2015a). In view of the recent ban on pet-coke and furnace oil (FO), the fuel use in industries has been replaced by coal and light diesel oil, respectively. Moreover, with introduction of new norms for sulphur dioxide (SO_2) and nitrogen oxides (NOx), 25% and 50% industrial units have been assumed to be installed with wet scrubber in 2025 and 2030, respectively. The growth rate of construction sectors is taken as 5% up to 2021 and 2% thereafter (NCRPD, 2015b). In order to account for recent initiatives to enforce construction waste guidelines and other measures like graded action plan, a 30% reduction in construction emissions has been assumed by 2030. In order to derive the growth rate of brick production in the region, the growth rate of the construction sector is tapered after accounting for the use of alternative construction materials in future. Finally, a growth rate of 4% has been adopted for the sector up to 2021 and thereafter a 1.7% growth is envisaged. The Government of India has notified Zig Zag technology for the sector and hence, 25%-50% penetration of the technology has been assumed by 2025-2030, respectively. In the residential sector, population growth rate of 4.5% have been assumed and increased penetration of LPG is considered, based on the growth witnessed during last 3 years after the launch of Pradhan Mantri Ujjawala Yojana. In this scenario, LPG has been assumed to replace the equivalent amount of biomass based on calorific value and stove cooking efficiency. As per NCR Regional Plan 2021 (NCRPD, 2015b), no new power plants will be set up in NCR and increased demand in electricity will be met by purchasing power from the neighboring states. Accordingly, no growth in the emissions of power plants has been assumed in the future. The Badarpur power plant has been assumed to shut down in the future scenario. With extensive electrification of villages, kerosene consumption for lighting purposes has also been assumed to be zero in the year 2025 onwards. The growth in the agricultural sector is assumed at 4.93% and 50% reduction in residue burning have been envisaged in the BAU scenario by 2030. The reduction is assumed on account of recent efforts by the judiciary, government, industries, and NGOs to enforce the ban on burning of residues and also to use them for useful purposes (happy seeder technique, bio-methanation and gasification etc). In absence of any strict enforcement of the regulations, the emissions of refuse burning and restaurants have been assumed to increase with the growth of population. The description of the planned control strategies and growth rate in each of the sectors is shown in Table 6.1.

Table 6.1 : Growth rate and planned strategies in various sectors in BAU.

SECTOR	GROWTH ASSUMPTIONS	PLANNED STRATEGIES
Transport and road dust	7% growth rate up to 2025, thereafter 4%	BSVI in 2020 and expansion in CNG network in NCR, penetration of electric and hybrid vehicle
Industries	7%	Wet scrubber installed in 25% and 50% of units in 2025 and 2030, respectively. Pet coke is replaced by coal and fuel oil is replaced by Light Diesel Oil
Power plant	No growth	In future, power demand will be met by purchasing power from neighbouring states. Badarpur power plant assumed to be closed.
Residential	Based on population growth rate (4.5%)	Increased penetration of LPG based on recent trends
Agri Burning	4.93% growth based on primary sector GDP growth rate	50% reduction in agricultural residue burning due to happy-seeder, bio-methanation and gasification etc.
Construction	5% up to 2021 thereafter 2%	30% control by 2030
DG sets	No growth	With improved electricity availability, 50% reduction in usage by 2030
Refuse burning	Based on population growth rate (4.5%)	None
Crematoria	Based on population growth rate (4.5%)	None
Restaurants	Based on population growth rate (4.5%)	None
Stone crushers	5% growth rate up to 2025, thereafter 2%	None
Brick kiln	4% up to 2021 thereafter 1.7%	25% and 50% of brick kiln on zig-zag technology by 2025 and 2030, respectively.

* Other sectoral emissions, boundary conditions, and meteorology have been kept constant in future

Based on Table 6.1, the BAU scenario has been developed and emission loads for different pollutants like PM_{10}, $PM_{2.5}$, NOx, and SO_2 have been estimated. The estimates in the years 2016, 2025, and 2030 are shown in Figure6.1. From 2016 to 2030, the total PM_{10}, $PM_{2.5}$, and NOx emissions are projected to increase by 52%, 50%, 3%, respectively, while SO_2 emissions are expected to decrease by 52% during 2016-2030.

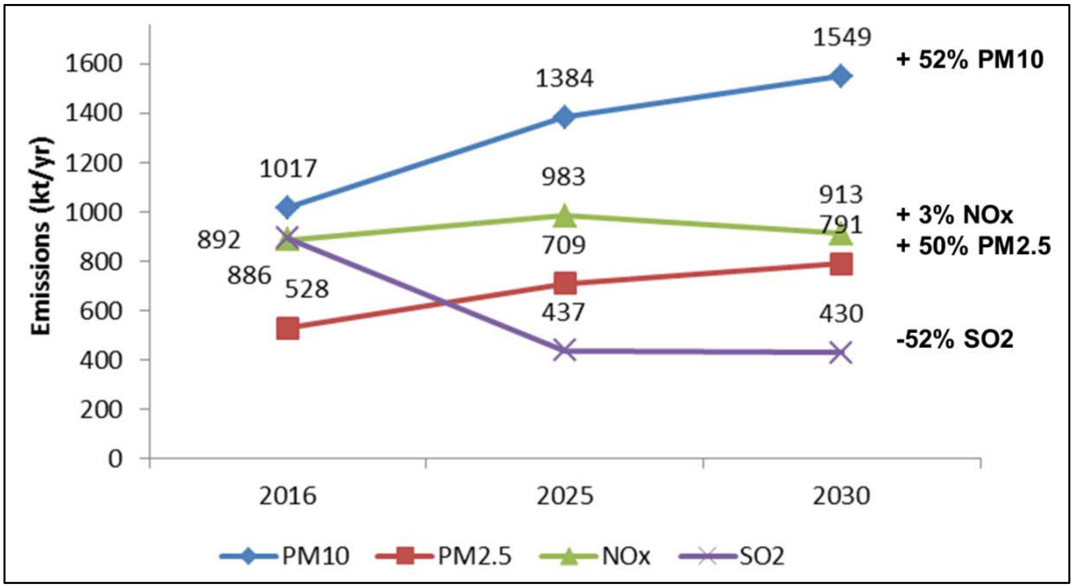


Figure 6.1: Estimated total PM_{10}, $PM_{2.5}$, NOx and SO_2 emission load in BAU scenario during 2016-2030

Figure 6.1 shows that emissions of PM_{10} are increasing at a faster pace as compared to the emissions of $PM_{2.5}$. This is expected as the combustion-based sectors like biomass and transport are expected to reduce their shares with the implementation of BS-VI norms in 2020 and increased penetration of natural gas in both the transport and residential sectors. It has been estimated that introduction of BS-VI in 2020 can help in reducing PM_{10}, $PM_{2.5}$, and NOx emissions in 2025 and the corresponding reductions in $PM_{2.5}$ and PM_{10} concentrations would be 8.9 and 9.3 µg/m^3, respectively(which is 8% and 6% of total $PM_{2.5}$ and PM_{10} concentrations, respectively) . Similar reductions in 2030 in $PM_{2.5}$ and PM_{10} concentrations would be 17.1and 18 µg/m^3, respectively (which are 14% and 11% of total $PM_{2.5}$ and PM_{10} concentrations, respectively).

It may be seen that emissions of NOx stabilize during 2016 and 2030, mainly due to introduction of BS-VI emission norms in the vehicular sector, stringent NOx and SO_2 standards in industries, 50% reduction in usage of DG sets by 2030. The emissions of SO_2 are projected to decrease drastically in the future due to the replacement of high sulphur petcoke by coal in industries, and introduction of stringent standards for industries. With LPG penetration, emissions have more or less stabilized despite population growth by the year 2030. However, emissions of $PM_{2.5}$ in the sector have been decreased due to envisaged elimination of kerosene use for lightning purposes which primarily emits finer fractions of PM. With 100% electrification of villages, kerosene use for lightning purpose is expected to reduce drastically. Sector-wise percentage change in emissions of PM_{10}, $PM_{2.5}$, NOx, and SO_2 in 2030 with respect to BAU are shown in Figure 6.2. Emissions of PM_{10} and $PM_{2.5}$ have been projected to double in the industrial sector, while they increase by 82%-69% in road dust and construction sectors by 2030, respectively. With introduction of BS-VI norms, the PM emissions from the vehicular sector are expected to be 49% lc

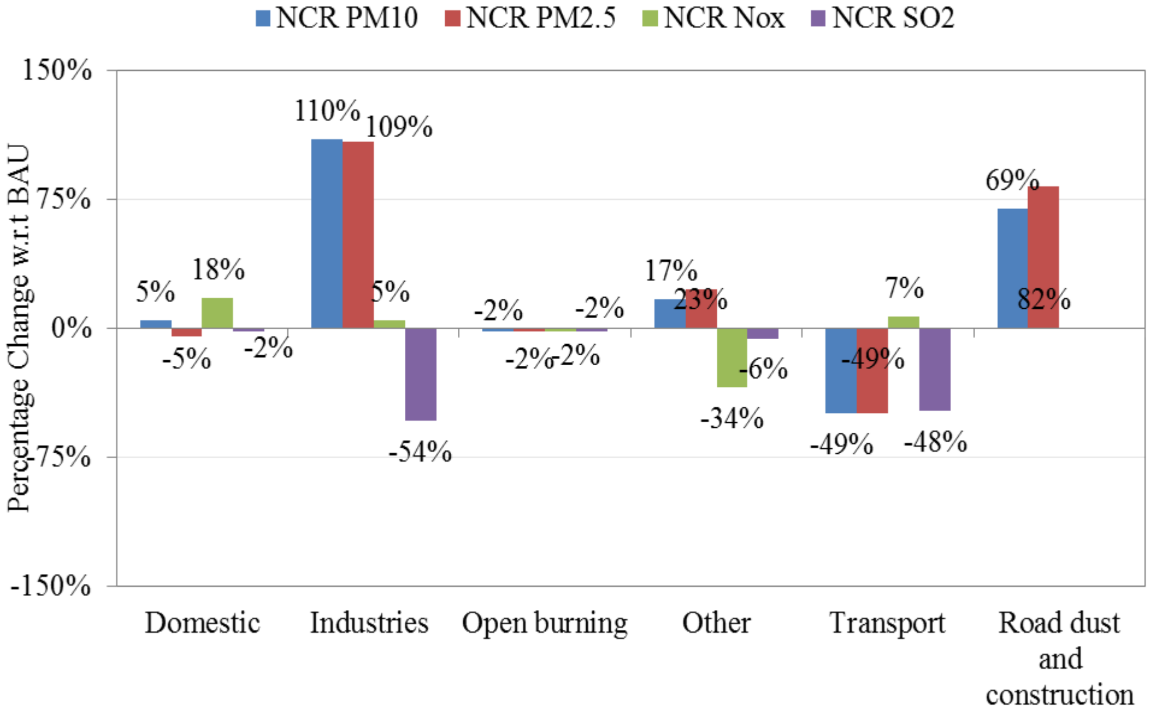


Figure 6.2: Percentage change in emissions of PM_{10}, $PM_{2.5}$, NOx and SO_2 from different sectors in the year 2030 with respect to those in the year 2016.

The estimated total emissions loads of PM_{10}, $PM_{2.5}$, NOx, SO_2, CO, and HC in the years 2025 and 2030 are shown in the Table 6.2 and sectoral contribution is shown in Figure6.2.

Table 6.2 : Emissions (kt/yr) of PM_{10}, $PM_{2.5}$, SO_2 and NOx in NCR in BAU scenario.

Sector	2016 (kt/yr)						2025 (kt/yr)						2030 (kt/yr)					
	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR
	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	HC	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	HC	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	HC
Transport	69	66	529	4	1751	886	47	46	647	1	1209	924	35	34	564	0	1096	736
Industries	288	127	85	556	620	27	589	277	88	128	804	50	722	330	106	120	834	70
Power Plants	74	40	133	297	13	9	69	37	122	274	13	9	69	37	122	274	13	9
Residential	204	131	38	17	1700	374	193	113	40	18	1659	399	214	125	45	19	1844	442
Agri residue burning	174	102	31	9	781	209	182	107	32	9	817	219	171	100	30	9	766	205
Road dust	137	31	0	0	0	0	217	49	0	0	0	0	252	60	0	0	0	0
Construction	44	8					55	10	0	0	0	0	54	10	0	0	0	0
DG sets	4	3	53	3	11	4	3	2	36	2	8	3	2	2	26	2	6	2
Refuse burning	18	14	6	1	56	33	22	18	7	1	69	41	24	20	8	1	78	46
Crematoria	2	1	0	0	8	4	2	1	0	0	11	6	2	1	0	0	11	6
Restaurant	2	1	1	2	3	0	2	1	1	2	4	1	2	1	1	2	4	1
Airport	0	0	7	1	14	7	0	0	7	1	14	7	0	0	7	1	14	7
Waste incinerators	1	0	4	2	1	0	1	0	4	2	1	0	1	0	4	2	1	0
Landfill fires	2	2	1	0	6	2	2	2	1	0	6	2	2	2	1	0	6	2
Solvents						113	0	0	0	0	0	191	0	0	0	0	0	255
Total	1017	527	886	892	4964	1671	1384	663	983	437	4613	1851	1549	722	913	430	4673	1781

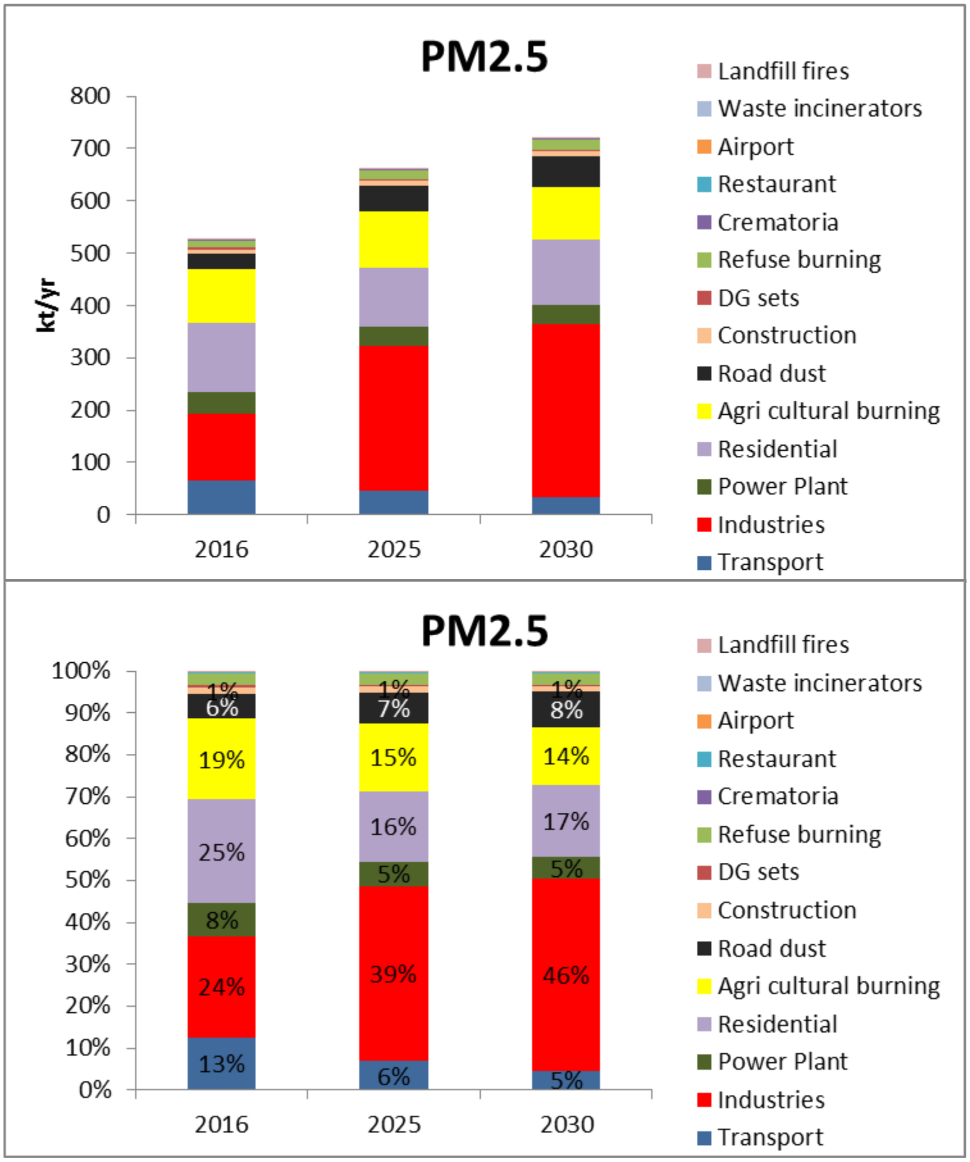


Figure 6.3: Sectoral contribution in emissions of $PM_{2.5}$ in BAU in 2025 and 2030.

As seen in Figure 6.3, industries remains the major contributing sector, as their share increases from 24% in 2016 to 39% and 46% of $PM_{2.5}$ emissions in 2025 and 2030, respectively. Contribution of the residential sector reduces from 25% to 17%, while share of transport has reduced from 13% in 2016 to 6% in 2025 and 5% in 2030. Contribution of road dust is projected to increase slightly.

6.2 No Further Control (NFC) scenario

The BAU scenario shows some increase in pollutant emissions of PM_{10}, NOx, and $PM_{2.5}$. However, the increase could be even higher if the strategies envisaged in BAU are not implemented. Figure 6.4 and Figure6.5 show the growth in emissions loads and concentration of PM_{10} and $PM_{2.5}$, respectively, if strategies mentioned in Table 6.3 are not implemented. This shows that the strategies planned by the government, which are included in the BAU scenario are expected to contribute significantly in reducing emissions and concentration of PM_{10} and $PM_{2.5}$ by the year 2030. In the absence of these planned strategies (NFC scenario), the emissions of PM_{10} and $PM_{2.5}$ in 2030 would increase by 29% and 33% with respect to BAU, respectively.

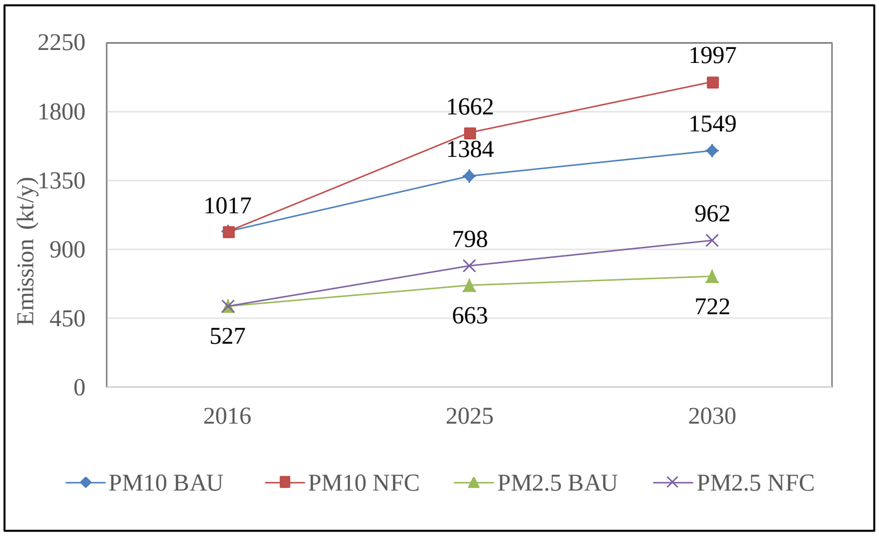


Figure 6.4: Emission loads of PM_{10} and $PM_{2.5}$ in NCR in BAU and NFC scenario

The increase in emissions in NFC scenario has been used to model the impact on PM_{10} and $PM_{2.5}$ concentrations in NCR including Delhi. The increase in the concentration with respect to BAU is estimated to be about 30% in both pollutants in the NCR region including Delhi. Conclusively, BAU scenario accounts for around 30% reduction in PM concentrations with respect to the possible increase depicted in NFC scenario.

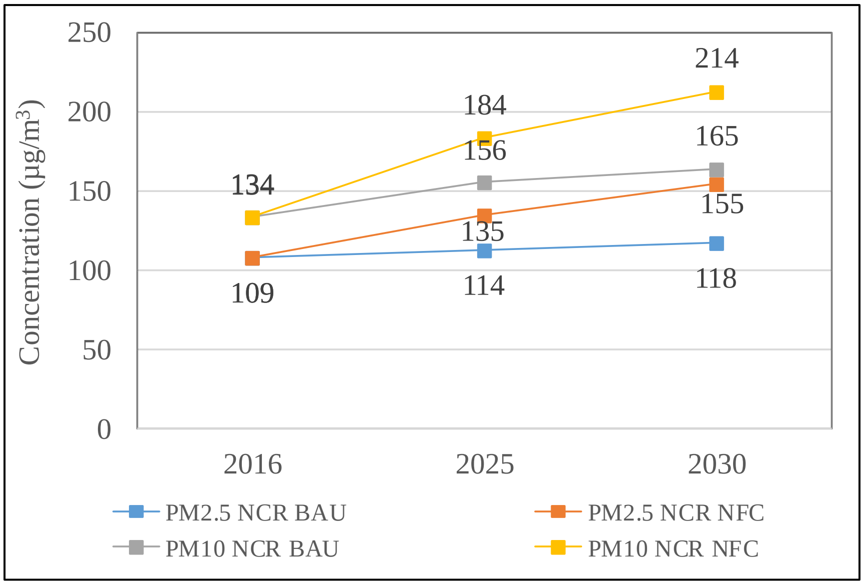


Figure 6.5: Average concentrations (for both seasons) of PM_{10} and $PM_{2.5}$ in NCR in BAU with and without strategy

6.3 Sectoral contributions in BAU in NCR

The emissions projected for 2025 and 2030 in the BAU scenario has been fed into the model and through the source sensitivity approach (as used in the baseline 2016 assessment), sectoral shares in the project PM_{10} and $PM_{2.5}$ concentrations have been estimated for the year 2025 and 2030 (Table 6.3). The industry is projected to be the major contributor to $PM_{2.5}$ and PM_{10} concentrations in 2025 and 2030. With introduction of BS-VI norms, contribution of transport sector is projected to reduce in $PM_{2.5}$ and PM_{10} in 2030. Contribution of residential and agri burning sector remain similar in 2016 and 2030, while contribution of road dust may increase from 5% in 2016 to 8% in 2030 and contribution of other sectors is projected to decrease from 8% to 7% in 2030 in $PM_{2.5}$ concentration.

Table 6.3: Sectoral contribution in $PM_{2.5}$ and PM_{10} concentrations (average for both seasons) in BAU for NCR including Delhi

Sector	$PM_{2.5}$			PM_{10}		
	2016	2025	2030	2016	2025	2030
Residential	10%	9%	10%	9%	9%	9%
Industry	27%	33%	37%	25%	31%	34%
Agri. Burning	5%	5%	5%	5%	5%	4%
Others	8%	8%	7%	7%	6%	6%
Dust (road, construction, natural)	28%	30%	30%	35%	37%	38%
Transport	21%	16%	12%	18%	12%	9%

6.4 Species contribution in $PM_{2.5}$ concentrations in BAU in NCR including Delhi

Figure 6.6 shows the species-wise distribution of $PM_{2.5}$, in both the seasons, which has been derived using simulations of future air quality using the same approach as in the baseline scenario. It is evident that contribution of secondary particulate matter, such as sulphate, and nitrate, will decrease in 2030 as compared to 2016. This could be attributed to number of interventions, such as banning of petcoke and FO, stringent SO_2 and NOx standards for industries, introduction of BS-VI emission norms, etc. The share of elemental and organic carbon is expected to be the same, while the other elements are projected to increase in 2030 as compared to 2016. The increase in dust can be attributed to limited controls or no major intervention planned for sectors, such as road dust, construction activities, etc.

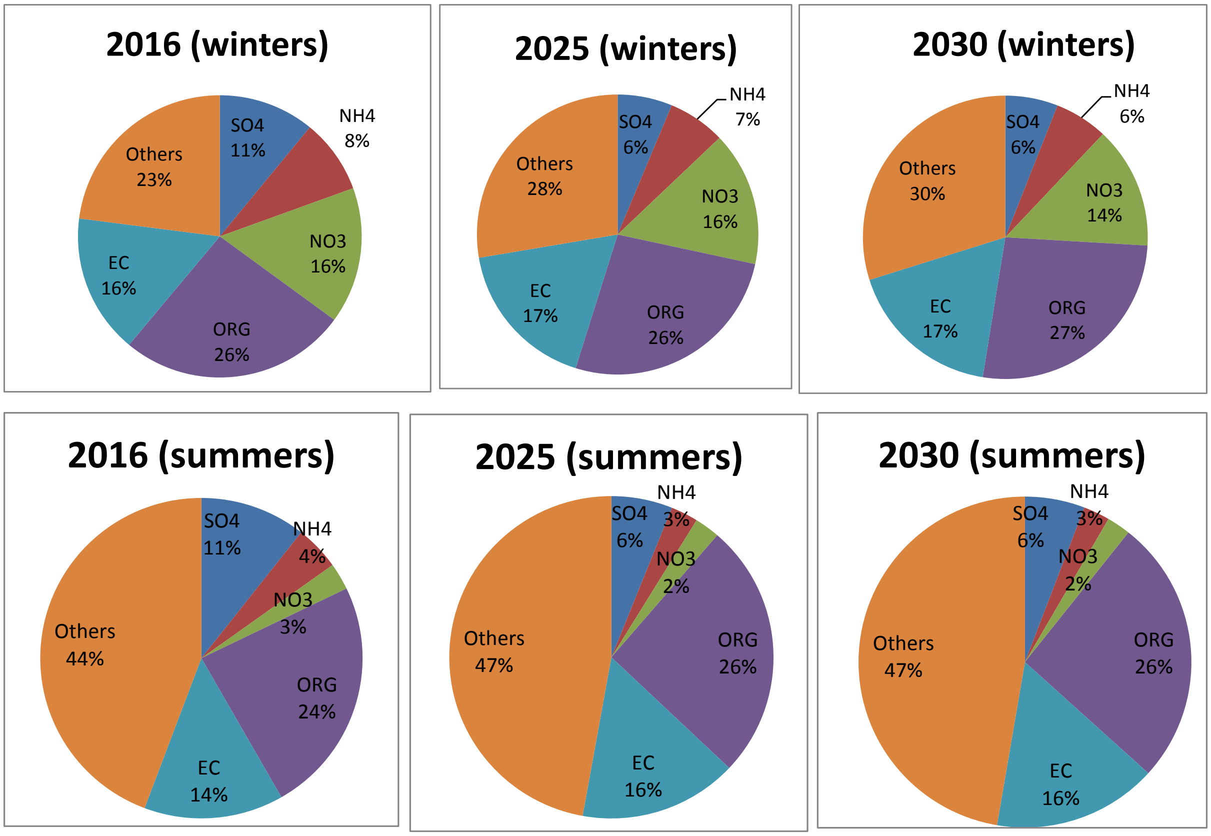


Figure 6.6: Species wise contribution in 2016, 2025 and 2030 in BAU during winter and summer season for $PM_{2.5}$ in NCR towns (including Delhi).

(EC: Elemental Carbon; ORG: Organic carbon; SO_4: Sulphates; NH_4: Ammonium; and NO_3: Nitrates)

6.5 Spatial distribution

The average simulation results for the summers and winter seasons for $PM_{2.5}$ and PM_{10} concentrations are depicted in Figure 6.7 and Figure 6.8, respectively. Evidently, the concentrations are significantly higher during winters than in summers, due to adverse meteorological conditions. Reduction in wind speed and boundary layer height during winter reduces the dispersive capacity of the atmosphere and leads to higher concentration of pollutants near the ground. In BAU, concentrations of $PM_{2.5}$ and PM_{10} are increasing in the NCR region. Particulate matter concentration will further increase in areas in the downwind of Delhi such as Noida, Bulandshahr, Hapur, and Ghaziabad as air quality in these areas will be affected by their own emissions as well as pollution from Delhi.

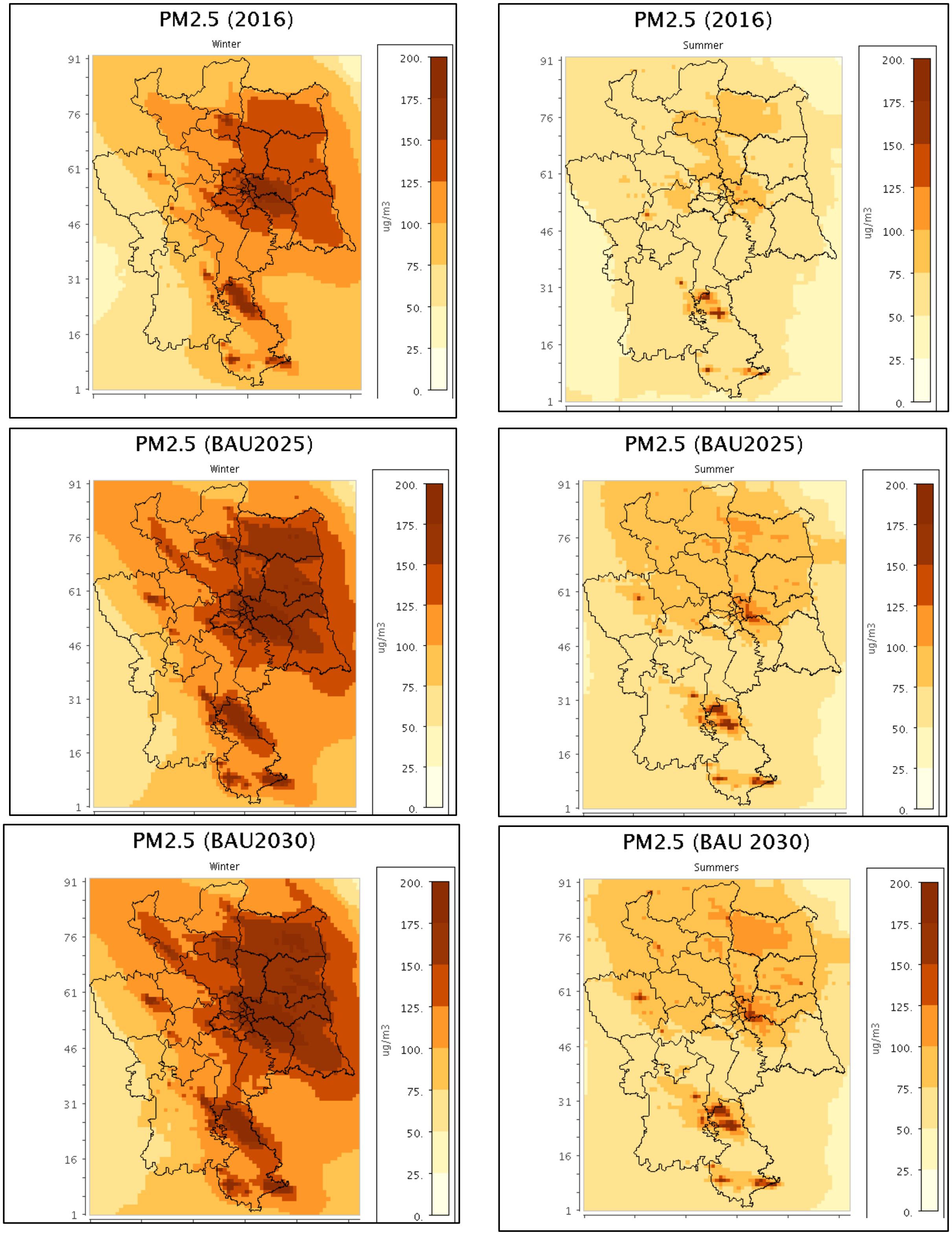


Figure 6.7: Spatial distribution of $PM_{2.5}$ concentrations in the BAU scenario during 2016, 2025 and 2030 (winter and summer season)

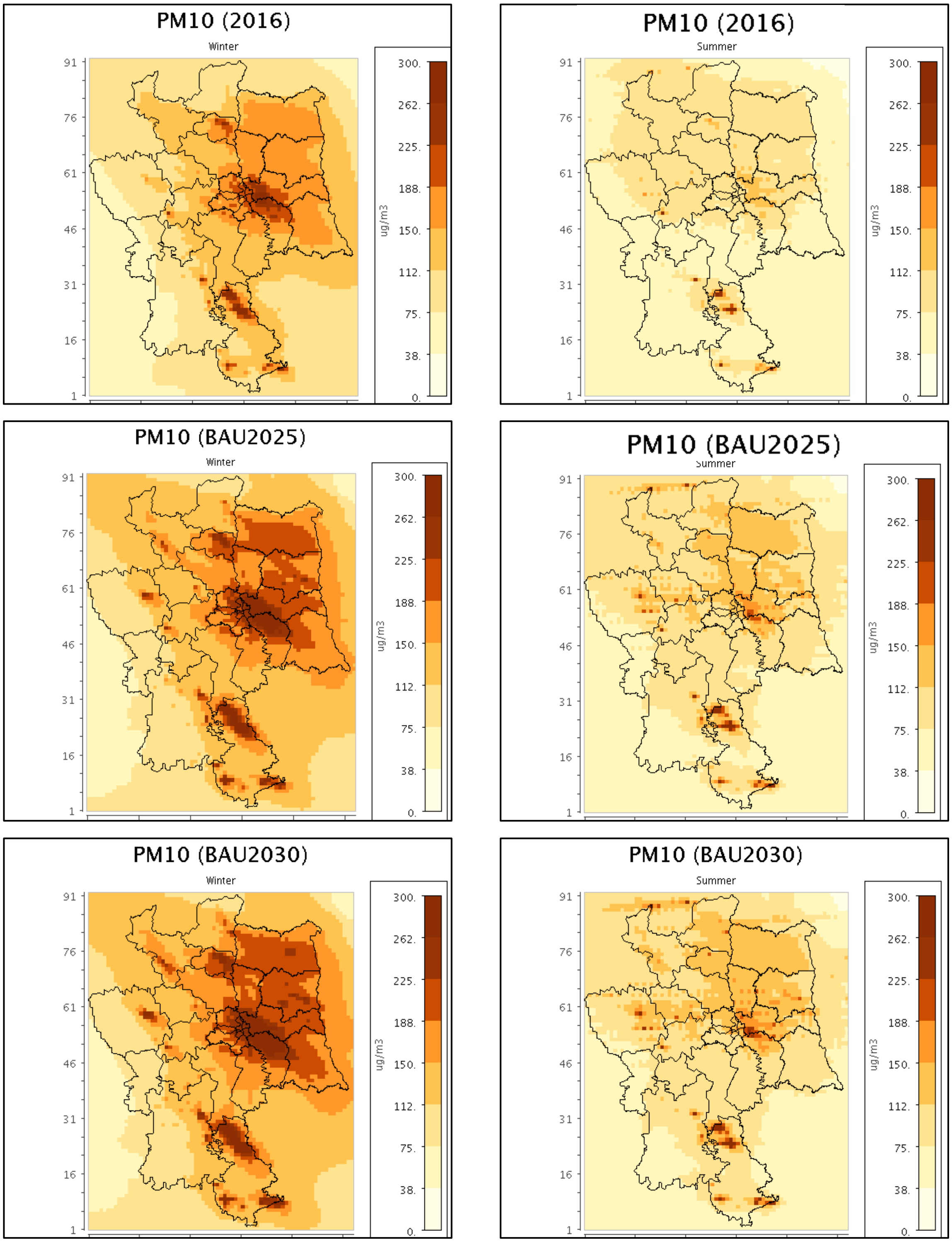


Figure 6.8: Spatial distribution of PM_{10} concentrations in the BAU scenario during 2016, 2025 and 2030 (winter and summer season)

6.6 Alternative strategies and scenario

In order to construct the alternative scenario, intervention analysis is performed to estimate the emission and concentration reduction potential of different control strategies in transport, biomass, industries, and other sectors. A detailed description of control strategies in different sectors which have been tested for their potential is provided in Table 6.4.

Table 6.4 : Details of further interventions considered in various sectors.

S.No.	Strategies	Description
	Biomass Burning	
1	Increase in LPG penetration in residential sector in NCR by 75% in 2025- 100% in 2030	Convert 75% and 100% biomass to LPG in 2025 and 2030, respectively.
2	Supply and use improved biomass cook-stoves	Supply improved biomass cook-stoves to 75% and 100% of households using biomass in 2025 and 2030, respectively.
3	Supply and use improved induction cook-stoves	Supply improved induction cook-stoves 75% and 100% to households using biomass in 2025 and 2030, respectively.
4	Use of agricultural residues in WTE	Zero open burning through WTE plants (With adequate tail-pipe controls)
5	Use of agricultural residues in power plants	Zero-open burning and use of residue briquettes in power plants
6	Use of agricultural residues in local households	Zero-open burning and use of residues briquettes in local households
	Transport	
7	Electrification of vehicular fleet	Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%) in 2025 - 2030
7a	Public transportation- Buses	25% and 50% electric buses in 2025 and 2030
7b	Electric vehicles- 2/3 wheelers	20% in 2025 and 40% in 2030 electric two-wheelers, and 100% three-wheelers
7c	Electric vehicles - Cars	20% in 2025 and 40% in 2030 electric cars
8	Fleet modernization - Restricted entry/movement of pre-BS-VI vehicles	All vehicles to be BS-VI equivalent
9	Banning entry of pre BS-IV trucks and buses	All old trucks and buses to be modernised to BS-VI equivalent
10	Improved inspection and maintenance system	High emitter emissions go down from 25% to 10% (2025) and 25% to 5% in 2030
11	Reducing real world emissions from vehicles by congestion management	Reduce real world emissions to 50% in both 2025 and 2030
12	Shift of 50% cars and 2-w to shared commuter vehicles	Shift 50% of personal transport on shared commuter transport on EV in 2025 and 2030
13	Increased penetration of biodiesel	12% penetration by 2025 and 20% by 2030

S.No.	Strategies	Description
14	Increased penetration of hybrid and EV cars	35% hybrid and 15% EV cars by 2025 and 70% hybrid and 30% EV by 2030
	Industries	
15	Power plant controls with continuous monitoring	Implement stricter NOx and SO_2 standards
16	Stricter enforcement of standards in industries through continuous monitoring	In industries, reduce real world emissions by 50% in both 2025 and 2030
17	Introduction and enforcement of new SO_2 and NO_x standards	75% and 100% enforcement of SO_2/NOx standards in other industries in 2025 and 2030, respectively.
18	Enforcement of Zig-Zag brick kiln technology	75% and 100% enforcement of Zig-Zag brick kiln technology in 2025 and 2030, respectively.
19	Fuel switch to gas from solid fuels	50% and 100% fuel switch to gas from solid fuels in 2025 and 2030, respectively.
20	Strict PM control on stone crushers	Increase PM_{10} control efficiency to 80% and $PM_{2.5}$ to 40% in both 2025 and 2030.
21	Introduce stringent PM_{10} and $PM_{2.5}$ norms	Introduce and implement stricter PM standards in industries through installations of wet scrubbers
	Road dust and construction	
22	Vacuum cleaning of roads	Silt load reduction 25% and 50% (in 2025 and 2030, respectively)
23	Wall to wall paving	Silt load reduction 25% and 50% (in 2025 and 2030, respectively)
24	Control of dust from construction activities	Barriers and water based controls -30% and 60% in 2025 and 2030, respectively.
	Others	
25	Full ban on refuse burning activities and use of refuse in Waste to Energy (WTE)	reduced emissions form refuse burning in Waste to Energy (WTE)
26	Landfill fire control	Zero landfill emissions
27	DG sets controls using innovative technologies	PM and NOx controls at DG sets (80% reduction in PM and NOx emissions in 2030)
28	Supply 24x7 electricity	Supply 24x7 electricity, DG set emissions falls to 10% and 5% in 2025 and 2030, respectively.

These strategies have been used to derive overall emission reductions in the domain. Sector-wise strategies have been compared for their potential to reduce emissions of different pollutants.

5.12.6.1 Biomass burning

Biomass burning contributed around 15% and 14% of $PM_{2.5}$ and PM_{10} concentrations, respectively, in NCR in the year 2016 and 2030 in the BAU scenario (Table 6.4). Figure 6.9 shows the emissions reduction potential of a number of strategies which were tested to reduce emissions from major biomass burning sectors like rural kitchens and agricultural fields. The strategies in the residential sector showed that enhanced LPG penetration or induction-based cookstoves can reduce total $PM_{2.5}$ emissions in NCR by about 10%, and somewhat lower emission reductions (7%) can be envisaged with provision of improved biomass based cookstoves. Strategies for agricultural residues aim at collection and use of these residues for useful purposes like waste to energy (WTE) plants, power plants, and households (which already use biomass for fuels). The impact of these strategies on emissions is shown in Figure 6.9. All the three strategies show similar percentages reduction in $PM_{2.5}$ emissions, while the strategy to replace coal in power plants shows additional benefit of reduction in SO_2 emissions. The coal used in power plants has about 0.5% sulphur and SO_2 emission can additionally be reduced through usage of agricultural residues in the power plants. The National Thermal Power Corporation (NTPC) is presently testing these options. It is estimated that (Figure 6.9) a maximum 15% of reduction in emissions of $PM_{2.5}$ can be achieved by using agri residue in power plants (by replacing coal as briquettes) or in local households as pellets.

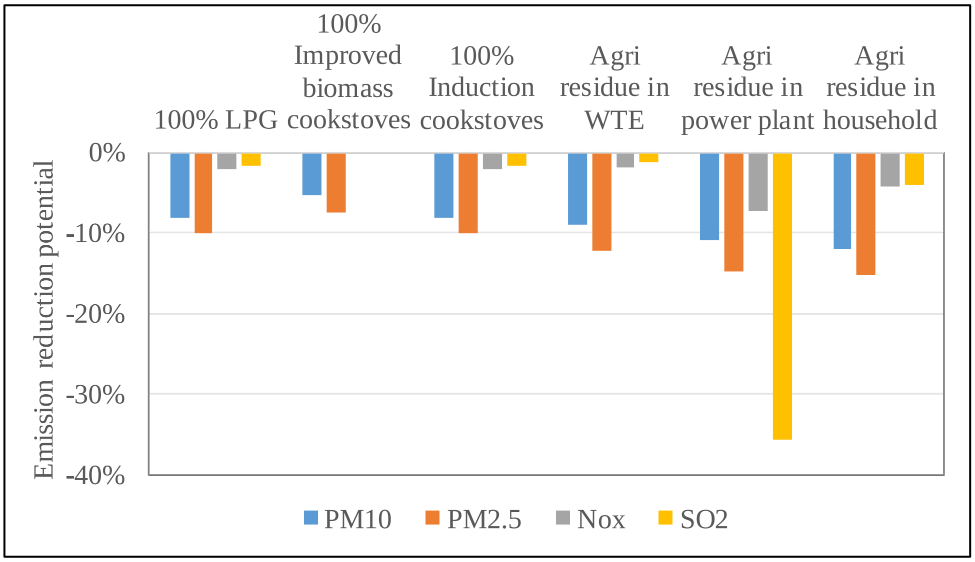


Figure 6.9: Emission reduction potential of various strategies to control biomass burning in NCR in the year 2030

The reduced emissions for different strategies are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ and PM_{10} concentrations. Concentration reduction potential of various strategies are not similar as emission reduction potential due to meteorological factors and location of sources. It was found that a maximum of 7%-6% reduction in ambient concentration of $PM_{2.5}$ and PM_{10}, respectively, in 2030 can be achieved by using agricultural residues as pellets in households (Figure 6.10). This reduction is even higher than the reductions when agricultural residues are burnt in power plants by replacing coal, which leads to a reduction of 8% in both $PM_{2.5}$ and PM_{10} concentrations. By eliminating coal, the sulphates have also been reduced which form the constituent of $PM_{2.5}$ concentrations. The main reduction is by eliminating the agricultural burning activity and additional benefits of pelleting have also been accounted. The PM_{10} and CO emissions from a stove fall by 43% and 55%, respectively; when pellets are used instead of loose biomass (Shen et al., 2012).

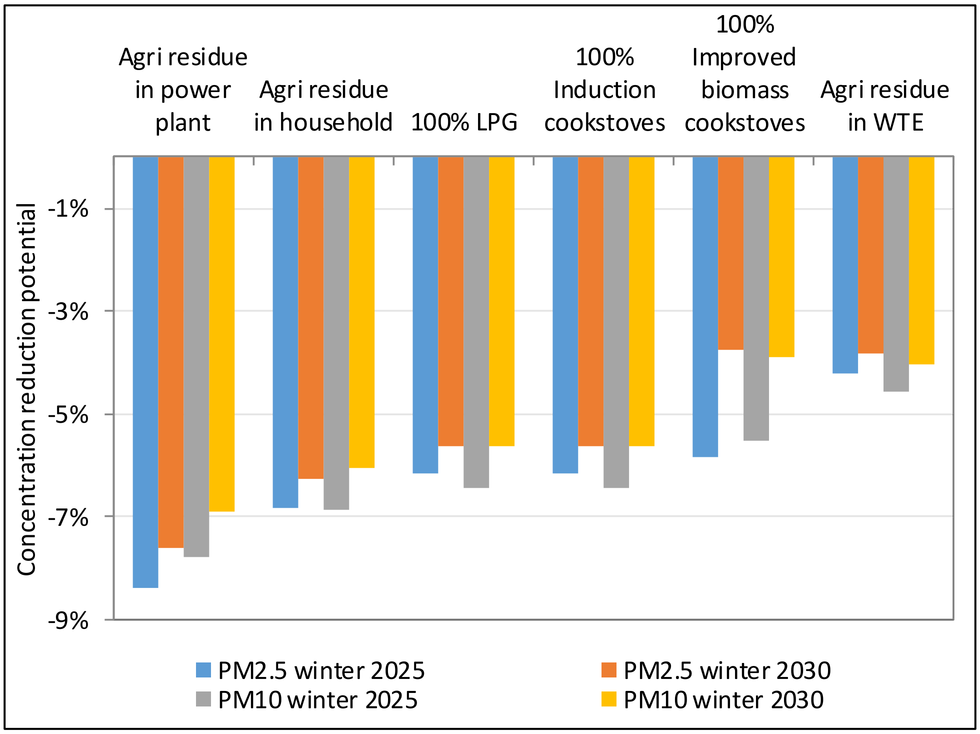


Figure 6.10: Concentration reduction potential of various control strategies to control biomass burning in NCR during winter season of 2025 and 2030.

5.12.6.2 Transport

Transport sector is one of the important contributors in $PM_{2.5}$ concentration in 2016. However, in 2025 and 2030 its shares decline mainly due to introduction of BS-VI emissions norms. However, in order to further reduce its share, various strategies have been tested out using the model. These strategies include:

a) Electrification of public and personal vehicles
b) Fleet modernization
c) Banning entry of old heavy duty vehicles
d) Improved inspection and maintenance (I&M) system
e) Reduced real-world emissions through congestion management
f) Shifting private transport (cars and 2-w) to shared commuter vehicles.
g) Use of biodiesel
h) Increased penetration of hybrid and EV cars

The details of these strategies are given in Table 6.4. The emission reduction potential of these strategies have been assessed and are presented in the Figures 6.11. The share of transport is high in total NOx emissions in NCR, hence higher reductions have been observed in NOx emissions than in other pollutants. Electrification of vehicular fleet such as buses, autos, 2-w and cars resulted in maximum reduction of 1.4%, 0.6%, and 24% in $PM_{2.5}$, PM_{10}, and NOx emissions in NCR, respectively in 2030 (Figure 6.11). Corresponding reductions in emissions due to shift of 50% of personal transport to commuter vehicles on EVs is 0.4%, 0.2%, and 6%, respectively.

Congestion management can result in decrease of real world emissions. Fleet modernization (replacing older vehicles with BS-VI) can lead to 1%, 0.4%, 9% decrease in total $PM_{2.5}$, PM_{10}, and NOx emissions, respectively in NCR in 2030. Improved I&M systems will help identifying and rectifying the high emitters and are expected to reduce 1%and 0.3% total $PM_{2.5}$ and PM_{10} emissions, respectively, in NCR in 2030. Use of biodiesel resulted in 0.3%, 0.6%, and 1% decrease in total $PM_{2.5}$, PM_{10} and NOx emissions, respectively, in NCR in 2030. Higher penetration of hybrid and electric cars resulted in 0.1%, 0.3% and 12.9% reduction in PM_{10}, $PM_{2.5}$ and NOx emissions, respectively in 2030.

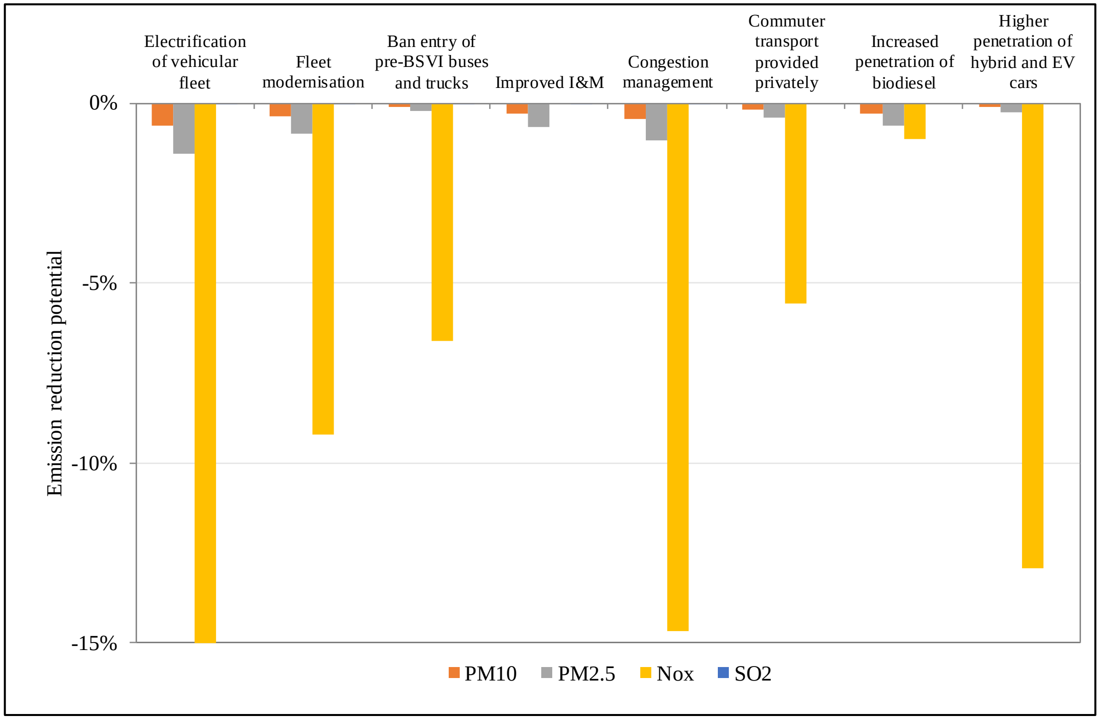


Figure 6.11: Emission reduction potential of various control strategies in transport sector in the year 2030

The reduced emissions for different strategies are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ and PM_{10} concentrations. As the share of transport is already low (9%-12% average in both seasons), the impact of strategies in transport sector is found to be somewhat lower than other sectors. Electrification (buses 50%, autos 100%, 2-wheelers and cars 40%), of vehicular fleet shows the maximum reduction of 6% and 5% in $PM_{2.5}$ and PM_{10} concentrations, respectively in winter by 2030 in NCR (Figure Figure 6.12). Congestion reduction can result in decrease of 4% and 3% in $PM_{2.5}$ and PM_{10} concentrations, respectively. Fleet modernization leads to 3%-2% reduction in $PM_{2.5}$ and PM10 concentrations in winter by 2030. The reductions were estimated to be higher (8%) in 2025, due to presence of older vehicles. The impact of other strategies in winter by 2030 is less than 1%

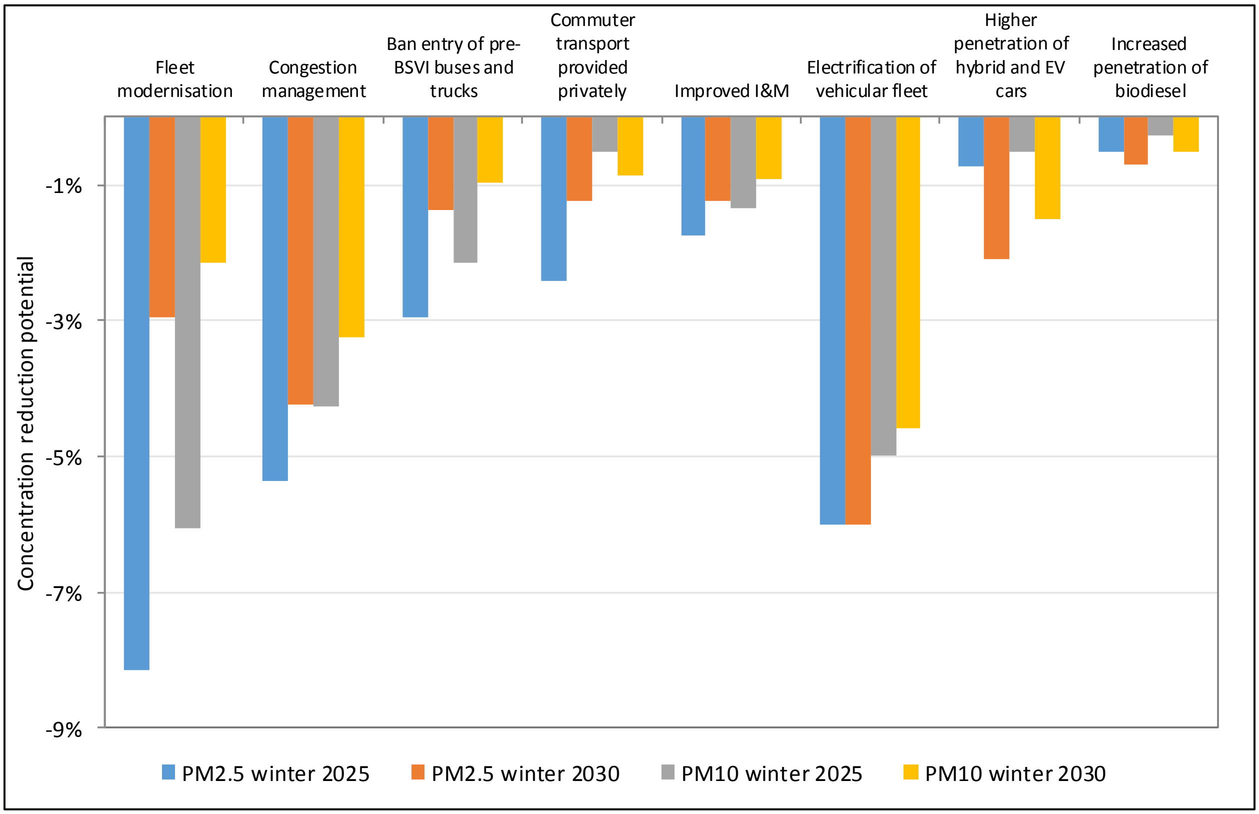


Figure 6.12: Concentration reduction potential of various control strategies in transport sector in the year 2030

5.12.6.3 Industries

Industries contributed around 25%-27% in $PM_{2.5}$ and PM_{10} concentrations in the year 2016, and even higher (34%-37%) in 2030. Evidently, the sector has higher potential for control of emissions and PM concentrations. The emission reduction potential of various strategies is analysed for the industrial sector and results are presented in Figure 6.13 and Figure 6.14. The strategies considered for reducing emissions from industries include stringent gaseous pollutant norms for power plant, industries, improving the enforcement through continuous monitoring, switching to cleaner gaseous fuels, shifting brick kilns from conventional to Zig-Zag technology and introducing stringent stack emission standards for $PM_{2.5}$ and PM_{10} in industries. Details of these strategies are given in Table 6.4.

It has been realised that the maximum reduction in emissions of $PM_{2.5}$ and PM_{10} can be achieved by switching solid fuel to gaseous fuel in industries. Implementing stringent NOx and SO_2 standards may reduce total SO_2 emissions in NCR drastically, although mainly from power plants. The reduction potential of the stringent NOx and SO_2 standards becomes still lower as pet-coke and FO (high sulphur fuels) are already banned in the region (Figure 73). Presently, only suspended particulate matter (SPM) standard exists for industrial stack and introducing new stringent stack emission standards for $PM_{2.5}$ and PM_{10} in industries can lead to more than 10% reduction in PM_{10} and $PM_{2.5}$ emissions. Enhanced penetration of Zig-Zag technology in the brick kiln sector may lead to reduction of 3 %, 4%, and 6% in total $PM_{2.5}$, PM_{10}, and SO_2 emissions, respectively, in NCR in 2030. Strict PM control on stone crushers lead to 6% and 3% reduction in PM_{10} and $PM_{2.5}$ emissions, respectively.

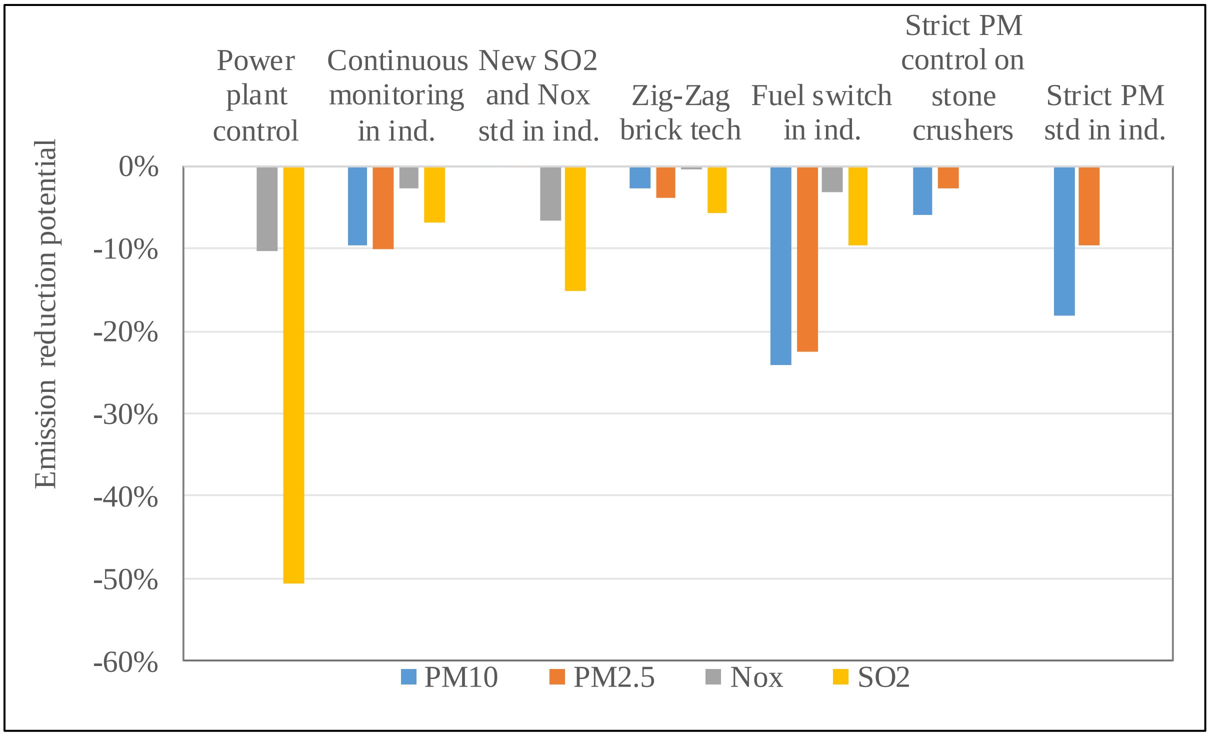


Figure 6.13: Emission reduction potential of various control strategies in industries sector in the year 2030

The reduced emissions for different industrial emission control strategies are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ and PM_{10} concentrations. As the share of industries is high (34%-37% average in both seasons), the impact of strategies on PM concentrations is found to be higher than other sectors. Fuel switch to gaseous fuels can lead to a massive reduction of 23% in PM_{10} and $PM_{2.5}$ concentrations in winter season in 2030. Implementation of a stringent standard for $PM_{2.5}$/PM_{10} in industries can lead to 11%-12% reduction in PM concentrations. Better enforcement with continuous monitoring of industrial emissions will result in lower real world industrial emissions and a reduction of 9%-10% can be achieved in $PM_{2.5}$ and PM_{10} concentration in winter by 2030. The impact of other strategies on $PM_{2.5}$ and PM_{10} concentration in winter season in 2025 and 2030 is less than 4%.

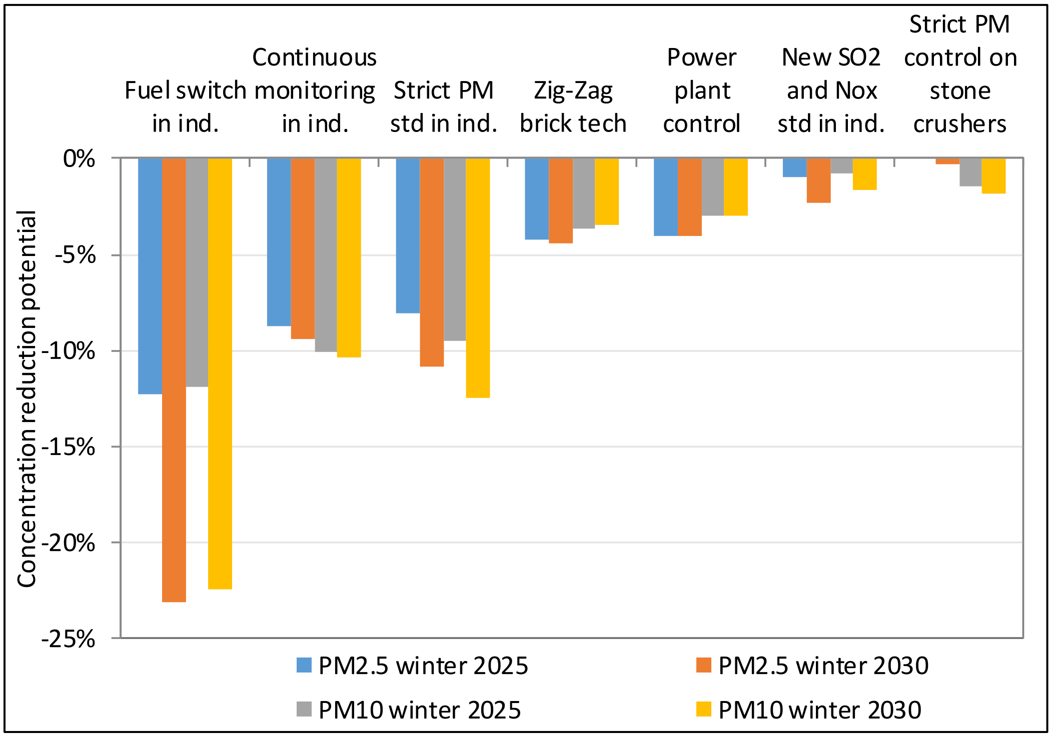


Figure 6.14: Concentration reduction potential of various control strategies in road dust sector during winter season of 2025 and 2030.

5.12.6.4 Road dust and construction

Fugitive dust emissions from road and construction and demolition (C&D) activities have contributed around 5%-15% in $PM_{2.5}$ and PM_{10} concentrations in 2016. In 2030, the share of this sector will increase to 8%-21% for the two pollutants. Emission reduction potential of controls such as vacuum cleaning of roads, wall-to-wall paving and use of barrier and water to control dust from construction and demolition (C&D) activities are assessed, which are shown in the Figure 6.15. Vacuum cleaning of road and wall-to-wall paving are assumed to have a reduction of 50% in silt content and 12% and 7% reduction in total PM_{10} and $PM_{2.5}$ emissions of NCR, respectively. Control of dust from construction and demolition activities with the help of barriers and water sprinkling may reduce total PM_{10} and $PM_{2.5}$ emissions in NCR by 2% and 1%, respectively.

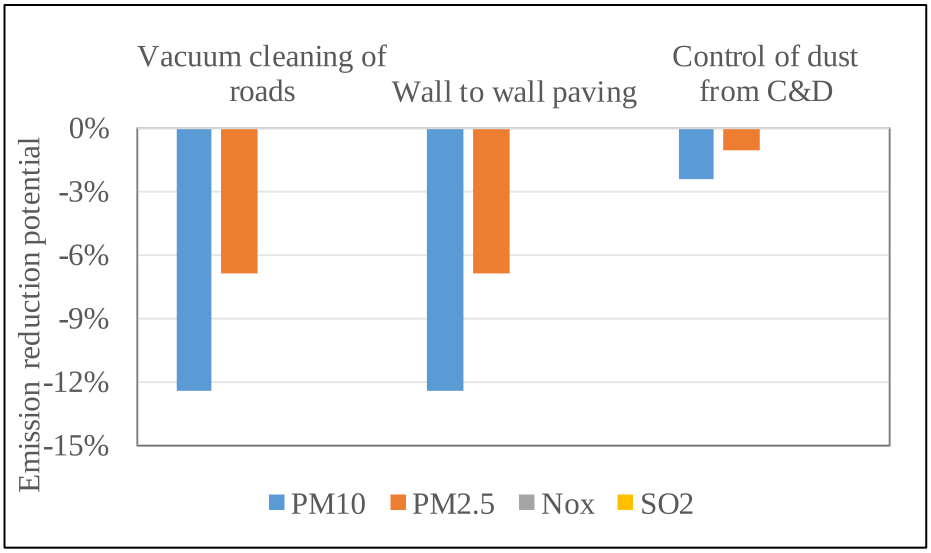


Figure 6.15: Emission reduction potential of various control strategies in road dust sector in the year 2030.

The reduced emissions for different dust emission control strategies are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ and PM_{10} concentrations. As share of dust in PM_{10} concentration in 2030 is high, that is, 21%, therefore, vacuum cleaning of roads and wall-to-wall paving resulted in 6% reduction in PM_{10} and 2% reduction in $PM_{2.5}$ concentrations during the winter season in 2030. Control of dust from C&D activities may reduce 2% and 1% of PM_{10} and $PM_{2.5}$ concentrations, respectively, in NCR by 2030 during the winter (Figure 6.16).

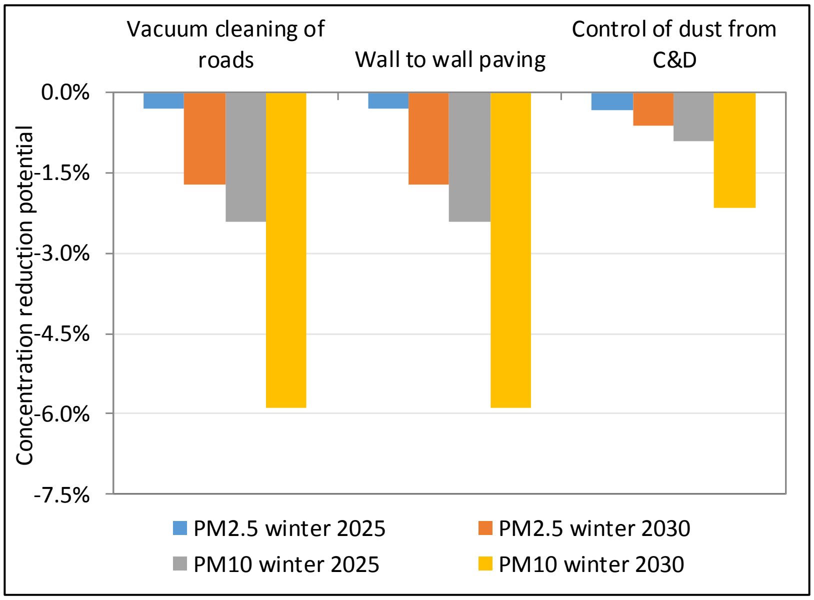


Figure 6.16: Concentration reduction potential of various control strategies in road dust sector during winter season of 2025 and 2030.

5.12.6.5 Others

Others (DG sets, refuse, incinerators, landfills, airport, restaurants, etc.) have contributed around 8% in $PM_{2.5}$ and 7% in PM_{10} concentrations in 2016. The share of this sector in 2025 and 2030 remains almost of the same as in 2016. Effects of various interventions such as use of refuse in waste to energy (WTE) plants, control on PM and NOx emissions from DG sets, 24x7 electricity supply leading to minimal usage of DG sets, no land fill fire, etc., are assessed on emissions, which is shown in Figure 6.17. Use of refuse in WTE plants and landfill fire control has led to reduction of PM_{10} and $PM_{2.5}$ emissions while DG sets controls have majorly reduced NOx emissions. Maximum reduction, that is, 3% and 5% in PM_{10} and $PM_{2.5}$ emissions, respectively, can be achieved by completely using refuse in WTE plant. Landfill fire control may reduce 0.2%, 0.4%, and 0.1% of PM_{10}, $PM_{2.5}$, and NOx emissions, respectively, in NCR in 2030. Stringent PM and NOx emission control on DG sets may lead to 0.1%, 0.3%, and 3.9% reductions in PM_{10}, $PM_{2.5}$, and NOx emissions, respectively. Higher reductions in PM_{10}, $PM_{2.5}$, and NOx emissions (i.e. 0.2%, 0.4%, and 5.4%, respectively) can be achieved by 24x7 electricity supply, which will lead to minimal usage of DG sets.

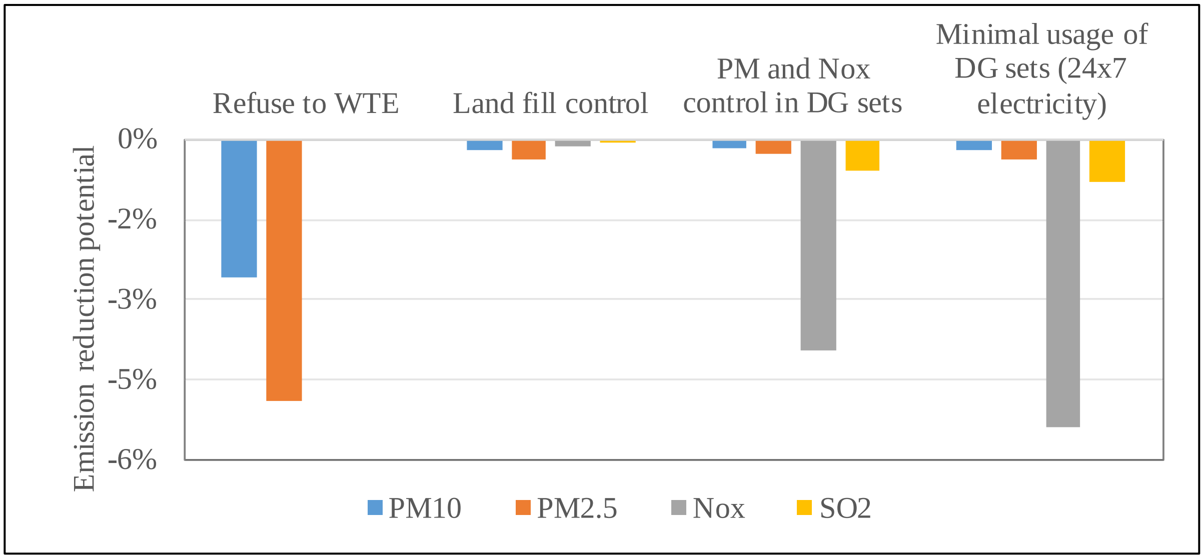


Figure 6.17: Emission reduction potential of various control strategies in others sector in the year 2030.

The reduced emissions for different control strategies in others sector are fed into the model to estimate the impact of these strategies on $PM_{2.5}$ and PM_{10} concentrations. Ban on refuse burning activities has the maximum potential to reduce PM_{10} and $PM_{2.5}$ concentrations by 3% and 4%, respectively, in NCR by 2030 during the winter . Rest of the strategies in others sector have PM_{10} and $PM_{2.5}$ concentration reduction potential of less than 3% (Figure6.18).

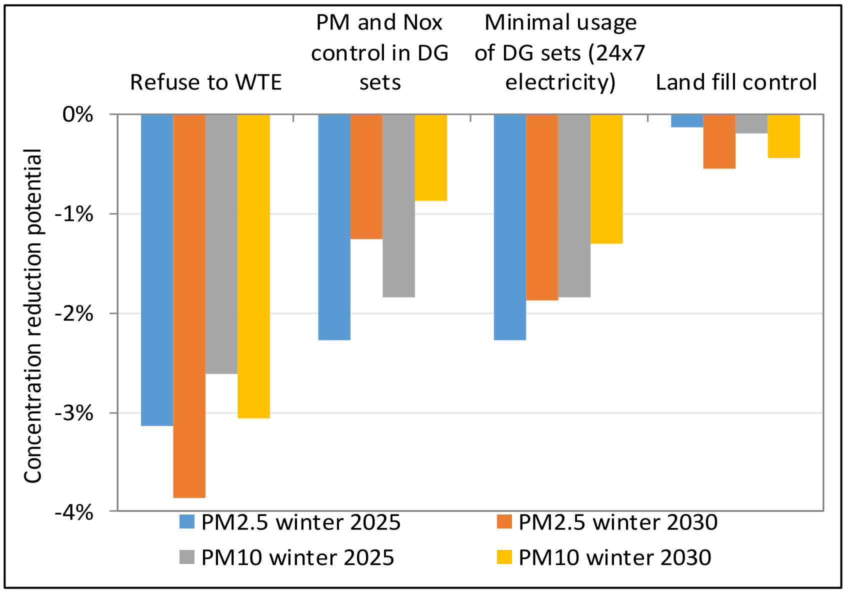


Figure 6.18: Concentration reduction potential of various control strategies in others sector in the year 2030

Details of these strategies are given in Table 6.4. Further, details on season wise reductions in concentration of $PM_{2.5}$ and PM_{10} in 2025 and 2030 due to various interventions in different sectors is shown in Table6.5.

Table 6.5: Concentration reduction potential of various strategies listed in during summer and winter season in 2025 and 2030.

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Biomass													
1	Increase in LPG penetration in residential sector in NCR by 75% in 2025-100% in 2030	Convert 75% and 100% biomass to LPG in 2025 and 2030, respectively.	-7%	-9%	-6%	-6%	-4%	-7%	-6%	-6%	-7%	-8%	-5%	-6%
2	Supply and use of improved biomass cook-stoves	Supply improved biomass cook-stoves 75% and 100% to households using biomass in 2025 and 2030, respectively.	0%	-2%	-6%	-6%	0%	-1%	-4%	-4%	-3%	-4%	-2%	-3%
3	Supply and use of improved induction cook-stoves	Supply improved induction cook-stoves 75% and 100% to households using biomass in 2025 and 2030, respectively.	-7%	-9%	-6%	-6%	-4%	-7%	-6%	-6%	-7%	-8%	-5%	-6%

S.No	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
4	Use of agricultural residues in WTE	Zero open burning through WTE plants (With adequate tail-pipe controls)	-5%	-5%	-4%	-5%	-5%	-4%	-4%	-4%	-5%	-5%	-4%	-4%
5	Use of agricultural residues in power plants	Zero-open burning and use of residue briquettes in power plants	-8%	-7%	-8%	-8%	-8%	-6%	-8%	-7%	-8%	-8%	-8%	-7%
6	Use of agricultural residues pellets in local households	Zero-open burning and use of residues briquettes in local households	-11%	-12%	-7%	-7%	-9%	-12%	-6%	-6%	-9%	-9%	-8%	-9%
	Transport													
7	Electrification of vehicular fleet	Bus (25-50%), two (20-40%) and three wheelers (100%), and cars (20-40%	-2.7%	-2.2%	-5.9%	-4.9%	-2.3%	-1.8%	-6.3%	-4.8%	-4.8%	-3.6%	-4.3%	-3.3%
7a	Public transportation system on electric vehicles	25% and 50% electric buses in 2025 and 2030, respectively.	0%	0%	-1%	-1%	0%	0%	-1%	-1%	-1%	0%	-1%	-1%

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			PM$_{2.5}$	PM$_{10}$	PM$_{2.5}$	PM$_{10}$	PM$_{2.5}$	PM$_{10}$	PM$_{2.5}$	PM$_{10}$	PM$_{2.5}$	PM$_{10}$	PM$_{2.5}$	PM$_{10}$
7b	Electric vehicles- two wheelers and three-wheelers	20% in 2025 and 40% in 2030 electric two-wheelers, and 100% three-wheelers	-2.7%	-2.2%	-4.7%	-3.5%	-2.0%	-1.6%	-3.9%	-2.8%	-3.7%	-3.0%	-2.2%	-3.0%
7c	Electric vehicles –cars	20% in 2025 and 40% in 2030 electric cars	0.0%	0.0%	-0.2%	-0.2%	-0.3%	-0.2%	-1.4%	-1.0%	-0.1%	-0.1%	-0.8%	-0.6%
8	Fleet modernization - Restricted entry/movement of pre-BS-IV/VI vehicles	All vehicles to be BS-VI	-5%	-4%	-8%	-6%	-2%	-1%	-3%	-2%	-6%	-5%	-2%	-2%
9	Banning entry of pre BS-IV trucks and buses	All old trucks and buses to be modernized to BS-VI	-1%	-1%	-3%	-2%	0%	0%	-1%	-1%	-2%	-2%	-1%	-1%
10	Improved inspection and maintenance system	High emitter emissions go down from 25% to 10% (2025) and 25% to 5% in 2030	-2%	-1%	-2%	-1%	-1%	-1%	-1%	-1%	-2%	-1%	-1%	-1%

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
11	Reducing real world emissions from vehicles by congestion management	Reduce real world 100% to 50% in both 2025 and 2030	-2%	-2%	-5%	-4%	-2%	-1%	-4%	-3%	-4%	-3%	-3%	-2%
12	Commuter transport provided privately	Shift 50% of personal transport on shared commuter transport on EV in 2025 and 2030	-1%	-1%	-2%	-1%	-1%	0%	-1%	-1%	-2%	-1%	-1%	-1%
13	Increased penetration of biodiesel	12% penetration by 2025 and 20% by 2030	-0.4%	-0.3%	-0.5%	-0.3%	-0.5%	-0.4%	-0.7%	-0.5%	-0.4%	-0.3%	-0.6%	-0.5%
14	Increased penetration of hybrid and EV cars	35% hybrid and 15% EV cars by 2025 and 70% hybrid and 30% EV by 2030	-0.2%	-0.2%	-0.7%	-0.5%	-0.2%	-0.1%	-2.1%	-1.5%	-0.5%	-0.4%	-1.1%	-0.8%
	Industries													
15	Power plant controls with continuous monitoring	Implement stricter NOx and SO2 standards	-3%	-2%	-4%	-3%	-3%	-2%	-4%	-3%	-4%	-3%	-3%	-2%

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
16	Stricter enforcement of standards in industries through continuous monitoring	In industries, reduce real world emissions by 50% in both 2025 and 2030	-5%	-5%	-9%	-10%	-7%	-6%	-9%	-10%	-7%	-8%	-8%	-8%
17	Introduction and enforcement of new SO2 and NOx standards	75% and 100% enforcement of SO2/NOx standards in other industries in 2025 and 2030, respectively.	0%	-1%	-1%	-1%	-1%	0%	-2%	-2%	-1%	-1%	-2%	-1%
18	Enforcement of Zig-Zag brick kiln technology	75% and 100% enforcement of Zig-Zag brick kiln technology in 2025 and 2030, respectively.	-3%	-2%	-4%	-4%	-3%	-3%	-4%	-3%	-3%	-3%	-4%	-3%
19	Fuel switch to gas from solid fuels	50% and 100% Fuel switch to gas from solid fuels in 2025 and 2030, respectively.	-8%	-6%	-12%	-12%	-17%	-12%	-23%	-23%	-10%	-9%	-20%	-18%

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
20	Strict PM control on stone crushers	Increase PM10 control efficiency to 80% and PM2.5 to 40% in 2025 and 2030.	-1%	-2%	-0.1%	-1%	-1.5%	-2%	-0.1%	-2%	-1%	-2%	-1%	-2%
21	Introduce and implement stringent PM_{10} and $PM_{2.5}$ norms	Introduce and implement stricter PM standards through installations of wet scrubbers	-5%	-5%	-8%	-10%	-8%	-5%	-11%	-12%	-7%	-8%	-10%	-9%
	Road dust and construction													
22	Vacuum cleaning of roads	Silt load reduction 25% and 50% (in 2025 and 2030, respectively)	-2%	-6%	-0.3%	-2%	-5%	-11%	-2%	-6%	-1%	-4%	-4%	-9%
23	Wall to wall paving	Silt load reduction 25% and 50% (in 2025 and 2030, respectively)	-2%	-6%	-0.3%	-2%	-5%	-11%	-2%	-6%	-1%	-4%	-4%	-9%
24	Control of dust from construction activities	Barriers and water controls -30% and 60% in 2025 and 2030, respectively.	0%	0%	-0.3%	-1%	0%	-2%	-1%	-2%	0%	-1%	-1%	-2%

S.N 0	Strategies	ALT	2025				2030				2025 Avg.		2030 Avg.	
			Summers		Winter		Summers		Winter					
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
	Others													
25	Refuse to WTE	Zero emissions from refuse burning and combustion in WTE	-5%	-6%	-4%	-3%	-6%	-6%	-4%	-3%	-5%	-5%	-5%	-5%
26	Landfill fire control	Zero landfill emissions	-1%	-2%	-0.1%	-0.2%	-2%	-2%	-0.5%	-0.4%	-1%	-1%	-1%	-1%
27	DG sets controls	PM and NOx controls at DG sets (80% reduction in PM and NOx emissions in 2030)	-1%	0%	-2%	-2%	0%	-1%	-1%	-1%	-2%	-1%	-1%	-1%
28	Supply 24x7 electricity	Supply 24x7 electricity, DG set emissions to 10% and 5% in 2025 and 2030, respectively.	-1%	-1%	-2%	-2%	0%	-1%	-2%	-1%	-2%	-2%	-1%	-1%

5.12.7 Alternative scenario

The $PM_{2.5}$ and PM_{10} concentrations in BAU scenario in 2030 were estimated to be 118 and 165 µg/m³, which is much higher than Daily average NAAQS of 60 and 100 µg/m³ for $PM_{2.5}$ and PM_{10}, respectively. In order to meet Daily and annual average NAAQS of $PM_{2.5}$ and PM_{10}, a set of eighteen interventions, which are feasible to implement and have significant impact on concentrations, are selected for constructing an alternative scenario. These interventions include, increased penetration of LPG in rural kitchens, use of agriculture residue in power plants, fleet modernization, shifting public transportation on EVs, improving I&M of in-use vehicles, stricter type of approval testing for vehicles, shift from personal to public transportation, strict SO_2 and NOx standards for power plants and industries, increased penetration of Zig-Zag technology in brick kiln, strict PM standards for stone crushers, shift from solid to gaseous fuel in industries, vacuum cleaning and wall-to-wall paving of roads, increased usage of barriers and water control to reduce C&D dust and 24x7 electricity supply leading to minimal usage of DG sets. The details of theses interventions are provided in Table 6.6.

Table 6.6 :List of interventions selected for alternative scenario.

S.No.	Strategies	Alternative scenario	Time frame	Responsible agency
	Biomass Burning (PM2.5 and PM10 concentration reduction in 2030: 14% and 10%, respectively)			
1	Increase in LPG penetration in residential sector in NCR by 75% in 2025- 100% in 2030	Convert 75% and 100% biomass to LPG in 2025 and 2030, respectively	100% LPG penetration by 2026	MoPNG
2	Use of agricultural residues in power plants	Zero-open burning and use of residue briquettes in power plants	Agricultural residue to be used in power plants by 2020	MoP, MoA
	Transport ($PM_{2.5}$ and PM_{10} concentration reduction in 2030: 9% and 7%, respectively)			
3	Public transportation system on electric vehicles	25% and 50% electric buses in 2025 and 2030, respectively	25% and 50% electric buses in 2025 and 2030, respectively	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
4	Improved inspection and maintenance system from 2020	Setting up OBD/remote sensing based and advanced I&M centers. High emitter emissions go down from 25% to 10% (in 2025) and 25% to 5% in 2030.	15 advanced I&M centers in NCR by 2021 and 30 by 2025. To support, existing PUCs to be upgraded for OBD based testing.	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
5	Fleet modernization	All vehicles to be BS-VI	Fleet modernisation mechanisms along with scrappage centres by 2025	MoRTH, State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)

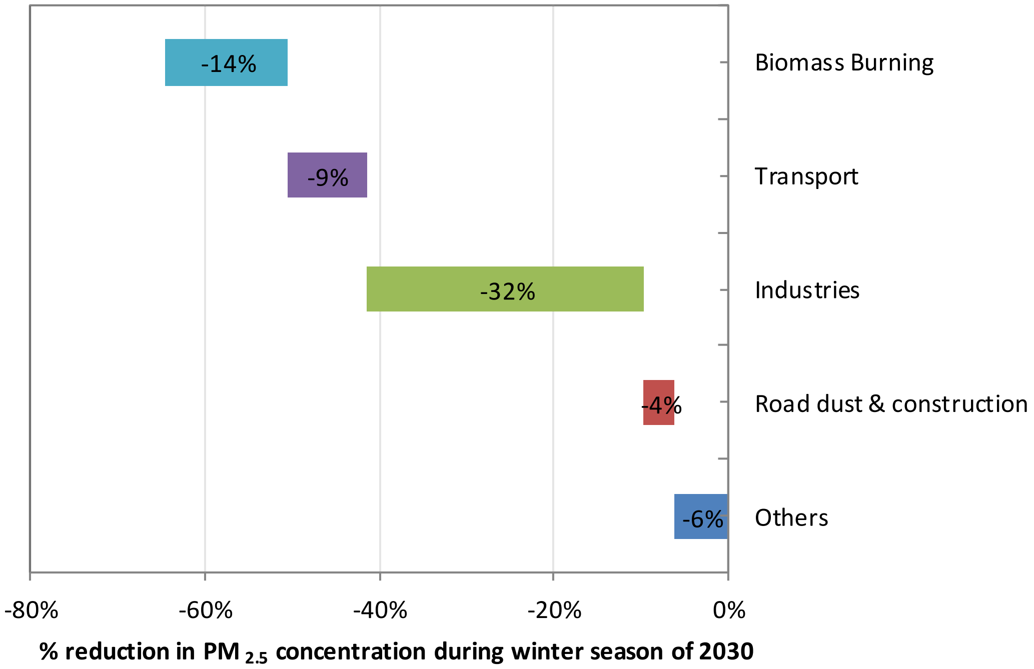
S.No.	Strategies	Alternative scenario	Time frame	Responsible agency
6	Reducing real world emissions from vehicles by congestion management	Reduce real world emissions by 50% in 2025 and 2030	Introduce congestion pricing schemes in Delhi by 2019 and expand to NCR by 2021to shift from private to public modes of transportation*	MoUD and states urban development and transport departments
7	Shift of 50% cars and 2-w to shared taxis (MUVs, petrol, EVs)	Shift 50% of personal transport on shared taxis in 2025 and 2030	Promote private players to enhance shared transport modes by 2019.	State transport departments-NCR(Delhi, UP, Haryana, Rajasthan)
	Industries ($PM_{2.5}$ and PM_{10} concentration reduction in 2030: 32% and 31%, respectively)			
8	Power plant controls with continuous monitoring	Implement stricter NOx and SO2 standards	Install tail pipe control devices by 2020.	Power plant companies, MoP, SPCBs and CPCB
9	Introduction and enforcement of new SO2 and NOx standards	75% and 100% enforcement of SO2/NOx standards in other industries in 2025 and 2030, respectively	Install tail pipe control devices in 75% of industries by 2021 and 100% by 2026.	Industries, SPCBs and CPCB
10	Enforcement of Zig-Zag brick kiln technology	75% and 100% enforcement of Zig-Zag brick technology in 2025 and 2030, respectively	75% and 100% enforcement of Zig-Zag brick technology in 2021 and 2026, respectively	SPCBs and CPCB
11	Strict PM control on stone crushers	Increase PM_{10} control efficiency to 80% and $PM_{2.5}$ 40% in both 2025 and 2030	Install wet dust suppression system and dry collection techniques in all stone crushers by 2021.	SPCBs and CPCB
12	Fuel switch to gas from solid fuels	50% and 100% Fuel switch to gas from solid fuels in 2025 and 2030, respectively	Fuel switch to gas from solid fuels in 50% and 100% industries in 2025 and 2030, respectively	MoPNG
	Road dust and construction ($PM_{2.5}$ and PM_{10} concentration reduction in 2030: 4% and 11%, respectively)			
13	Vacuum cleaning of roads	Silt load reduction 25 % and 50% in 2025 and 2030, respectively	Mechanized road cleaning at 25% and 50% roads in 2025 and 2030, respectively	Municipal corporations

S.No.	Strategies	Alternative scenario	Time frame	Responsible agency
14	Wall to wall paving of roads	Silt load reduction 25 % and 50% in 2025 and 2030, respectively	Wall to wall paving of 25% and 50% roads in 2025 and 2030, respectively	PWD
15	Control of dust from construction activities	Barriers and water controls (30% and 60% control on PM emissions in 2025 and 2030, respectively)	Mandatory implementation of barriers and water controls in major construction sites by 2021 and all by 2026.	PWD, NHAI, Municipal Corp.
	Others ($PM_{2.5}$ and PM_{10} concentration reduction in 2030: 6% and 6%, respectively)			
16	Use refuse in WTE	Reduced emissions from refuse burning in WTE plant fitted with control	Immediate market mechanism for collection and transportation of refuse to WTE	Municipal corporations and panchayats
17	Supply 24x7 electricity	Supply 24x7 electricity , DG set emissions to 10% and 5% in 2025 and 2030, respectively	Immediate arrangements for regulatory and tariff structure to make use of the power surplus situation and thereby ensuring 24x7 power supply	State electricity departments

This only shows the reduction potential of different strategies and detailed techno-economic feasibility studies will be required for some of the strategies before actual implementation.

*the revenues collected from congestion pricing scheme should mandatorily be used for enhancement of public transport.

Percentage $PM_{2.5}$ concentration reduction potential of different sectors after implementing the proposed strategies is shown in the Figure 6.19.



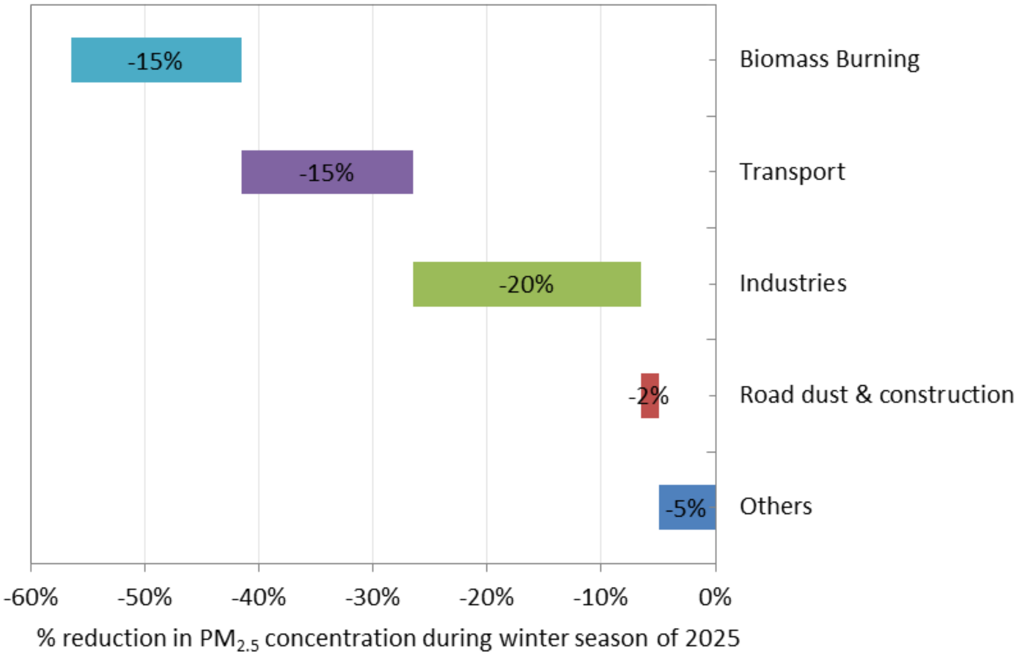


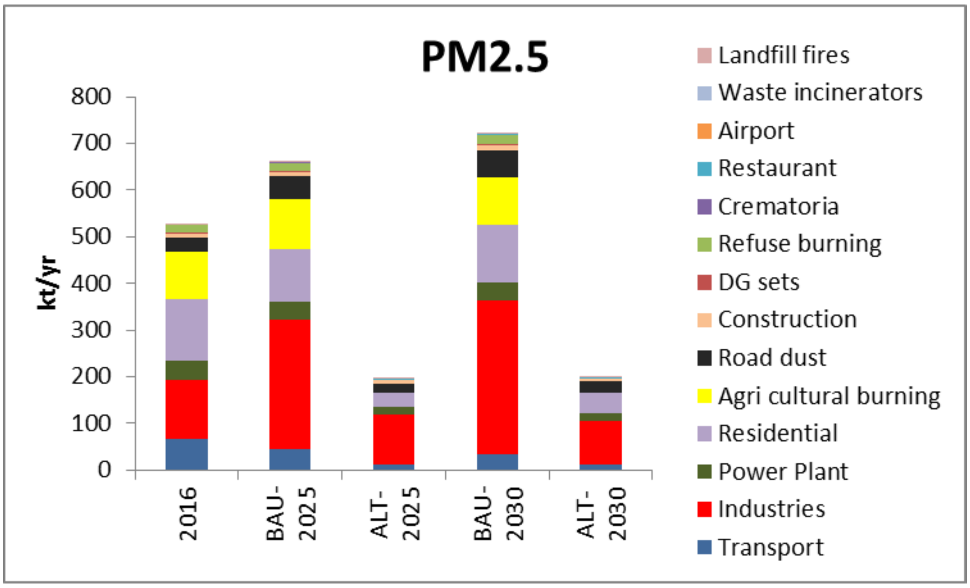
Figure 6.19: Step diagram for various interventions accounted in alternative scenario.

After applying the set of interventions listed in Table 6.6, detailed sector-wise emissions are given in Table 6.7 and sectoral contributions are shown in the Figure 6.19. The emissions of PM_{10}, $PM_{2.5}$, NOx, and SO_2 in alternative scenario in NCR in 2030 fall by 77%, 72%, 60%, and 79%respectively, in the alternative scenario as compared to BAU.

Table 6.7 : Emissions (kt/yr) of PM$_{10}$, PM$_{2.5}$, NOx and SO$_2$ from different sectors in alternative scenario.

Sector	2016						2025						2030					
	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR	NCR
	PM$_{10}$	PM$_{2.5}$	NOx	SO$_2$	CO	HC	PM$_{10}$	PM$_{2.5}$	NOx	SO$_2$	CO	HC	PM$_{10}$	PM$_{2.5}$	NOx	SO$_2$	CO	HC
Transport	69	66	529	4	1751	886	12	12	239	0	907	693	12	11	238	0	685	460
Industries	288	127	85	556	620	27	175	106	48	43	804	50	105	93	67	49	834	70
Power Plants	74	40	133	297	13	9	34	17	15	22	13	9	36	18	16	24	0	0
Residential	204	131	38	20	1700	374	50	29	15	5	1659	399	61	42	25	12	1844	442
Agri cultural burning	174	102	31	9	781	209	0	0	0	0	0	0	0	0	0	0	0	0
Road dust	137	31	0	0	0	0	89	20	0	0	0	0	103	25	0	0	0	0
Construction	44	8	0	0	0	0	47	8	0	0	0	0	31	5	0	0	0	0
DG sets	4	3	53	3	11	4	0	0	5	0	8	3	0	0	1	0	6	2
Refuse burning	18	14	6	1	56	33	0	0	0	0	69	41	0	0	3	0	78	46
Crematoria	2	1	0	0	8	4	2	1	0	0	11	6	2	1	0	0	11	6
Restaurant	2	1	1	2	3	0	2	1	1	2	4	1	2	1	1	2	4	1
Airport	0	0	7	1	14	7	0	0	7	1	14	7	0	0	7	1	14	7
Waste incinerators	1	0	4	2	1	0	1	0	4	2	1	0	1	0	4	2	1	0
Landfill fires	2	2	1	0	6	2	2	2	1	0	6	2	2	2	1	0	6	2
Solvents	0	0	0	0	0	113	0	0	0	0	0	191	0	0	0	0	0	255
Total	1017	527	886	894	4964	1671	414	198	334	74	3494	1401	354	200	363	90	3483	1292

Sectoral contributions to $PM_{2.5}$ emissions in 2025 and 2030 in the alternative scenario are shown in Figure 6.20. As seen in the Figure 6.20, in 2030, share of the industrial sector has increased from 46% in BAU to 47% in alternative, residential has increased from 17% in BAU to 21% in alternative, and share of transport has increased from 5% in BAU to 6% in alternative scenario. Share of sectors such as agriculture burning, refuse burning, and DG sets in $PM_{2.5}$ emissions in 2030 has become zero in the alternative scenario. Overall, in 2030 in alternative scenario, industry is the largest polluting sector followed by residential, road dust, power plants, and transport.



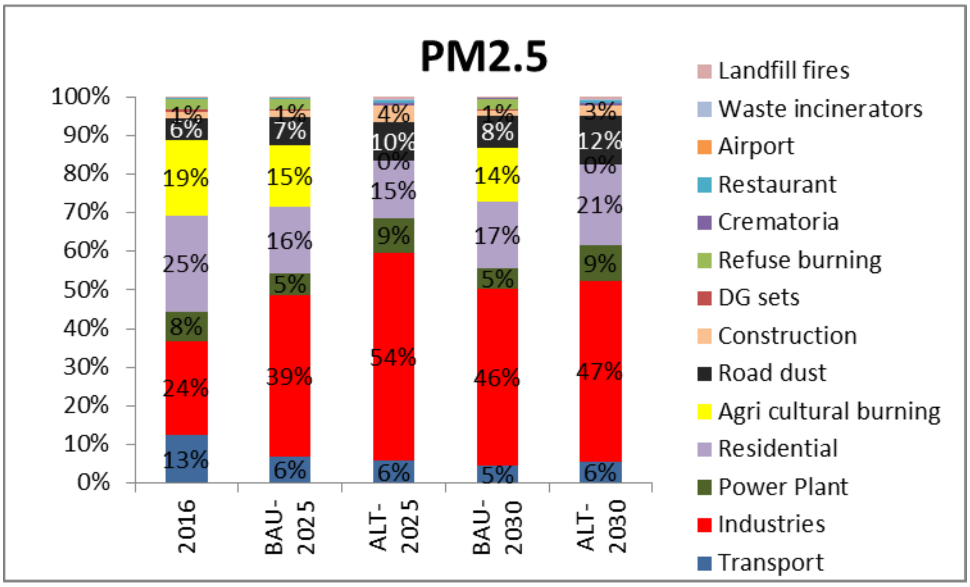


Figure 6.20: Sectoral contribution in $PM_{2.5}$ emissions in BAU and alternative scenario during 2025 and 2030.

Figure 6.21 shows the change in emissions and concentrations of $PM_{2.5}$ and PM_{10} in BAU and alternative scenario. In the alternative scenario, in 2030, $PM_{2.5}$ emissions fall by 72% and PM_{10} emissions fall by 77% and the corresponding reduction in average concentrations (of both seasons) are 58% in $PM_{2.5}$ and 61% in PM_{10}.

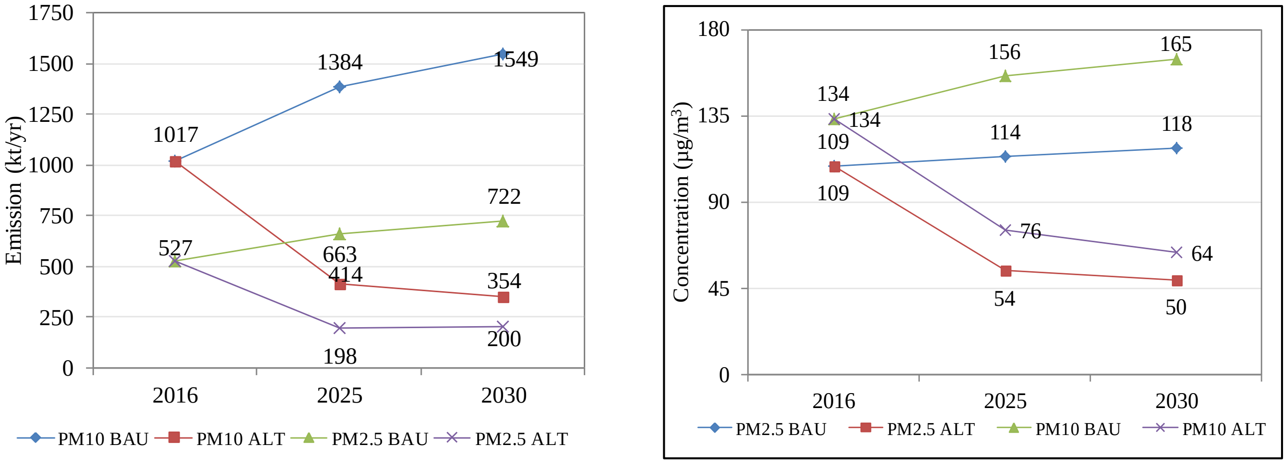


Figure 6.21: Emissions and concentration of $PM_{2.5}$ and PM_{10} in BAU and ALT scenario

Figure 6.22 shows the seasonal impact of the alternative scenario on PM_{10} and $PM_{2.5}$ concentrations in the study domain. The concentrations at several locations in Delhi are expected to meet the prescribed daily standard of 60 µg/m³ for $PM_{2.5}$ and 100 µg/m³ for PM_{10} in both seasons.

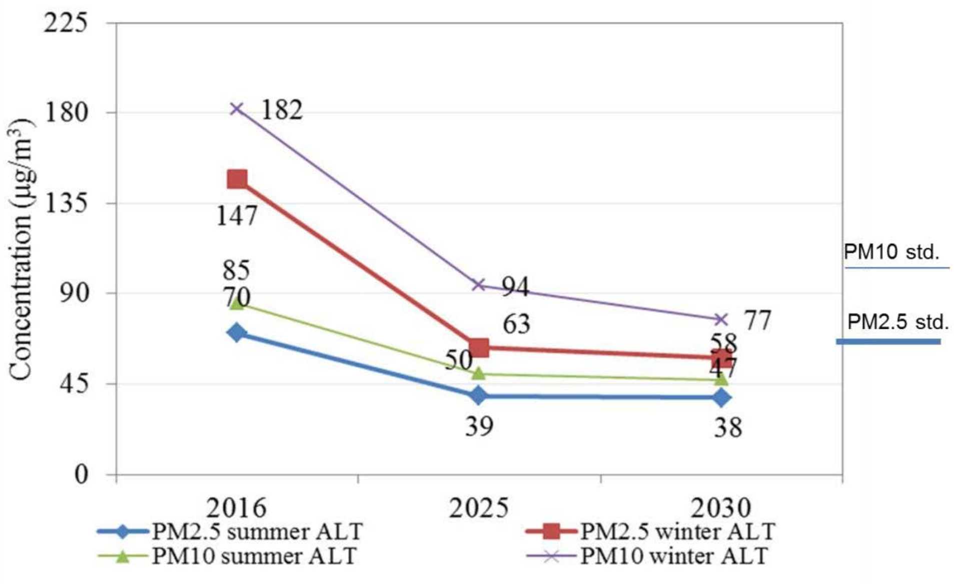


Figure 6.22: Concentration of $PM_{2.5}$ and PM_{10} in ALT scenario in two seasons

Figures 6.23 and 6.24 show the spatial impact of alternative scenario on PM_{10} and $PM_{2.5}$ concentration in the two seasons. The concentrations at several locations, especially in Delhi, are expected to meet the prescribed daily standard of 60 µg/m³ for $PM_{2.5}$ and 80 µg/m³ for PM_{10} in both seasons.

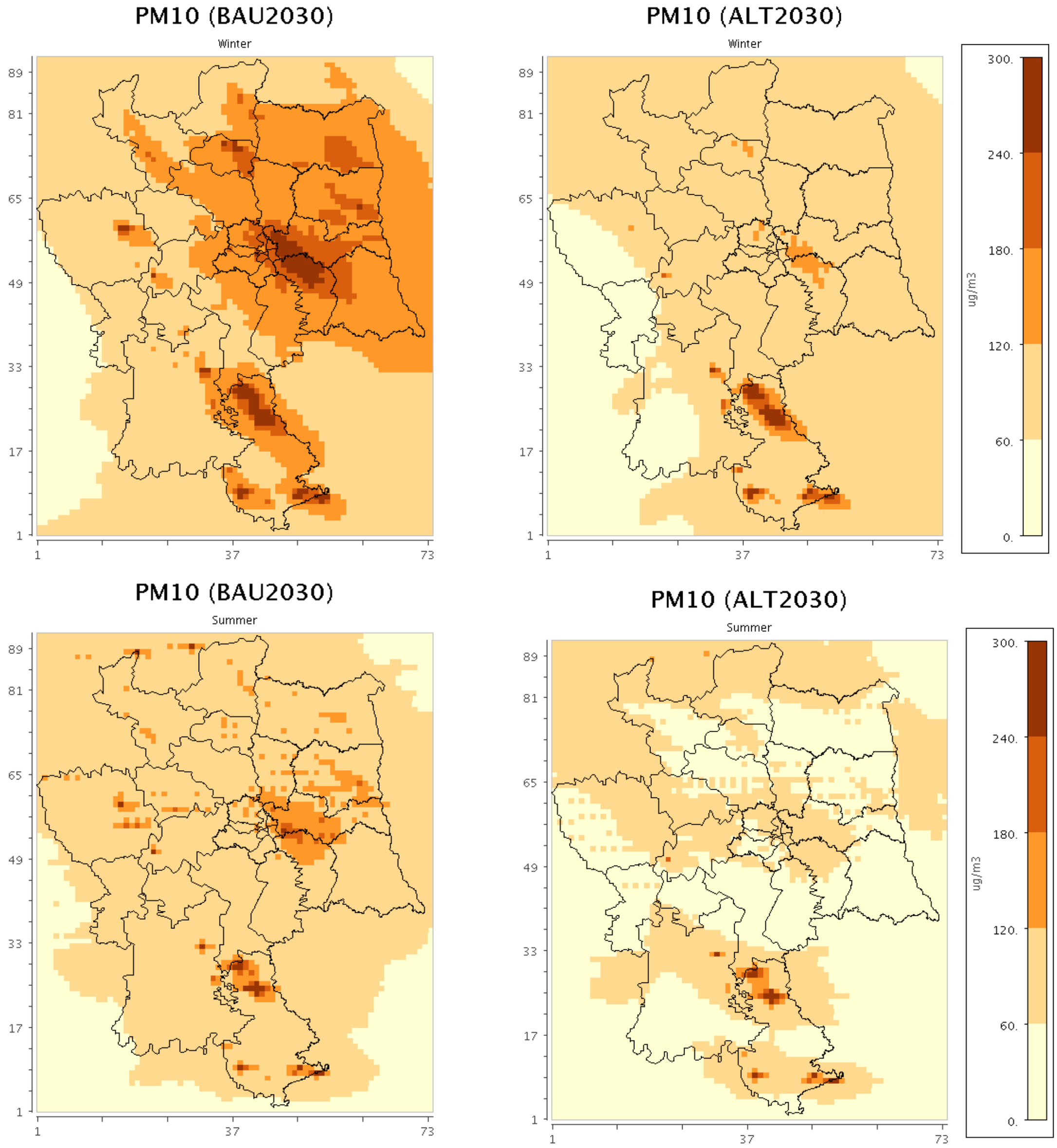


Figure 6.23: Concentration of PM_{10} in BAU and ALT scenario in two seasons in 2030

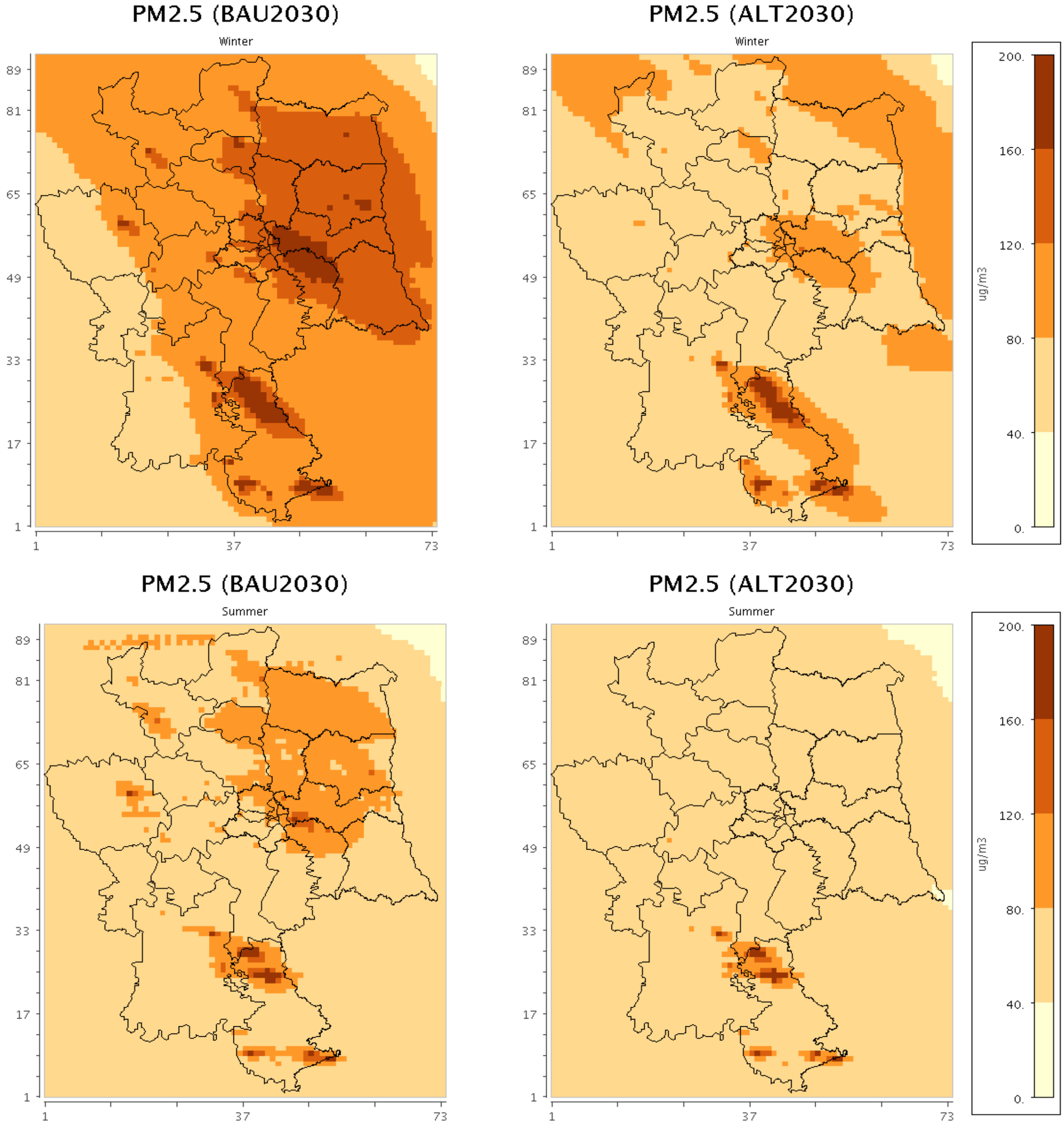


Figure 6.24: Concentration of $PM_{2.5}$ in BAU and ALT scenario in two seasons in 2030

Chapter 7: Summary

- This study carried out source apportionment of $PM_{2.5}$ and PM_{10} concentrations in Delhi NCR using two modelling-based approaches. The first approach relied upon monitoring and chemical characterization of PM_{10} and $PM_{2.5}$ samples. The chemically speciated samples along with source profiles were fed into the receptor model to derive source contributions. On the other hand, source-wise emission inventory, along with meteorological inputs are fed into a dispersion model to simulate PM_{10} and $PM_{2.5}$ concentrations. The modelled concentrations were compared with actual observations for validation. The validated model has been used to carry out source sensitivity to derive source contributions in PM_{10} and $PM_{2.5}$ concentrations. The key conclusions that can be derived are as follows :
- Air pollution levels are extremely high in Delhi and NCR, especially in winters.
- The assessment of both the scientific approaches reveals that transport, biomass burning, and industries are the three major contributors to $PM_{2.5}$ concentration in Delhi NCR during winter. In summer, the contributions of dust from inside and outside of India eclipses the shares of these three major sectors in the $PM_{2.5}$ concentrations, however, the contributions still remain significant.
- The assessment for PM_{10} shows that other than transport, biomass burning, and industries, road dust and construction dust also contribute significantly to concentrations. Like $PM_{2.5}$, during summers, the contributions of dust from outside of India reduce the shares of these local sectors in the PM_{10} concentrations.
- The study has quantified the contributions of different sources at present and in future time-frames (2025–2030). The $PM_{2.5}$ concentrations are expected to increase by 5% in 2025 and by 8% in 2030 with respect to 2016, in a BAU scenario. The PM_{10} concentrations are expected to increase by 16 and 23% in 2025 and 2030, respectively, in a BAU scenario. This is after accounting for growth in different sectors and also taking into account the possible enforcement of the interventions which have already been notified for control of air pollution. Discounting these planned interventions, the growth in $PM_{2.5}$ concentrations could be 30% higher in 2030.
- The study analysed various interventions and estimated their possible impacts over $PM_{2.5}$ and PM_{10} concentrations in Delhi and NCR. An alternative scenario has been developed considering the interventions which can provide maximum air quality benefits. The alternative scenario results in a reduction of 58% and 61% in $PM_{2.5}$ and PM_{10} concentrations in 2030, with respect to the BAU scenario, and achieves Daily ambient air quality standards for PM_{10} and $PM_{2.5}$.
- The interventions which have identified as the ones with highest impact on PM concentrations in 2030 are:
  - Complete phase out of biomass use in NCR by enhanced LPG penetration in rural households
  - Use of agricultural residues in power plants and other industries to replace high ash coal and open burning in fields
  - Introduction of gaseous fuels and enforcement of new and stringent SO_2/NO_x/$PM_{2.5}$ standards for industries using solid fuels
  - Strict implementation of BS-VI norms
  - Improvement and strengthening of inspection and maintenance system of vehicles

- Fleet modernization and retro-fitment programmes with control devices
- Enhanced Penetration of electric and hybrid vehicles
- Reducing real world emissions by congestion management
- Stricter enforcement of standards in large industries through continuous monitoring
- Full enforcement of zig-zag brick technology in brick kilns
- Vacuum cleaning of roads, wall to wall paving of roads
- Control of dust from construction activities using enclosures, fogging machines, and barriers
- Elimination of DG set usage by provision of 24x7 electricity and control by innovative tail-pipe control technologies

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