INDIA	SEPTEMBER 2021	FACTSHEET

$PM_{2.5}$ in Ecologically Different Districts in India: Characteristics & Health Effects

Supported by

SHAKTI SUSTAINABLE ENERGY FOUNDATION

Shakti Sustainable Energy Foundation

Prepared by

The Energy and Resources Institute (TERI)

Darbari Seth Block, Habitat Place, Lodhi Road, New Delhi – 110 003

Suggested format for citation

T E R I. 2021

$PM_{2.5}$ in Ecologically Different Districts in India: Characteristics & Health Effects

New Delhi: The Energy and Resources Institute. 19 pp.

Supported by

Shakti Sustainable Energy Foundation

For more information

Project Monitoring Cell
T E R I
Darbari Seth Block
IHC Complex, Lodhi Road
New Delhi – 110 003
India

Tel. 2468 2100 or 2468 2111
E-mail pmc@teri.res.in
Fax 2468 2144 or 2468 2145
Web www.teriin.org
India +91 • Delhi (0)11

TEAM

Project Investigator: Ms. Meena Sehgal

Team Members:

Kanhaiya Lal, Mahima Uttreja, Arindam Datta, R. Suresh, Ved Prakash Sharma, Vidhu Gupta, Ashish Patil, Johnson, Gaurav, Kulwant

Secretarial assistance: Kiran Shivpuri

Reviewers:

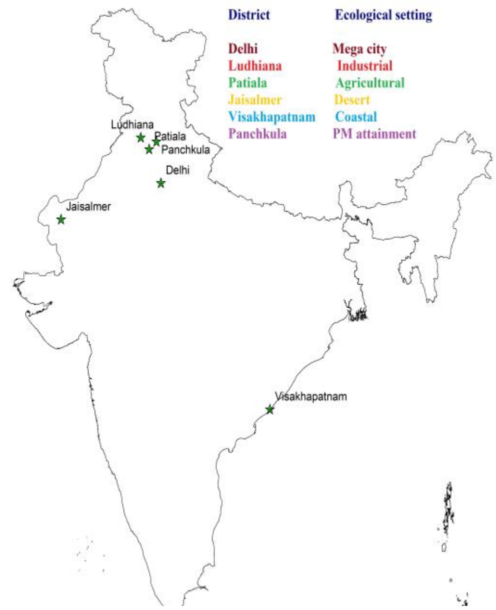
Dr. Prodipto Ghosh, Dr. Suneel Pandey

ACKNOWLEDGMENTS

We thank Shakti Sustainable Energy Foundation for their support to carry out this work. We also thank Dr Javed Ahsan Quadri and Dr A. Sharrif, Clinical Ecotoxicology (Diagnostic & Research) Facility, All India Institute of Medical Sciences (AIIMS), New Delhi, for analyzing heavy metals in the $PM_{2.5}$ samples.

KEY TAKE-AWAYS

- ***$PM_{2.5}$ mass concentration had crossed the regulatory daily limit (60 µg/m^3) for the selected cities, except Panchkula during March 2020.***
- ***Chromium, Copper, Zinc, Molybdenum and Lead were identified as major metal constituents of $PM_{2.5}$ as these metals were present in relatively higher concentration in most of the $PM_{2.5}$ samples***
- ***The metal/heavy metal in $PM_{2.5}$ of Ludhiana and Delhi have been mainly linked to anthropogenic activities such as vehicular exhaust from heavy traffic and industrial operations***
- ***A Heavy Metal Exposure Index (HEI) had been developed accounting the concentration of toxic heavy metals in $PM_{2.5}$. Based on the Index, the study districts can be arranged as follow: Ludhiana> Delhi> Panchkula> Visakhapatnam> Patiala > Jaisalmer***
- ***The study suggests urgent need to take proactive actions to prevent local pollution and need to index toxicity based on characteristics of $PM_{2.5}$ to prioritize action districts/cities where risk to health is highest.***
- ***The damaging effect of $PM_{2.5}$ on human health is usually through the free radical peroxidation. Several studies have shown that the metals (such as iron, copper, zinc etc.) and organic components of $PM_{2.5}$ induce free radical production in lung, consuming antioxidant ingredients and causing oxidative stress.***
- ***National Clean Air Programme (NCAP) should define targets and timeline to phase out heavy metal toxic exposures at the earliest.***
- ***States should provide incentives to adopt emission control technologies so that violation could be minimized.***



Respiratory Health Survey: School Children in KV AGCR Colony,

Air pollution is a serious problem which compromises the health of millions of people around the world. It not only affects the ambient air quality of a region, but also the human respiratory system which is vulnerable to exposure to fine Particulate Matter ($PM_{2.5}$). Population of all the age groups are under the impact of particulate pollution, however children are more likely to be exposed to varying levels of PM in different microenvironments[1]. In order to address this issue several initiatives have been taken by the different ministries and other governing bodies. To overcome the complex challenges of air pollution, it is important to identify district level sources for prioritize action. This factsheet highlights sources of pollution among six districts of India and actions taken to improve the air quality and protect human health.

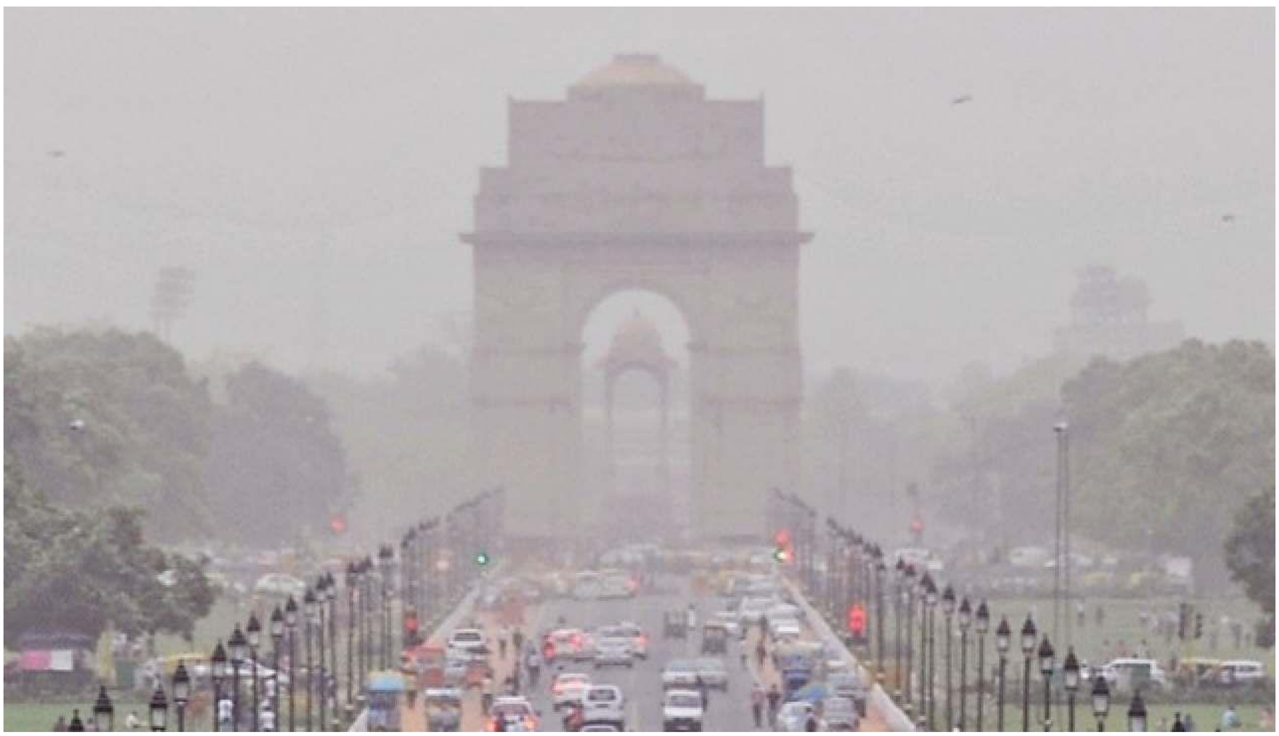
THE AIR POLLUTION PROBLEM

India's air quality has deteriorated severely in the past few years, due to a number of reasons including rapid urbanization, industrialization, and increasing population[2]. In 2019, India experienced approximately 1.2 million premature deaths attributed to both ambient and household air pollution[3]. In many locations, concentrations of particulate matter ($PM_{2.5}$) significantly exceed recommended national and international standards resulting in severe implications for human health[4]. According to recent estimates by the World Health Organization, 11 out of the top 12 cities are located in India with the highest levels of particulate pollution[5]. In addition, 94% of the populations live in areas where it exceeds India's national ambient air quality standards.

India is the second most polluted country in the world. Recent estimates by University of Chicago, reveal that air pollution shortens the average Indian life expectancy by 6.3 years[6]. However, some of the areas are much worse than average, with mean expected life shortening by 13.2 years in Delhi and 11.2 years in Haryana, being the most polluted states. In one of our recent studies, the highest number of respiratory complaints were reported by the elderly population (>40-60y) and the lowest by the young population (>18-40 y) during the October – November crop residue burning period. Further, the decline in lung function with increase in $PM_{2.5}$ concentration during this crop residue burning period was noted in all age groups in Patiala. The youngest age group (10-18y) reports the highest reduction in lung function as compared to the other age categories (>18-40y and >40-60y) both for male and female groups. While India's air pollution problem is persistently affecting the entire country, the northern region suffers more during winter season[7]. The geographical and meteorological conditions and low temperature during winter further contributes to the high $PM_{2.5}$ levels. In contrast, the COVID-19 lockdown restriction has resulted in more than 50% reduction in ambient air particulate matters (PM_{10} & $PM_{2.5}$) in Delhi and various other cities[4].

The Central Pollution Control Board (CPCB) has identified 132 cities in 25 states of India's as "non-attainment/ Million plus cities in India under NCAP" in the year 2018 for exceeding the pollutant levels set under the National Ambient Air Quality Standards (CPCB, 2018)[8]. Ambient air quality is monitored by the CPCB using manual stations in 793 locations covering 344 cities/ towns in 29 states and 6 Union Territories of the country. There is also an existing network of continuous ambient air quality monitoring stations (CAAQMS) in the country. As of September 2019, under the guidance of CPCB, there were 200 CAAQMS operating in 20 states and covering 116 districts with at least one monitor[9]. In addition, on the basis of the thumb rule proposed by CPCB and the district level urban and rural population, there is a need for 4,000 CAAQMS (2,800 in the urban areas and 1,200 in the rural areas of the districts) to spatially, temporally, and statistically represent the $PM_{2.5}$ pollution in the urban and the rural areas of India[i].

The air pollution interventions highlighted in this factsheet include six ecologically different districts in India - *Delhi, Ludhiana, Patiala, Jaisalmer, Panchkula and Visakhapatnam*. This factsheet also describes some pollution mitigation efforts that need to be taken in these districts.



Transport emissions are a major source of pollution in Delhi (Mega City) Image source: File Photo

DELHI

Delhi is the national capital, with nearly 31 million population across the large metropolitan area of the National Capital Region (NCR). Delhi has the highest level of pollution in the country, with pollution levels being 14 times the WHO guideline. Being megacity air pollution is no longer just a problem in Delhi, but adds to the pollution levels of other states in the regions. Cities and towns in the neighboring states i.e. Haryana and Uttar Pradesh are also highly polluted.

The main sources of air pollution in Delhi include vehicle exhaust, heavy industry such as power generation, small-scale industries like brick kilns, suspended dust particles, open waste burning, combustion of fuels for cooking, lighting, and heating, and diesel generator sets. Along with this there are seasonal emissions from dust storms and open field fires during post-harvest season. The present study reported that the average concentration of $PM_{2.5}$ was 145±46 μg/m^3 (before lockdown in Oct 2019) and 88±42 μg/m^3 (after lockdown in Sep 2020). Thus, the lockdown restrictions have resulted in 39% reduction in $PM_{2.5}$ concentration in Delhi region. In addition, the mean levels of heavy metals detected in $PM_{2.5}$ samples were chromium (76.1 ng/m^3), copper (147.2 ng/m^3), zinc (615.4 ng/m^3), molybdenum (278.4 ng/m^3) and lead (406.1 ng/m^3) during Oct 2019. The study also reported toxic metallic elements such as nickel (4.8 ng/m^3), arsenic (11.0 ng/m^3) and cadmium (21.0 ng/m^3) in noticeable concentrations. Remarkably, the level of lead (Pb) in $PM_{2.5}$ of 2020 had been reduced to 43% of its level in in October 2019. Moreover, samples were also analyzed for molecular markers and major PAHs detected were Benzo[b]fluoranthene (13.6 ng/m^3), Benzo[a]pyrene (15.8 ng/m^3) and Benzo[k]fluoranthene (20.4 ng/m^3). Thus, lockdown restrictions resulted in a noticeable reduction for $PM_{2.5}$ and other characteristic compounds.

In this regard, the government officials, health experts, and civil society groups, as well as the judiciary, appointed Environment Pollution Control Authority (EPCA), and the National Green Tribunal in formulating emergency response plans (like the Graded Response Action Plan, or GRAP) and longer-term strategies to address Delhi's air pollution distresses. The Supreme Court also put restrictions on burning fireworks on Diwali in order to reduce exposure high pollution levels in Delhi. Moreover, some longer-term actions were proposed to respond to air pollution in Delhi, including a comprehensive electric vehicle (EV) policy. Delhi's draft EV policy sets a target for 25% of all vehicles to be EVs by 2023. Furthermore, Ministry of Power and Environment notified emission standards for coal power plants and brick manufacturing industries, respectively.

LUDHIANA

Ludhiana is one of India's biggest industrial cities with a population exceeding 2 million. The WHO urban air quality database and several international and Indian studies have identified Ludhiana as one of the most polluted cities in India, and it is among the non-attainment cities recently identified by the CPCB in the National Clean Air Plan. The city has two industrial clusters i.e. Industrial Focal Point and Industrial Estate. Besides this, there are scattered industrial units contributing to ambient air pollution such as plastic recycling units, brick kilns, induction furnace, Paper mills, Milk Plants, Engineering Goods industries, Distillery etc. Moreover, with the development of industries and growth of population the demand for vehicles has also increased. Therefore, the presence of a considerable number of the manufacturing hub, large population, and heavy traffic, burden on natural and human-made resources has led to the city being severely polluted. Hence, the present study has focused on understanding the extent of decline of pollution during the lockdown in this city. The average $PM_{2.5}$ concentration was 338±75 $\mu g/m^3$ in November 2020 and concentration range varies from 127 $\mu g/m^3$ to as high as 900 $\mu g/m^3$. The major heavy metals present were Cr (244.4 ng/m^3), Cu (224.9 ng/m^3), Zn (1364.5 ng/m^3), Mo (376.3 ng/m^3) and Pb (237.1 ng/m^3). The concentration of toxic heavy metals such as nickel (Ni), arsenic (As) and cadmium (Cd) were 0.9 ng/m^3, 10.1 ng/m^3 and 4.3 ng/m^3, respectively. The main sources of atmospheric metal pollution are mining, smelting and refining of metals, burning of fossil fuels, production and use of metallic commercial products, and vehicular exhaust. Toxic metals such as mercury, lead and cadmium can be found around many industrial areas like Ludhiana, with other contaminants such as polycyclic aromatic hydrocarbons (PAHs), black carbon (as well as volatile organic compounds (VOCs).

In Ludhiana, there is one continuous monitoring station reporting data for all the criteria pollutants and 4 manual stations reporting data on PM_{10}, SO_2, and NO_2. As per recent estimates, Ludhiana's ranking amongst the most polluted cities has dropped over the past three years-from being 95^{th} in 2018, it ranked 142 in 2020. However, $PM_{2.5}$ levels are still alarming in Ludhiana. Therefore, it is necessary to scale up monitoring and generate evidences of local and regional source of air pollution. To improve the city's air quality, local authorities have prepared an air pollution action plan. As part of this plan, development of Environment Protection Monitoring System was established in order to keep track of the progress made by concerned stakeholder departments on various projects, activities and initiatives.

PATIALA

Patiala district is one of the famous princely States of erstwhile Punjab, with a population of 7.63 lakhs in 2020. Patiala district forms a part of the Indo-Gangetic plain (IGP). The city is well connected by roads and is located at a distance of about 75 km towards southwest from Chandigarh, and is about 250 km from Delhi. Patiala has been identified as one of the non-attainment cities as the ambient quality does not conform to the NAAQS. The region has a small industrial hub mainly dominated by micro and small enterprises such as rice shellers, food and beverages, plastic and other manufacturing industries. Patiala is surrounded by agriculture fields. Burning of paddy stubble by the farmers in the fields also adversely affects the ambient quality of the city. Due to extensive paddy stubble burning, the air quality drops here during paddy harvesting period (Oct - Nov) every year. In this regard, the present study estimated the $PM_{2.5}$ ambient concentration during November 2019. The average $PM_{2.5}$ concentration estimated was 272±186 μg/m^3. The daily average $PM_{2.5}$ concentration has crossed the CPCB standard i.e. 60 μg/m^3 for a 24 hour exposure period. The $PM_{2.5}$ samples majorly constituted Pb (54.5 ng/m^3) Ni (5.8 ng/m^3), while As (1.9 ng/m^3) and Cd (1.5 ng/m^3) were present in minute concentrations. The concentrations of heavy metals were significantly lower as there are no industrial establishments nearby the study area. **However, because of paddy stubble burning the concentration of organic carbon (OC) and elemental carbon (EC) concentrations in $PM_{2.5}$ was found to be 25.9 μg/m^3 (i.e. 5.8 times greater than $PM_{2.5}$ sampled from Delhi) and 1.4 μg/m^3, respectively.** In addition, the concentration of Benzo[b]fluoranthene, and Benzo[a]pyrene were found to be 28.7 ng/m^3 and 9.9 ng/m^3. The high levels of PAHs during October and November clearly indicate the contribution of burning practices.

Paddy Stubble burning in Punjab (©The Hindu)

The Punjab Pollution Control Board (PPCB) and NGT have formulated some action plans to address the problem. In order to control vehicular pollution the district installed remote sensor based PUC system, in planning to widen the roads and improvement of infrastructure, to check fuel adulteration and awareness campaign for air pollution control, vehicle maintenance, less use of personal vehicle etc. In addition, to reduce the emissions from open burning of crops and waste the district Administration, Department of Agriculture, Department of Cooperative Societies and PPCB have launched the extensive drive against open burning of biomass/crop residue. Along with this the Municipal Corporation has also constructed an advanced waste management site to do Integrated MSW Management for Patiala region.

JAISALMER

Jaisalmer is a small arid city located in the central region of The Thar Desert in Rajasthan. With a population of more than 7 lacs, it is the largest district of the state with 38,401 sq. km area. Jaisalmer district is renowned for its mineral wealth. The district has come into limelight with the discovery of steel grade limestone and cement grade limestone. There are various kinds of industries in the city with the travel and tourism industry being the most prominent. Other industries that also hold important places in Jaisalmer's industrial sector are stone-cutting and sculpturing, the khadi industry, and the mineral-oriented industry. Despite being a tourist destination, the city is trying to develop in other sectors with the energy sector also growing gradually. Jaisalmer has also shown positive evidence of Hydro Carbon accumulation (Natural Gas), and has among the largest wind-farms in the world.

The overall average concentration of $PM_{2.5}$ estimated before the covid 19 lockdown (Dec 2019) and after te lockdown (Dec 2020) was 127±57 $\mu g/m^3$ and 87±57 $\mu g/m^3$, respectively. Thus, the study noted an approximately 31% reduction $PM_{2.5}$ concentration due to COVID-19 restrictions. Cr (86.8 ng/m^3), Cu (134.8 ng/m^3), Mn (0.3 ng/m^3) and Mo (52.2 ng/m^3) in 2019 was noticeably lower as compared to the Dec 2020 levels. The Rajasthan State Pollution Control Board (RSPCB) has prepared the plan under the National Clean Air Programme (NCAP) and now taken the lead to enhance the implementation strategies for an effective impact. The Rajasthan State Pollution Control Board (RSPCB) has initiated multi-sectoral strategies in different districts of Rajasthan, to encompass industry, power plants, vehicles and transportation, waste management and solid fuels in households. Through this, by adopting a mitigating strategy to control pollution at a regional scale air quality gains may be realized.

PANCHKULA

Panchkula is a planned city in Haryana, India. Panchkula presents another example of how Indian cities are trying to improve air quality. The air quality is usually good throughout the year in Panchkula. It is categorized under PM attainment city due to lower level of particulate matter in the ambient air. Last year, Panchkula was in the 'satisfactory' category with 96 AQI. However, the areas located near to roads might have $PM_{2.5}$ level higher than the CPCB standard. The air monitoring in Panchkula was conducted in March and Nov 2020.

The overall average $PM_{2.5}$ level estimated during the study period was 44±26 μg/m³ in March 2020. However, it exceeded the CPCB standard in Nov 2020 and hence PM control strategy should be adopted during winter. Further, heavy metals such as chromium, copper, zinc, molybdenum and lead were detected in noticeable concentrations. During March 2020 the mean concentration of Cu was 1614.5 ng/m³, while in November 2020 it was 209.4 ng/m³. The presence of Cu attributed to copper metal work in the region. Thus, there is approx. 87% reduction in average Cu concentration in the post lockdown period. The marginally higher levels of metals such as Cr, Mn, Mo and Pb can be seen in $PM_{2.5}$ sample taken during Nov 2020. The concentration of lead in ambient air was measured to be 27.6 ng/m³ (March 2020) and 96.5 ng/m³ (Dec 2020). Moreover, the Benzo[b]fluoranthene and Benzo[a]pyrene were also present in remarkable mean concentrations i.e. 19.9 ng/m³, 3.6 ng/m³, respectively.

VISAKHAPATNAM

Visakhapatnam is a coastal city and industrial center in the Indian state of Andhra Pradesh, with a population of 2.2 million. It is located in South-Eastern coast and the entire city lies within two major hill ranges. These two hill range causes an inversion conditions mainly during winter season. The residential area and industrial hub co-exist in the bowl area. It is the most industrialized city in Andhra Pradesh and also falls among the five non-attainment cities of Andhra Pradesh. PM has been identified as the key air pollutant as it doesn't meet the NAAQS.

Coastal sand, vehicular and industrial exhausts are the major sources of air pollution in Visakhapatnam. Therefore, three distinct locations - Lawsons Bay (near RK beach), Arilova (near main road) and LG Polymer (industry), were chosen to get the representative $PM_{2.5}$ samples. Due to COVID restrictions air monitoring was conducted during June 2020 after the announcement of unlock phase 1. The overall average $PM_{2.5}$ mass concentration estimated was 83±64 μg/m³. The major metal constituents in $PM_{2.5}$

samples from Visakhapatnam were chromium (69 ng/m^3), manganese (108 ng/m^3), copper (113 ng/m^3), zinc (120 ng/m^3) and molybdenum (41 ng/m^3), respectively.

Andhra Pradesh Pollution Control Board (APPCB) prepared an action plan to bring down the critical levels of air pollution. The initiatives were made to reduce stack emissions by installation of stack control equipment, reduction of fugitive emissions while uploading, use of containers instead of wagons, and enhancing online pollution monitoring. The GRAP action plan for Visakhapatnam has been proposed to prevent air pollution. The major actions taken were: restricting entry of diesel trucks, stopping construction activities, and introducing odd even scheme for private vehicles during severe or emergency conditions. However, during severe to very poor conditions actions that need to be taken are closing of: brick kilns, hot mix plants, stone crushers, minimizing operation of coal power plants, increasing frequency of mechanized road cleaning, sprinkling of water on roads, stopping use of diesel generators, stopping use of coal/firewood, and alerting the citizens through advertisements.

KEY FACTS OF AIR MONITORING

- **$PM_{2.5}$ levels among six districts**

  Ludhiana> Patiala>Delhi> Jaisalmer>Visakhapatnam> Panchkula

- **Metal/ Heavy metal among six districts**

  Ludhiana > Delhi > Visakhapatnam > Patiala > Panchkula > Jaisalmer

- **Level of sulfate (SO_4^{2-}) in $PM_{2.5}$ samples**

  Patiala > Jaisalmer > Delhi > Panchkula

- **Level of Organic Carbon (OC) in $PM_{2.5}$ samples**

  Patiala > Jaisalmer > Panchkula > Delhi

Heavy Metal Exposure Index (HEI)

On the basis of substance priority list given by Agency for Toxic Substances and Disease Registry (ATSDR) the present study estimated the Heavy Metal Exposure Index (HEI). For calculating HEI, the first step is to note-down the toxicity points given by ATSDR to specific substances. As per ATSDR, a toxic chemical can have a maximum of 1800 points. Weight of heavy metals (As, Pb, Hg, Cd, Co, Ni, Cr, Zn, Cu, Mn, Se, Al) was calculated using Equation (1). To calculate the heavy metal exposure index (HEI) which is mathematically weighted geometric mean (WGM) as given by Equation (2), the mean concentration of heavy metals (x_i) was corrected by adding 1 (i.e. $1+x_i$) to get non-zero multiplication value. The HEI shows the most significant potential threat of heavy metals to human health due to their known or suspected toxicity.

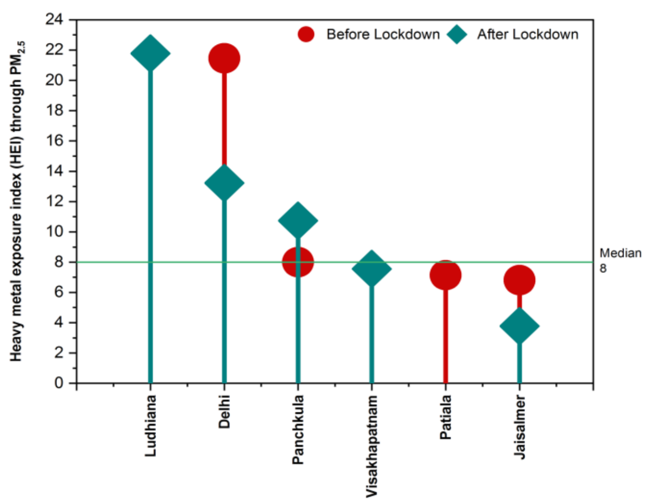
$$\text{Weight of heavy metal } (w_i) = \frac{T_{p_i}}{T_p(max)} \qquad \text{(Equation 1)}$$

$$Heavy\ metal\ exposure\ index\ (HEI) = \exp\left(\frac{\sum_{i=1}^{n} w_i \ln(1+x_i)}{\sum_{i=1}^{n} w_i}\right) \qquad \text{(Equation 2)}$$

where, T_{pi} denotes the total points of a toxic pollutant and $T_p(max)$ is the maximum points as per ATSDR substance priority list.

Similar approach had been used for calculating heavy metal pollution load index (PLI) in soil, sediment, and dust samples[24-26].

Heavy Metal Exposure Index (HEI)



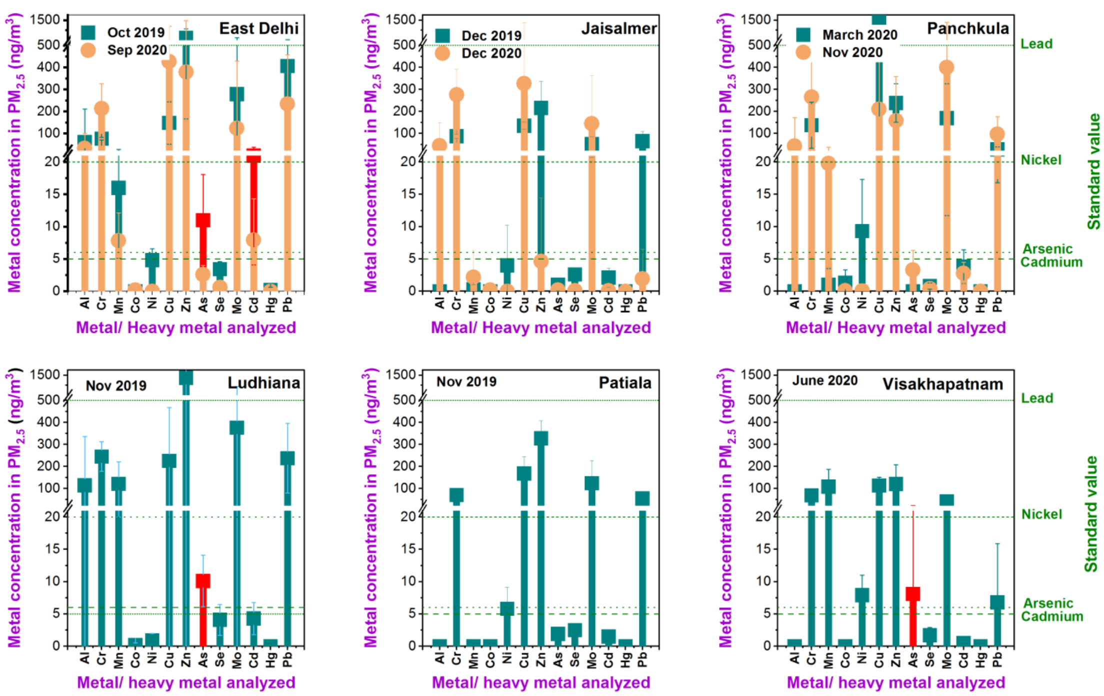
- The HEI estimated in Delhi before lockdown was more as compared to after lockdown
- In Ludhiana and Visakhapatnam, the HEI was highest attributed to the industrial setting in the region
- Although Panchkula is an $PM_{2.5}$ attainment city but still the heavy metal contamination is there both before and after lockdown attributing to the industrial and vehicular sources (one of the monitoring location was near to the road and market)
- In case of Jaisalmer the HEI is very low showing the lowest exposure to heavy metals as compared to other districts
- Based in the HEI value, the districts can be arranged as follows: Ludhiana > Delhi> Panchkula > Visakhapatnam > Patiala > Jaisalmer
- Heavy metal exposure index (HEI) can be very helpful in prioritizing the heavy metal toxicity of $PM_{2.5}$ and can help making policy decision at regional level. Hence, HEI assessment of $PM_{2.5}$ is recommended as a routine practice.

ADVERSE HEALTH EFFECTS OF $PM_{2.5}$

Over the past two decades, there have been numerous attempts to measure particulate pollution (PM levels) in terms of $PM_{2.5}$ association with serious health outcomes such as respiratory and cardiovascular diseases. The vulnerable population facing serious impacts of $PM_{2.5}$ exposure includes the elderly, children, adolescents, pregnant women, and patients with cardiopulmonary problems. $PM_{2.5}$ is known to adversely affect asthmatics, respiratory inflammation, and even promotes cancers. **The damaging effect of $PM_{2.5}$ on human health is usually through the free radical peroxidation. Studies have shown that metals (such as iron, copper, zinc etc.) and organic components of $PM_{2.5}$ induce free radical production in the lungs, consuming antioxidant ingredients and causing oxidative stress**[10, 27, 28]. This can further damage the DNA or suppress DNA repair. $PM_{2.5}$ is also known to stimulate the expression of various inflammatory cytokines and therefore resulting in inflammatory injury. This further increases the neutrophils. The alveolar macrophages affected by $PM_{2.5}$ express high levels of a few cytokines such as IL-12, TNF-α while cytokines such as IL-4, IL-10 and IL-13 may have low levels. This interaction between inflammatory cells and cytokines can damage the lung cells**. Thus, the major mechanisms of action of $PM_{2.5}$ on human health are inflammation, oxidative stress and genotoxicity**[10, 27, 28].

HEALTH EFFECTS OF $PM_{2.5}$ CONSTITUENTS

In the present study, heavy metals were identified as major components of $PM_{2.5}$, characteristics (refer to the bar graph below) that may result in potential health effects under prolonged exposure.



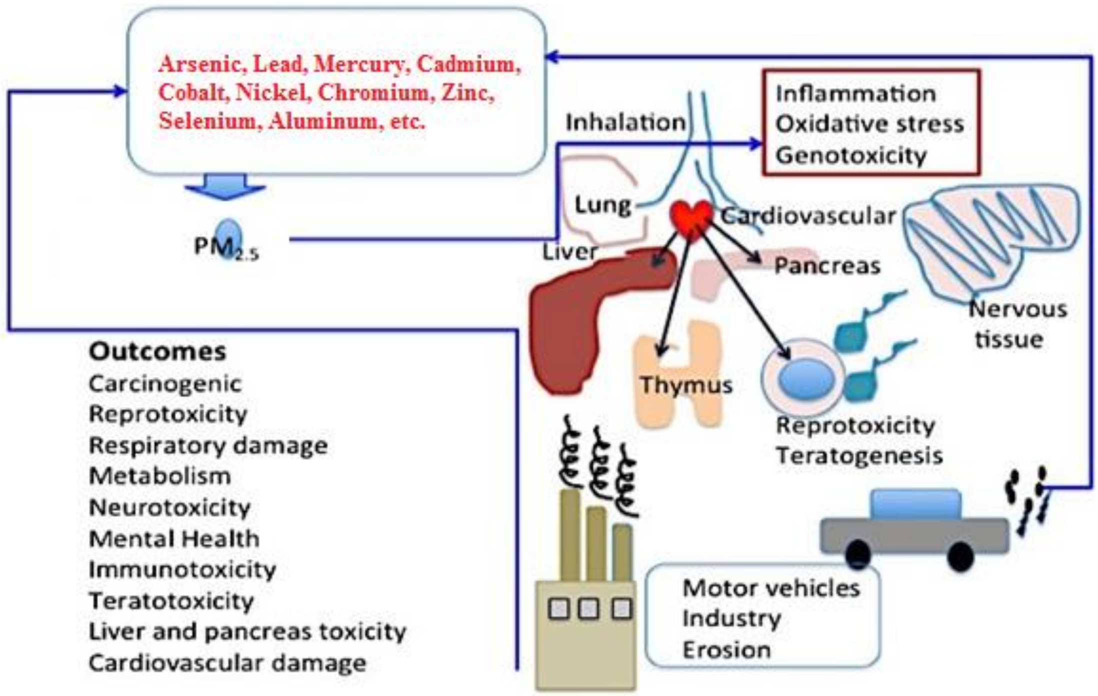
Metals adhered to PM first enter into the respiratory system (Nasopharynx to Trachea and Alveoli) and then spread through circulatory system. Several attempts have been made to document the health effects of such pollutants as summarised in Table 1. Heavy metals can cause health problems because of oxidative stress (e.g. Cd, Cr, Pb, As), neurological damage (e.g. Pb), DNA damage (e.g. As, Cr, Cd), changes in the metabolism of glucose (e.g, As) and calcium (e.g. Cd, Pb) and interfere with essential elements (e.g. Cd, Hg[10]. Moreover, metals like chromium (Cr) copper (Cu), nickel (Ni), zinc (Zn) and lead (Pb) have the potential to produce reactive oxygen species (ROS)[11]. Furthermore, waste incinerators produce heavy metals, specifically Cd, Pb, Hg, Cr and As.

Environmental pollution by heavy metals that are produced by the combustion of hydrocarbons is a major public health concern, which affects different organs such as central nervous system[12]. Lead has neurotoxic effects and it may cause an irreversible reduction in cognitive ability in children resulting in an intelligence quotient (IQ) decrease[13]. Lead and chromium are immune-toxic in nature. Inhaled metals namely arsenic, lead, cadmium, manganese may cause potential damage to the central nervous system which lead to mental and behavioral disorders[14, 15]. Besides this, Pb has been associated with depression, irritability, bipolar states, and mental retardation[16]. Cadmium has the ability to replace iron and copper, which induces an increase in the production of ROS, causing irritability, depression, amnesia and cognitive disorders[17]. Moreover, inhaled air pollutants which travel through the blood, also produce changes in the integrity of liver parenchyma, which leads to a slowly and irreversible liver damage[18, 19]). Arsenic crosses lung alveolar membrane and reaches the blood stream; it can also induce liver cancer[20]. Metals like cadmium, lead, mercury, manganese, chromium and nickel have female repro-toxic effects[21].

Table 1 - Major Toxic Constituents of $PM_{2.5}$ and Their Possible Health Effects

Metals/Heavy Metals/PAHs associated with $PM_{2.5}$	Health Effects	CPCB Standards
Cadmium (Cd)	Lung cancer, kidney and bone damage	5*
Arsenic (As)	Respiratory and vascular diseases, hypertension, diabetes, skin diseases, neurological effects,	6 ng/m^3 (annual)
Nickel (Ni)	Skin and respiratory diseases, increased risk of lung and nasal cancers	20 ng/m^3 (annual)
Lead (Pb)	Can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system	500 ng/m^3 (annual), 1000 (24 hours)
Chromium (Cr)	May produce cancer of respiratory tract	NA
Copper (Cu)	May potentially interfere with brain development	NA
Zinc (Zn)	Fever, nausea, aching	NA
BaP	May cause lung, skin, and bladder cancers	1 ng/m^3 (annual)

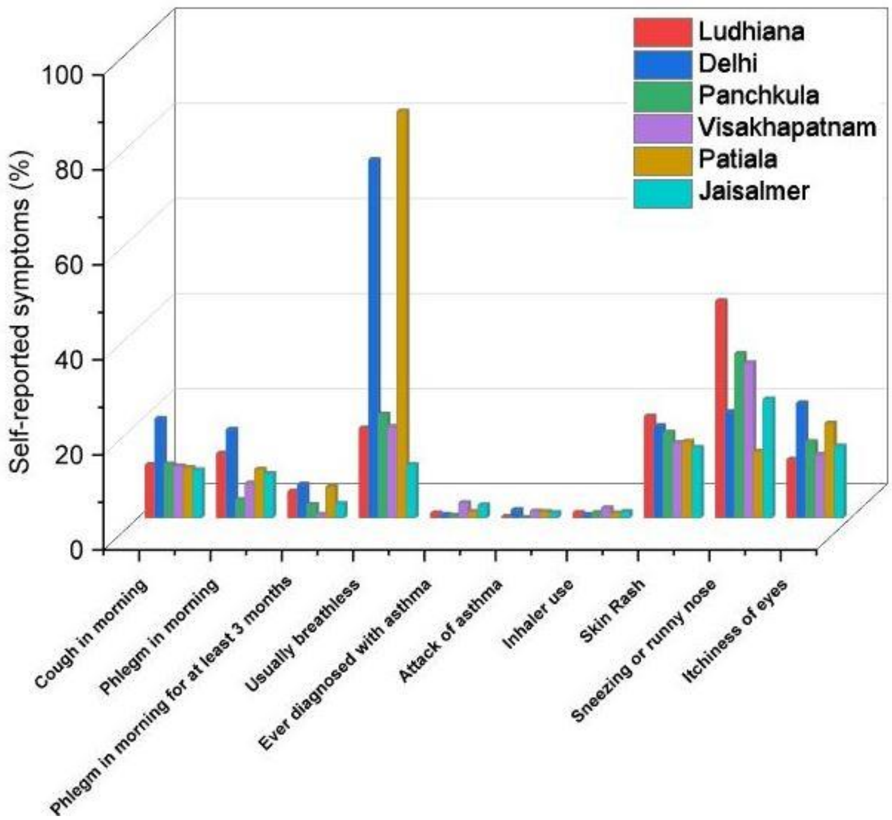
*WHO air quality guideline for cadmium of 5 ng/m^3 has been recommended in order to prevent any further increases in cadmium levels in agricultural soils (WHO, Regional Office for Europe. Air Quality Guidelines for Europe, Second Copenhagen: WHO Regional Publications, European Series; 2001). NA = Not available.



$PM_{2.5}$ associated metals into human body system and their adverse health effects (adapted from Fortoul et al., 2014)[10].

HEALTH SURVEY FINDINGS IN SIX DISTRICTS

The present study conducted a health survey on a study group of adolescent children from Kendriya Vidyalaya (KV) schools of the age category 14-17 years mainly from class 9th- 12th in the six study districts. The study population for this health survey comprised of a total of 2427 participants across six ecologically distinct districts of India. The overall study population of the survey comprised 53% male and 47% female respondents. The self-reported respiratory symptoms including wheezing, breathlessness on exertion, cough in morning and night and other symptoms such as skin rashes, running nose or itchiness of eyes were assessed for the study population. In survey analysis we noted the highest number of complaints for usually breathless in Delhi and Patiala while highest sneezing and running nose complain was noted in Ludhiana (refer to Figure below). Thus, the effect of bad air quality (elevated $PM_{2.5}$ level in highly polluted districts of this study) on respiratory health was evident.



Self-reported health parameters observed in the study population across Ludhiana (Industrial), East Delhi (Megacity), Vishakhapatnam (Coastal), Patiala (Agricultural biomass burning), Panchkula (PM2.5 attained- city) and Jaisalmer (Desert)

NATIONAL POLICY ON ENVIRONMENT AND HEALTH
The National Environment Policy, 2006: The National Environment Policy is envisioned to be a guide to action: in regulatory reform, conservation of critical environmental resources, livelihood security to poor, efficiency in use of environmental resources and environmental governance (MOEF, 2006)[22].   **National Health Policy (NHP), 2017:** The primary aim of NHP is to "inform, clarify, strengthen and prioritize the role of the Government in shaping health systems in all its dimensions- investments in health, organization of healthcare services, prevention of diseases and promotion of good health through cross sectoral actions, access to technologies, developing human resources, encouraging medical pluralism, building knowledge base, developing better financial protection strategies, strengthening regulation and health assurance."

NATIONAL CLEAN AIR PROGRAM

- The government of India launched a flagship program named National Clean Air Program **(NCAP)**[23] in 2019, to address the issues at both national and urban scales through air quality management planning, capacity building, and to increase knowledge about technologies to control air pollution. It is planned as a collaborative, multi-scale and cross-sectoral coordination between all relevant central ministries, state government and local bodies.
- The goal of the NCAP is to meet the prescribed annual average ambient air quality standards at all locations in the country, and the target is to reduce the concentration of $PM_{2.5}$ and PM_{10} by 20-30% by 2024 while keeping 2017 as a base year for the comparison of concentration.
- NCAP aims to establish a three-tier system that include real-time physical data collection, data archiving and data analytics infrastructure, and action trigger system. NCAP also highlights the role of instrument and calibration to ensure the data quality.
- The MoEF&CC has designated the Council of Scientific and Industrial Research-National Physical Laboratory (CSIR-NPL) as a national agency that shall be responsible for carrying out certification for instruments and equipment for monitoring emissions and ambient air. NCAP intends to operationalize the NPL-India Certification Scheme (NPL-ICS) at the central and regional levels to cater the country's needs with respect to the online monitoring of air pollution. The program will further partner with international organizations, philanthropic foundations, and leading technical institutions to achieve its goals.

RECOMMENDATIONS

The findings and gaps identified by the study lead to some the individual, city/state level and government level initiatives and solutions. These are highlighted below in the text boxes. There is a widespread need of air quality data for India to critically analyze related health effects and dissemination of these data to the public, medical community, and policy makers. So that effective mitigation strategies can be formulated to prepare a city level air quality monitoring framework and address long term capacity building.

Individual Level Action

- Use of more public transport instead of private
- Efficient use of energy sources
- Avoid using single use plastics, crackers, high electricity consuming devices
- Individuals should do proper waste management in order to reduce emissions from burning and open dumping
- Use of organic products
- Increasing the green area through afforestation

City Level Action

- **Characterziation of $PM_{2.5}$:** To create data repository on chemical characteristics of $PM_{2.5}$ of the cities
- **Create Heavy Metal Exposure Index (HEI):** To generate information on toxicity level of fine particles ($PM_{2.5}$) to priortize the cities where action is most urgently needed
- **To prepare emission inventory**: There is an urgent need to build a comprehensive nationwide air pollution monitoring network that provides reliable and real time air pollution information on criteria pollutants, including composition of fine particulate matter mass.
- **Low cost sensor**: deployment of monitors with low-cost sensors in significant numbers can assist in creating emission inventories of pollutants and detecting pollution hotspots, as well as allowing real-time exposure assessments for designing mitigation strategies.
- **Cities should follow Integrated Solid Waste Management technique** to reduce waste burning, proper collection, segregation and treatment to generate energy
- **Transport**: Electric vehicle for public transport and establishment of charging stations, arrangement of multilevel parking, use of bio-ethanol, widening of roads, remote sensor based PUC system
- **Improve the energy efficiency** of household appliances, buildings, lighting, heating and cooling; encourage roof-top solar installations
- Integration of citizen with community health warnings to local areas, during extreme conditions
- **Industry**: state level monitoring of industrial emissions through Online Continuous Emission Monitoring System, keep tracking of pollution monitoring through web cam and to develop technologies for side hood furnace, brick kilns
- **To control road dust**: increase green areas, maintain potholes free roads, introduce water fountains, wall to wall pavement

Ministry Level Action

- **Health studies**: development of data infrastructure to track the potential health impacts of air pollution
- **Transport**: government should initiate Odd-Even scheme as needed
- **Industries**: shifting of air polluting industries to conforming zones and strict regulation on implementation of air pollution control devices
- **Agricultural crop residue**: management of agricultural residues and strict enforcement of bans on open burning, technological interventions such as producing **Bio-CNG from paddy stubble**
- **Transition to clean fuels:** electricity, natural gas, liquefied petroleum gas (LPG) in cities, and LPG and advanced biomass cooking and heating stoves in rural areas; substitution of coal by briquettes, use of processed fuel. Maximum coverage of LPG/PNG with 100% target
- **State-of-the-art estimation and modeling methodologies should be developed and made available to state governing bodies**
- **Effective communication strategies**: need to develop effective communication strategies to inform the public about air pollution concentrations, health impacts and solutions
- Initiate efforts to support QA/QC (Quality Assurance/Quality Control) work on CPCB monitoring data with additional resources or partnership with other government labs/agencies

REFERENCES

1. Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R.S., Brauer, M., Cohen, A.J., Stanaway, J.D., Beig, G., Joshi, T.K., Aggarwal, A.N. and Sabde, Y., 2019. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. The Lancet Planetary Health, 3(1), pp.e26-e39.
2. Agrawal, G., Mohan, D. and Rahman, H., 2021. Ambient air pollution in selected small cities in India: Observed trends and future challenges. *IATSS Research*, *45*(1), pp.19-30.
3. HEI, (Health Effects Institute). 2019. State of Global Air Report 2019 India-Specific Findings Isaksson, C. 2010. Pollution and its impact on wild animals: a meta-analysis on oxidative stress. EcoHealth 7 (3): 342–50
4. IEA, 2021. Air Quality and Climate Policy Integration in India: Frameworks to deliver co-benefits, International Energy Agency Report
5. World Health Organization (WHO), WHO Global Ambient Air Quality Database (update 2018) https://www.who.int/airpollution/data/cities/en/
6. AQLI, 2020. India Factsheet 2020, Air Quality Life Index, Retrieved from: https://aqli.epic.uchicago.edu/country-spotlight/india/
7. Manisalidis, I., Stavropoulou, E., Stavropoulos, A. and Bezirtzoglou, E., 2020. Environmental and health impacts of air pollution: a review. Frontiers in public health, 8, p.14.
8. CPCB (2018). List of 132 Non-attainment/ Million plus cities in India under NCAP. https://cpcb.nic.in/uploads/Non-Attainment_Cities.pdf
9. Caserta, D., Graziano, A., Monte, G.L., Bordi, G. and Moscarini, M., 2013. Heavy metals and placental fetal-maternal barrier: a mini-review on the major concerns. Eur Rev Med Pharmacol Sci, 17(16), pp.2198-2206.
10. Fortoul, T.I., Rodriguez-Lara, V., Gonzalez-Villalva, A., Rojas-Lemus, M., Colin-Barenque, L., Bizarro-Nevares, P., García-Peláez, I., Ustarroz-Cano, M., López-Zepeda, S., Cervantes-Yépez, S. and López-Valdez, N., 2015. Health effects of metals in particulate matter. IntechOpen.
11. Ritchie, G.D., Still, K.R., Alexander, W.K., Nordholm, A.F., Wilson, C.L., Rossi Iii, J. and Mattie, D.R., 2001. A review of the neurotoxicity risk of selected hydrocarbon fuels. Journal of Toxicology and Environmental Health Part B: Critical Reviews, 4(3), pp.223-312.
12. Needleman, H.L., Geiger, S.K. and Frank, R., 1985. Lead and IQ scores: a reanalysis. Science, 227(4688), pp.701-704.
13. Jarup, L., 2003. Hazards of heavy metal contamination. British medical bulletin, 68(1), pp.167-182.
14. Landrigan, P., Nordberg, M., Lucchini, R., Nordberg, G., Grandjean, P., Iregren, A., & Alessio, L. (2007). The Declaration of Brescia on Prevention of the Neurotoxicity of Metals. American Journal of Industrial Medicine, 50(10), 709–711. doi:10.1002/ajim.20404
15. Mason, L.H., Harp, J.P. and Han, D.Y., 2014. Pb neurotoxicity: neuropsychological effects of lead toxicity. BioMed research international, 2014.
16. Schoeters, G., HOND, E.D., Zuurbier, M., Naginiene, R., Van den Hazel, P., Stilianakis, N., Ronchetti, R. and Koppe, J.G., 2006. Cadmium and children: exposure and health effects. Acta Paediatrica, 95, pp.50-54.
17. Tan, H.H., Fiel, M.I., Sun, Q., Guo, J., Gordon, R.E., Chen, L.C., Friedman, S.L., Odin, J.A. and Allina, J., 2009. Kupffer cell activation by ambient air particulate matter exposure may exacerbate non-alcoholic fatty liver disease. Journal of immunotoxicology, 6(4), pp.266-275.
18. Laing, S., Wang, G., Briazova, T., Zhang, C., Wang, A., Zheng, Z., Gow, A., Chen, A.F., Rajagopalan, S., Chen, L.C. and Sun, Q., 2010. Airborne particulate matter selectively activates endoplasmic

reticulum stress response in the lung and liver tissues. American journal of physiology-cell physiology, 299(4), pp.C736-C749.

19. Dutta, K., Prasad, P. and Sinha, D., 2015. Chronic low level arsenic exposure evokes inflammatory responses and DNA damage. International journal of hygiene and environmental health, 218(6), pp.564-574.
20. Gerhard, I., Waibel, S., Daniel, V. and Runnebaum, B., 1998. Impact of heavy metals on hormonal and immunological factors in women with repeated miscarriages. Human reproduction update, 4(3), pp.301-309.
21. MOEF (Ministry of Environment and Forest), 2006. National Environment Policy, Government of India.
22. NCAP, 2019. National Clean Air Programme, Central Pollution Control Board. Ministry of Environmental Forests and Climate Change, The Government of India
23. https://ibkp.dbtindia.gov.in/DBT_Content_Test/CMS/Guidelines/20190411103521431_National%20Environment%20Policy,%202006.pdf
24. Kowalska, J., Mazurek, R., Gasiorek, M., Zaleski, T., 2018. Pollution indices as useful tools for the comprehensive evaluation of the degree of soil contamination – A review 0123456789, 2395–2420. doi:10.1007/s10653-018-0106-z
25. Luo, H., Wang, Q., Guan, Q., Ma, Y., Ni, F., Yang, E., Zhang, J., 2022. Heavy metal pollution levels, source apportionment and risk assessment in dust storms in key cities in Northwest China. J. Hazard. Mater. 422, 126878. doi:10.1016/j.jhazmat.2021.126878
26. Gloaguen, T.V., Motta, P.N.S.D., Couto, C.F., 2021. A grain-size correction for metal pollution indexes in river sediments. Int. J. Sediment Res. 36, 362–372. doi:10.1016/j.ijsrc.2020.10.005
27. Dellinger, B., Pryor, W. A., Cueto, R., Squadrito, G. L., Hegde, V., & Deutsch, W. A. (2001). Role of Free Radicals in the Toxicity of Airborne Fine Particulate Matter. Chemical Research in Toxicology, 14(10), 1371–1377. doi:10.1021/tx010050x
28. Park, M., Joo, H. S., Lee, K., Jang, M., Kim, S. D., Kim, I., … Park, K. (2018). Differential toxicities of fine particulate matters from various sources. Scientific Reports, 8(1). doi:10.1038/s41598-018-35398-0

---

[i] http://www.indiaairquality.info/wp-content/uploads/docs/2003_CPCB_Guidelines_for_Air_Monitoring.pdf