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Could the National Capital Region serve as a control region for effective air quality management in Delhi?

Isha Khanna, Sumit Sharma

Dr. Isha Khanna is an Air Quality Scientist at the Puget Sound Clean Air Agency, Seattle, Washington, USA

Dr. Sumit Sharma is Director, Earth Science and Climate Change Division, The Energy & Resources Institute, New Delhi, India

Reviewed by

Sagnik Dey
Dr. Sagnik Dey is an Associate Professor at the Centre for Atmospheric Sciences, and coordinator of Centre of Excellence for Research on Clean Air (CERCA), IIT Delhi

Edited by

Santosh Harish and Kirk R. Smith
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Executive Summary

Air pollution does not follow administrative boundaries, and needs to be tackled at the regional "airshed" level at which it is caused. Identifying the appropriate candidates for airshed management requires scientific analysis using systematically developed emissions inventories and dispersion models to simulate the impact of the estimated emissions on air quality. Our analysis suggests that the National Capital Region (NCR) could form a good approximation for one such airshed boundary, and that tackling the much scrutinized air pollution issue in Delhi would benefit from greater coordination at the NCR level. 50-70% of the contribution to air pollution in Delhi and the other NCR cities is from within their city boundaries and from the rest of the NCR. In addition, given the many pollution control efforts over the last two decades in and around Delhi, there is a foundation on which to build.

Compared to air pollution in the developed world, the problem is more complex and severe in India, mainly due to a combination of rapid urbanization, fast-paced industrial development and also due to continued use of traditional fuels and combustion technologies. This deterioration of ambient air quality has been attributed with 1.24 million premature deaths and 38.7 million disability adjusted life-years (DALYs) loss in India resulting in a national public health crisis. DALYs attributable to ambient particulate matter pollution was highest in the north Indian states of Uttar Pradesh, Haryana, Delhi, Punjab, and Rajasthan.

While Delhi has its own sources, there are also several sources that contribute to deterioration of air quality from outside its boundaries. The rapidly developed towns around Delhi not just contribute to air pollution in their own areas but also add to Delhi's $PM_{2.5}$ concentrations. Similarly, Delhi's pollution affects the air quality in these towns as well. In addition to these towns, the rural region through its biomass-based sources, contribute significantly to regional air pollution problem. Besides Delhi with a population of 18 million, the NCR includes 18 cities and towns, and rural areas. In total, the population in this region is about 46 million. The towns have witnessed even higher rates of development, industrialization and urbanization than Delhi, and have also shown equally bad air quality parameters. In fact, cities like Ghaziabad and Noida, which are downwind predominantly to Delhi, show even higher pollutant levels than Delhi.

Besides vehicles, biomass burning for household purposes also plays a major role in NCR's air quality with about 1.5 million households still using biomass. While several industries have been moved out of Delhi, they have been set up the NCR and continue to contribute to pollution. Further, there are 11 thermal power plants in NCR: of which only one has taken measures to comply with the gaseous pollutant standards. Additionally, there are more than 5000 brick kilns operating in NCR, only some of which have converted to the cleaner zig-zag technology. There are seasonal sources as well. Stubble burning is a major contributor at the onset of winters, while dust from western parts of India and countries on the western side of India plays an important role during the summers.

These sources fall under the administrative control of different states. Besides Delhi, the NCR consists of areas falling in three neighboring states: Uttar Pradesh, Haryana, and Rajasthan. Atmospheric transport of pollution leads to impacts of far-off sources in the downwind areas from the source. While air pollution recognizes no administrative boundaries, the administrative bodies have so far not been able to significantly coordinate and take collective decisions for air pollution management in NCR.

Air Quality Management Districts (AQMDs) have been successfully created in various parts of the world, including in the United States, China and Mexico. An agency to manage air quality at the level of the NCR therefore merits consideration. The AQMD could have a governing board with representation from all the districts in the NCR, and with an advisory board with academic and civil society groups. A large number of state pollution control boards lack capacity in terms of manpower and finances, and hence, developing mechanisms to share resources would help in capacity development by leveraging the technical capabilities of one state for other states as well.

Importantly, airshed management does not mean that city or state governments can shirk responsibility. Instead, regional management only complements and coordinates across actions within these cities and states.

Introduction

Degradation of air quality at several places in the world is one of the major concerns today (Cheng at al., 2016). The problem has been more complex and severe in developing countries like India, mainly due to rapid urbanization, fast-paced industrial development and also due to use of traditional fuels and combustion technologies. 241 out of 313 Indian cities (76%) where air quality is being monitored violate the prescribed standards of ambient PM_{10} concentrations in 2017 (Greenpeace, 2019). This deterioration of ambient air quality has been attributed with 1.24 million premature deaths and 38.7 million disability adjusted life-years (DALYs) loss in India resulting in a national public health crisis (Balakrishnan et al., 2019). DALYs attributable to ambient particulate matter pollution was highest in the north Indian states of Uttar Pradesh, Haryana, Delhi, Punjab, and Rajasthan. Research studies have also shown significant reduction in crop yields in India due to high ground level ozone concentration – another important pollutant for national capital region (Burney and Ramanathan, 2014; Sharma and Khare, 2017).

As the national capital, Delhi has been in the limelight for its severely high air pollutant levels. While the city has its own sources, there are also several sources that contribute to deterioration of air quality in Delhi from outside the city limits. This broader region is known as the national capital region (NCR). Naturally, Delhi's pollution also affects these other areas too.

Many of these sources fall under the administrative control of different states. Besides Delhi, the NCR consists of areas falling in three neighboring states- Uttar Pradesh, Haryana, and Rajasthan. While air pollution recognizes no administrative boundaries, the administrative bodies have so far not been able to significantly coordinate and take collective decisions for air pollution management in NCR.

Figure 1: Delhi and National Capital Region

POLICY BRIEF

In this context, this paper argues for the need for an air quality management district (AQMD) for Delhi-NCR region to manage the problem of air pollution including the crop residue burning which leads to episodic conditions. The paper recommends an AQMD to coordinate planning and policy measures within this region. The proposed AQMD will take into account a much wider airshed, and will be covering 50-70% of the source contributions affecting $PM_{2.5}$ levels in the Delhi city. Such regional coordination of pollution management could significantly bring down not just in Delhi but the whole NCR that includes other cities like Gurgaon, Noida and Ghaziabad.

Background on Delhi-NCR

Besides Delhi (ca. 18 million), there is a national capital region (NCR) around the city which includes 18 surrounding towns and other rural areas (Figure 1). In total, the population in this region is about 46 million. These towns have witnessed even higher rates of development, industrialization and urbanization, and have also shown equally bad air quality parameters as Delhi. In fact, cities like Ghaziabad and Noida, which are downwind predominantly to the city of Delhi, show even higher pollutant levels than Delhi.

Figure 2 shows the trend of PM_{10} concentrations in Delhi since 1999 when monitoring was started in Delhi. In spite of various measures, the concentrations have stayed way above the standard values. The annual average $PM_{2.5}$ concentration in Delhi for 2017 has been observed to be 101.33±13.21 µg/m³ which is almost three times higher than the prescribed standard of 40 µg/m³ (NAMP, 2017). The concentrations range from 83-114 µg/m³ across different places in the city, mainly depicting the influence of site-specific sources over and above the background of concentrations generated by urban and regional sources.

The annual average PM_{10} concentrations for Delhi have been reported to be 232.1 ± 131.1 µg/m³ (annual standard – 60 µg/m³) (Tiwari et al., 2015; Khanna et al., 2018). These values are 3-4 times higher than the prescribed NAAQS by CPCB and more than ten times higher than the WHO limits. Figure 3 shows the comparative PM_{10} and $PM_{2.5}$ levels observed in different cities of NCR as reported in TERI & ARAI (2018). It is evident that air pollutant levels are severely high in most towns of NCR. Several interventions have been taken for management of air pollution in Delhi city, however, the extensive growth of NCR has annulled the benefits accrued due to these interventions. Evidently, the focus of air control measures has remained on the current scenario, and future growth patterns have not been taken into account in the air quality management planning. While a small dip was observed in PM_{10} concentrations in Delhi in the last decade, there was an increasing trend observed in NOx concentrations, suggesting the need for more stringent NOx controls.

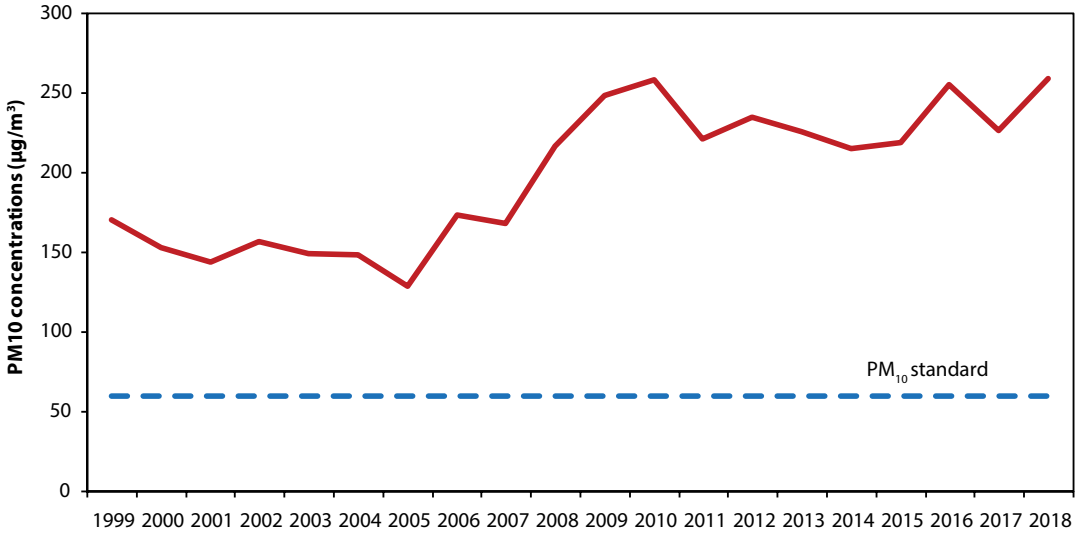


Figure 2: Trend of PM_{10} concentrations in Delhi during 1999-2018

Source: National Ambient Air Quality Monitoring Programme (NAMP) (Avg. of all manual stations in Delhi)

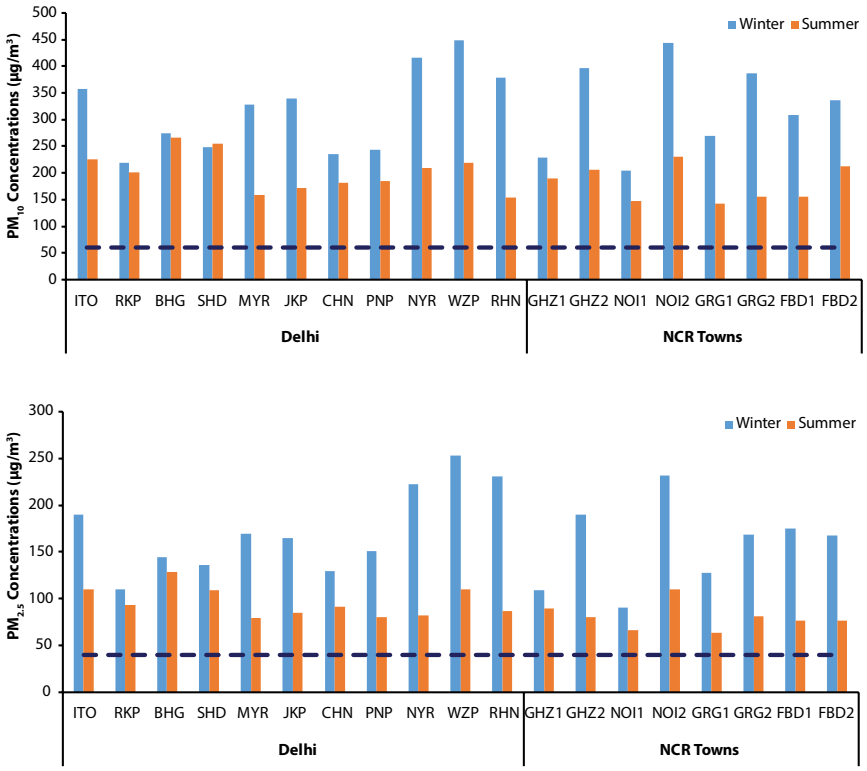


Figure 3: PM_{10} and $PM_{2.5}$ concentrations in Delhi and NCR stations seasonally in 2016-17 (blue: winter; red: summer)

Data source: TERI & ARAI, 2018

Activities in NCR

NCR has witnessed a tremendous increase in vehicle population at a rate of 7-9% annually. The total number of registered vehicles in Delhi was more than 9.7 million in 2015–16. For trade and other reasons, there is a huge movement of vehicles registered in other states (like Haryana, Uttar Pradesh, Punjab) within and out of Delhi. Other than vehicles, biomass burning for household purposes also plays a major role in NCR's air quality with about 1.5 million households still using biomass. A lot of industries and power plants have been moved out of Delhi, but they have set up in NCR which leads to inflow of pollution. Additionally, there are more than 5000 brick kilns operating in NCR, only some of which have converted to the cleaner zig-zag technology.

Additionally, we also encounter the problem of agricultural residue burning during rice harvesting season in Punjab and Haryana. Crop residue burning is a significant source of *episodic* atmospheric pollution in the Indo-Gangetic plains particularly during wheat, rice, sugarcane and cotton harvesting periods. Each year, residue burning leads to intensification of pollutant concentrations in the air and significant episodic pollution levels in the region in the months of October and November. The problem is made more severe due to a change in weather patterns in the winter months, which reduces the dispersion of pollution. Figure 4 shows the increasing trend of $PM_{2.5}$ concentrations in 2017 and 2018, associated with the rise in the number of fire events detected around Delhi (300 km radius around Delhi) from satellite data.

Crop residue burning not only contributes to local pollutant concentrations but also is a major regional source of pollution, contributing significantly to PM concentrations in the entire northern Indo-Gangetic Plains. It also results in emission of other harmful gases like methane, nitrogen oxide and ammonia. A new study by International Food Policy Research Institute (IFPRI) and partner institutes estimates the economic costs of crop residue burning in northern India at over USD 35 billion annually (Chakrabarti et al, 2019). All these sources cumulatively contribute to Delhi and NCR's worsening air quality and hence, they require a collective management strategy in the form of an Air Quality Management District.

POLICY BRIEF

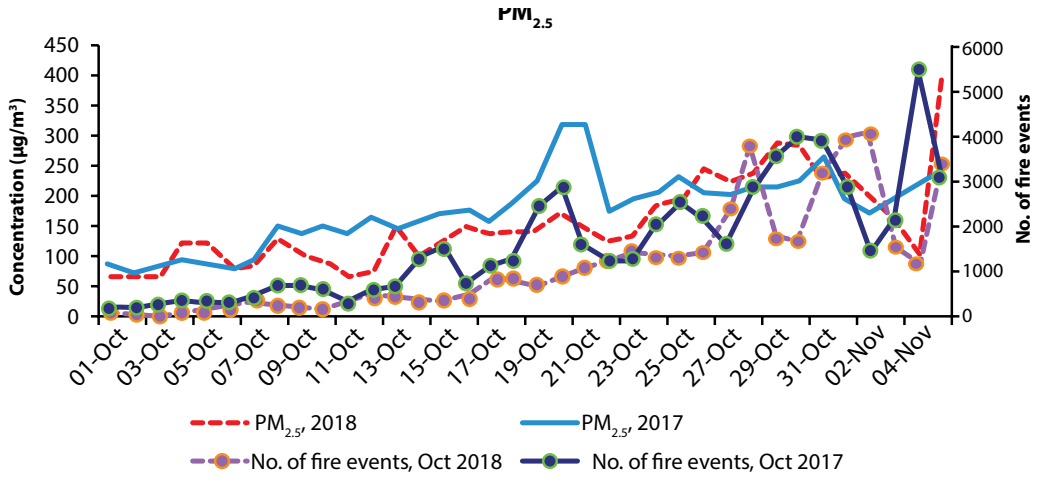


Figure 4: $PM_{2.5}$ concentrations and number of fire events around Delhi in 2017 and 2018

Source : Average daily PM2.5 levels for 4 stations in Delhi (Punjabi Bagh, Mandir Marg, R K Puram, Anand Vihar) from CPCB website

Methods for assessing source contributions

Emission Inventories

An emissions inventory includes the estimates of emissions (in units of mass, like tons) of air pollutants from each source into the atmosphere during a year. Emission estimates are based on activity type, emissions factors, pollution abatement technology used, and the efficiency of control, with activity data collected from both primary and secondary sources. These inventories are used to help determine significant sources of air pollutants, to target regulatory actions, and also to assess the effect of potential regulatory actions on air quality. Figure 5 shows the latest emission inventories developed by TERI and ARAI (2018) for Delhi-NCR.

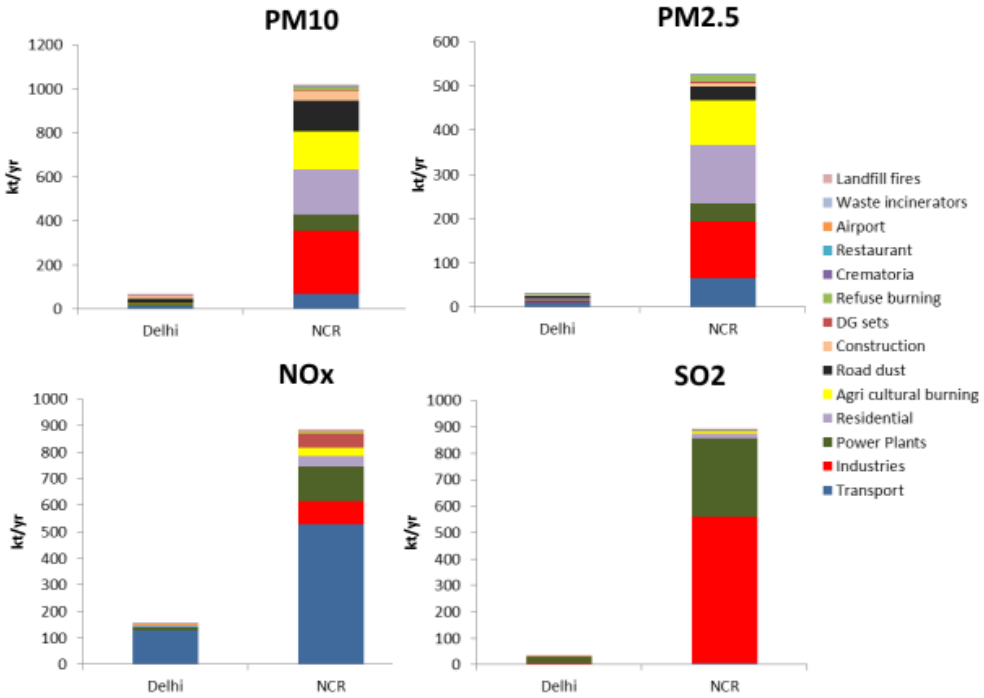


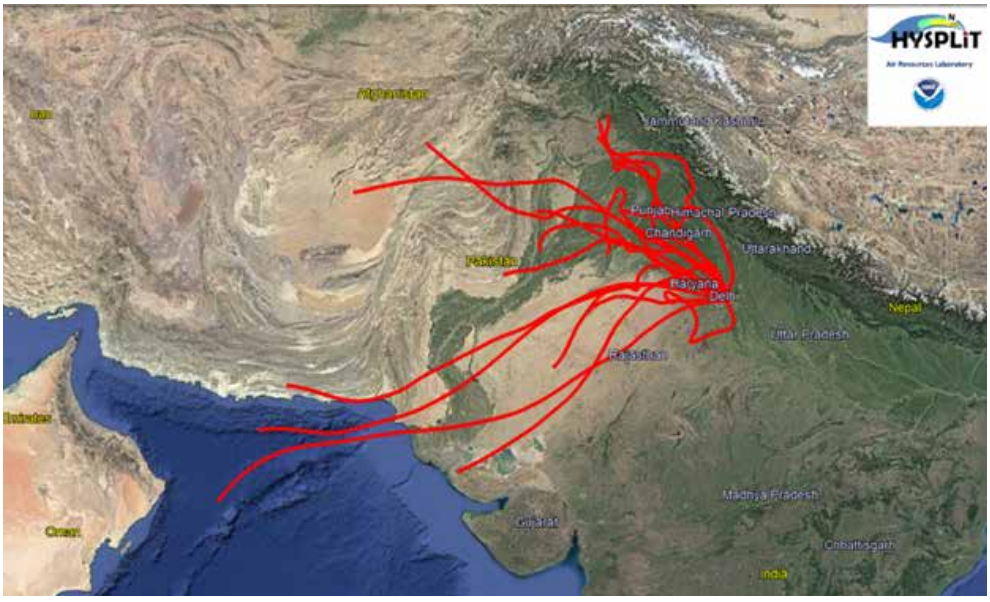
Figure 5: Emission inventory for Delhi and NCR (including Delhi) (TERI & ARAI, 2018)

As per IIT Kanpur study, the most prominent source of emissions of PM_{10} and $PM_{2.5}$ in Delhi is road dust followed by concrete batching, industrial point sources and vehicles for PM_{10} with a total load of 143 tons/day (IIT Kanpur, 2015). However, in case of $PM_{2.5}$, the most prominent sources are vehicles and domestic burning. The study reported that half of NOx emissions are ascribed to industries and power plants, followed by vehicles. As per TERI's latest emission inventory, the major sources remain similar for PM loads in Delhi and NCR, however, their percentage share (in kt/year) differs significantly. For $PM_{2.5}$, major sources in Delhi are transport followed by road dust and power plants[1]; whereas, for NCR are residential burning followed by industries, and agricultural residue burning. For PM_{10}, major sources in Delhi are road dust, landfill fires and transport; however, in NCR are industries, residential burning, agricultural residue burning and road dust. For NOx, the sources in Delhi and NCR are transport followed by power plants and industries. SO2 is primarily contributed by power plants (71%) in Delhi whereas in NCR, it is contributed by industries (62%) and power plants (33%).

Meteorological conditions

While emission inventories show the sectoral contributions in terms of emissions, it is not necessary that they reach the ambient environment and affect concentrations in the same ratios, due to meteorological conditions playing an important role. Sectoral contribution to ambient air quality is calculated by source apportionment studies after incorporating meteorological conditions. Temperatures, wind speeds, relative humidity, mixing heights are the key parameters that influence air pollution concentrations in a city. In winters, lower wind speeds and temperatures (leading to lower mixing heights) lead to lesser dispersion of pollutants in winters.

In order to understand the wind flow patterns in Delhi, 48-hour back-trajectories for Delhi have been generated using HYSPLIT model for summer (1st-31st May 2019) and winter (1st-31st January 2019) season (Figure 6). A new trajectory from the point is started every 24 hours, hence these lines denote the back-trajectories for every day in May and January months. The data shows that wind is predominantly flowing from north-west and south-east in winter and north-west and west in summer season (Figure 6). Moreover, this can be noted that wind trajectories are longer depicting higher wind speeds in summers. This also means that the winds in summers may carry the natural or anthropogenic dust from western regions in India and Pakistan. In winters, north-western regions of Punjab, Haryana may contribute significantly to the long-range transport of pollutants.



[1] At the time of the study, Delhi had 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—was later shut down on 15th October 2018.

POLICY BRIEF

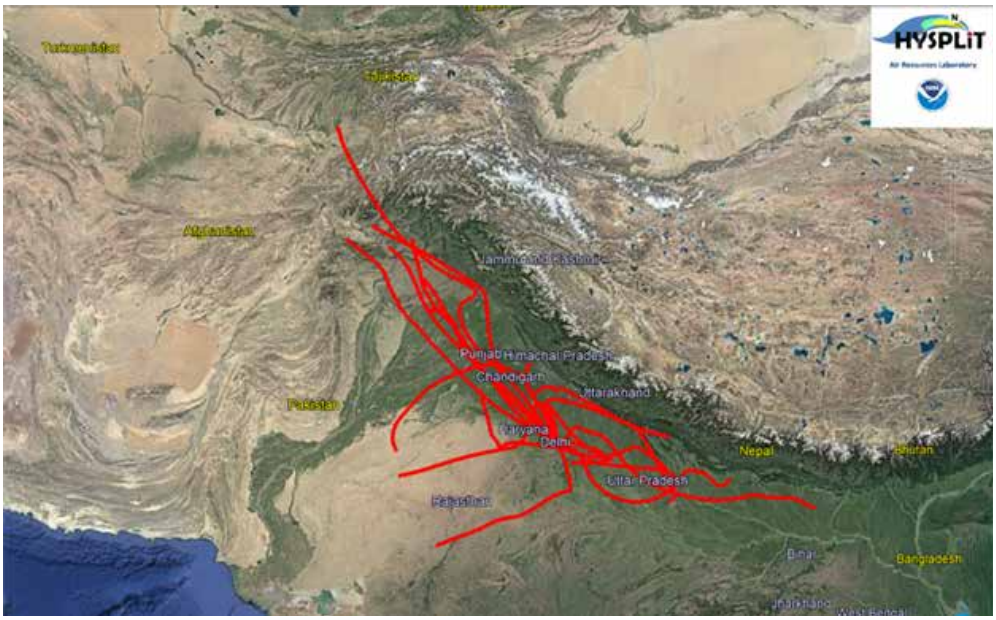


Figure 6: Wind dispersion trajectories during Summer (top) and Winter (bottom) seasons.

Moreover, winds also lead to atmospheric transport of air pollutants from long distances. Studies have shown that emissions from Delhi contribute only 11-41% of the PM_{10} concentrations in Delhi during the summer of June 2010 (Gupta and Mohan, 2013). The remaining portion is contributed from outside Delhi due to long-range transport of pollutants. Another recent study has highlighted the role of long-range transport of PM in transporting air parcels from the eastern Indo-Gangetic plains and the western region (Arabia, Thar Desert, Middle East and Afghanistan) to Indo-Gangetic plains (Pawar et al., 2015). The study showed that long-range dispersion of pollutants from the west leads to 9-57 % contribution of the total $PM_{10-2.5}$ mass during different seasons.

Source apportionment studies

Source apportionment studies include receptor modelling to assess the contribution of each source to the ambient concentrations of pollutants. These receptor models take into account ambient concentrations and meteorological conditions, and use a bottom-up approach to calculate sectoral contributions. Contributions estimated by different studies from prominent sources in Delhi- vehicles, biomass burning, road dust and construction, and industrial emissions are shown in Figure 7.

Different studies have shown different percentages for the sectoral contributions; however, the major sources are common in these studies. These differences arise due to differences in representativeness of monitoring locations, monitoring season and frequency, analysis methodology, etc. Hence, it is important to carefully assess the weight of evidence provided in these studies to arrive on accurate results. Comparing seasonal distributions as per the receptor modelling results, dust and construction (13-35%) are major source in summer whereas vehicles (22-30%) and biomass burning (10-34%) are more prominent in winter. As per TERI and ARAI (2018), during summer, most prominent sources of $PM_{2.5}$ are dust (35%) followed by vehicles (20%), industries (20%), biomass burning (16%); whereas during winters, vehicles are the major contributor (30%), followed by biomass burning (23%), industries (20%) and dust (16%).

Influx of emissions from NCR to Delhi

In-house emissions from Delhi add to the background concentrations generated due to regional PM loading in NCR, and deteriorate air quality. TERI and ARAI (2018) estimated that the contribution of sources within Delhi to Delhi's $PM_{2.5}$ concentrations was 36% in winter and 26% in summer (Figure 8). 24-34% contributions are received from rest of the NCR in two seasons. In all, Delhi's air quality is influenced by sources within NCR by 70% in winters and 50% in summers. Another study showed that

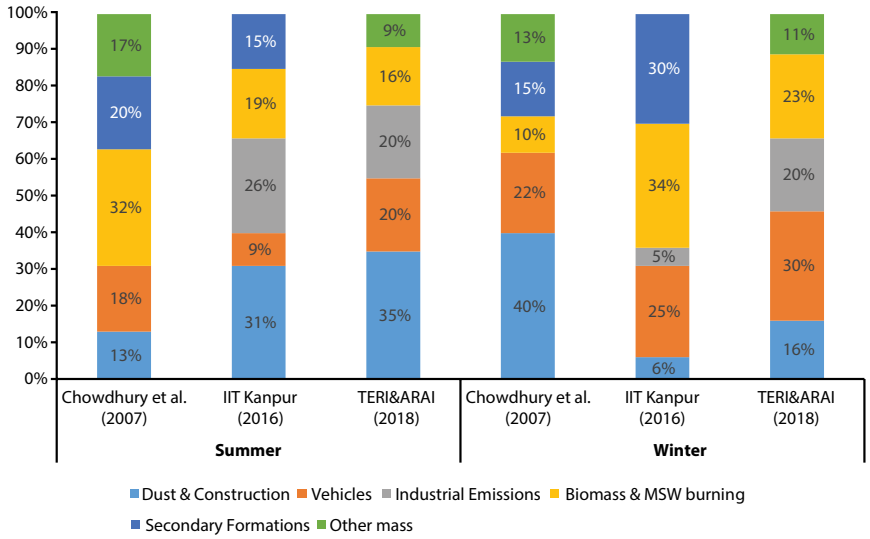


Figure 7: Source Contribution of PM2.5 concentrations in Delhi city

sources lying outside Delhi were responsible for 30–80% at different locations in Delhi (Marrapu et al., 2014). The report by IIT Kanpur (2015) also showed more than 50% of secondary particulates were associated with the coal and biomass burning occurring outside Delhi city. It is not that only Delhi is polluted by emissions from outside, Delhi's pollution also moves forward and contributes to air pollution in downwind areas (for example, in Noida).

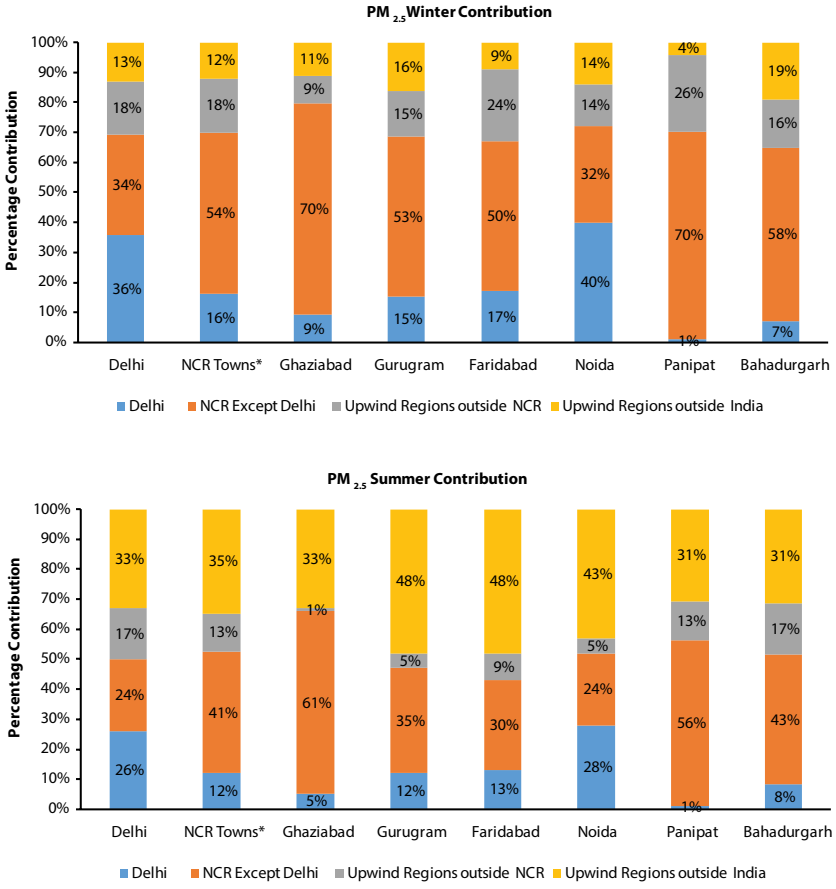


Figure 8: Geographical contribution to $PM_{2.5}$ concentrations in Delhi-NCR (TERI & ARAI, 2018)

POLICY BRIEF

* Average of NCR towns excluding Delhi

These findings are extremely important for policy formulations and decision-making regarding the air quality issues faced by Delhi and neighbouring states. As there is a large inflow of pollutants from NCR to Delhi, managing emissions within Delhi alone will have limited impact on ambient concentrations in Delhi. Hence, there is a need for managing emissions in the complete airshed for any significant improvements in the Delhi's air quality. Likewise, improving air quality in cities like Ghaziabad and Gurgaon in NCR will require coordinated measures all over NCR and within-city actions alone will not suffice.

Need for an Air Quality Management District

In view of the air quality problems in Delhi and NCR, this paper proposes an Air Quality Management District (AQMD) which covers the whole NCR surrounding the city of Delhi tasked with monitoring and managing various emission sources in the region. The mission of AQMD is to improve air quality through efficient and effective control strategies. Under the provisions of the Air (Prevention & Control of Pollution) Act, 1981, the CPCB has notified NAAQS in 2009 that all states must achieve. AQMD should be created for Delhi-NCR region by the states to enable compliance with the NAAQS and to develop control and management guidelines for the region.

The role of an AQMD agency will be to understand and take into account all the major sources in the airshed and develop air quality management plans for the whole region, rather than just for the individual cities falling in the region. The management measures could coordinate across city-specific action plans created under NCAP to reduce air pollution from specific sources. In addition to developing air pollution regulations, AQMD agency can be brought under a legal framework to enforce these regulations in the whole region.

There are various social, economic and political aspects of managing pollution and implementation of regional scale policies. The situation gets tricky specially when trans-boundary pollution is involved as the politics between the cities and states can greatly affect how control measures are identified, financed, and implemented.

State Pollution Control Boards are severely constrained with respect to financial resources, staff, and laboratory facilities. Moreover, while the capacity of SPCBs has remained almost stagnant, their responsibilities have increased over time. There are also sector-specific issues like MSME units in India operating out of non-conforming areas are unregistered, hence rendering it difficult to ensure they are meeting guidelines. Unless adequate resources are provided, it is difficult to handle the issue of trans-boundary pollution or providing reforms at regional scale.

Actions taken for regional scale management of air quality

A wide range of policy initiatives and frameworks have been adopted in Delhi and other neighboring states. Some of these have been effective in reducing the impacts of air pollution– for instance, lead content of petrol; sulphur content of fuels, odd-even scheme, leap-frog from BS-IV to BS-VI, moving industries and brick kilns out of Delhi, etc.; however, there is a need for regional-scale action for reducing the air pollution in Delhi-NCR region.

At a national scale, MoEFCC has recently launched National Clean Air Programme (NCAP) with the goal of reaching the prescribed NAAQS at all places in the country with a 20-30% reduction in PM concentrations by 2024. It also aims at managing trans-boundary air pollution from western region by linking it with the NDC target of additional forest cover of approximately 3 billion tons of CO_2 equivalent. NCAP also focusses on activating the initiatives under 'Male Declaration' and South Asia Co-operative Environment Programme (SACEP).

At a regional scale, NCR has its own regulatory bodies like National Capital Region Planning Board (NCRPB) which works on enforcement and implementation of regional plans; and Environment Pollution (Prevention & Control) Authority (EPCA), a Supreme Court mandated body, which works for improving the air quality particularly in NCR region.

However, there has been a lack of uniformity in the stringency of emission norms and enforcement of control mechanisms across the NCR- for instance; Delhi has introduced BS-VI fuel already, whereas neighbouring states are still lagging behind. Limits on emissions from industrial and energy sources in neighbouring states and/

or towns need to be backed up with robust monitoring and independent audit/checking from a regulatory authority. A strategy to deal with regional transboundary pollution should be based on robust data on emissions in all towns/cities, dispersion and atmospheric processes affecting levels of primary air pollutants and secondary pollutants, followed by robust monitoring to demonstrate the effectiveness of interventions to improve air quality in the region. There is a need for overall regional-scale strategy, which can be built upon the foundation laid by institutions and programmes like NCAP, EPCA and NCRPB to strengthen the initiative so that it can be effective at a regional scale.

International Experience of AQMD

AQMDs have been successfully created in various parts of United States and some regions in China. China has implemented their Air Pollution Prevention and Control Action Plan (2013-2017) at a regional scale by combining two or more cities into a region. They set the framework for managing pollution in China with a focus on three key regions – Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta in which the former region had more stringent goals than the latter two regions.

Similarly, in USA, several AQMDs have been set up, for instance, the Air District set up in California in 1955 as the first regional AQMD in USA. It is governed by a Board of Directors representing each of the nine Bay Area counties. A similar approach had been taken by the South Coast Air Quality Management District (SCAQMD) in 1976.

Proposed structure of AQMD for Delhi-NCR

The proposed AQMD committee/agency for Delhi-NCR could be responsible for making the region compliant with India's NAAQS. The agency can be formulated by the central government with a governing board consisting of high level members representing all the states within the AQMD. In addition, an administrative board (with representation from cities and rural districts in these states) could be made responsible for execution of the rules for air pollution control and penalties/fines, if applied. The AQMD can be assisted by an advisory council/board (with members from research institutes, academia and NGOs) which will be responsible to deliberate ways to improve air quality and initiate efficient clean air programs in the region.

A large number of state pollution control boards lack capacity in terms of manpower and finances, and hence, developing mechanisms to share resources would help in capacity development by leveraging the technical capabilities of one state for other states as well. NCAP also has provisions for engaging a knowledge network for implementation of the corrective measures. An AQMD can play a key role in Delhi-NCR for the implementation of control measures, and thus, serve as complementary to the NCAP at national level and to city-level efforts. In order to initiate the process, the AQMD agency can initiate regional level studies to develop consensus on source contributions among the participating states. Based on which, a regional level action plan can be developed with prioritized list of actions by different states, districts and cities.

AQMD may or may not need to generate its revenue. SCAQMD generates approximately 73% of its revenue through various fees and penalties (SCAQMD, 2019). The San Joaquin Valley AQMD also obtains revenue from permit fees and vehicle registration fees. In this case, the finances of AQMD agency can be managed with contributions from all four states falling within NCR. Initially, the AQMD can primarily serve the role of coordination and convening, with the respective administrative agencies responsible for financing measures in their own jurisdictions.

Conclusion

Cities in Delhi-NCR are among the most polluted cities in the world. With rapidly growing towns, it is highly likely that air quality will worsen if no aggressive measures are taken at a regional scale. Air quality management plans and listed control measures are being implemented in these cities individually, with varying levels of stringency, to little effect. The AQMD can look at the issue at a larger scale, integrate action plans, reduce duplication of efforts, and may bring economies of scale in implementation.

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