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Quantitative evaluation of source interventions for urban air quality improvement - A case study of Delhi city

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ABSTRACT

Air pollution in Delhi city is an alarming level from last few years. The major challenge for the policy makers is to reduce/manage the elevated air pollution level and related acute and chronic health impacts. Air pollution continues to be a nightmare for Delhiites despite implementation of several diversified source interventions. However, the efficacy of these interventions in the reduction of air pollution level did not evaluate before their implementation in the city. The present study has made an attempt towards the quantitative evaluation of selected management strategies in the reduction of air pollution in Delhi city. The results indicate that efficient cleaning of road dust, restricted use of coal based tandoors in hotels/restaurants and together can reduce the $PM_{2.5}$ concentrations at selected locations up to 25%. The NO_x concentration can reduce by restricting the use of diesel generator sets and coal based tandoors in the hotels up to 6%. Results also indicated that individual sources are not sufficient in controlling the increasing air pollution in the city. A stringent policy portfolio involving the combination of various mitigation measures is necessary to attain the NAAQS along with the policies to control the transboundary movement of air pollutants.

1. Introduction

The management of increased ambient urban air pollution remains a massive task for the policy makers in developing countries including India. It is being deteriorated especially in terms of high PM level (Gurjar et al., 2008) which results in adverse health impacts of millions of populations. In India, ambient air pollution reported as the fifth leading cause of deaths and ~620,000 premature deaths were estimated in the year 2012 (WHO, 2014). As per WHO (2016) report, Delhi city is one of the highly polluted cities of the world in terms of high level of $PM_{2.5}$ (particulate matter having an aerodynamic diameter equal to or less than 2.5 μm). These deaths might be caused by diseases such as asthma, stroke, chronic obstructive pulmonary diseases, ischemic heart diseases, lower respiratory infections and trachea, bronchus and lung cancer which are a by-product of poor air quality (Heal et al., 2012; Dholakia et al., 2013). However, these data need to be compared with hospital records. In one of the recent studies, Kumar et al. (2017) found that daily average $PM_{2.5}$ concentrations at four different residential, commercial and road trafficked sites in Delhi have exceeded the national ambient air quality standards (NAAQS) of 60 μg/m^3. The sources of $PM_{2.5}$ are numerous and heterogeneous in Delhi city which varies from day to night and season to season. For example, emission from burning of wood/biomass for heating purposes will be higher during the winter when compared to summer season (negligible). Similarly, entry of heavy duty diesel vehicles is allowed during night times only when pollutant dispersion potential of the atmosphere is at low level compared to day time (Kumar et al., 2017). Some of the major and significant sources of $PM_{2.5}$ in the Delhi's environment were found to be re-suspension of the road dust, emission from vehicle exhaust and open biomass burning (Sharma and Dikshit, 2016). The re-suspension of the road dust was found to be the major contributor during the months of summer season while vehicular emissions and biomass burning were the major contributors during the winter season (Sahu et al., 2011; Sharma and Dikshit, 2016). Additionally, Brick kilns situated at the periphery of Delhi (in states of Haryana and UP), construction activities, and DG sets emission were also reported to be the significant sources of PM in Delhi's atmosphere (Guttikunda and Calori, 2013). The share of *trans*-boundary pollution in Delhi city is also very huge which needs to be controlled to attain NAAQS. Certain studies have indicated the need to control the baseline emissions as a preliminary measure to tackle the degrading air quality of Delhi (Gulia et al., 2015a; Kumar et al., 2015, 2017). In Delhi NCT, total 25 notified industrial areas are present having small and medium enterprising industries. Industrial sources and vehicles were majorly responsible for

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the high emission of NO_x and contributed nearly 79% and 18.3% of the total emissions in the year 2007–08 (NEERI, 2010). However, the contribution of industrial sectors reduced to 52% and vehicles contribution increased to 36% in the year 2013–14 (Sharma and Dikshit, 2016). These changes might be due to the implementation of stringent emission norms on industries and increasing vehicles population in the city. The road transport sector mainly uses Diesel and Petrol as fuel in India and also contributes to air pollution. Nielsen (2013) has reported that the trend of consumption of Diesel and Petrol in India has increased from 3.84 to 1.45 million tonnes in year 1970–71 to 69.08 million tonnes and 15.75 million tons, respectively. The transport sector uses 73.5% of total Diesel consumption and 100% of Petrol consumption which is majorly consumed by 2 wheelers (61.42%).

Policy makers have tried to curb the high concentrations of $PM_{2.5}$ and NO_x, by implementing various scattered air quality control actions. Some of these actions are the introduction of stringent emission norms for vehicles, transferring entire public transportation to CNG fuel, ban on entry of HDDV for certain hours in a day, odd-even car trial scheme and many more. However, their efficacy in air pollution reduction was not evaluated before their implementation and generates lots of questions for debates on success and failure of these interventions in reducing air pollution.

1.1. Air pollution control strategies in Delhi city

Rapidly growing economy and continuously increasing vehicle ownership has impacted the effectiveness of the measures to control air pollution from vehicular exhaust. Shrivastva et al. (2013) have reviewed the vehicle's emission norms introduced in India from year 2000 (BS I, nationwide) to 2010 (BS IV in metro cities) and assessed their impact in reduction of air pollution level. The comparison of emission norms clearly shows reduction in tailpipe emission. Recently, GoI has made compulsory to implement BSIV to entire country from April 2017 and will shift directly to BSVI from April 2018 onwards (MoRTH, 2017). Implementation of BS VI will significantly reduce the tailpipe emission especially particulate matter. Further, Table 1 has listed out the chronology of vehicle emission control strategies introduced by policy makers in last two decades for Delhi and other Indian cities. Introduction of the CNG bus fleet had resulted in the reduction of suspended particulate matter and other pollutants by nearly 10% (Goyal, 2003); however, NO_x level has increased after implementation of CNG fuel bus fleet which is not yet studied scientifically. Single fuel policy for public transportation was a breakthrough measure in combating the elevated pollution level, but its implementation had put forward certain financial challenges which were discouraging for the society to adopt (Krelling and Badami, 2016). Recently implemented odd-even car policy (during Jan'16 & Apr'16) can be concluded as apart from certain clean hours, the persistence of overnight emissions from heavy goods vehicles into the morning odd-even hours (0800–1100 h) made them ineffective (Kumar et al., 2017). The major setback to the odd-even car policy during winters can be attributed to the stable atmosphere (winds are not strong enough to disperse the $PM_{2.5}$) and the failure to control the $PM_{2.5}$ from outside the periphery of the city. Therefore, the quantitative evaluation of these measures/actions needs to carried out for better understanding the post implementation impact on air quality especially when combination of control actions introduced simultaneously. Air quality modelling is an important tool to quantify the efficiency of such control actions in air pollution reduction at city scale level (Elbir et al., 2010; Gulia et al., 2015b).

Therefore, the present study is an attempt to evaluate quantitatively the effectiveness of the selected management strategies for reduction of air pollution level in Delhi using applications of advanced air quality modelling. The study has been designed with the aim of prioritizing the control strategies based on their efficiency for policy makers so that history does not repeat.

2. Materials and methods

2.1. Study area

Delhi city is a land-locked mega city and surrounded by neighboring cities of the National Capital Region. The major neighborhood cities are Sonipat (in the north–west), Bahadurgarh, Jhajjar and Rohtak (in west direction), Gurgaon and Manesar (in the south direction), Faridabad (in south–east), and Noida and Ghaziabad (in the east direction). The Delhi city population has reached 17.08 million in the year 2016 with a decadal growth rate of 47% over an area of 1483 km^2 (NCR, 2013). This drastic population growth (mainly due to the immigration of people for better livelihood opportunities) has resulted in massive consumption of energy resources to meet their transportation and other basic demands. As per 2011 data, total vehicles in Delhi were approx. 6.93 million which is predicted to increase to 25.6 million by 2030 (Kumar et al., 2017). The current total road length in Delhi city is 33,198 km with 864 signalised and 418 blinkers traffic intersections (GoD, 2016; NCR, 2013).

Delhi city is one of the seventeen declared non–attainment areas in India and located at an altitude of about 215 m above mean sea level. Delhi experiences four major seasons across the year: summer (March–May), monsoon (June–August), post–monsoon (September–November) and winter (December–February). The summer is dry with ambient temperature up to 48 °C. The monsoon season experiences more than 80% of the total annual rainfall (Perrino et al., 2011). During winter, frequent ground–based inversion conditions occur with temperatures going down to 4 °C. In Delhi city, a total of 21 continuous ambient air monitoring stations are run by the Central Pollution Control Board (CPCB, 7 stations), Delhi Pollution Control

Table 1
Various mitigation measures implemented in Delhi city.

Serial No.	Control Strategy	Year	Implemented on
1.	Catalytic converter	1995	4 wheeled Petrol Vehicles
2.	Low-lead petrol	1994	All Vehicles
3.	Bharat stage I introduced	2000	All Vehicles
4.	Bharat stage II introduced	2000	Initially in metro cities and then Nationwide in 2005
5.	Shifting from Diesel to CNG	2001	Public Transportation system
6.	Bharat stage III	2005	NCR and 13 cities and Nationwide in 2010
7.	Bharat stage IV	2010	NCR and 13 cities and Nationwide in 2017
8.	Entry allowed during 10:00p.m.–07:00 a.m.	2014	Heavy Vehicles
9.	Complete ban on open waste burning (NGT order)	2015	Open waste burning
10.	Ban on registration on vehicles having engine capacity above 2000 cc	2016	Luxury Diesel Vehicles
11.	Entry banned from NH-2,10 & 58	2016	Heavy commercial vehicles
12.	Odd-Even Car Scheme	2016	Private Cars
13.	De-register vehicles older than 10 years or more	2016	Diesel vehicles
14	Bharat Stage VI	2018	NCR