Assessment of gaseous and respirable suspended particulate matter (PM_{10}) emission estimates over megacity Delhi: Past trends and Future Scenario (2000-2020)

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1. INTRODUCTION

Delhi, the capital city of India, home to more than 16 million people (Singh and Dey, 2012), is one of the fastest growing economic centers of southeast Asia (Sindhwani and Goyal, 2014) and among the most polluted cities in the world (Gurjar et al. 2008) (Fig 1). In the past decade, Delhi has increased manifold across all sectors, industry, transport, and housing, which has resulted in increase in city air pollution (Guttikunda and Gurjar, 2012). Its poor air quality has been held responsible for more than ~18600 premature deaths per year (TERI, 2001).

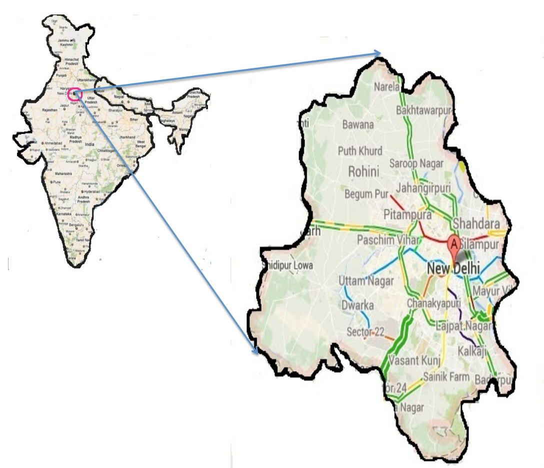

Fig 1: Map of the study area

Numerous studies have been made in the past to estimate emissions from megacity Delhi. Gurjar et al. (2004) estimated emissions for 1990-2000 period and concluded that SO_2 (~68%) and Total suspended particulate matter (TSP) (~80%) are largely emitted by power plants whereas transport sector contributed >80% of NOx, CO and VOC towards total emissions. Ramachandra and Shwetmala (2009) developed a decentralized emission inventory for vehicular transport sector of India for different metropolitan cities for the period 2003-2006. It quantified that Delhi city emitted 284.43 x 10^6, 87.74 x 10^6, 129.99 x 10^6, 9.13 x 10^6 and 42.38 x 10^6 g/km^2 of CO, HC, NOx, PM and SO_2 respectively. Kansal et al (2011) estimated emissions from power plants, vehicles and industries for the year 2006 and presented that vehicular emissions are major sources of TSP (54%), followed by power plants (32%). Power plants and transport sector added ~67% and ~33% of SO_2 and 10% and 90% towards NOx emissions respectively. Mohan et al. (2012) estimated emissions for the period of 2000-2008 period based on emission factors (EFs) from previous studies and concluded that >90 % of SO_2 and TSP are contributed by power plants, whereas transport sector contributes ~60% of NOx toward total emissions.

Goyal et al. (2013) developed a gridded vehicular emission inventory for the base year 2008 of criteria anthropogenic pollutants namely CO, NOx and PM which covered the metropolitan area of Delhi i.e., 26 km x 30 km (780 km^2). Passenger cars (PCs) were found to be major sources of CO and NOx emissions ~34% and ~50% respectively. However, 2-Wheelers (2W) and heavy commercial vehicles (HCVs) were found to be major contributor of CO (~61%) and PM (~92%) respectively. Nagpure et al. (2013) presented traffic–induced emission trends for megacity Delhi for the years 2000-2005 and concluded that the levels of NOx and TSP did not show appreciable increase, which might be due to CNG effectiveness as an alternative fuel.

Various policy measures have been implemented in the past to tackle the problem of rising emissions from these sectors which included switching to cleaner fuels (i.e. unleaded gasoline, reduction of sulphur in diesel, reduction of benzene content in gasoline), phasing–out of old age vehicles and maintenance of in–use vehicles, conversion of all buses and public transport vehicles to natural gas, implementation of Bharat

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Stage II norms for passenger vehicles in 2000 and Bharat stage III norms for all categories of four-wheeler vehicles in 2005, introduction of Metro Rail, and closing or relocating polluting industries and industries operating in non–conforming areas (Khare and Kansal, 2004). However, in spite of these measures, Goyal et al. (2006) reported that vehicular pollution contributed about 72% towards total air pollution load in Delhi, which was only 23% in 1970–71. Thus, for the further improvement in the air quality of the region, a clear understanding of the emissions from various sectors and their contribution towards the total pollution load is very important as these emissions from megacities like Delhi contribute to large scale phenomena such as acidification and eutrophication (Guttikunda et al., 2003) and the occurrence of large scale haze (Lelieveld et al., 2001). Generally, emission inventories that are available in the literature have focused on a particular year (Sahu et al., 2011; Guttikunda and Calori, 2013) or a particular sector (Nagpure et al., 2013) and a historical trend of emissions have been missing for a period of the years.

Thus, The present study aims to estimate emissions of criteria pollutants (CO, NOx, SO_2 and PM_{10}) contributed by different sectors of Delhi from 2000-2010. Further, estimation of emissions for the next 10 years (2011-2020) have been made using business as-usual scenario (BAU) and emission abatement policy scenario (EAP). EAP scenario includes effect of imposing stringent emission reduction measures on total emissions.

2. STUDY AREA

Delhi (Latitude 28°35'N, Longitude 77°12'E), with an area of 1483 km^2, is situated in the northern part of India. Geographically, Delhi is 160 km to the south of Himalayas, at an elevation of 216 m above mean sea level (Kansal et al., 2011). The river Yamuna forms the eastern boundary of the city whereas the Thar Desert of Rajasthan lies to its west, central hot plains to its south and the cooler hilly region to the north and east. Delhi has a semi-arid climate with extremely hot summers, average rainfall and very cold winters. The summer (March, April, May) is governed by high temperature, the monsoon (June, July and August) is dominated by rain where as the post–monsoon (September, October, November) has moderate temperature (Kumar and Goyal, 2011). The most important season in Delhi is winter, which starts in December and ends in February. Wind speed is typically higher in summer and monsoon, whereas calms are frequent in winters. Normally, northwesterly winds prevail during the year while in the months of June and July southeasterly winds predominate.

3. METHODOLOGY

Emissions from power plants, transport, domestic, industries and waste sectors in Delhi have been estimated in terms of criteria pollutants namely CO, NOx, SO_2 and PM_{10}.

3.1 Emissions from Power Plants

Three coal fired (i.e., Badarpur, Indraprastha (IP) and Rajghat) and two gas-fired (Gas Turbine (G.T.) station and Pragati Gas Station) power plants were operational during the period 2000-2010. These power plants are located in the heart of Delhi city. IP power plant was shut down in 2010 whereas Pragati-I gas station started in the year 2002. The amount of fuel consumed is calculated using equations given by Gurjar et al. (2004).

$$\text{Gross Generation (GWH)} = \text{PLF (\%)} \times \text{capacity} \times 24 \times 365 \quad (1)$$

$$\text{Fuel use (kt)} = \text{Gross Generation} \times \text{fossil fuel use per GWH} \quad (2)$$

Plant Load Factor (PLF) of different power plants is taken from performance review report of thermal power plants issued by Central Electricity Authority (CEA). Emission factors (EFs) for PM_{10} are based on Sahu et al., 2011 whereas EFs for SO_2 and CO have been taken from CPCB (2010) and for NOx (as NO_2) from Kansal et al. (2011).

3.2 Emissions from Transport Sector

The urban population in Delhi is predominantly dependent on road transport. With rapid urbanization, vehicular population in Delhi has sharply increased by an average annual rate 7.40% for private vehicles and 9.15% for commercial vehicles (GNCTD, 2010). The number of vehicles per kilometer of road in Delhi has gone up from 128 to 191 between 2003 and 2009 (Goyal et al. 2013).

Emission load from road transport has been estimated using the following equation (IPCC, 2006; Sahu et al., 2011).

$$E_i = \sum (Veh_j \times D_j) \times EF_{i,j,km} \quad (3)$$

where, E_i : Emission of pollutant $(_i)$(Gg); Veh_j : number of vehicles per type $(_j)$; D_j : Distance travelled per vehicle in per year ($_j$)(km); $EF_{i,j\ km}$: emissions of pollutant ($_i$) vehicle type($_j$) per driven kilometer(g/km).

Population data of different vehicle types (e.g., Bus, Light commercial vehicle (LCV), Heavy Commercial Vehicle (HCV), Taxi Car, etc.) for Delhi is derived from the Statistical Abstract of Delhi, (2012). Annual average vehicle-km travelled is estimated as 10,000 for passenger cars; 36,000 for taxis and auto-rickshaws; 50,000 for buses and 30,000 for HCV and LCV (Guttikunda and Calori, 2013) and 27,000 for 2-wheelers (2W) (Sahu et al., 2011). Auto rickshaws (or 3-Wheelers (3W)) have been assumed to use only compressed natural gas (CNG) as fuel during the period of study except for year 2000 and 2001. Among the total buses in the fleet, 23% use diesel and 77% use CNG (CPCB, 2010). CNG vehicle population data for the period of study has been taken from Khailwal et al., (2006). Diesel vehicles population data is based on data of Delhi Transport Authority as used in previous studies (Goyal, 2007). Two wheeler vehicles classified as 2-Stroke (2S) and 4-Stroke (4S) use gasoline fuel and amongst the total 2W, 72% are motorbikes, and while the rest 28% are scooters. Since 4S-2W emits less pollution load in comparison to 2S-2W, thus a ratio of 72:28 has been considered for 4S-2W and 2S-2W. The age-wise distribution of vehicular population of Delhi has been taken from CPCB (2010) and Kumar et al (2014). According to the age of vehicles, present engine technology, type of fuel used by them, corresponding EFs ($E_{i,j\ km}$) of 2W, 3W, PCs, LCV and HCV are developed by The Automotive Research Association of India (ARAI) (2007) and CPCB(2010). EFs for SO_2 are based on reports of UNEP (1999).

3.3 Emissions from Domestic sector

Emissions from fuel consumption in domestic sector are calculated as

$$E_i = \sum (Fuel_j \times EF_{ij}) \quad (4)$$

where, E_i: emission per pollutant (i) (Gg); $Fuel_j$: consumption of fuel per fuel type ($_j$)(kt); $EF_{i,j}$: emissions of pollutant ($_i$) per unit of energy ($_j$)(g/kg).

According to Executive Summary of Inventorization of Green House Gases - Sources and Sinks in Delhi, LPG is the most commonly used cooking fuel (68.4%) followed by kerosene (24.4%) and biomass (3.9%). According to TERI (2010) report on Emissions from residential and commercial sector, the major fuels used in domestic sector are fuel wood, dung cake, kerosene, crop waste and cooking gas (LPG). The total LPG and Kerosene supply in Delhi during year 2006-07 was reported as 586 kt and 162 kt as obtained from Petroleum Planning and Analysis Cell (PPAC) and Food Supplies and Consumers Affairs Department (CPCB, 2010).

Gurjar (2004) assumed that petrol, high-speed oil and light diesel are used in transport sector whereas LPG cooking gas and kerosene is used in household stoves. Other energy products are assumed as biomass such as fuel wood, cow dung and crop waste. Based on the similar assumption, emissions from domestic sector were calculated.

3.4 Emissions from Industrial sector

After the order of Honorable Supreme Court of India, banning non-conforming industrial units and other environmental safety norms, there was no significant increase in the number of industries in Delhi. A total of 2210 polluting industries were closed /relocated during 1998-2001 in Delhi (GNCTD, 2010). Generally, fuels used in the industries include LSHS, Light duty oil (LDO), High speed diesel (HSD), Liquefied petroleum gas (LPG), natural gas (NG) and coal. According to Delhi Pollution control committee (DPCC), use of coal is banned in industries in New Delhi and supply of coal is limited to power plants only (CPCB, 2010). Thus emissions from the industrial sector are mainly due to consumption of industrial fuels such as HSD and LDO.

The emissions from industrial fuel consumption are calculated as:

$$E_i = \sum (Fuel_j \times EF_{ij}) \quad (5)$$

where, E_i: emission per pollutant (i)(Gg); $Fuel_j$: consumption of fuel per fuel type (j)(kt); $EF_{i,j}$: emissions of pollutant (i) per unit of fuel (j) consumed (g/kg). Emission factors of these fuels are taken from CPCB (2010).

3.5 Emissions from Waste sector

Municipal solid waste (MSW) mainly comprises of biodegradable materials, which undergo anaerobic decomposition in landfills generating landfill gas (LFG) consisting of about 60% methane (CH_4) together with small quantities of non-methane organic compounds and other trace gases (Chakraborty et al., 2011). Landfills are important sources of anthropogenic emissions especially for greenhouse gases in fast urbanizing cities. Solid waste management remains one of the most neglected sectors in Delhi. Municipal Corporation of Delhi (MCD) along with the Cantonment Board and the New Delhi Municipal Corporation (NDMC) is responsible for the disposal of municipal solid waste collected within the periphery of National Capital Territory (NCT) of Delhi. About 80% of the collected MSW is disposed in landfills, and the remainder is composted. Latest estimates indicate that about 6500-7000 tons of municipal solid waste (MSW) is generated each day in Delhi with per capita generation rate of 0.47 kg per day (Chakraborty et al., 2011). All the MSW generated in the city is transported to landfill sites in Ghazipur (GL; in East Delhi), Bhalswa (BL; in North Delhi) and Okhla (OL; in South East Delhi) landfill sites. Brief descriptions of these landfills are given in Table 4. All the three landfills in Delhi have been receiving waste for more than 15 years; with GL being the oldest site operating since 1984; followed by BL which started in 1992 and OL became operational in 1996 (Chakraborty et al., 2011). CH_4 emissions from solid waste disposal are calculated using the following formula (Gurjar et al., 2004).

$$\text{Total Emission } CH_4 = [(MSW \times MCF \times DOC \times DOC_f \times F \times (16/12) - R] \times [1 - OF] \quad (6)$$

where, MSW = Municipal Solid Waste [per capita waste produced x Delhi population]; MCF = Methane Correction Factor DOC = Degradable Organic Carbon; DOC_f = Fraction of DOC dissimilated; F = Fraction of CH_4 in landfill gas and; OF = Oxidation factor. EFs for methane have been taken from Chakraborty et al. 2011 and Gurjar et al. 2004.

Further, for the estimation of emission till 2020, projection of Delhi's population till 2020 has been taken statistical Abstract of Delhi (2012). Growth of Vehicles till 2020 has been estimated using methodology adopted by Das et al. (2012). In addition to it estimation of emissions from domestic, industries, waste and power plants has been estimated using population projection.

4. RESULTS AND DISCUSSIONS

The sector-wise emission trends of the criteria pollutants CO, NOx, SO_2, PM_{10} during 2000-2010 in Delhi are shown in Fig 2. It has been found that CO is mainly emitted from transport and domestic sector. Major contribution of NOx comes from transport followed by power plants and domestic sector respectively and has followed an increasing trend during 2000-2010. The most significant contribution to PM_{10} emissions is from power plants and transport sector. PM_{10} emissions from transport sector have greatly reduced after to implementation of Bharat Stage –III norms and use of CNG fuel in public transport (buses), auto-rickshaws and taxis in 2000. But Major contribution towards SO_2 emissions still comes from power plants.

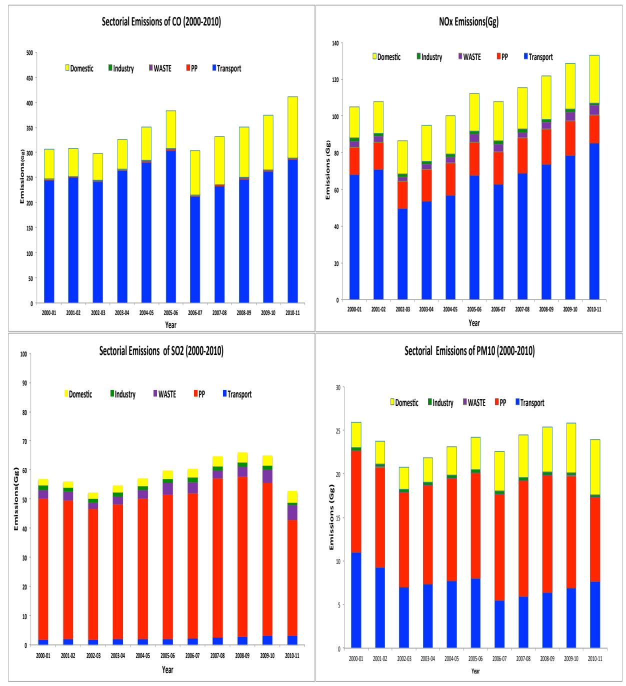

Fig 2: Sector wise emissions of CO, NOx, SO2 and PM10 from 2000-2010

To limit the presentation of results to manageable size, only PM10 emissions under BAU and EAP scenario are discussed. Under BAU scenario, following assumptions have been considered.

1) Proportionate growth across all sectors in relation to increase in population.
2) Population projected by 2020 has been taken from statistical abstract of Delhi, 2012.
3) Population growth rate has been considered to project future emissions from domestic, waste, and industries.
4) Vehicular growth rate has been estimated on the basis of growth rate witnessed in the past years.
5) Rising population would result in more number of private cars in Delhi.

Under EAP scenario, the assumptions are following.

1) For power plants, due to rising emissions from coal based power plants Rajghat (135 MW) and badarpur (735 MW) power plants would be shut down by 2015 and 2017 respectively. Further, to meet the rising demand of electricity gas based Pragati power plant (750 MW) would be operational by 2015.
2) Implementation of EURO IV norms on two and three wheeler vehicles.

3) Implementation of EURO V norms by 2015.
4) About 30% increase in public buses.
5) Landfill sites to be increased from 3 to 5 with proper sanitary landfill sites.
6) No further growth in small and medium scale industries.
7) Use of Kerosene, cow dung, wood in domestic sector to be reduced by promoting use of LPG in slum areas of Delhi.

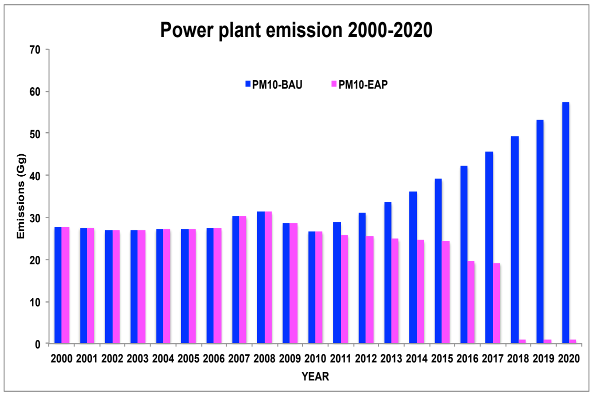

Fig 3: Emissions of PM10 from power plants under BAU and EAP scenario from 2000-2010.

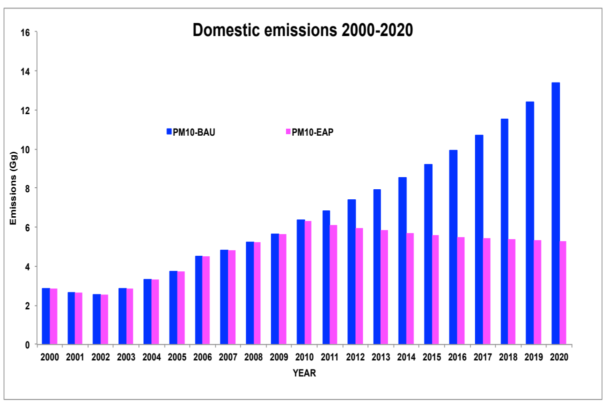

Fig 4: Emissions of PM10 from domestic sector under BAU and EAP scenario from 2000-2010.

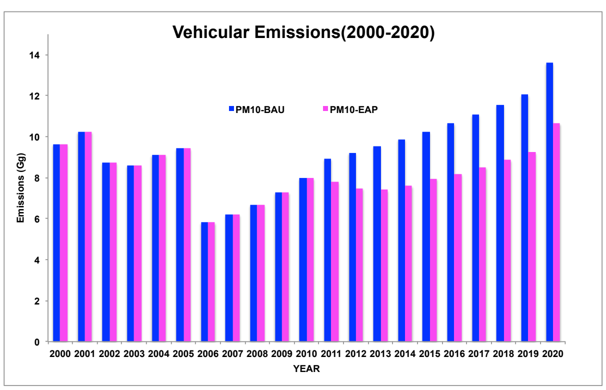

Fig 5: Emissions of PM10 from vehicles under BAU and EAP scenario from 2000-2010.

It has been observed that apart from vehicular emissions all other sectors would show considerable reduction in emissions under EAP scenario. Growth in population and as a result increase in number of private vehicles will negate the impact of implementation of Euro V norms on 4-wheelers by 2015. Moreover, according to a leading daily newspaper (TOI, 3 may 2014) completion of Phase III of Delhi metro by 2016 is expected to be delayed which would further intensify the vehicular emissions.

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