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Health Impacts Assessment due to $PM_{2.5}$, PM_{10} and NO_2 Exposure in National Capital Territory (NCT) Delhi

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ABSTRACT: The human health impacts caused due to exposure to criteria outdoor air pollutants $PM_{2.5}$, PM_{10} and NO_2 were assessed in present study. The human health effects associated with exposure to atmospheric air pollution in NCT Delhi were estimated utilizing the AirQ+ v1.3 software tool integrated with Ri-MAP during the study period 2013-2018 considering 80% of the whole population subjected to air pollution exposure. Taking into account the World Health Organization (WHO) (2016) guidelines, the inter-annual average concentrations of $PM_{2.5}$, PM_{10}, and NO_2, concentration response relationships and population attributable fraction (AF) or impact fraction (IF) concepts were adopted. The excess number of cases (ENCs) of Mortality (all) natural cases 30+ years, acute lower respiratory infection (ALRI), lung cancer (LC), ischaemic heart disease (IHD), stroke, incidence of chronic bronchitis in children, postneonatal infant mortality, chronic obstructive pulmonary disease (COPD), prevalence of bronchitis in children, incidence of asthma symptoms in asthmatic children in the year 2013 were 48332, 2729, 5645, 26853, 22737, 120754, 34510, 5125, 9813, 3054, 17203 and 682, respectively. Within half of a decade i.e. in year 2018, the ENCs of Mortality (all) natural cases 30+ years, ALRI, COPD, LC, IHD, stroke, incidence of chronic bronchitis in children, postneonatal infant mortality, prevalence of bronchitis in children, incidence of asthma symptoms in asthmatic children increased significantly and were 72254, 3471, 6547, 7568, 32358, 28233, 150110, 50810, 9019, 862, 29570 and 1189, respectively.

Keywords: Morbidity, Mortality, Cardiovascular diseases, Respiratory diseases, AirQ+ v1.3.

INTRODUCTION

In the NCT Delhi, India the atmospheric air pollutants $PM_{2.5}$, PM_{10} and NO_2 exceed both the world health organization (WHO) guidelines and Indian national ambient air quality standards (NAAQS). Since 1990s, NCT of Delhi has been ranked as one of the utmost polluted city among the world's developing countries (Gurjar et al., 2004). From most of the scientific studies performed for assessing air quality it has been observed that the root source of atmospheric air contamination is combustion, which leads to varieties of diseases and health risks, for instance respiratory and cardiovascular diseases mortality and morbidity specifically in industrialized mega cities (Mage et al., 1996; Gurjar et al., 2004; Madronich, 2006; Butler et al., 2018; Kumar et al., 2008; Gurjar et al., 2010; Kumar et al., 2011; Nagpure et al., 2013). The main significance of conducting human health risk assessment studies is to draw the attention of national and international organizations to mitigate air pollution to

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safe level by applying national and international air quality guidelines and by setting new rules and norms (Gurjar et al., 2008; Nagpure et al., 2010; Shukla et al., 2013; Babaee et al., 2014). Gurjar et al. (2010) used inter annual concentrations of SO_2, PM and NO_2 in AirQ 2.2 version and Ri-MAP model to compute health impacts regarding mortality and morbidity in NCT Delhi for 1998-2005. Gholampour et al. (2014) have utilized AirQ+ in order to study ambient particulate matter exposure & associated health effects in two industrial and urban regions in Tabriz, Iran. The resultant mortalities caused due to exposure to PM_{10}, and $PM_{2.5}$ and TSP concentrations were 363, 360 & 327 respectively; cardiovascular mortality due to exposure to $PM_{10}$and TSP were 227 and 202, respectively; and mortality caused due to RD were 67 (PM_{10}) and 99 (TSP). Similarly Nagpure et al. (2014) used data of SO_2, NO_2 and TSP to assess the human health impacts in terms of mortality and morbidity district wise in NCT Delhi utilizing the same out dated version of AirQ2.2 and Ri-MAP excel spreadsheet model for 1991-2010. Miri et al. (2016) have used AirQ+ software for studying the human health impacts in terms of respiratory and cardiovascular mortality, total mortality, hospital admissions due to RD and CVD, acute myocardial infraction and COPD of criteria air pollutants $PM_{2.5}$, SO_2, PM_{10}, O_3 and NO_2 of Mashhad city, Iran. Miri et al. (2016) reported that for every 10µg/m^3 increase in pollutant concentration relative risk (RR) for ENCs of total mortality due to $PM_{2.5}$, NO_2, PM_{10}, O_3 and SO_2 were increased by 1.5, 0.3, 0.6, 0.46 and 0.4 percent, respectively. The attributable amount of total mortality associated with $PM_{2.5}$, SO_2, PM_{10}, O_3 and NO_2 were 4.57, 0.99, 4.24, 1.61 and 2.21%, respectively. Skotak and Swiatczak (2008) also used AirQ+ software for the assessment of health impacts caused due to exposure to PM_{10} in some areas in Poland, and their results indicated that health risks were found only in polluted industrial zones in the southern Poland. It was found that long-term, repeated exposures to air pollution increases the cumulative risk of chronic pulmonary and cardiovascular disease and even death (Pope et al., 2004; Brook et al., 2004; Pope et al., 2002; Clancy et al., 2002; Hoek et al., 2002). The updated version AirQ+ v1.3 software tool, in which Ri-MAP spreadsheet model is also integrated by WHO in 2016,was utilized for assessing human health impacts accompanied with exposure to air pollution. AirQ+ v1.3 has the capability to evaluate mortality and morbidity associated with different air pollutants e.g. PM_{10}, NO_2, $PM_{2.5}$, black carbon (BC) & O_3 in accordance to the software mechanism and methodology. AirQ+ v1.3 is utilized to appraise the influence of long term and short-term exposure to outdoor and indoor air pollution for the population size of a particular region(Kumar & Mishra, 2017). The present study focuses on evaluation of human health impacts attributable to criteria air pollutants $PM_{2.5}$, PM_{10} and NO_2 exposure during 2013-2018 in NCT Delhi, India, which has serious concern for civilized societies and controlled and systematic organizations.

MATERIALS AND METHODS

Computation of Disease Burden: In epidemiological studies, the relative risk (RR) is the forecast of a disease emergence brought about by exposure to different air contaminants (Rothman et al., 2008; WHO, 2005). The WHO defaults measurements of (RR) per 10µg/m^3 increment of 24hrs averages of PM_{10}, NO_2 and $PM_{2.5}$ and the values of baseline incidence (BI) per 100 000 population were considered in accordance to relevant disease and probable mortality and morbidity as shown in Table 1. WHO (RR) default values have been adopted automatically by the software for the estimation of desired diseases and the BI values were taken from literature (Gurjar et al., 2010; Khaniabadi et al., 2018). Once the RR values are predefined or computed the attributable fraction of population (AF) or (impact fraction IF) is calculated using Equation 1 (Nagpure et al., 2014).

$$AF = \frac{\sum_{i=}^{n} PiRRi - 1}{\sum_{i=}^{n} PiRRi} \quad (1)$$

where Pi is the fraction of population category i of exposure, RRi is the changed relative risk of health impact in category i. Changed relative risk (RRi) response factor is determined as in Equation 2(Maji et al., 2017).

$$RRi = \frac{M - K}{10(RR - 1) + 1} \quad (2)$$

where Mis monitored concentration of pollutant, K is cutoff value of pollutant defined by WHO and RR is relative risk for the target health impact. In Equation 1 different category of attributable population fraction exposed to various levels of pollution can be calculated. For instance the number of citizens of different cities in a country. If the total population of one region with single level of exposure is considered Equation 1 can be rewritten in such a way that Pi=1 as the whole population is exposed and simply one RR value would apply as in Equation 3.

$$AF = \frac{RR - 1}{RR} \quad (3)$$

The ENCs per population unit can be computed when the baseline frequency which is also called as baseline incidence (BI) of the specific health endpoint in the population subjected to air pollution is known (for instance the number of cases per 100000 population at risk) BI of expected health endpoints should be predefined then excess number of cases for the targeted population exposed to air pollution (i.e., I_E) is calculated as in Equation 4.

$$I_E = I_W \times AF \quad (4)$$

Where I_E is the ENCs attributable to air pollution per unit of population Iw is the population unit. For a population size of N, the I_E can be changed to compute number of cases ascribed to exposures (i.e. N_E) using equation (5).

$$N_E = I_E \times N \quad (5)$$

Similarly, the recurrence of health impacts outcomes in the non-exposed population i.e. I_{NE} is determined as in Equation 6.

$$I_{NE} = I_W - I_E = I_W(1 - AF) \quad (6)$$

Last but not the least specific class of pollution exposure (i) with pre-identified RR and the estimated incidence in population not exposed to air pollution with pre-determined population size (P) under investigation the ENCs $\Delta N_{(c)}$ is estimated as in Equation 7.

$$\Delta N_{(c)} = [RRi - 1] \times Pi \times I_{NE} \times P \quad (7)$$

Equation 6 is utilized to compute and assess the excess number of mortality and morbidity due to long-term and short-term effects of pollution exposure to different air pollutants.

The obtained results of current study are the outputs of input data $PM_{2.5}$, PM_{10}, NO_2, and population census during the years 2013-2018 summarized in Table 2 fed into AirQ+ v1.3. The above-mentioned methodology is the manual description of the mechanism based on which the AirQ+ software operates. In the present study for the NCT of Delhi, India the computation of disease burden has been carried out in AirQ+ v1.3 software tool, which is the latest version. The AirQ+ v1.3 software maybe used to assess long term and short-term effects due to exposure to $PM_{2.5}$, PM_{10}, NO_2, black carbon (BC) and O_3. The AirQ+ input data include mean concentration of desired pollutant, cutoff concentration (particulate pollutant $\mu g/m^3$), total population, percentage of population at risk, baseline incidence per 100000 population. The optional input data include location, area size, latitude and longitude.

The uncertainty analysis is carried out with the purpose to assess the probabilistic health outcomes because of uncertainty. AirQ+ v1.3 software tool calculates the relative health outcomes including upper and lower limits (i.e range) for the 95% confidence interval based on the input parameters given in Table 1.In each of the subsequent Figures 2, 3, 4, 5 and 6 the thick bars indicate the ENCs of morbidity and mortality and thin vertical lines show the estimated values of lower and upper limits with confidence interval of 95%.It can been seen from the figures that mortality (all) natural cases 30+ years due to $PM_{2.5}$, Hospital admission due to respiratory disease (HARD) due to exposure to $PM_{2.5}$, mortality all natural cases due to NO_2 exposure in long term, incidence of chronic bronchitis in children due to PM_{10} long-term exposure and incidence of asthma in asthmatic children due to exposure PM_{10}in short term showed high uncertainties while acute lower respiratory infection (ALRI) mortality children (0-5) years due to $PM_{2.5}$, Hospital admission due to cardiovascular (HACVD) disease including stroke from exposure to $PM_{2.5}$ in short term, prevalence of bronchitis in children due to NO_2 and PM_{10} exposure in long term resulted in least uncertainties.

In order to examine and apply the analytical approaches and methodology explained in Materials and Methods Section, a case study has been accomplished for NCT Delhi, India for estimating the inter annual excess number of cases. The explained methodology is primarily dependent upon the population census for 2013-2018 and atmospheric air pollutants' concentrations. In past studies performed for NCT of Delhi for human health risk assessment Gurjar et al. (2010) and Nagpure et al. (2014) used criteria pollutants SO_2, NO_2, SPM and utilized AirQ2.2 and Ri-MAP software tools which are now outdated. On the contrary, in the present study criteria, pollutants such as $PM_{2.5}$, PM_{10}, and NO_2 and latest version of AirQ+ v1.3 in which Ri-MAP is also integrated have been used. The air quality data from 17 monitoring stations operating within the NCT of Delhi by Central Pollution Control Board (CPCB) as shown in Figure 1 were used for the present study. The pollutants monitoring is accomplished in a period of twenty-four hours (for gaseous pollutants 4 hours period and eight hours for sampling of particulate matter) with a frequency of 2 times in a week in order to achieve 104 observations throughout the year. The data for $PM_{2.5}$, PM_{10} and NO_2 have been extracted from open government data OGD platform (data.gov.in) and National Ambient air quality monitoring program NAAMP (2019) (cpcb.nic.in/manual-monitoring/). The data are released under national data sharing and accessibility policy (NDSAP) contributed by Ministry of Environment and Forests Central Pollution Control Board (CPCB) Government of India and is made publicly available free of cost. The population data have been downloaded from website of Registrar General & Census Commissioner, India, Ministry of Home Affairs, Government of India (censusindia.gov.in/2011-Common/CensusData2011.html). The population data and concentration of air pollutants $PM_{2.5}$, PM_{10}, and NO_2 considered for health impacts assessment are summarized in Table 2.

Table 1. WHO Specified Default Values of RR per 10 μg/m^3 Increase of Daily Average for PM_{10}, $PM_{2.5}$ and NO_2 Corresponding to Mortality and Morbidity

Pollutant	Mortality/Morbidity	Relative Risk (RR) (95% CI) per 10 μg/m3	Baseline Incidence Per 100 000 (I)	References
PM_{10}	**Long-term effects, cutoff value for PM_{10}= 20 μg/m3**			
	Incidence of chronic bronchitis in adults	1.117 (1.04-1.189)	1013	Khaniabadi et al., 2018
	Postneonatal infant Mortality, all cases	1.04 (1.02-1.07)	497	Khaniabadi et al., 2018
	Prevalence of bronchitis in children	1.08 (0.98-1.19)	66	Khaniabadi et al., 2018
	Short term effects, cutoff value for PM_{10}= 50μg/m3			
	Incidence of asthma symptoms in asthmatic children	1.028(1.006- 1.051)	66	Maji et al., 2017
NO_2	**Long-term effects, cutoff value for NO_2= 40 μg/m3**			
	Mortality all natural cases	1.041 (1.019-1.064)	497	Gurjar et al., 2010
	Prevalence of bronchitis symptoms in asthmatic children	1.021 (0.99-1.06)	101.4	Gurjar et al., 2010
$PM_{2.5}$	**Long-term effects , cutoff value for $PM_{2.5}$= 10 μg/m3**			
	Mortality, all natural cases (adults age 30+ years)	1.062(1.04-1.083)	1013	Khaniabadi et al., 2018
	Mortality due to ALRI for children (0-5 years)	GDB 2015/2016 (integrated function 2016)	49	Khaniabadi et al., 2018
	Mortality due to COPD for adults(30+ year)	GDB 2015/2016 (integrated function 2016)	101	Khaniabadi et al., 2018
	Mortality due to LC for adults (30+ years)	GDB 2015/2016 (integrated function 2016)	132	Khaniabadi et al., 2018
	Mortality due to IHD for adults (25+ years)	GDB 2015/2016 (integrated function 2016)	436	Khaniabadi et al., 2018
	Mortality due to Stroke for adults (25+ years)	GDB 2015/2016 (integrated function 2016)	436	Khaniabadi et al., 2018
	Short term effects, cutoff value for $PM_{2.5}$= 20μg/m3			
	Hospital admission respiratory disease	1.019(0.9982-1.0402)	1260	Khaniabadi et al.,2018
	Hospital admission cardiovascular disease including stroke	1.0091(1.007-1.0166)	101	Khaniabadi et al., 2018
	Mortality all natural cases 30+ years	1.0123(1.0045-1.0201)	1013	Khaniabadi et al., 2018

ICD: International Classification of diseases ; ALRI: Acute lower respiratory infection; COPD: Chronic obstructive pulmonary disease; IHD: Ischaemic heart disease; LC: Lung cancer; BI: Baseline incidence per 100000 has been adopted as per WHO default values; GDB: Global disease burden

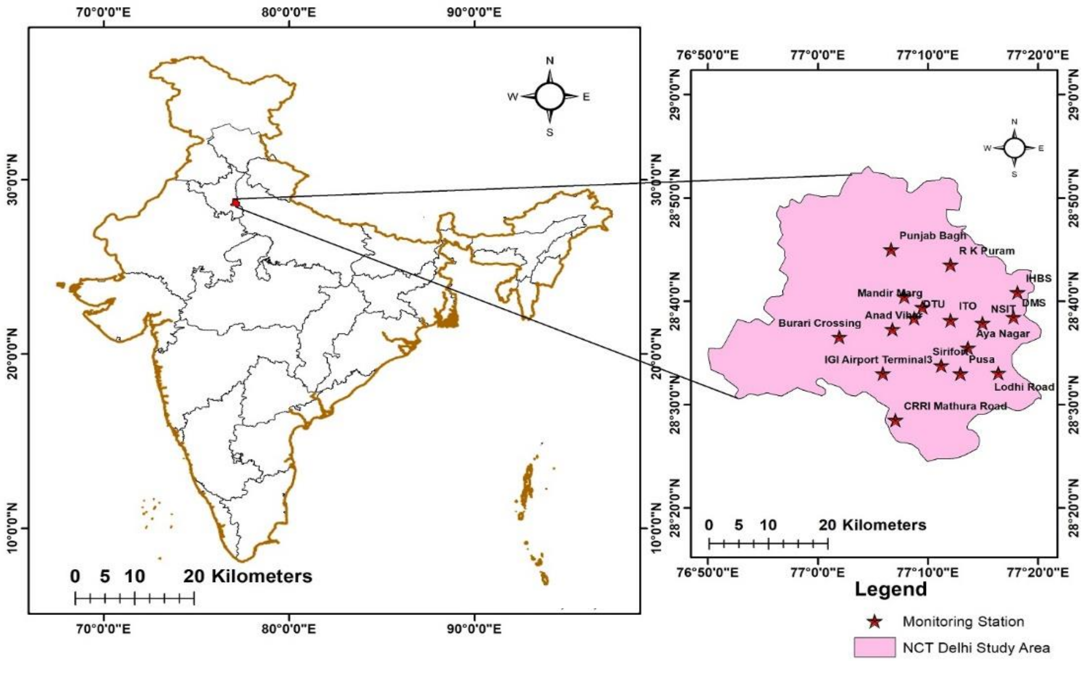

Fig. 1. Study Area Map with Allocation of Central Pollution Control Board (CPCB) Monitoring Stations

Table 2. Population Census and Inter-Annual Concentrations of $PM_{2.5}$, PM_{10} and NO_2

Year	Population	$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	NO_2 (μg/m^3)
2013	17354281	80	196.8	61.7
2014	17635897	80	195.1	52.2
2015	17916359	96	198.1	47.8
2016	18195583	82.9	249.9	59.6
2017	19072564	101.3	226.9	60.8
2018	19483678	111.7	292	67

RESULTS AND DISCUSSION

The excess number of cases (ENCs) of mortality all natural cases due to long term effects of $PM_{2.5}$, short term effects of $PM_{2.5}$ and long term effects of NO_2 are shown in Figure 2, 3 and 4, respectively. In the year 2018 mortality, all natural cases due to $PM_{2.5}$ long-term effects were at its peak with value 72254 and 95% confidence limits of 51936-87718. The ENCs of mortality due to $PM_{2.5}$ short-term effects had similar trend with peak value at highest $PM_{2.5}$ concentration of 111.7μg/m^3 in 2018. The ENCs of mortalities all natural cases due to long term exposure to $PM_{2.5}$ were 48332, 49116, 58642, 52349 and 65317 in years 2013, 2014, 2015, 2016 and 2017, respectively. The ENCs mortality all natural cases due to short-term effects of $PM_{2.5}$ were also at its peak in 2018 with value of 15879 and 95% confidence limits of 6028-25022. The ENCs mortalities all natural cases due to short term effects of $PM_{2.5}$ were 9145, 9294, 1271, 10073 and 1376 during 2013, 2014, 2015, 2016 and 2017, respectively. ENCs mortalities all natural cases due to NO_2 long-term effects were comparatively less than those of $PM_{2.5}$ long-term and short-term effects. The ENCs mortality all natural cases due to NO_2 were maximum with value 7965 and 95% confidence interval limits 3838-19947 at highest NO_2 concentration of 67 μg/m^3 in 2018. The lowest ENCs due to NO_2 were 2198 with 95% confidence limits 1038-3365 at lowest concentration of NO_2 in 2015. The ENCs due to NO_2 rose sharply in 2016 with value 5479 and steadily reached to 6080 in 2017.

Nagpure et al. (2014) evaluated human health risks in NCT Delhi due to exposure to SO_2, NO_2 and TSP during the years 1991-2010. The ENCs of mortality in 1991 were 8945 after a decade due to increase in urbanization and increase in the concentration of pollutants the ENCs of mortality reached up to 11364 and in the year 2010 ENCs were 18219. As well as Gurjar et al. 2010 concluded that the ENCs of total mortality in NCT Delhi in population size of one million ranged between 750-930 during the years 1998-2005. As with the improvement of economy growth, urbanization, industrialization and abandoned excess number of vehicles there has been a steady growth in population and pollution level in NCT Delhi. Based on the results of present study the ENCs of mortality all natural cases as compared with previous studies have been recorded 96098 highest in 2018.

Acute Lower Respiratory Infection (ALRI) mortality in children (0-5) years of age was due to long-term exposure to $PM_{2.5}$ as shown in Figure 2. The ENCs with value 3471 and 95% confidence limits 2705-4133 were highest in 2018. The ENCs were lowest with value 2729 and 95% confidence limits of 2154-3247 in 2013. ENCs were trailed with values 2773, 3026, 2903 and 3284 in the years 2014, 2015, 2016 and 2017, respectively. According to the results of Lelieveld et al. (2015) from a survey of global disease burden GDB 2010 the estimated ENCs of lower respiratory infection in children (0-5) years in entire India were 3503152. The highest recorded ENCs of ALRI mortality in children (0-5) years of age were 3471 in 2018 which indicates that the NCT Delhi has higher trends of the ALRI mortality in recent years as compared to previous studies.

The ENCs of Chronic Obstructive Pulmonary Mortality in Adults Aged above 30 Years (COPD) mortality as shown in Figure 2 were considered due to long-term exposure to $PM_{2.5}$. ENCs of 6547 were maximum in 2018. The ENCs of 5125 were lowest in 2013. The ENCs of COPD mortality were 5208, 5686, 5451 and 6179 in years 2014, 2015, 2016 and 2017, respectively. According to Gurjar et al. (2010) the ENCs of COPD mortality ranged between (105-130) with 95% confidence interval of (0-245) during the years (1998-2005) in the entire NCT of Delhi. Nagpure et al. (2014) evaluated the ENCs of COPD mortality in NCT Delhi. In their research the ENCs of COPD mortality were 12809, 16253 and 26525 in 1991, 2000 and 2010, respectively. The ENCs due to chronic obstructive pulmonary (COPD) mortality in adults aged above 30 years of the present study in 2013 were 5125 and 6547 in 2018, which showed lower trends as compared to previous studies.

The estimated ENCs due to Ischaemic Heart Disease (IHD) Mortality in Adults Aged above 25 Years due to long-term effects of $PM_{2.5}$ exposure are shown in Figure 2. The peak ENCs 32358 with 95% confidence limits 2013-44785 were in 2018. The lowest ENCs with value 26853 were in 2013. The ENCs with values 27289, 288740, 28378, and 31048 were in the years 2014, 2015, 2016 and 2017, respectively. Based on the results of GDB 2010 Lelieveld et al. (2015) found that the estimated ENCs of IHD mortality in entire India were 305266. The results of the present study for NCT Delhi ranks on top in comparison with all other Indian metropolitan cities.

Among the criteria pollutants, Lung Cancer (LC) Mortality in Adults 25+ Years was only caused due to long-term $PM_{2.5}$ exposure as shown in Figure 2. In the assessed LC mortality the ENCs with value 7668 and 95% confidence limits of 5547-9338 were highest in 2018. The lowest ENCs with value 5645 and 95% confidence limits of 3929-7204 were in 2013 during the study period. The ENCs were 5737, 6436, 6037, and 7047 in years 2014, 2015, 2016 and 2017, respectively. According to Lelieveld et al. (2015) based on the GDB 2010 results of lung cancer (LC) mortality the estimated ENCs were 12729 and the maximum recorded ENCs of LC mortality only for NCT Delhi in the year 2018 were 7668 as a result NCT Delhi has highest ENCs of LC mortality as compared to other Indian mega cities.

ENCs of Mortality due to Stroke in Adults 25+ Years due to long-term exposure to $PM_{2.5}$ are shown in Figure 2. The peak ENCs with value 28233 and 95% confidence limits of 16554-37175 were in 2018 and lowest ENCs with value 22737 with 95% confidence limits 12692-30455 were estimated in 2013. The ENCs estimated in the years 2014, 2015, 2016 and 2017 were 23106, 24824, 24107 and 2685, respectively. The estimated ENCs of mortality due to Stroke in adults 25+ years of present study in 2018 were 28233 and the stroke mortality in entire India according to the research of Lelieveld et al. (2015) based on GDB (2010) ECNs were 4485358. Due to increase in population census and air pollution the stroke mortality in NCT Delhi has higher trends in recent years than any other metropolitan city in India.

The ENCs of Hospital Admission (Morbidity) due to Cardiovascular Disease (CVD) + Stroke and Respiratory Disease (RD) were similar to various mortalities in the same study period from 2013 to 2018 (Figure 3). All the cases were assessed due to short-term exposure to $PM_{2.5}$. The ENCs due to CVD including stroke in each of the study years from 2013 to 2018 in 80% of the population attributable to air pollution were 682, 639, 702, 751, 1029, and 1189, respectively. On the other hand, the ENCs of (morbidity) hospital admission due to RD had higher values than those of CVD including stroke. In the study period the

ENCs were 17203, 17482, 2251, 18937, 25716 and 29570 in years 2013, 2014, 2015, 2016, 2017 and 2018, respectively. In a case study conducted by Maji et al. (2017) on human health risk assessment due to exposure to air pollution in mega city Mumbai evaluated that ENCs terms of CVD and RD per 1 million population size were 7928 (5510-10860 at 95% CI) and 20620 with confidence interval of (12961-27678 at 95% CI), respectively. Maji et al. (2017) concluded that during the years 1992-2002 and 2003-2013 in mega city Mumbai all sorts of ENCs of mortality and morbidity exceeded by 30 % excluding COPD mortality. Hence morbidity due to CVD+ Stroke and RD in the NCT Delhi during the years 2013-2018 of the present study showed less number of ENCs as compared to mega city Mumbai during the years 1992-2002 and 2003-2013.

The estimated ENCs of postneonatal infant mortality all cases due to long-term PM_{10} exposure are shown in Figure 4. A steady increase was observed in ENCs from 2013 to 2018 and the reason for that was the resemblance of PM_{10} concentration trend in the same study period. The highest ENCs with value 50810 and 95% confidence limits of 32262-65168 were in 2018. The lowest ENCs with value 34510 and 95% confidence limits of 20382-48130 were in 2013. During the years 2014, 2015, 2016 and 2017 ENCs were 34835, 35809, 42982, and 42148, respectively. Gurjar et al. (2010) estimated that average ENCs of respiratory mortality per one million population during the years (1998-2005) in the NCT Delhi fluctuated between 110-140 with uncertainty interval of (60-210 at 95% CI). Nagpure et al. (2014) concluded that the estimated ENCs due to respiratory mortality in NCT Delhi in 1991 were 1302, in 2001 were 1703 and in 2010 were 2701. The calculated ENCs of postneonatal infant mortality all cases of the present study showed higher trends as compared to earlier studies.

The ENCs of prevalence of bronchitis incidence in asthmatic children due to long term NO_2 exposure and only bronchitis in children due to long term PM_{10} are shown in Figure 4 and Figure 5, respectively. ENCs of prevalence of bronchitis in children due to PM_{10} exposure with value 9019 and due to long-term NO_2 exposure with value 862 were estimated as highest in 2018. In terms of both pollutants PM_{10} and NO_2 ENCs of prevalence incidence had a steady increase from 2013 to 2018. ENCs due to PM_{10} during 2013, 2014, 2015, 2016 and 2017 were 6813, 6892, 7058, 7970 and 8021, respectively and due to NO_2 were 621, 369, 234, 589 and 655, respectively. Nagpure et al. (2014) reported that the estimated ENCs due to respiratory mortality in NCT Delhi in 1991 were 1302, in 2001 were 1703 and in 2010 were 2701. The calculated ENCs of prevalence of bronchitis symptoms in asthmatic children and prevalence of bronchitis in children due to NO_2 exposure in long term of the present study showed higher trends as compared to earlier studies.

Excess number of cases due to incidence of asthma symptoms in asthmatic children due to short-term PM_{10} exposure are shown in Figure 6. The ENCs with value 5014 and 95% confidence limits of 1386-7201 were highest in 2018 and ENCs with value 3054 and 95% confidence limits of 770-4748 were lowest in 2013. The ENCs of incidence of asthma symptoms in asthmatic children due to short term PM_{10} exposure were 3075, 3175, 4079 and 4383 in 2014, 2015, 2016 and 2017, respectively. Gurjar et al. (2010) reported that average ENCs of respiratory mortality per one million population during the years (1998-2005) computed in AirQ+ in the NCT Delhi fluctuated between 110-140 with uncertainty interval of (60-210 at 95% CI) . The estimated ENCs due to incidence of asthma symptoms in asthmatic children due to short-term PM_{10} exposure of the present study showed higher trends in comparison with earlier studies.

With improvement in economical growth,

urbanization and industrialization, over population and abandoned number of vehicles in the NCT of Delhi the atmospheric pollution has increased significantly, which in response has resulted in enormous number of ENCs in terms of mortality and morbidity. In performing present study ENCs were computed with reference to concentration of $PM_{2.5}$, PM_{10} and NO_2 in excess of the limits as per WHO guidelines. However, long-term exposure to criteria pollutants such as PM_{10} at lower concentration than WHO guidelines also results in mortality and morbidity. Therefore, immediate actions and initiatives are necessary to improve the air quality in NCT Delhi and mitigate the excess concentration of PM_{10} and $PM_{2.5}$. For conducting all-encompassing and better study for human health impacts assessment, all relevant pollutants such as CO, SO_2, O_3 and poly aromatic hydrocarbons including PM_{10}, $PM_{2.5}$ and NO_2 should be considered. In general, the WHO AirQ+ v1.3 tool is useful for estimating the overall air pollution impacts on human health in metropolitan cities. The results of ENCs for different health outcomes in terms of mortality and morbidity in present study during years 2013-2018 have been recorded as highest as compared to the studies conducted in earlier years for the NCT Delhi, India. NCT Delhi is ranked at the top in death tragedies due to air pollution exposure as compared to other megacities in the world.

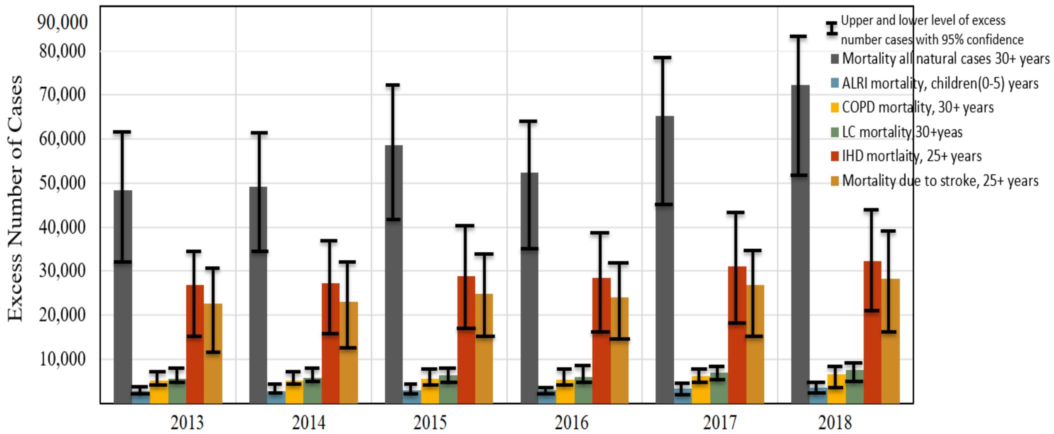

Fig. 2. Mortality due to Long-Term Exposure to $PM_{2.5}$

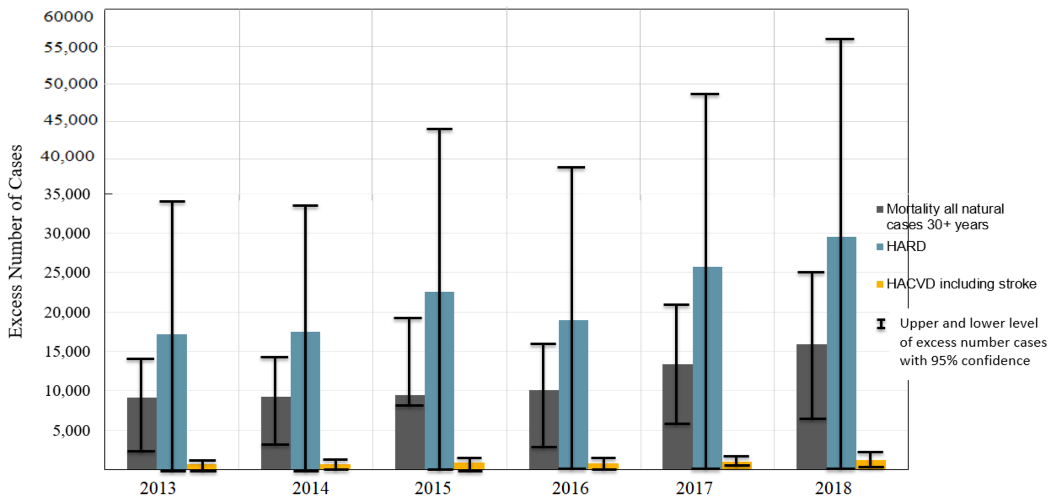

Fig. 3. Morbidity due to Short-Term Exposure to $PM_{2.5}$

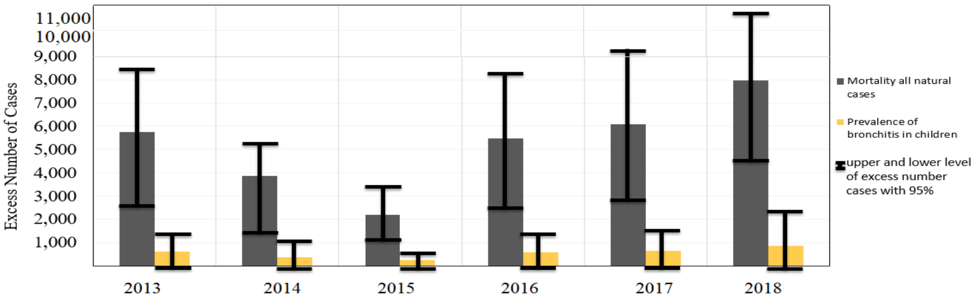

Fig. 4. Mortality due Long-Term Exposure to NO_2

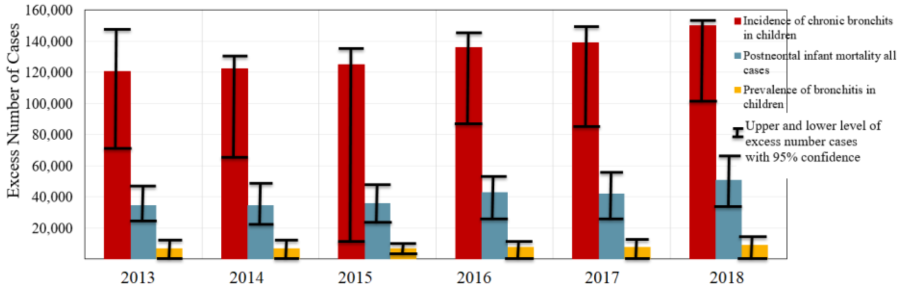

Fig. 5. Mortality and Morbidity due to Long-Term Exposure to PM_{10}

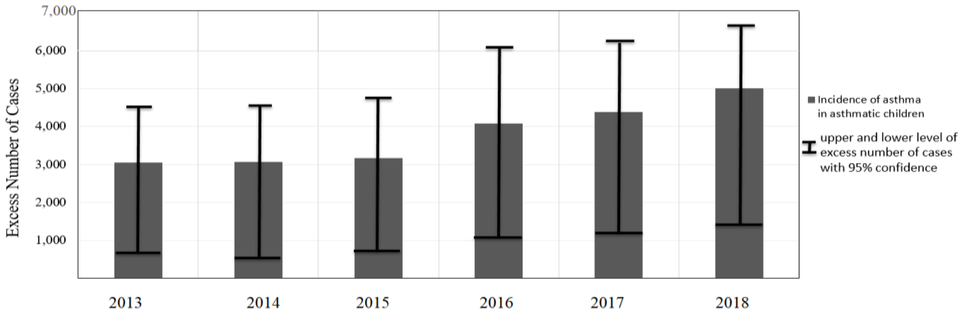

Fig. 6. Morbidity to due Short-Term Exposure to PM_{10}

The methodological approaches employed in performing present study have constraints and uncertainties that limit the accuracy of the techniques used. In order to make the methodology more feasible in future it needs to be improved.

1). Burnett et al. (2014) observed a non-linear relationship between air pollution and the associated health impacts, hence in the present study log-linear relationship (which is WHO default) was considered.

2). The RR values employed in present study are rationally developed in the USA, yet a great deal of uncertainties will occur in case RR values are experienced in some other nations such as India, because the atmospheric conditions and economy differ significantly.

3). Generally residents are prone to exposure of pollutants' mixture, both atmospheric and indoor, developed with associated combined impacts, which were not considered in performing present and earlier studies by Gurjar et al. (2010) and Fattore et al. (2011).

4). In assessing the relatives risks (RR) values in present study the inter-annual average concentrations of pollutants ($PM_{2.5}$, PM_{10} and NO_2) were considered while the RR values give best results using daily average concentrations. As a matter of fact in present study the daily average concentrations of pollutants were not used, which may lead to erroneous in RR computed.

5). There are also possible drawbacks in the accuracy of data provided by CPCB, for example, electricity failure, unavailability of labors, regulation error and insufficiency of air quality monitoring infrastructures.

CONCLUSIONS

In the present study human health effects regarding mortality and morbidity have been assessed in NCT Delhi during 2013-2018, taking into account 80% of the total population vulnerable to air pollution exposure of three criteria pollutants $PM_{2.5}$, PM_{10} and NO_2 using the updated version of AirQ+ v1.3 software integrated with Ri-MAP model developed by WHO in 2016. The estimated excess number of cases (ENCs) of mortality all (natural) cases, ALRI, stroke, incidence of chronic bronchitis in children, incidence of asthma in asthmatic children and hospital admission due to CVD and respiratory diseases in the year 2013 were 48332, 2729, 5125, 5645, 26853, 22737, 12075, 34510, 9813, 3054, 17203 and 682, respectively. After half of a decade i.e. in 2018, the ENCs increased significantly and were increased by 66.9, 78.6, 78.2, 82.9, 80.5, 8.04, 67.9, 58 and 57.4%, respectively and only ENCs of postneonatal mortality and prevalence of bronchitis in children were decreased by 91 and 28% respectively. AirQ+ v1.3 estimates the health effects caused due to exposure to an individual pollutant and is not capable of assessing the synergistic effects of 2 or more pollutants.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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