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Human Health Risk Assessment Due to Air Pollution in the Megacity Mumbai in India

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ABSTRACT

This study evaluated the human health risk in terms of the excess number of mortality and morbidity in the megacity Mumbai, India due to air pollution. AirQ software was used to enumerate the various health impacts of critical pollutants in Mumbai in past 22 years during 1992-2013. A relationship concept based on concentration-response relative risk and population attributable-risk proportion was employed by adopting World Health Organization (WHO) guideline for concentrations of air pollutants like PM_{10}, SO_2 and NO_2. For the year 1992 in Mumbai, it was observed that excess number of cases of total mortality, cardiovascular mortality, respiratory mortality, hospital admission due to COPD, respiratory disease and cardiovascular disease were 8420, 4914, 889, 149, 10568 and 4081 respectively. However, after 22 years these figures increased to 15872, 9962, 1628, 580, 20527 and 7905 respectively, but all of these reached maximum in the year 2006. From the result, it is also noted that except COPD morbidity the excess number of cases from 1992-2002 to 2003-2013 increased almost by 30%; and the excess number of mortality and morbidity is basically due to particulate matter (PM_{10}) than due to gaseous pollutants.

Key words: Human health risk, Criteria pollutants, Mortality, Morbidity, Relative risk

1. INTRODUCTION

Clean air is the most essential requirement for healthy living. However, due to uncontrolled urbanization, rapid increase in number of vehicles in cities and high energy demand for modern civilization, the air is continuously polluted. Episodic events of severe air pollution in Europe (Meuse Valley and London) and in the United States (Donora, Pennsylvania) in the 20th century caused acute disease and deaths of several thousands of people. Hence, there is no denying the fact that air pollution causes adverse effects on human health (Ciocco and Thompson, 1961; Nemery *et al.*, 2001). Urban people die of severe asthma due to nitrogen dioxide and ozone (Korek *et al.*, 2015; Pope *et al.*, 2011; Sunyer *et al.*, 2002; Romieu *et al.*, 1997). Peroxyacytyl nitrate (PAN) causes severe irritation in eyes and it is unequivocally bad for lungs and damages plants too (Taylor, 1969). Polycyclic aromatic hydrocarbons (PAHs) have been found in placental tissues of women and in umbilical cord blood samples of newborn babies with irreversible damage to DNA (Ravindra and Mittal, 2001). Particulate matter (PM) is the complex mixture of organic and inorganic matter, nitrogen compounds, sulphur compounds, PAHs, several heavy metals and radionuclides. Health effects associated with exposure to PM are lung inflammatory reactions, adverse effect on the cardiovascular systems and increase in mortalities, and also reduced lung function in children and increased chances of lung cancers (WHO, 2006). Regular exposure to sulfur dioxide (SO_2) causes asthma, chronic bronchitis and cardiovascular disease for the particularly sensitive people (WHO, 2003). Even the concentration of air pollutants lower than WHO guideline is also known to effect human health adversely (Downs *et al.*, 2007).

An assessment study on the global burden of disease (GBD) showed 0.695 million premature deaths and loss of 18.2 million disability-adjusted life years (DALYs) due to outdoor $PM_{2.5}$ and ozone pollution in 2010 and became the fifth leading cause of deaths in India (Lelieveld *et al.*, 2015). Other studies observed that about 0.62 million and 0.69 million premature death cases occurred due to outdoor air pollution and corresponding economic cost was 232.74 and 416.7 billion US$ in 2005 and 2010 respectively (OECD, 2014). According to the recent GBD study, in 2013 alone, total premature deaths due to PM in India was 0.59 million and years of life lost (YLLs) and DALYs were

16.12 million and 16.66 million respectively (Brauer *et al.*, 2015; Salomon *et al.*, 2015).

Different city level studies linked air pollution and health impact have been done in India (Maji *et al.*, 2016a, b; Lelieveld *et al.*, 2015; Nagpure *et al.*, 2014; Gurjar *et al.*, 2010). The city level study helps pollution control authorities to make air quality management and policy development for air quality control at regional level. Various causes of air pollution have triggered megacity cities like Mumbai in India to be high risk areas and their inhabitants are facing various health problems. Such health risks need to be estimated to improve the sustainability of city life and to consolidate the baseline of environmental policy and management.

In this paper human health risk like total mortality, cardiovascular mortality, respiratory mortality, hospital admissions COPD, hospital admissions respiratory disease (HARD) and hospital admissions cardiovascular disease (HACD) due to particulate matter having aerodynamic diameter 10 micrometer or less (PM_{10}), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) are calculated for the megacity Mumbai in India from 1992 to 2013. And the trend of pollution level from past 22 years are analyzed by excess cases of mortality and morbidity per one million population. For these calculations, Air Quality (AirQ) software for Health Impact Assessment developed by WHO was used.

2. METHODOLOGY

The relative risk (RR) is derived from dividing the probability that an exposed group will develop disease by the probability that unexposed group will develop the disease (Rothman *et al.*, 2008). The approach to human health risk (HHR) assessment for the present study used AirQ 2.2.3 software (WHO, 2004) developed by the WHO European Centre for Environment Health, Bilthoven Division. This software adopted **Ri**sk of **M**ortality/Morbidity due to **A**ir **P**ollution (Ri-MAP) model in the present study to estimate the potential impact of exposure to particular air pollutant on the health of people living in an urban area during a certain time period.

The HHR assessment is based on the population attributable risk (PAR) (also called "population attributable risk proportion") concept, defined as the fraction of the excess rate of disease in a given population distinguishable to exposure to a particular atmospheric pollutant, assuming a proven causal relation between exposure and excess rate of disease with no major confounding effects in that association (Maji *et al.*, 2016a; Jeong, 2013; Northridge, 1995). The PAR can be easily calculated by the following general equation:

$$PAR = \sum[\{RR(c)-1\}] \times p(c) / \sum[\{RR(c)-1\} \times p(c)+1] \quad (1)$$

where, RR(c) is the changed relative risk for the health outcome in category "c" of exposure and $RR(c) = 1 + (C_a - C_w) \times (RR - 1)/10$. C_a is the ambient air pollutant concentration, C_w is the WHO recommended threshold level of that pollutant and R_r is the relative risk of exposure-disease relation (the ratio of the conditional disease probabilities among exposed and non-exposed). p(c) is the proportion of the population in category "c" of exposure.

If the baseline frequency (at WHO recommended threshold concentration value) of selected health outcomes (i.e., I_w) in the population under investigation is known then the excess number of cases (ENCs) per unit population (rate) attributed to the exposure in population (i.e., I_E) can be calculated as (WHO, 1999):

$$I_E = I_w \times PAR \quad (2)$$

Consequently, the frequency of the outcome to the non-exposed population (i.e., I_{NE}) can be calculated as follows:

$$I_{NE} = I_w - I_E = I_w \times (1 - PAR) \quad (3)$$

Finally at a certain category of exposure (c) with known RR and the estimated incidence in non-exposed population having population size under investigation (P), the ENCs ($\Delta N(c)$) can be calculated:

$$\Delta N(c) = [R_r(c) - 1] \times p(c) \times I_{NE} \times P \quad (4)$$

Equation 4 is used to estimate ENCs of mortality or morbidity in the exposed population. In practice, however, the range of the estimated health outcome (i.e. uncertainty of the impact) is greater due to measurement errors in exposure assessment because pollutant concentration change time to time and it depends on the area (e.g. industrial or residential), and non-statistical uncertainty of the concentration-response function (WHO, 2003).

The AirQ software uses WHO specified input of RR values (per 10 $\mu g/m^3$ increase of concentration for hazardous substances) and corresponding baseline incidences (per 10^5 population) for different air pollutants (particulate matter having aerodynamic diameter ≤ 10 (PM_{10}), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) etc.) as well as types of diseases (e.g., cardiovascular, respiratory, COPD, hospital admissions respiratory disease etc.) associated with those values (Table 1), based on various previous studies (Burnett *et al.*, 1997; Sunyer, 1997; Touloumi and Katsouyanni, 1997). Annual averages as per WHO guideline for outdoor air quality for NO_2, SO_2 and PM_{10} are 40, 20 and

Table 1. WHO specified default values of Relative risk (RR) (per 10 μg/m^3 increase of daily averages for PM_{10}, SO_2 and NO_2) with 95% confidence intervals (95% CI), implemented in AirQ 2.2.3 software and used for the health effect estimates in this study.

Pollutants	Mortality/Morbidity	Relative Risk (RR)[b] (95% CI) per 10 μg/m^3	Baseline Incidence per 100,000[c]
PM_{10}	Total Mortality[x]	1.0074 (1.0062-1.0086)	1013
	Cardiovascular Mortality[y]	1.0080 (1.0050-1.0180)	497
	Respiratory Mortality[z]	1.0120 (1.0080-1.0370)	66
	Respiratory Disease (Hospital Admission)	1.0080 (1.0048-1.0112)	1260
	Cardiovascular Disease (Hospital Admission)	1.0090 (1.0060-1.0130)	436
SO_2	Total Mortality[x]	1.0040 (1.0030-1.0048)	1013
	Cardiovascular Mortality[y]	1.0080 (1.0020-1.0120)	497
	Respiratory Mortality[z]	1.0100 (1.0060-1.0140)	66
	COPD[a] (Hospital Admission)	1.0044 (1-1.0110)	101.4
NO_2	Cardiovascular Mortality[y]	1.0020 (1-1.0040)	497
	COPD[a] (Hospital Admission)	1.0038 (1.0004-1.0094)	101.4

[a]COPD: Chronic Obstructive Pulmonary Disease
[b]Lower and upper limits (range) of RR values
[c]Baseline Incidence per 100,000 is based on threshold limit given in WHO guideline
International Classification of Diseases (ICD) code number: [x]ICD-9-CM < 800; [y]ICD-9-CM 390-459; [z]ICD-9-CM 460-519

20 μg/m^3 respectively (WHO, 2006) were used in this study.

2. 1 Uncertainly Analysis

The purpose is to study the possible consequences (i.e. uncertainty caused) because of not adopting area specific (e.g., residential/industrial) ambient air pollution concentrations as compared to the city level average concentrations, instrumental uncertainty and uncertainty due to power cut. The AirQ model calculates central relative risks with the addition of lower and upper bounds (i.e. range) for the 95% confidence interval based on the input parameters (Table 1) for all the pollutants. In each of the subsequent figures, solid bars show estimated values of excess number of cases of mortality and morbidity and thin vertical lines show their lower and upper limits i.e. range for the 95% confidence interval. Cardiovascular mortality and hospital admission of COPD are having the highest uncertainties while respiratory mortality is having the least uncertainties (Gurjar *et al*., 2010).

2. 2 Case Study: Mumbai, India

Mumbai metro is the capital of Maharashtra state in the western region of India. With an approximate population of 18.4 million (CI, 2011), it is the second most populous region in India. Such a huge population makes Mumbai the largest energy consumer but environmental conservation mandates and mild weather condition make its per capita energy use the lowest among all Indian states (EGI, 2014). Mumbai is the financial, commercial and entertainment hub of India. It is also one of the world's top ten centers of commerce in terms of global financial flow, generating 6.16% of India's GDP and accounting for 25% of industrial output, 70% of maritime trade in India and 70 % of capital transactions to India's economy (TCPD, 2014). Major industries in Mumbai include chemical products, electrical and non-electrical machinery, pharmaceuticals, textiles, petroleum and allied products.

The methodology as recommended by WHO depends mainly on the concentration of ambient air pollutants and population data. The simple method by using all air quality monitoring station data in the city and taking average of the concentrations for each time unit is followed to evaluate human exposure. This average value is the indicator of exposure of entire city population. Monthly average of ambient air pollution concentrations (μg/m^3) for the critical pollutants namely PM_{10}, SO_2 and NO_2 from all monitoring stations in Mumbai during 1992-2013 are taken from Maharashtra Pollution Control Board (MPCB) and the published data from the zonal laboratory of National Environmental Engineering Research Institute (NEERI) in Mumbai. Monthly average of all monitoring stations data are calculated [with standard deviation (SD)] and considered as overall pollution level in Mumbai (Fig. 1).

Population data in year 1991, 2001 and 2011 are taken from Press Information Bureau, Government of India (PIB, 2011) and Census of India (CI, 2011). Population in consequent years from 1992 to 2013 are calculated by population growth equation, $P = P_0 \exp(kt)$ where P is final population, P_0 is initial population, t is time (in years) and k is exponential growth factor. For all the pollutants, the required parameters for the software (annual, winter and summer maximum; annual,

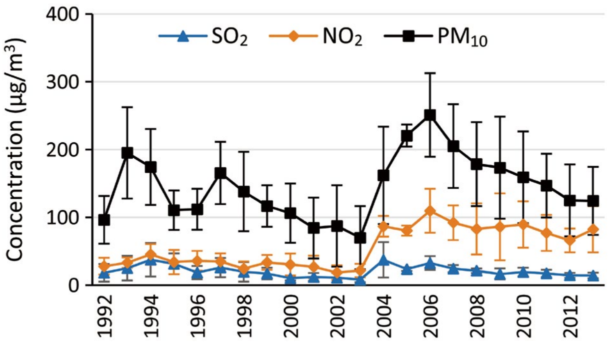

Fig. 1. Trends in annual average concentration (±SD) of SO_2, NO_2 and PM_{10} in Mumbai.

winter and summer mean; and annual 98th percentiles) are estimated and concentrations were recorded to 10 μg/m^3 categories corresponding to equivalent exposure. AirQ model computes mean relative risks with addition of lower and upper bounds (i.e. range) for the 95% confidence interval (CI) based on input parameters for all pollutants.

3. RESULTS

3.1 Application of AirQ Model

The excess number of mortality and morbidly due to PM_{10}, SO_2 and NO_2 from year 1992 to 2013 is shown in Table S1. Trend for excess cases of mortality and morbidity attributable to air pollution in Mumbai from 1992 to 2013 are given in Fig. 2(a) for total mortality, 2(b) for cardiovascular mortality, 2(c) for respiratory mortality, 2(d) for COPD morbidity (hospital admission), 2(e) for respiratory disease (hospital admission) and 2(f) for cardiovascular disease (hospital admission).

3.2 Total Mortality

The excess number of premature deaths (i.e. total mortality) in Fig. 2(a) has been taken into account by using the effects caused by the total sum of two critical pollutants (PM_{10} and SO_2). The excess number of cases [29315 (25035-33322 at 95% CI)] was the highest in 2006, it was parallel to the trend of maximum annual average concentration of PM_{10} (251 μg/m^3), though the concentration of SO_2 (33 μg/m^3) was not highest. In 1992, the excess number of cases was 8420 followed by 16911 in 1997, 7518 in 2003, 20955 in 2004 and 15872 in 2013 (Fig. 2(a)). From 1992 to 2013, the average of excess number of cases was 16259 (13776-18629 at 95% CI). Excess number of cases (89-99%) was responsible due to PM_{10} while 1-11% cases occurred because of SO_2 pollution during the study period.

3.3 Cardiovascular Mortality

Fig. 2(b) shows the excess number of mortality cases estimated by AirQ software due to cardiovascular problems owing to the total sum of three considered pollutants (PM_{10}, SO_2 and NO_2). The excess number of cases [17809 (10079-32721 at 95% CI)] was highest in 2006. In 1992, the excess number of cases was 4914 followed by 9769 in 1997, 4235 in 2003, 13139 in 2004 and 9962 in 2013. From 1992 to 2013 the average excess number of cases was 9678 with high uncertainty (5502-18778 at 95% CI). About 76-93% excess number of cases have been observed due to PM_{10}, 2-24% cases due to SO_2 pollution and 3-13% cases were because of NO_2 pollution.

3.4 Respiratory Mortality

The excess number of respiratory mortality is shown in Fig. 2(c) has taken into account the sum total of effects caused by the two critical pollutants (PM_{10} and SO_2). The excess number of cases [2923 (2082-5896 at 95% CI)] was highest in 2006, it was parallel with the trend of annual average concentration of PM_{10} though the concentration of SO_2 was not high. In 1992, the excess number of cases was 889 followed by 1747 in 1997, 778 in 2003, 2187 in 2004 and 1628 in 2013. The average excess number of cases from 1992 to 2013 was 1663 with high uncertainty (1157-3786 at 95% CI). About 83-98% excess number of cases have been observed due to harmful effect of PM_{10} while 2-17% cases were because of SO_2 pollution.

3.5 Hospital Admission Due to COPD

As shows in Fig. 2(d), the morbidity (hospital admission) cases due to Chronic Obstructive Pulmonary Disease (COPD) is shown a pattern similar to different mortality. In 1992 the excess number of cases was 149 followed by 266 in 1997, 95 in 2003, 699 in 2004 and 580 in 2013. Average excess number of cases was 383/year (32-918 at 95% CI). About 9-52% excess number of cases have been observed due to the harmful effect of SO_2 while 48-91% cases have been noticed because of NO_2 pollution. After 2003 excess number of cases due to COPD was mainly dominated by NO_2 pollution.

3.6 Hospital Admission Due to Respiratory Disease and Cardiovascular Disease

The excess number of morbidity (hospital admission) cases due to respiratory and cardiovascular disease is shown in Fig. 2(e) and Fig. 2(f), which is caused by PM_{10} only. In 1992 the excess number of morbidity due to respiratory disease was 10568 followed by 21029 in 1997, 9960 in 2003, 25430 in 2004 and 20527 in 2013 (Fig. 2(e)). And, in 1992 the excess number morbidity due to cardiovascular disease was 4081 followed by

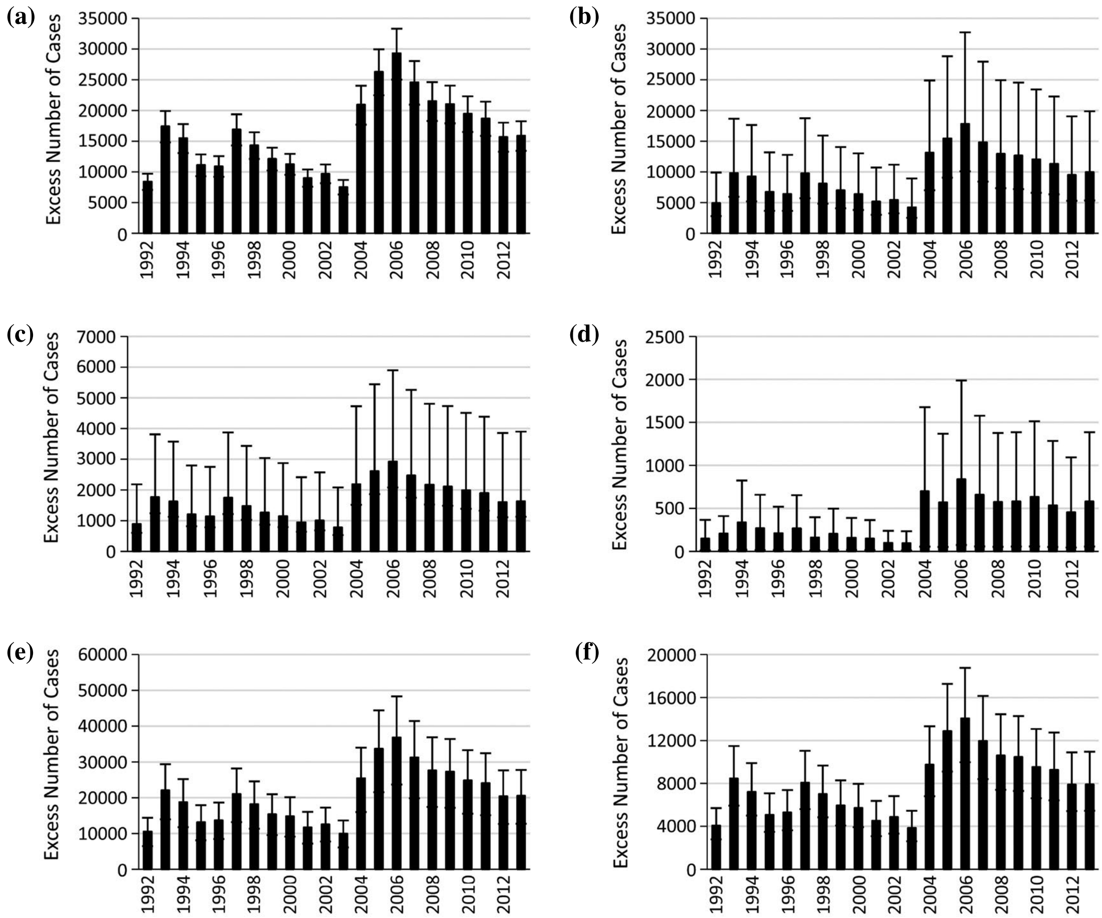

Fig. 2. Excess number of cases of (a) total mortality, (b) cardiovascular mortality, (c) respiratory mortality, (d) COPD morbidity, (e) hospital admission respiratory disease and (f) hospital admission cardiovascular disease in Mumbai (Note: In this and subsequent figures, thick bars show estimated values of excess number of cases and thin vertical lines show their range for the 95% confidence interval).

8072 in 1997, 3855 in 2003, 9755 in 2004 and 7905 in 2013 (Fig. 2(f)). Average excess number of cases due to respiratory disease was 20620 (12961-27678 at 95% CI) and for cardiovascular disease was 7928 (5510-10860 at 95% CI).

All the figures in Fig. 2 are following the same trend except COPD morbidity, because of decreasing trend of SO_2 and NO_2 after the year 2006. The sudden increase of excess number of cases in 2004 was due to increasing widespread construction activities, increasing number of vehicles and uncontrolled bakery industry within the city, certain growth of illegal small scale industries, crematoria emissions, open refuse burning and solid waste landfill burning. To avoid biases generated by different population size and area (e.g. industrial or residential), excess number of cases in one million population had been estimated (Table 2). The average excess number of cases per million population/year were estimated from 1992-2002 and 2003-2013 and it showed that except COPD, all types of mortality/ morbidity increased by more than 30%. The increase of health endpoints are due to increase of PM_{10} in Mumbai. In 1992, average PM_{10} concentration was 96 $\mu g/m^3$ and it became 124 $\mu g/m^3$ in 2013.

4. DISCUSSION

This paper offers a case study using the WHO approach to assess the impact of atmospheric pollution on human health in Mumbai city. The health risk was estimated based on exposure to PM_{10}, SO_2 and NO_2. It was observed that, in Mumbai, from 1992-2002, the per million average excess number of cases for total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD, hospital admis-

Table 2. Per million excess number of cases of mortality and mobility in average from year 1992-2002 and year 2003-2013.

	Total mortality	Cardiovascular mortality	Respiratory mortality	COPD mobility	HARD	HACD
1992-2002	850	492	88	14	1069	412
2003-2013	1131	685	115	32	1442	553
% increased	33.04	39.37	29.58	129.57	34.88	34.38

sion due to respiratory disease and cardiovascular disease were 850, 492, 88, 14, 1069 and 412 respectively, however, from 2003-2013 these figures became 1131, 685, 115, 32, 1442 and 553.

In the previous study, Nagpure *et al.* (2014) observed that in NCT Delhi in 2010, 11394, 3912, 1697 and 16253 excess number of cases of total mortality, cardiovascular mortality, respiratory mortality and hospital admission of COPD respectively were observed, however, in year 2010 these figures became 18229, 6374, 2701 and 26525. In Pune city, the annual average excess number of cases of total mortality, cardiovascular mortality, respiratory mortality, hospital admission of COPD, hospital admission due to respiratory disease and cardiovascular disease were 3502, 2143, 372, 97, 4303, and 1660, respectively, during 2005 to 2013 (Maji *et al.*, 2016a). Gurjar *et al.* (2010) observed that for entire Delhi from 1998 to 2005, the per million average excess number of cases for total mortality, cardiovascular mortality, respiratory mortality and hospital admissions COPD varied between 750 to 930, 250 to 310, 110 to 140 and 105 to 130 respectively. Lelieveld *et al.* (2015) showed that air pollution is responsible for 13500 deaths in Kolkata in year 2010.

From the current and previous studies, it is observed that the excess number of mortality and morbidity is quite high and it is basically due to particulate matter (PM_{10}) rather than due to gaseous pollutants (SO_2 and NO_2). Different combustion processes were the main contributors for PM in Mumbai like power plant, open burning, commercial food sector and road transport, and they contributed by 37%, 24%, 18% and 10% respectively. A study by NEERI (CPCB, 2010) in 2010 found out that open burning and landfill fires of municipal solid waste (MSW) were a major source of air pollution in Mumbai. The survey result showed that about 2% of total generated MSW was burnt on the streets and in slum areas, 10% of the total generated MSW was burnt in landfills by management authorities or due to accidental fires at landfill sites and huge amount of CO, PM, carcinogenic HC and NO_X were emitted. The fine particulate matter $PM_{2.5}$ (particles with aerodynamic diameter $<2.5\ \mu m$) having much more negative influence on lung function owing to smaller size, was not considered in this study. Although, the concentration of $PM_{2.5}$ in Mumbai was higher than the WHO guideline (10 $\mu g/m^3$). The annual average $PM_{2.5}$ concentration in Mumbai from 2000 to 2010 was $78.8 \pm 42\ \mu g/m^3$, and in that period $PM_{2.5}$ concentration increased 24.6 $\mu g/m^3$ (Day *et al.*, 2012). In 2015, the annual average $PM_{2.5}$ was 81 $\mu g/m^3$ (http://mpcb.gov.in/). In the recent year 2016, the average PM_{10} concentration is 138 $\mu g/m^3$, which is about seven times higher than WHO recommended guideline.

The implementation of clean fuel technology (CNG) and EURO norms in vehicular emission standards and phasing out industries from the city area are responsible for low concentration of SO_2 in Mumbai.

The pollution control authorities in Mumbai urgently need proper policies to elevate ambient air quality in terms of PM_{10} levels to decrease the economic costs of air pollution-related health impacts.

4. 1 Limitations and Assumption

There are a number of methodological uncertainties and limitations in the approach which need further improvement to make the method robust. In particular:

a) In the present study, linear association between air pollution concentration and health outcomes is used but recent studies revealed the nonlinear feature of health effects by air pollution (Burnett *et al.*, 2014).

b) Relative risk values used in this study are experimentally developed in United States of America (USA), but a lot of uncertainty is involved when these values are used in any other country like India, as the climatic conditions and economic backgrounds differ starkly from USA.

c) Pollutants are generally of mixed kind - outdoor and indoor air pollutants - associated with synergistic effect which is not considered in the study (Fattore *et al.*, 2011).

d) Since daily resolved data were not available for cities, thus the annual average air quality concentrations were used whereas relative risk values pertain to increases in daily average concentrations. This may be a source of error in risk estimates.

e) The accuracy of the air quality data as available through pollution control board is uncertain due to a wide variety of reasons such as frequent power cut, manpower availability problem, calibration error, and failures of air quality monitoring instruments that might cause an error.

5. CONCLUSION

The proposed and applied methodology is a straightforward spreadsheet model using AirQ software to assess human health effects attributable to air pollutants in Mumbai. AirQ calculates the mortality and morbidity for different pollutants individually and does not consider the synergistic effects of multiple compounds. Estimated excess number of cases are only with reference to the concentrations of pollutants in excess of the levels adopted in the WHO guidelines. However, concentrations lower than the WHO guideline have also excess morbidity and mortality such as long time exposure to PM_{10}. Hence, the pollution control authorities in Mumbai urgently need proper policy to improve ambient air quality in terms of PM_{10} levels. Since all relevant air pollutant components were not included, these mortality and morbidity numbers should be interpreted as lower limits.

In India, $PM_{2.5}$ and PM_{10} ratio is very high about 0.65 (Satsangi *et al*., 2011), which is much greater than USA and Europe (Barmpadimos *et al*., 2012). Long term exposure to $PM_{2.5}$ is strongly related with ischaemic heart disease, cerebrovascular disease, lung cancer and acute lower respiratory infections. Coal based power plant is a major source of energy and particulate matter emissions from coal burning power plants was responsible for 80 to 115 thousand premature deaths in 2011-2012 (Guttikunda and Jawahar, 2014).

For more extensive study, one needs to estimate human health risk due to all the relevant pollutants such as PM_{10}, $PM_{2.5}$, O_3, CO, NO_2, SO_2 and polyaromatic hydrocarbons. And then, the governing parameter like relative risk in WHO model should be developed for the country specific studies. In the absence of these parametric values, WHO approach to assess the impact of atmospheric pollution on human health can be used to get an overall risk levels in the mega cities.

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Table S1. Different health endpoints due to PM_{10}, SO_2 and NO_2 from year 1992 to 2013.

Year	Total mortality	Cardiovascular mortality	Respiratory mortality	COPD mobility	HARD	HACD
Health endpoints due to PM_{10}						
1992	7898	4169	804	–	10568	4081
1993	16588	8711	1628	–	22085	8458
1994	14083	7408	1399	–	18781	7213
1995	9854	5198	998	–	13177	5082
1996	10276	5419	1040	–	13739	5298
1997	15772	8295	1564	–	21029	8072
1998	13647	7187	1366	–	18220	7009
1999	11549	6089	1167	–	15438	5951
2000	11083	5846	1123	–	14821	5717
2001	8754	4623	896	–	11721	4531
2002	9411	4969	961	–	12598	4868
2003	7433	3929	765	–	9960	3855
2004	19081	10030	1886	–	25430	9755
2005	25340	13284	2455	–	33678	12860
2006	27743	14530	2670	–	36836	14045
2007	23477	12331	2293	–	31236	11949
2008	20756	10907	2047	–	27652	10601
2009	20464	10756	2021	–	27269	10458
2010	18610	9791	1850	–	24822	9534
2011	18076	9513	1801	–	24116	9268
2012	15289	8057	1538	–	20425	7896
2013	15365	8097	1546	–	20527	7905
Health endpoints due to SO_2						
1992	522	510	85	58	–	–
1993	847	826	137	93	–	–
1994	1413	1373	227	156	–	–
1995	1266	1231	204	139	–	–
1996	629	614	102	69	–	–
1997	1139	1109	183	125	–	–
1998	689	673	111	76	–	–
1999	577	564	93	64	–	–
2000	162	159	26	18	–	–
2001	249	244	51	28	–	–
2002	280	275	46	31	–	–
2003	85	84	13	9	–	–
2004	1874	1819	300	206	–	–
2005	982	958	159	108	–	–
2006	1572	1529	253	173	–	–
2007	1122	1094	181	123	–	–
2008	778	760	126	86	–	–
2009	576	563	93	63	–	–
2010	857	837	139	94	–	–
2011	620	601	100	68	–	–
2012	408	399	66	45	–	–
2013	506	497	82	56	–	–
Health endpoints due to NO_2						
1992	–	235	–	91	–	–
1993	–	295	–	114	–	–
1994	–	471	–	182	–	–
1995	–	335	–	129	–	–
1996	–	368	–	142	–	–
1997	–	365	–	141	–	–
1998	–	219	–	85	–	–
1999	–	360	–	139	–	–
2000	–	363	–	140	–	–
2001	–	312	–	121	–	–

Table S1. Continued.

Year	Total mortality	Cardiovascular mortality	Respiratory mortality	COPD mobility	HARD	HACD
Health endpoints due to NO_2						
2002	–	172	–	67	–	–
2003	–	222	–	86	–	–
2004	–	1290	–	493	–	–
2005	–	1208	–	462	–	–
2006	–	1751	–	667	–	–
2007	–	1405	–	537	–	–
2008	–	1279	–	489	–	–
2009	–	1351	–	517	–	–
2010	–	1410	–	539	–	–
2011	–	1219	–	467	–	–
2012	–	1068	–	410	–	–
2013	–	1369	–	524	–	–