



## Assessment of City Level Human Health Impact and Corresponding Monetary Cost Burden due to Air Pollution in India Taking Agra as a Model City

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### ABSTRACT

Objectives of the present study are to provide quantitative estimations of air pollution health impacts and monetary burden on people living in Agra city, the fourth most populated city in Uttar Pradesh, India. To estimate the direct health impacts of air pollution in Agra city during year 2002 to 2014, ‘Risk of Mortality/Morbidity due to Air Pollution’ model was used which is adopted from air quality health impact assessment software, developed by world health organization (WHO). Concentrations of NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub> have been used to assess human health impacts in terms of attributable proportion of the health outcome as- annual number of excess cases of total mortality, cardiovascular mortality, respiratory mortality, hospital admission chronic obstructive pulmonary disease (COPD), hospital admission respiratory disease and hospital admission cardiovascular disease and it was observed that attributable number of cases were 1325, 908, 155, 138, 1230 and 348 respectively in year 2002. However, after thirteen years these figures increased to 1607, 1095, 189, 167, 1568 and 394 respectively. From these results, it was observed that from 2002 to 2014, the attributable number of cases increased almost by 13.43 to 27.52%. As a result, the monetary cost burden due to air pollution related health effects also increased very highly; it was 67.99 million US\$ in 2002, which transformed into 254.52 million US\$ in 2014. In future, if air quality continues to follow current pollutant concentration trend, the monetary cost burden will reach a level of US\$ 570.12 million in year 2020, which is not only a thoughtful matter but also a threatful matter and it signifies the importance of rectification measures for air quality in Agra city.

**Keywords:** Air pollution; Relative risk; AirQ; Health endpoint; Monetary cost.

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### INTRODUCTION

Air Pollution is posing a great threat for human health because of its unfavorable health impacts like cardiovascular mortality, respiratory mortality, cancer, COPD, asthma etc. (Pope *et al.*, 1995; Sunyer *et al.*, 1997; Brunekreef and Holgate, 2002; Brunekreef, 2010; Correia *et al.*, 2013; Averett, 2015; Barrett, 2015). Epidemiological time series studies of air quality health impacts had been carried out in different cities in the world namely Tehran in Iran (Naddafi *et al.*, 2012); Beijing (Zhang *et al.*, 2007), Taiyuan, Shanxi (Zhang *et al.*, 2010a), Shanghai (Kan and Chen, 2004) and Lanzhou (Tao *et al.*, 2014) in China; ten Canadian cities (Vanos *et al.*, 2013); Bangkok in Thailand (Vichit-Vadakan *et al.*, 2008); Alabama, Philadelphia and Pennsylvania in

United States (Smoyer *et al.*, 2000; Caiazzo *et al.*, 2013). Similar studies have also been carried out in different cities of India as: Kolkata (Ghose *et al.*, 2005; Gurjar *et al.*, 2016), Delhi (Alberini *et al.*, 1997; Gurjar *et al.*, 2010; HEI, 2011; Rizwan *et al.*, 2013; Nagpure *et al.*, 2014), Mumbai (Joseph *et al.*, 2003; Maji *et al.*, 2016), Chandigarh (Gupta *et al.*, 2001) and Chennai (Jayanthi and Krishnamoorthy, 2006; HEI, 2011).

It is necessary to assess the monetary cost due to air pollution related health effects, for more effective air quality control and public awareness about environmental protection. There are different approaches to assess economic cost due to air pollution like willingness-to-pay (WTP), cost of illness (CoI) and value of a statistical life (VSL). WTP considers how much income or wealth individuals would be willing to exchange for decrease in the risk of particular health impairments or premature mortality due to air pollution. CoI measures the total cost of illness including travel cost, hospital admission cost, medical cost and day loss. VSL represents the value of a small change in relation to the risk of dying for a person in a large group.

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Economic cost assessment of the health impact related to air pollution was carried out for different cities like Beijing, Guangzhou, Shanghai and Nanjing in China (Kan and Chen, 2004; Zhang *et al.*, 2008), Singapore (Quah and Boon, 2003), Nigeria (Yaduma *et al.*, 2012), Mumbai (Patankar and Trivedi, 2011) and Chennai (Madheswaran, 2007).

Rapid industrial growth and urbanization has posed huge challenges of balancing between economy and environment for developing countries like India. During the past decade India is emerged as one of the fastest growing economic country in the world with 7.46% growth rate (IMF, 2015). In 2014, the gross domestic product (GDP) of India was USD 2.067 trillion with an increment rate of 7.3% (WB, 2015). To achieve an ambitious growth rate of 9%, India has started utilizing its natural resources much more vigorously. In 2012, India consumed 744.5 million tons of coal, 121.6 million barrels of motor gasoline, 40.4 million barrels of jet fuel, 70 million barrels of kerosene and 140 million barrels of liquefied petroleum gas (LPG) resulting into dramatically deteriorated air quality and polluted natural environment (EIA, 2015).

In India, premature death cases occurred due to outdoor air pollution about 0.62 million in 2005 and 0.69 million in 2010 (OECD, 2014). The total economic cost of health impacts due to outdoor air pollution was about US\$ 80 billion in 2010, which was equivalent to 5.7% of Indian GDP. The cost of serious health consequences due to PM<sub>10</sub>, caused by fossil fuel burning, was amounted about 3% (1.7% by outdoor air pollution and 1.3% by indoor air pollution) of India's GDP (WB, 2013).

The time series study in this paper focuses on quantitative assessment of short term health impact like total mortality (TM), cardiovascular mortality (CM), respiratory mortality (RM), hospital admission chronic obstructive pulmonary disease (HA-COPD), hospital admission respiratory disease (HA-RD) and hospital admission cardiovascular disease (HA-CD) due to critical pollutants [NO<sub>2</sub>, SO<sub>2</sub> and particulate matter having aerodynamic diameter ≤ 10 (PM<sub>10</sub>)] in Agra city in Uttar Pradesh, India from 2002 to 2014, using 'Risk of Mortality/ Morbidity due to Air Pollution' (Ri-MAP). Health impact related monetary cost also has been calculated in the present study.

## METHODOLOGY

### *Air Pollutants Concentration and Population Data*

The Agra city is situated in western Uttar Pradesh between 27.11°N and 78.20°E, on the bank of river Yamuna. It is 23<sup>rd</sup> most populated city in India. In 2011, its population was 1574542 with an area of 188.4 km<sup>2</sup> (Census of India, 2015). In Agra, maximum and minimum temperature during summer is 45°C and 21.9°C, while during winter, it is 31.7°C and 4.2°C. This city is home to Tajmahal, one of the Seven Wonders of the World. The Ri-MAP model is used in this study depending mainly upon ambient air pollution concentrations and population data. The yearly average ambient air pollution concentrations (µg m<sup>-3</sup>) data from 2002 to 2014 for criteria pollutants, namely; NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub> are taken from four monitoring stations which

belong to Central Pollution Control Board (CPCB) (CPCB, 2015). Stations are located at Tajmahal, Etmad-ud-daulah, Rambagh and Nunhai. Population data in 2001 and 2011 have been taken from Census of India (Census of India, 2015) and population of subsequent years from 2002 to 2014 was calculated by population growth equation:  $P = P_0 \exp(kt)$  (WOU, 2015), where  $P$ ,  $P_0$ ,  $t$  and  $k$  denote final population, initial population, time (year) and exponential growth factor respectively.

### **Human Health Risk Assessment**

The relative risk ( $R_r$ ) is the ratio of the probability that an exposed group will develop disease relative to the probability of an unexposed group developing the same disease due to air pollutants (Rothman *et al.*, 2008). Present research uses the AirQ 2.2.3 software (WHO, 2015) developed by the WHO European Centre for Environment Health, Bilthoven Division for assessment of human health impact (HHI). This software uses *Ri-MAP* model to estimate the potential impact of particular air pollutant exposure on human health in an urban area during a specified time period.

The HHI 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 (Gefeller, 1992; Northridge, 1995). The *PAR* can be easily calculated by the following general equation (Krzyzanowski, 1997; WHO, 1999; Rodrigues-Silva *et al.*, 2012; Mahapatra *et al.*, 2014):

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

where,  $R_r(c)$  is the changed relative risk for the health outcome in category "c" of exposure and  $R_r(c) = 1 + (C_a - C_w) \times (R_r - 1) / 10$ .  $C_a$  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.

At a baseline frequency (as per WHO guideline) of selected health outcome in the population ( $I_w$ ) (Table 1), the rate (or number of cases per 10<sup>5</sup> population) attributed to the exposure in population (i.e.,  $I_E$ ) can be estimated as (WHO, 1999):

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

If size of population is known, the number of cases attributable to the exposure will be estimated as the following equation:

$$I_{NE} = I_E \times N \quad (3)$$

where  $I_{NE}$  is the estimated number of cases attributed to the

**Table 1.** Relative risk ( $R_r$ ) (per  $10 \mu\text{g m}^{-3}$  increase of  $\text{NO}_2$ ,  $\text{SO}_2$  and  $\text{PM}_{10}$ ) with 95% confidence intervals (95% CI), and baseline incidence (per 100000) corresponding to short term mortality and morbidity implement in AirQ software.

Pollutants	Mortality/Morbidity	Relative Risk ( $R_r$ ) <sup>b</sup> (95% CI) per $10 \mu\text{g m}^{-3}$	Baseline Incidence per 100,000 <sup>c</sup> ( $I_w$ )	Reference
$\text{NO}_2$	Total Mortality	1.0242 (1.0157–1.0327)	543.5	Huang et al., 2011; Shang et al., 2013
	Cardiovascular Mortality <sup>y</sup>	1.0206 (1.0082–1.0332)	497	Huang et al., 2011; Shang et al., 2013
	Respiratory Mortality	1.0371 (1.0109–1.064)	48.4	Huang et al., 2011; Shang et al., 2013
	COPD <sup>a</sup> Morbidity (Hospital Admissions)	1.0090 (1.0051–1.0129)	101.4	Lai et al., 2013
	Respiratory Disease (Hospital Admissions)	1.006 (1.0013–1.0106)	1260	Chen et al., 2010; Lai et al., 2013
	Cardiovascular Disease (Hospital Admissions)	1.0095 (1.0054–1.0136)	436	Chen et al., 2010; Lai et al., 2013
$\text{SO}_2$	Total Mortality <sup>x</sup>	1.0068 (1.0024–1.0112)	1013	Wong et al., 2008; Shang et al., 2013
	Cardiovascular Mortality <sup>y</sup>	1.0103 (1.0021–1.0185)	497	Wong et al., 2008; Shang et al., 2013
	Respiratory Mortality <sup>z</sup>	1.0106 (1.0006–1.0206)	66	Wong et al., 2008; Shang et al., 2013
	COPD <sup>a</sup> Morbidity (Hospital Admissions)	1.0070 (1–1.0141)	101.4	Lai et al., 2013
	Respiratory Disease (Hospital Admissions)	1.0014 (1–1.0043)	1260	Chen et al., 2010; Lai et al., 2013
	Cardiovascular Disease (Hospital Admissions)	1.0079 (1–1.0163)	436	Chen et al., 2010; Lai et al., 2013
$\text{PM}_{10}$	Total Mortality <sup>x</sup>	1.0044 (1.0017–1.0071)	1013	Balakrishnan et al., 2011; Dholakia et al., 2014
	Cardiovascular Mortality <sup>y</sup>	1.006 (1.0029–1.0091)	497	Zhang et al., 2010b; Shang et al., 2013
	Respiratory Mortality <sup>z</sup>	1.0082 (1.0004–1.0161)	66	Zhang et al., 2010b; Shang et al., 2013
	COPD <sup>a</sup> Morbidity (Hospital Admissions)	1.0050 (1.0030–1.0070)	101.4	Lai et al., 2013
	Respiratory Disease (Hospital Admissions)	1.0039 (1–1.0082)	1260	Chen et al., 2010; Lai et al., 2013
	Cardiovascular Disease (Hospital Admissions)	1.0021 (1.0001–1.0041)	436	Chen et al., 2010; Lai et al., 2013

<sup>a</sup> COPD: Chronic Obstructive Pulmonary Disease.

<sup>b</sup> Lower and upper limits (range) of  $R_r$  values.

<sup>c</sup> Baseline Incidence per 100,000 is based on threshold limit given in WHO guideline.

International Classification of Diseases (ICD) code number: <sup>x</sup> ICD-9-CM < 800; <sup>y</sup> ICD-9-CM 390–459; <sup>z</sup> ICD-9-CM 460–519.

exposure. N indicates the size of the investigated population.

Eq. (3) is used to estimate number of cases of mortality or morbidity in the exposed population. The AirQ software is applied using pollutants concentration specified input of  $R_r$  values and corresponding baseline incidences for different air pollutants as well as types of diseases associated with those values (Table 1), based on previous studies (Wong et al., 2008; Chen et al., 2010; Zhang et al., 2010b; Balakrishnan et al., 2011; Huang et al., 2011; Lai et al., 2013; Shang et al., 2013; Shang et al., 2013; Dholakia et al., 2014).

### Monetary Costs of Health Effects

The value of a statistical life (VSL) represents an individual's willingness-to pay (WTP) for a marginal reduction in the risk of death. As an alternative choice, cost of illness (CoI) method was employed for some morbidity endpoints that could be valued from the existing WTP literatures. The VSL for residents of other cities were

determined from the marginal WTP, considering annual income differences between two cities. The VSL can be given as follows:  $VSL_{Agr} = VSL_{Mum} \times (Inc_{Agr}/Inc_{Mum})^e$  where  $VSL_{Agr}$  and  $VSL_{Mum}$  are the VSL of city Agra and Mumbai, respectively, while  $Inc_{Agr}$  and  $Inc_{Mum}$  represent the income of Agra and Mumbai, respectively. 'e' is the elastic coefficient of WTP and is assumed to be 1.0 (Zhang et al., 2008).

The cost for hospital admissions (HA-COPD, HA-CD and HA-RD) was estimated using CoI approach (Patankar and Trivedi, 2011; Srivastava and Kumar, 2002) and cost of death from outdoor air pollution per person (VSL) was estimated using WTP approach (ORCD, 2014). With the increasing cost of treatment, the monetary burden of health impacts is also increasing every year. That's why to estimate the trends in monetary burden, per year 10% increase in the price of medicines and hospital admission charges are considered (Patankar and Trivedi, 2011; ORCD, 2014) (Table 2).

**Table 2.** Unit values for various health endpoints in Agra in 2010 (in US\$).

Health endpoints	Value (in US\$)	Approach	Reference
Mortality	60000	WTP	OECD, 2014
HA-COPD	510.3	CoI	Patankar and Trivedi, 2011
HA-RD	130.3	CoI	Srivastava and Kumar, 2002
HA-CD	266.2	CoI	Patankar and Trivedi, 2011

## RESULTS

Annual average WHO guideline for outdoor air quality for NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub> are 40, 20 and 20 µg m<sup>-3</sup> respectively (WHO, 2006), used in this study. Yearly average pollution concentration data are shown in Fig. 1. Annual average NO<sub>2</sub> value never exceeded WHO air quality guideline. In some year, annual average of SO<sub>2</sub> value exceeded the guideline, but after 2008 a decreasing trend was observed. In case of PM<sub>10</sub> annual average concentrations were always higher than the WHO guideline at all four monitoring stations.

Average PAR percentage from 2002 to 2014 for morbidity and mortality for each pollutant has been estimated (Table 3) for HHI assessment based on WHO recommended input parameter (Table 1).

### Application of AirQ Model

Trend for attributable number of estimated cases of mortality and morbidity due to air pollution in Agra from 2002 to 2014 are illustrated in Fig. 2(a) for TM, 2(b) for

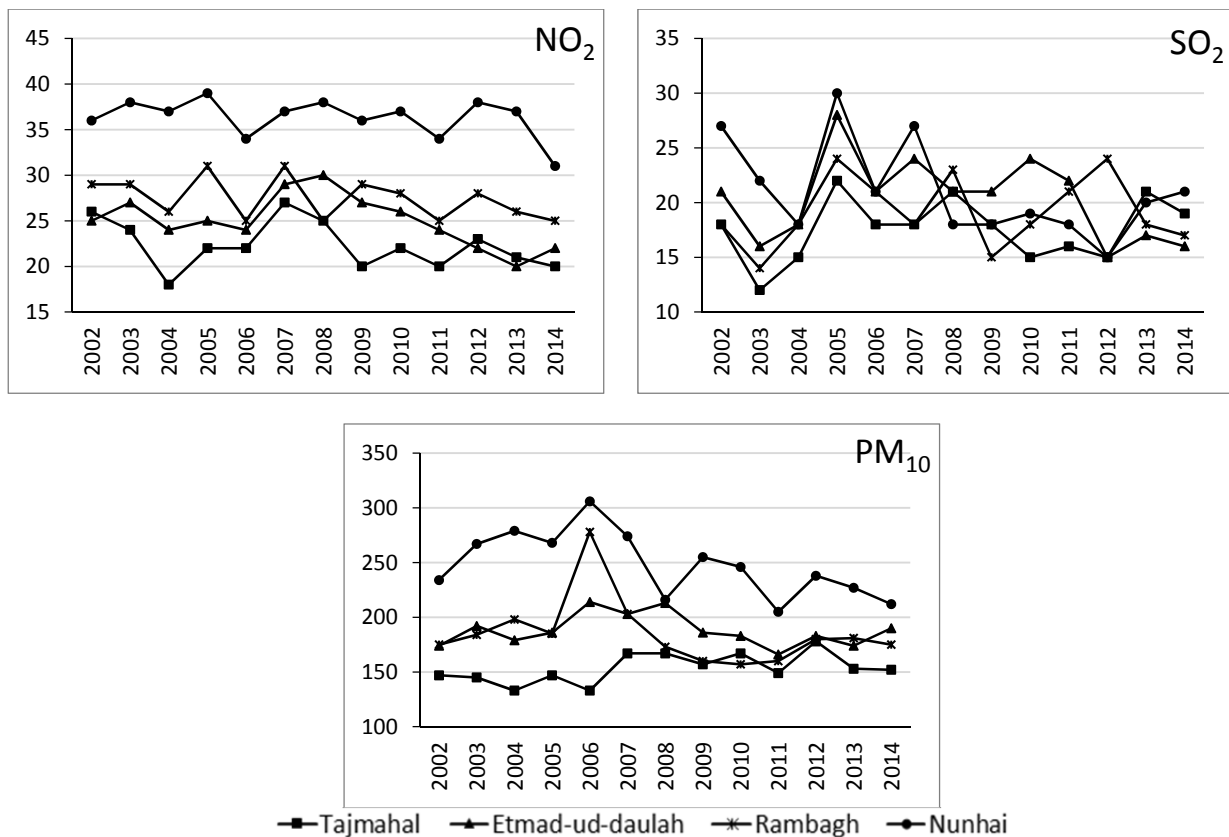
CM, 2(c) for RM, 2(d) for HA-COPD, 2(e) for HA-RD and 2(f) for HA-CD.

### Total Mortality

The attributable number of premature deaths (i.e., TM) in Fig. 2(a) has been taken into account by the effects of total sum of three critical pollutants NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>. In 2002, the attributable number of cases was 1325 (95% CI: 592–2088) followed by 1766 (95% CI: 783–2659) in 2006, 1473 (95% CI: 637–2220) in 2010 and 1607 (95% CI: 728–2421) in 2014. From 2002 to 2014, the annual average of attributable number of estimated cases was 1561 (95% CI: 708–2346) and it increased almost by 21.2%. Attributable numbers of estimated cases of total mortality has been observed - about 15.33–28.01% due to NO<sub>2</sub>, 3.10–10.06% due to SO<sub>2</sub> and 64.90–77.24% due to PM<sub>10</sub> concentration.

### Cardiovascular Mortality

Fig. 2(b) shows the attributable number of mortality cases due to cardiovascular problems owing to the total sum for



**Fig. 1.** Concentration (µg m<sup>-3</sup>) of (a) NO<sub>2</sub> (b) SO<sub>2</sub> and (c) PM<sub>10</sub> at (i) Tajmahal, (ii) Etmad-ud-daulah, (iii) Rambagh and (iv) Nunhai in Agra from 2002 to 2014.

**Table 3.** Average population attributable risk (PAR) (%) value and the rate (or number of cases per 10<sup>5</sup> population) attributed to the exposure in population (i.e.,  $I_E$ ) for mortality and morbidity in case of NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>.

Pollutants	TM	CM	RM	HA-COPD	HA-RD	HA-CD	
NO <sub>2</sub>	PAR	4.0110 (2.6414–5.3407)	3.4360 (1.3981–5.4177)	6.0138 (1.8496–9.9208)	1.5324 (0.8745–2.1812)	1.0272 (0.2244–1.7997)	1.6161 (0.9255–2.2967)
	$I_E$	21.7985 (14.2055–29.0248)	17.0752 (6.9497–26.9240)	2.9111 (0.8951–4.8012)	1.5539 (0.8858–2.2117)	12.9412 (2.8290–22.6758)	7.0461 (4.0349–10.0123)
SO <sub>2</sub>	PAR	0.5968 (0.2117–0.9782)	0.9005 (0.1853–1.6025)	0.9264 (0.0530–1.7802)	0.6143 (0–1.2274)	0.1237 (0–0.3785)	0.6925 (0–1.4154)
	$I_E$	6.0450 (2.1440–9.9071)	4.4750 (0.9209–7.9636)	0.6112 (0.0350–1.1747)	0.6228 (0–1.2451)	1.5576 (0–4.7682)	3.0176 (0–6.1700)
PM <sub>10</sub>	PAR	7.6363 (3.0971–11.7655)	10.1291 (5.1690–14.5919)	13.3430 (0.7466–23.1932)	8.5873 (5.3377–11.6193)	6.8285 (0–13.3430)	3.7978 (0.1877–7.1533)
	$I_E$	77.3530 (31.3724–119.1812)	50.3409 (25.6891–72.5186)	8.8050 (0.4932–15.3064)	8.7069 (5.4126–11.7813)	86.0344 (0–168.1159)	16.5581 (0.8187–31.1877)

three considered pollutants PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub>. In 2002, the attributable number of estimated cases was 908 (95% CI: 412–1372) followed by 1193 (95% CI: 559–1771) in 2006, 1004 (95% CI: 474–1496) in 2010 and 1095 (95% CI: 517–1632) in 2014. From 2002 to 2014 the annual average attributable number of cases was 1067 with high uncertainty (95% CI: 498–1593) and it increased about 20.6%. Attributable number of cases for cardiovascular mortality has been observed - about 17.76–31.80% due to NO<sub>2</sub>, 3.33–10.85% due to SO<sub>2</sub> and 60.88–74.0% due to PM<sub>10</sub>.

#### Respiratory Mortality

The attributable number of respiratory mortality, as shown in Fig. 2(c), has been estimated by taking into account the sum total of effects caused by critical pollutants NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>. In 2002, the attributable number of cases was 155 (95% CI: 17–270) followed by 203 (95% CI: 21–346) in 2006, 174 (95% CI: 20–301) in 2010 and 189 (95% CI: 21–329) in 2014. The annual average attributable number of cases from 2002 to 2014 was 183 (95% CI: 21–316). Out of total, attributable number of cases has been observed: 17.92–31.24% due to NO<sub>2</sub>, 2.63–8.73% due to SO<sub>2</sub> and 62.85–75.02% due to harmful effects of PM<sub>10</sub>. Contribution of SO<sub>2</sub> decreased after 2008, due to implementation of EURO norms in vehicles emission standards.

#### Hospital Admission due to COPD

As shown in Fig. 2(d), the morbidity (hospital admission) cases due to chronic obstructive pulmonary disease (COPD) have been calculated by taking into account the effects of total sum of three critical pollutant NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>. In 2002, the attributable number of estimated cases was 138 (95% CI: 76–197) followed by 186 (95% CI: 106–261) in 2006, 153 (95% CI: 90–213) in 2010 and 167 (95% CI: 99–232) in 2014. From 2002 to 2014 the annual average attributable number of cases was 162 (95% CI: 94–226) and it increased only by 21.37%. PM<sub>10</sub> is primarily responsible for attributable number of COPD and its concentration did not change much in Agra city. Attributable number of estimated cases has been observed - about 10.33–19.96% due to NO<sub>2</sub>, 3.16–9.96% due to SO<sub>2</sub> and 72.36–83.45%

due to PM<sub>10</sub>.

#### Hospital Admission due to Respiratory Disease

The attributable number of morbidity (hospital admission) case due to respiratory diseases is shown in Fig. 2(e), has been estimated by taking into account the sum total of effects caused by critical pollutants NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>. In 2002, the attributable number of estimated morbidity due to respiratory disease was 1230 (95% CI: 32–2423) followed by 1702 (95% CI: 35–3290) in 2006, 1438 (95% CI: 38–2802) in 2010 and 1568 (95% CI: 42–3057) in 2014. From 2002 to 2014 the annual average attributable number of estimated cases was 1493 (95% CI: 42–2905) and it increased almost by 27.52%. Attributable number of cases for cardiovascular mortality has been observed - about 9.39–17.85% due to NO<sub>2</sub>, 0.84–2.80% due to SO<sub>2</sub> and 79.95–88.40% due to PM<sub>10</sub>.

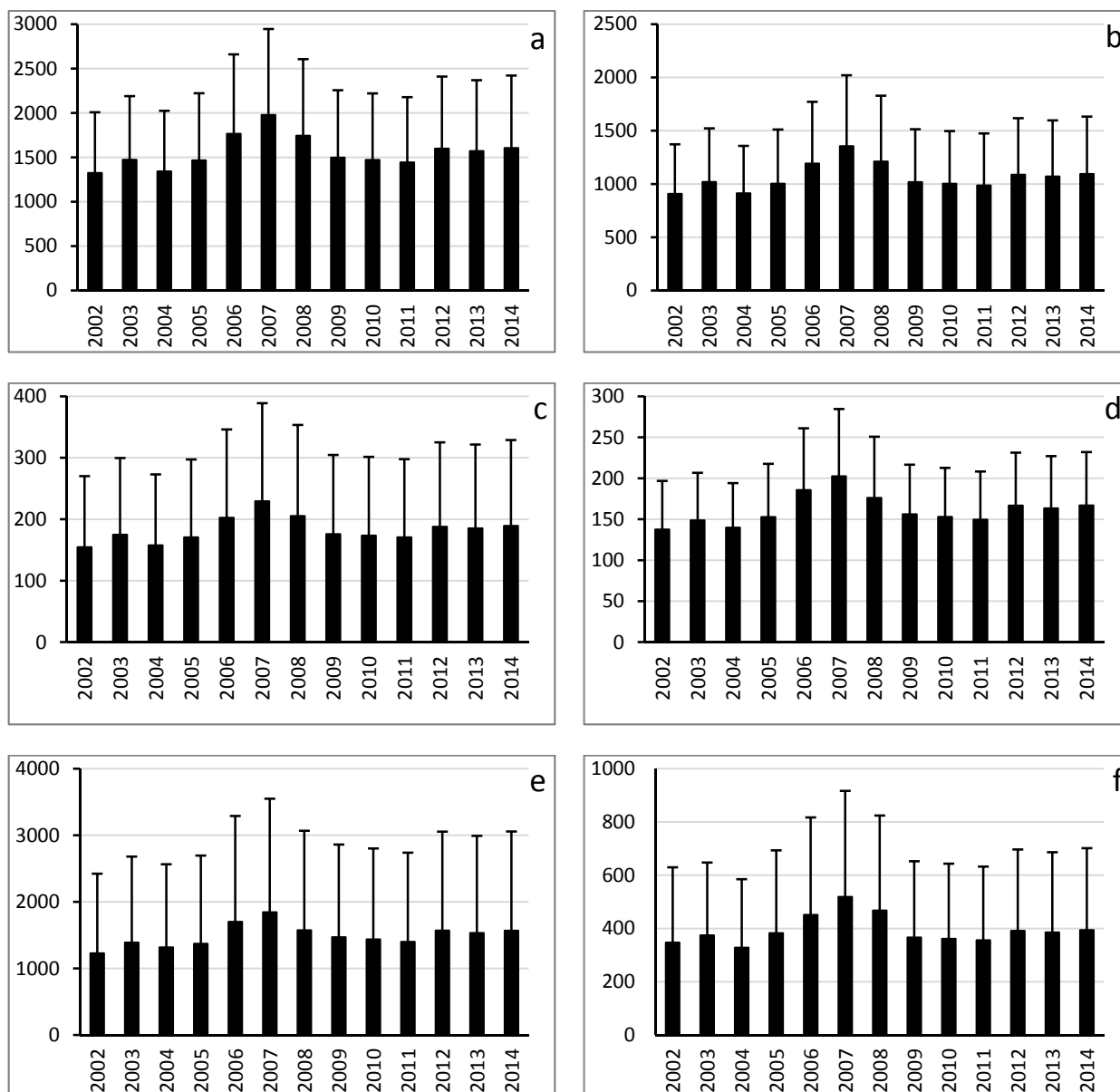
#### Hospital Admission due to Cardiovascular Disease

The attributable number of morbidity (hospital admission) case due to cardiovascular diseases are shown in Fig. 2(f), which are sum of the caused by NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub>. In 2002, the attributable number of estimated morbidity due to cardiovascular disease was 348 (95% CI: 56–630) followed by 451 (95% CI: 64–817) in 2006, 362 (95% CI: 66–643) in 2010 and 394 (95% CI: 72–702) in 2014. From 2002 to 2014 the annual average attributable number of estimated cases was 394 (95% CI: 72–702) and it increased almost by 13.43%. Attributable number of cases for cardiovascular mortality has been observed - about 19.30–35.95% due to NO<sub>2</sub>, 6.08–19.13% due to SO<sub>2</sub> and 51.72–67.53% due to PM<sub>10</sub>.

All the figures in Fig. 2, are following the same trend which is parallel with the trend of annual average concentration of PM<sub>10</sub>. Maximum estimated number of attributable cases was observed in year 2007 because of high value of annual average NO<sub>2</sub> (31 µg m<sup>-3</sup>), SO<sub>2</sub> (22 µg m<sup>-3</sup>) and PM<sub>10</sub> (212 µg m<sup>-3</sup>).

#### Estimation of Monetary Burden

Personal expenses towards cost of treatment; including travel cost, incurred expenditure of government for public



**Fig. 2.** Attributable number of cases of (a) total mortality, (b) cardiovascular mortality, (c) respiratory mortality, (d) HA-COPD (e) hospital admission respiratory disease (HARD) and (f) hospital admission cardiovascular disease (HACD) in Agra.

healthcare facilities and societal costs due to loss of productivity, were considered to assess the total monetary burden of mortality and morbidity caused by air pollution. Total economic cost burden in Agra city from 2002 to 2014 is shown in Table 4. From 2002 to 2014, the total economic cost burden increased 3.74 times but the attributable number of estimated mortality and morbidity (i.e., health endpoints) increased only by 1.13 to 1.28 times. However, within the total economic cost, premature death played a dominant role by contributing 99.77%.

## DISCUSSIONS

In this case study, area specific ambient air pollution concentrations are not considered to calculate HHI. For that, to avoid biases caused by population size, population

density, area type (i.e., residential or industrial) around different monitoring stations and to know individual pollutants contribution towards health endpoint, annual average attributable number of cases in one million population have been estimated (Table 5).

In this study,  $PM_{10}$  has the highest health effect on the people living (1.28 million in 2001 and 1.59 million in 2011) in Agra city. This is consistent with the results of Ri-MAP model studies, conducted for assessment of health impacts in different cities. A summary of the results of a number of similar studies is presented in Table 6.

The monetary burden of health impacts is likely to increase in future, as the cost of treatment increases 10% each year and population increases 2.2% per year as per Indian census data. In future, if annual average pollutant concentration does not show decreasing trend, then in year

**Table 4.** Monetary cost of health effects associated with air pollution in Agra from 2002 to 2014 (mean and 95% CI) (in million US\$)

Year	Mortality cost	HA-COPD cost	HA-RD cost	HA-CD cost	Total cost (million US\$)
2002	67.84 (28.98–103.69)	0.03 (0.02–0.05)	0.08 (0.00–0.15)	0.04 (0.01–0.08)	67.99 (29.01–103.97)
2003	84.25 (37.94–126.60)	0.04 (0.02–0.06)	0.10 (0.00–0.18)	0.05 (0.01–0.09)	84.44 (37.98–126.93)
2004	84.69 (33.99–128.16)	0.04 (0.03–0.06)	0.10 (0.00–0.20)	0.05 (0.01–0.09)	84.88 (34.02–128.51)
2005	102.95 (44.04–157.06)	0.05 (0.03–0.07)	0.12 (0.00–0.23)	0.07 (0.01–0.12)	103.19 (44.08–157.48)
2006	136.89 (59.00–206.83)	0.07 (0.04–0.10)	0.16 (0.00–0.31)	0.09 (0.01–0.16)	137.21 (59.05–207.39)
2007	171.48 (75.71–257.61)	0.08 (0.05–0.12)	0.19 (0.01–0.37)	0.11 (0.02–0.20)	171.86 (75.78–258.29)
2008	169.00 (74.42–255.90)	0.08 (0.04–0.11)	0.18 (0.01–0.36)	0.11 (0.02–0.20)	169.37 (74.49–256.56)
2009	159.98 (70.12–242.07)	0.08 (0.05–0.11)	0.19 (0.00–0.37)	0.10 (0.02–0.17)	160.34 (70.18–242.72)
2010	159.00 (67.86–241.03)	0.08 (0.05–0.11)	0.19 (0.00–0.37)	0.10 (0.02–0.17)	159.36 (67.93–241.67)
2011	171.68 (75.21–260.69)	0.08 (0.05–0.12)	0.20 (0.01–0.40)	0.11 (0.02–0.19)	172.07 (75.28–261.39)
2012	208.78 (91.51–315.94)	0.10 (0.06–0.14)	0.25 (0.01–0.49)	0.13 (0.02–0.23)	209.26 (91.60–316.80)
2013	225.82 (98.92–342.30)	0.11 (0.07–0.16)	0.27 (0.01–0.52)	0.14 (0.03–0.25)	226.34 (99.02–343.22)
2014	253.94 (111.26–384.94)	0.13 (0.07–0.18)	0.30 (0.01–0.59)	0.16 (0.03–0.28)	254.52 (111.37–385.98)

**Table 5.** Annual average attributable number of health endpoint cases in one million population for NO<sub>2</sub>, SO<sub>2</sub> and PM<sub>10</sub> (mean and 95% CI).

Pollutant	TM	CM	RM	HA-COPD	HA-RD	HA-CD
NO <sub>2</sub>	218 (142–290)	171 (69–269)	29 (9–48)	16 (9–22)	129 (28–227)	70 (40–100)
SO <sub>2</sub>	60 (21–99)	45 (9–80)	6 (0–12)	6 (0–12)	16 (0–48)	30 (0–62)
PM <sub>10</sub>	774 (314–1192)	503 (257–725)	88 (5–153)	87 (54–118)	860 (0–1681)	166 (8–312)
Total	1052 (477–1581)	719 (336–1074)	123 (14–213)	109 (63–152)	1005 (28–1956)	266 (49–474)

2020, the economic cost burden of health effects in Agra city will be US\$ 570.12 million (Fig. 3), with an increment rate of 12.42% each year. Trend of monetary burden from year 2002 to 2020 is shown in Fig. 3.

#### Reason of Pollution in Agra City

From the above study, it is observed that attributable number of estimated mortality and morbidity are mainly due to particulate matter (PM<sub>10</sub>). Emissions from 70 thousand generators which are used because of daily power shortages, increasing number of three-wheelers running on diesel, emissions from 212 coal based industrial units and the Mathura oil refinery located nearby city are major source of high levels of particulate matter in Agra. Electrical goods, plastic, iron casting, leather and shoes production are major industries of Agra city. The number of vehicles is increased alarmingly over the past few years in this city. Personal vehicles, along with diesel run three wheelers, known as Vikram, are the main source of vehicular pollution (DE, 2015). Other than these sectors MSW burning also emerged as a significant contributor. The total estimated municipal solid waste (MSW) burn in Agra is 223 tons/day in summer, which is about 24% of the city's total daily MSW generation (923 tons/day) (Nagpure et al., 2015). Vehicles and other machines, that burn fossil fuels, are primary source of black carbon, while burning of biomass and garbage are typical source of organic carbon, which has been consistently affecting the white aesthetics of Tajmahal (TI, 2015).

#### Uncertainly Analysis for Confidence Interval (CI)

In the present study, yearly average data of ambient air pollution is used, which belong to the CPCB. The accuracy

of air quality data, as available through CPCB, is uncertain. This could be a substantial source of error, especially in Agra city, because of insufficient resources, expertise and air quality monitoring infrastructure. The uncertainties because the study area are not categorized into residential or industrial area and the uncertainty also might be for instrumental error (absolute percentage error for SO<sub>2</sub>, NO<sub>2</sub> and PM<sub>10</sub> were 3.11, 4.47 and 5.83% respectively) (CPCB, 2015).

The Ri-MAP model calculates central value of mortality and morbidity with 95% CI, based on the input parameters (Table 1) for all the pollutants. In each subsequent figure (Fig. 2) solid bars show estimated values of attributable number of cases of health outcome and thin vertical lines show their lower and upper limits. It is also shown from the figures that CM and HA-COPD have highest uncertainties, while RM shows the least uncertainty for Agra city. PAR (Table 3), economic cost burden (Table 4) and annual average attributable number of estimated case in one million population (Table 5) have also been estimated with 95% CI.

#### Limitation and Assumption Made

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

- Relative risk values used in this study experimentally developed in United States of America, but so many uncertainties are involved when these values are used in any other country like India, as the climatic conditions and economic backgrounds differ starkly from United State of America.
- Pollutants are generally of mixed kind- outdoor and indoor air pollutants, associated with synergistic effect

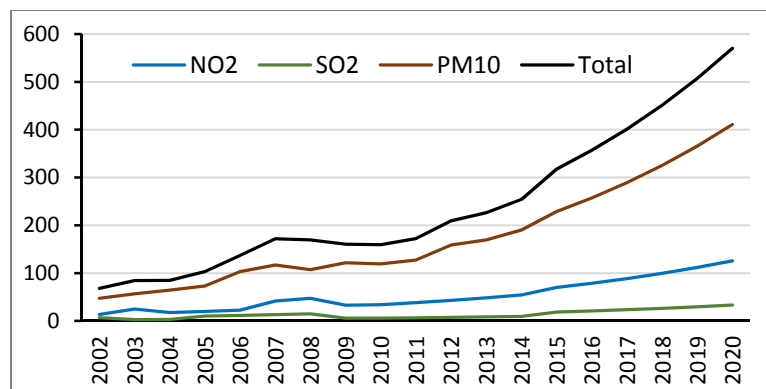
**Table 6.** Comparison of baseline incidence, relative risk, and number of excess cases attributable to short-term exposure to pollutants in different studies.

Study	Pollutant	Health endpoint	Relative risk (95% CI) per 10 $\mu\text{g m}^{-3}$	Baseline incidence/ 100000 people	Excess number of cases	Exposed population
Health endpoints of present work in 2014						
	NO <sub>2</sub>	TM	1.0242 (1.0157–1.0327)	543.5	322.3 (211.7–430.2)	1693000
		CM	1.0206 (1.0082–1.0332)	497	252.2 (102.2–399.1)	
		RM	1.0371 (1.0109–1.064)	48.4	43.3 (13.2–71.8)	
		HA-COPD	1.0090 (1.0051–1.0129)	101.4	22.9 (13–32.6)	
		HA-RD	1.006 (1.0013–1.0106)	1260	190.3 (41.5–333.9)	
		HA-CD	1.0095 (1.0054–1.0136)	436	103.7 (59.3–147.6)	
	SO <sub>2</sub>	TM	1.0068 (1.0024–1.0112)	1013	58.1 (20.6–95.5)	
		CM	1.0103 (1.0021–1.0185)	497	43.1 (8.8–77.1)	
		RM	1.0106 (1.0006–1.0206)	66	5.9 (0.3–11.4)	
		HA-COPD	1.0070 (1–1.0141)	101.4	6 (0–12)	
		HA-RD	1.0014 (1–1.0043)	1260	14.9 (0–45.8)	
		HA-CD	1.0079 (1–1.0163)	436	29 (0–59.7)	
	PM <sub>10</sub>	TM	1.0044 (1.0017–1.0071)	1013	1226.1 (495.5–1895.4)	
		CM	1.006 (1.0029–1.0091)	497	799.5 (406.4–1155.9)	
		RM	1.0082 (1.0004–1.0161)	66	140.2 (7.8–245.6)	
HA-COPD		1.0050 (1.0030–1.0070)	101.4	138.1 (85.6–187.3)		
HA-RD		1.0039 (1–1.0082)	1260	1362.9 (0–2677)		
HA-CD		1.0021 (1.0001–1.0041)	436	261.7 (12.9–494.2)		
Fattore <i>et al.</i> (2011)						
PM <sub>10</sub>	TM	1.006 (1.004–1.008)	735.7	4.4 (3.0–5.8)	24000	
	CM	1.009 (1.005–1.013)	283.4	2.5 (1.4–3.6)		
	RM	1.013 (1.005–1.020)	58.0	0.7 (0.3–1.1)		
NO <sub>2</sub>	TM	1.003 (1.002–1.004)	735.7	3.1 (2.3–3.9)		
	CM	1.004 (1.003–1.005)	283.4	1.6 (1.2–2.8)		
Naddafi <i>et al.</i> (2012)						
PM <sub>10</sub>	TM	1.006 (1.004–1.008)	543.5	2194 (1486–2880)	8700000	
	CM	1.009 (1.005–1.013)	231	1367 (738–1916)		
	RM	1.013 (1.005–1.020)	48.4	402 (164–588)		
	HA-RD	1.008 (1.0048–1.0112)	1260	6677 (4107–9126)		
	HA-CD	1.009 (1.006–1.013)	436	2580 (1760–3617)		
NO <sub>2</sub>	TM	1.003 (1.002–1.004)	543.5	1050 (705–1389)		
	CM	1.004 (1.003–1.005)	231	591 (446–733)		
	HA-COPD	1.0026 (1.0006–1.0044)	101.4	247 (27–586)		
SO <sub>2</sub>	TM	1.004 (1.003–1.0048)	543.5	1458 (1102–1739)		
	CM	1.008 (1.002–1.012)	231	1202 (315–1751)		
	RM	1.01 (1.006–1.014)	48.4	310 (192–422)		
	HA-COPD	1.0044 (1–1.011)	101.4	298 (0–710)		
Gholampour <i>et al.</i> (2014)						
PM <sub>10</sub>	TM	1.006 (1.004–1.008)	543.5	363(246–478)	1700000	
	CM	1.009 (1.005–1.013)	231	227(130–319)		
	RM	1.013 (1.005–1.020)	48.4	67(27–98)		
	HA-RD	1.008 (1.0048–1.0112)	1260	1107(680–1515)		
	HA-CD	1.009 (1.006–1.013)	436	428(291–601)		
Ghozikali <i>et al.</i> (2016)						
NO <sub>2</sub>	HA-COPD	1.0038 (1.0004–1.0094)	101.4	11.6 (1.20–28.4)	1500000	
SO <sub>2</sub>	HA-COPD	1.0044 (1–1.011)	101.4	8.20 (0–20.3)		
Mohammadi <i>et al.</i> (2015)						
PM <sub>10</sub>	TM	1.0074 (1.0062–1.0086)	1013	652.1(550.2–752.6)	1500000	
	CM	1.008 (1.005–1.018)	497	344.7(219.2–733.2)		
	RM	1.012 (1.008–1.037)	66	67.1(45.8–181.3)		
	HA-RD	1.009 (1.006–1.013)	436	837.9(534.2–1201.2)		
	HA-CD	1.008 (1.0048–1.0112)	1260	338.2(229.4–447.6)		
NO <sub>2</sub>	CM	1.004 (1.002–1.006)	497	20.5(0.0–41.0)		



**Table 6.** (continued).

Study	Pollutant	Health endpoint	Relative risk (95% CI) per 10 $\mu\text{g m}^{-3}$	Baseline incidence/ 100000 people	Excess number of cases	Exposed population
Jeong (2013)	SO <sub>2</sub>	TM	1.004 (1.003–1.0048)	1013	316.3(238.4–377.9)	1180000
		CM	1.008 (1.002–1.012)	497	304.0(78.4–446.9)	
		RM	1.01 (1.006–1.014)	66	50.0(30.6–68.6)	
	PM <sub>10</sub>	TM	1.006 (1.004–1.008)	380.5	105.5 (70.9–139.5)	
		CM	1.009 (1.005–1.013)	84.5	34.7 (19.6–49.3)	
		RM	1.013 (1.005–1.020)	28.8	16.8 (6.7–25.2)	
		HA-RD	1.008 (1.0048–1.0112)	1260	462.0 (280.9–634.8)	
		HA-CD	1.009 (1.006–1.013)	436	179.1 (120.9–254.6)	
	NO <sub>2</sub>	TM	1.003 (1.002–1.004)	543.5	81.3 (54.5–107.7)	
		CM	1.004 (1.003–1.005)	231	23.9 (18.0–29.7)	
		HA-COPD	1.0026 (1.0006–1.0044)	101.4	18.8 (4.4–31.5)	
	SO <sub>2</sub>	TM	1.004 (1.003–1.0048)	543.5	10.9 (8.1–13.0)	
		CM	1.008 (1.002–1.012)	231	4.8 (1.2–7.2)	
		RM	1.01 (1.006–1.014)	48.4	2.0 (1.2–2.9)	
		HA-COPD	1.0044 (1–1.011)	101.4	32.1 (16.6–47.8)	

**Fig. 3.** Trend of economic cost burden of health endpoint in Agra city from 2002 to 2020 (million US\$).

which are not considered in the study (Fattore *et al.*, 2011).

- c) Here the area specific (i.e., industrial or residential area) mortality and morbidity have not been considered. Air pollution may directly cause mortality and accidental morbidity, like in extreme cases when visibility is low, the probability of traffic accident is enhanced, which is not included in this study.
- d) The accuracy of the air quality data as available through CPCB is uncertain due to wide variety of reasons such as - frequent power cut, manpower availability problem, calibration error and failures of air quality monitoring instrument.
- e) In this study, only PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub> are considered but fine particulate matter PM<sub>2.5</sub> and ozone are not considered, which have more health impacts.

## CONCLUSIONS

In current study, a straightforward spreadsheet model with AirQ software has been used to assess the human health effects due to air pollutants in Agra city. Here excess

number of cases was observed - 1362 for total mortality, 908 for cardiovascular mortality, 155 for respiratory mortality, 138 for hospital admission COPD, 1230 for respiratory disease and 348 for cardiovascular disease in Agra city in year 2002. Although with 13.43–27.52% growth, these figures became 1607, 1095, 189, 167, 1568 and 394 respectively in 2014. Monetary cost due to outdoor air pollution increased from 67.99 to 254.52 million US\$ during 2002 to 2014. In previous study, the estimated annual premature deaths due to ambient suspended particulate matter (SPM) and corresponding monetary cost were respectively- 1569 and 55.69 million US\$ in 1991–1992, and 1449 and 39 million US\$ in 1995 (DE, 2015). Estimated attributable number of cases are only with reference to the concentrations of pollutants in excess to the standards adopted in the WHO guidelines. However, concentrations lower than the WHO guidelines have also contributed towards attributable morbidity and mortality, like due to long time exposure to PM<sub>10</sub>. For more extensive study one needs to estimate human health risk due to all the relevant pollutants such as TSP, PM<sub>10</sub>, PM<sub>2.5</sub>, O<sub>3</sub>, CO, NO<sub>2</sub>, SO<sub>2</sub> and polyaromatic hydrocarbons. This study shows PM<sub>10</sub> as the primary

responsible pollutant for human health risk in Agra city. Hence, the state pollution control authorities of Uttar Pradesh needs to put forward measures to control and reduce PM<sub>10</sub> levels in the city to decrease the economic costs of air pollution-related health impact. If such a trend be continued, economic cost of such ignorance would be as huge as US\$ 570.12 million in 2020, much higher than the cost of control measures. Current study shows the importance of evaluation and assessment of health impacts of air pollution on local scale to protect environment and economic balance.

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