Short-term and Long-term Exposure of Ambient Air Pollution and its Impact on Respiratory Morbidity and Mortality: A Systematic Review

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Introduction:

A well-established body of literature, documents and reports highlights how both short and long-term exposure to ambient [outdoor] air pollution (AAP) (mainly consisting of nitrogen oxides [NOx], sulfur dioxide [SO_2], nitrogen oxides [NO_x], Particulate matter [PM], ozone [O_3] and carbon monoxide [CO]) is associated with adverse health outcomes (Liu et al. 2013; Sehgal et al. 2015; Kesavachandran et al. 2015; Cohen et al. 2017; Haque & Singh, 2017). The health effects are measured by short-term exposure to pollutants by hours, days, or weeks and long-term exposure of months or years (Beverland et al. 2012). The effects of short-term exposure on human health include exacerbation of pre-existing respiratory disease (especially asthma, COPD, chronic respiratory [sputum, cough, wheezing problem, breathing problem] and pre-existing cardiovascular disease (including ischemia, arrhythmias, and cardiac failure). This leads to an increase in hospitalization and emergency department visits (Kumar et al. 2004; Gupta, 2008 & Patankar & Trivedi, 2011). The longer and more intense the exposure, greater is the impact on health, ranging from minor eye irritations, cough, wheezing, allergic rhinitis, respiratory symptoms to decreased lung and heart function, tuberculosis, cardiovascular diseases, hospitalization, and even premature death (Kumar & Foster, 2007; Guttikunda & Jawahar, 2012; Guttikunda & Goel, 2013; Ghosh & Mukherji, 2014; Tobollik et al. 2015 & Gawande et.al. 2016).

According to the World Health Organization (WHO), 14 cities from India feature in the top 20 world's most polluted cities in terms of $PM_{2.5.}$ The cities of Kanpur, Faridabad, Varanasi, Gaya, Patna, Delhi, Lucknow, Agra, Muzaffarpur, and Srinagar are listed in the top 10 (WHO, 2018). At present, Indian cities are among the most polluted cities in the world. It is estimated that ambient air pollution leads to approximately 670,000 deaths annually (Dholakia et al. 2014).

Epidemiological time series and case-crossover studies of AAP and their health impacts had been carried out in different cities in India namely, Delhi (Cropper et al. 1997; Chhabra et al. 2001; Pande et al. 2002, Rajarathnam et al. 2011); Kanpur (Gupta, 2008); Ludhiana (Kumar et al. 2010), Chennai (Public Health and Air Pollution in Asia, 2011); Mumbai, Shimla, Ahmedabad, Bangalore and Hyderabad (Dholakia et al. 2014). Apart from the above mentioned studies few have also investigated the effects of air pollution on health outcomes (Gurjar et al. 2010; Lelieveld et al. 2015; Dey et al. 2018). Therefore, we conducted a systematic review of AAP exposure for both shorter and longer time periods in order to understand and quantify the burden of diseases and mortality for the exposed population.

Methods: Search strategy and selection criteria

For this systematic review, we systematically searched Science Direct, JSTOR and Research Gate, Scopus, Book SC, Google Scholar, PubMed and Taylor and Francios using combinations of the following keywords: *"ambient air pollution", "long-term exposure", short-term exposure, "particulate matter", "respiratory morbidity", "respiratory mortality", "hospital admission"and "premature mortality"*. We also manually searched the references of every primary study for additional publications. Further publications were also identified by examining the review articles. Search results were screened by title, than by abstract, to eliminate irrelevant articles.

The inclusion and exclusion criteria for in this review:

The inclusion criteria for articles in this review we include only those articles which explain the impact of ambient air pollution on human health. Also, we select only those articles conducted in India or Indian cities. The publication between January 1, 1990, to January 31, 2018, in the English language only. We select only peer-reviewed original articles with full paper. The exclusion criteria for articles in this review we excluded abstracts of conference presentations because they did not contain sufficient information. We also exclude those study which has only explaining air pollution but not considers the health impact. Those articles fulfilling all inclusion and exclusion criteria were included in the list of literature for further review (figure 1).

Figure 1. Flow chart of the study selection process

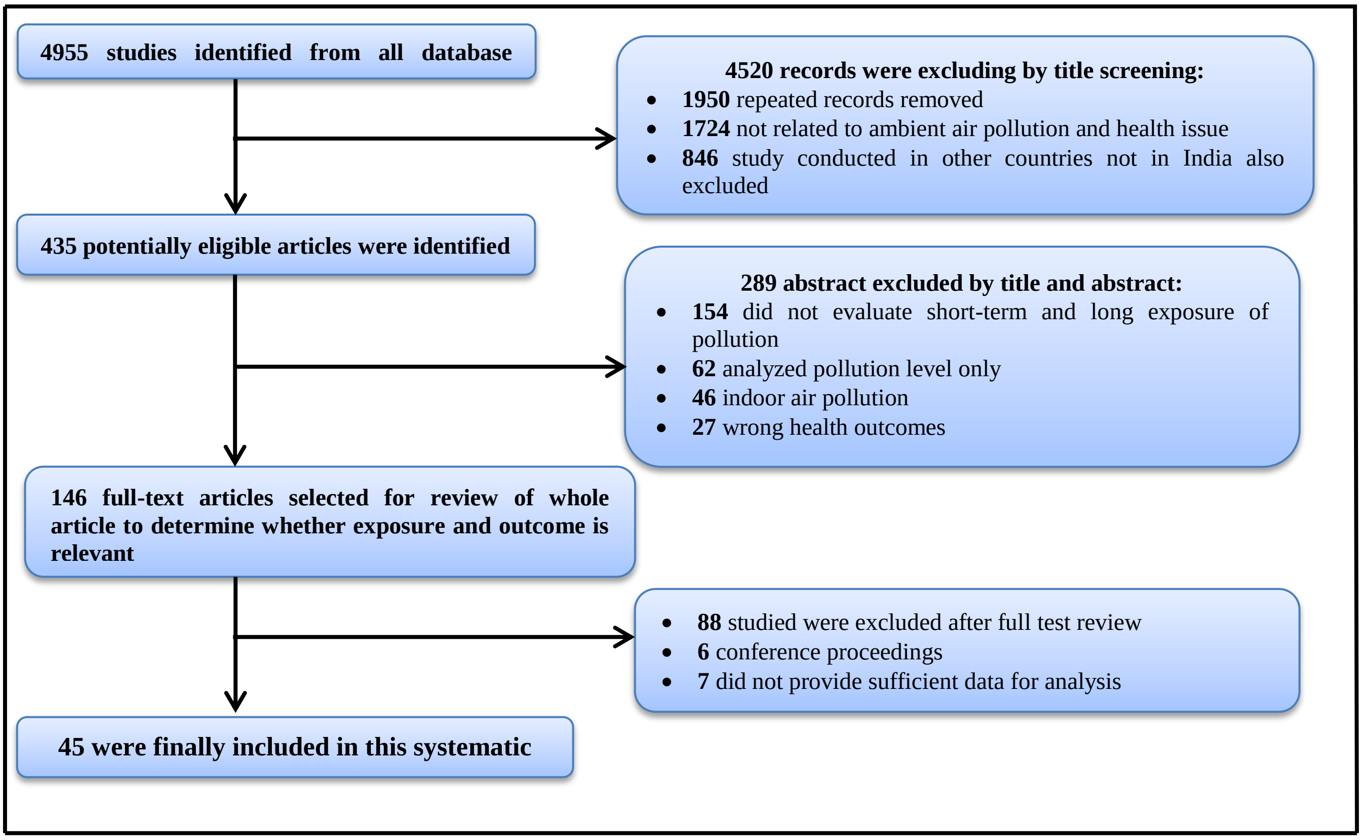


Table 1. Summary of selected epidemiologic studies between the study period of 1990-2018

Study Design	Short-Term	Long-Term	Pre-Mature Mortality	Total
Time Series	2	5	6	13
Cross Sectional	6	7	-	13
Case-Control	3	1	1	5
Cohort Study	1	1	6	8
Case Study	1	1	1	3
Modelling/Bottom up Modelling Study	-	-	2	2
Intervention Study	-	-	1	1
Total	**13**	**15**	**17**	**45**

Table 2. WHO specified default value of Relative Risk (RR)b per 10 ug/m$_3$ increase of daily average for PM_{10}, SO_2 & NO_2 with 95 % CI

Pollutants	Mortality/Morbidity	Relative Risk(RR)[b] (95 % CI) per 10 ug/m^3	Baseline Incidence per 100,000[c]
PM_{10}	Total Mortality [x]	1.0074 (1.0062-1.0086)	1013
	Cardiovascular Mortality [y]	1.008 (1.005-1.018)	497
	Respiratory Morbidity [z]	1.012 (1.008-1.037)	66
	Hospital admission respiratory diseases	1.008 (1.0048-1.0112)	1260
	Hospital admission Cardiovascular diseases	1.009 (1.006-1.013)	436
SO_2	Total Mortality [x]	1.004 (1.003-1.0048)	1013
	Cardiovascular Mortality [y]	1.008 (1.002-1.012)	497
	Respiratory Morbidity [z]	1.01 (1.006-1.014)	66
	COPD [a] Morbidity (hospital admission)	1.0044 (1-1.011)	101.4
NO_2	Cardiovascular Mortality [y]	1.002 (1-1.004)	497
	COPD Morbidity (hospital admission)	1.0038 (1.004-1.0094)	101.4

a COPD: Chronic obstructive Pulmonary diseases;
b Lower and upper limits (range) of RR value;
c Baseline incidence 100,000 is based of threshold limit is given in WHO guideline;
x International classification of diseases (ICD) code number: ICD-9-CM<800;
y ICD-9-CM 390-459; **z**ICD-9 460-519

Preliminary Result

Short-Term Effect:

The health effects of short-term exposure to air pollution are very important aspects of environmental epidemiology (Szyszkowicz, 2018). The vast majority of epidemiological studies reporting health effects associations with AAP in India use data from urban centers and mostly report on prevalence of respiratory morbidity. Through a systematic review of the literature, we identified six cross-sectional studies; three case-control studies, two time -series studies one case and cohort study. These studies are investigating the association between ambient exposure and respiratory morbidity, hospital admission/hospital visit and emergency room visit for asthma or other respiratory causes (Chhabra, et al. 2001; Pande et al. 2002; Kumar et al. 2004; Ingle et al. 2005; Jayanthi & Krishnamoorthy, 2006; Ghose, 2009; Patankar & Trivedi, 2011; Central Pollution Control Board, 2012; Liu, et al. 2013; Kesavachandran, et al. 2015; & Prasad & Sanyal, 2016; Cohen et al. 2017; Haque & Singh, 2017). Most of these existing studies on ambient air pollution and impact on health are based on the physical linkage approach, where a dose response function is estimated in order to observe the relationship between human health and air pollution. These studies largely concentrated in the metropolitan cities like Delhi, Mumbai, Chennai, and Kolkata and found that elevated levels of AAP are the main causes of prevalence of diminished lung function, acute and chronic respiratory symptoms (cough, wheeze, and asthma) in children and adults (Gordon et al. 2018; Sehgal et al. 2015; Gawande, et al. 2016; Public Health and Air Pollution in Asia [PAPA], 2011; Ghose, 2009; Chhabra et al. 2001; Pande et al. 2002).

Interestingly, the short-term exposure resulting from acute increases in $PM_{2.5}$ and PM_{10} are not limited to the critically ill or dying. In fact, much of the morbidity and mortality occurred among active individuals with one or more risk factors. Nagpure et al. (2014) evaluates the human health risks (mortality and morbidity) due to air pollution in Indian national capital territory of Delhi (NCT Delhi). The result shows that about 11394 (total mortality), 3912 (cardiovascular mortality), 1697 (respiratory mortality) and 16253 (hospital admission of COPD) respectively were observed for entire NCT Delhi in the year 2000. However, within one decade, in the year 2010, these figures became 18 229, 6374, 2701 and 26525 respectively. In national level Cohen et al. (2017) also explain that exposure to $PM_{2.5}$ caused 29 609.6 thousand (25 923.3 – 33 562.7) disability-adjusted life-years (DALYs) in India during 2015. Based on the results of this review, we conclude that if short-term ambient air pollutants ($PM_{2.5}$, PM_{10}, SO_2, and CO_2) cross their daily prescribed standards level (each 10-µg/m_3 or 50-µg/m_3) increased the risk of the burden of disease.

Table 3. Short-term exposure of Ambient Air Pollution and its impact on Respiratory Morbidity

Author	Follow-up Period	Pollutant	Outcome measure	Population size, characteristics pollution exposure	Result & Effect (95% CI)
Chhabra et al. 2001	1990-2000	TSPs, SO_2, NO_2	Bronchial, Asthma, chronic bronchitis, & COPD	Low SES= M: 716, F: 524; Middle SES= M: 815, F: 699; High SES= M: 813, F: 574.	Higher-pollution zone: **2.30 (1.74, 3.05)**; Lower pollution zone: **2.21 (1.80, 2.71)**
Kumar et al. 2004	1999 -2001	TSP, PM, SO_X & NO_x,	Sputum, Cough, Wheezing problem & Breathing problem	Study Town: M: 1105, F: 722; Reference Town: M: 908, F: 868	Chronic respiratory symptoms risk: **1.5 (1.2 -1.8)** Spirometric ventilatory defect risk: **2.4 (2.0 - 2.9)**
Ingle et al. 2005	2003- 2004	SPM, SO_x, NO_x, & CO	Coughing, Shortness of breath, respiratory tract Irritation.	60 Male in exposed group and 60 Male in control group	Frequent coughing **2.96 (2.4 - 3.6)**
Patankar & Trivedi, 2011	2003- 2004	PM_{10} and NO_2	Cough, breathlessness, wheezing and cold, and illnesses such as allergic rhinitis and COPD	1542 respondents (11+ years of age) Government	Cough = **0.35** net effect if PM10, 50-µgm_3 is increase. Breathlessness = **1.40** net effect if NO2 20- µgm_3 increase. COPD= **0.70** net effect if PM10, 50-µgm_3 is increase.
Ghose, 2009	2008- 2009	SPM, RPM, SO_2, NO_x, & $PM_{10.}$	Nose block, Sneezing, Cough & Hyperacidity	450 Male in exposed group and 410 Male in control group	Increased respiratory symptom: **1.98 (1.29–3.66)**, Reduced lung function: **2.23 (1.67–4.15)**, Higher siderophage numbers: **4.43 (2.54–7.68)**
Central Pollution Control Board, 2012	2002 - 2005	SPM, PM_{10}, SO_2, & NO_2	Lung function, attacks of shortness of breath, wheezing, dry or wet cough and chest tightness.	A total number of 16,164 children aged between 4-17 years participated in this study.	Dry cough: **1.48 (1.24 – 1.67);** Wet cough: **1.33 (1.12 – 1.56); ** Wheeze: **1.23 (1.04-1.45);** Breathlessness on exertion: **1.37 (1.15-1.63).** Medically-diagnosed asthma: **1.08 (0.87-1.42)**; Eye irritation: **2.45 (1.56-3.74)**
Gawande, et al. 2016	2013	SO_2, NO_x, CO_2 SPM, H_2S	Respiratory diseases and lung function among children	2000 school children in the age group 6-7 years and 13-14 years were selected	**Dry Cough: 29.5%** in Study and **21.3%** in Control, p=0.000 Significant by Chi Square test **Night Cough: 22.3%** in Study and **13.6%** in Control, p=0.000 Significant by Chi Square test **Sneezing: 17.8%** in Study and **10.2%** in Control, p=0.000 Significant by Chi Square test
Siddique et al. (2010)	2002-2005	SPM, RSPM, NO_2 & SO_2	Impair lung function in children. Children suffering from asthma were not included in this study. Only normal healthy children were recruited.	The exposed group consisted of 5,671 children (3,708 boys and 1,963 girls). The control group comprised of 2,245 children (1,438 boys and 807 girls)	Positive association between particulate pollution and asthma attacks **1.28 (1.07-1.42)**

Note: SES = socioeconomic status.

Ambient Air Pollution and its impact on Respiratory Morbidity

The recent study by Patankar & Trivedi, (2011) estimate that a cough is 0.35 net increases if PM_{10} is 50- µgm$_3$ increased. Similarly, breathlessness is 1.40 net increases if NO_2 is 20- µgm$_3$ increased and COPD are 1.15 increases if NO_2 is 20- µgm$_3$ increased respectively. Similalry, Kumar et al. (2004) examines the association of outdoor air pollution with chronic respiratory morbidity. The result shows that the prevalence of chronic respiratory symptoms (cough, phlegm, breathlessness, or wheezing) was 27.9 and 20.3% in the industrial town and reference towns (non-industrial town), respectively ($p<0.05$). Similarly, obstructive ventilatory defect was 24.9 and 11.8% ($p < 0.05$), respectively. Central Pollution Control Board in 2012, found a similar risk among school children in Delhi. The findings were compared with rural control school children in West Bengal. It was found that Delhi had 1.7-times higher prevalence of respiratory symptoms (in the past 3 months) compared with rural controls ($P < 0.001$); the odds ratio of upper respiratory symptoms in the past 3 months in Delhi was 1.59 (95% CI 1.32-1.91) and for lower respiratory symptoms (a dry cough, wheeze, breathlessness, chest discomfort) was 1.67 (95% CI 1.32-1.93). Another study by Ghose (2009) found that respiratory symptoms was increased (odds ratio [OR] = 1.98, 95 percent [CI], 1.29–3.66), lung function was reduced (OR = 2.23, 95 % CI, 1.67–4.15), and higher siderophage numbers (OR = 4.43, 95 % CI, 2.54 –7.68) respectively.

Table. 4 Short-term exposure of Ambient Air Pollution on respiratory admissions

Author	Follow -up period	Pollutant	Outcome measure	Population size, characteristics pollution exposure	Result & Effect (95% CI)
Pande et al. 2002	1997-1998	TSP,CO, SO_2 & NOx	Hospital visit, Emergency room visit for asthma, COAD & ACE	Total cardio-respiratory events: 6478 cases (In 1997), 9334 cases (in 1998) COAD: 1240 cases (in 1997), 1944 cases (in 1998) Asthma: 2138 cases (in 1997) 3151 cases (in 1998) ACE: 3100 cases (1997), 4239 cases (in 1998).	**Asthma,** observed **(7.23 + 7.82)**; expected **(5.96 + 4.55)** and increase **21.30 percent.** **COAD**, observed **(4.37 + 4.97);** expected **(3.50 + 2.48)** and increase **24.90 percent** **ACE,** observed **(10.09 + 2 7.09)**; expected **(8:11 + 3.07)** and increase **24.30 percent**
Gupta, 2008	2004	SO_2, NOx, & SPM	Household health, Number of days of illness, Hospitalization, doctor's consultation.	Selection of Households (HHs): The Low class category: 385 HHs. The lower middle class category: 116 HHs. High Class category: 104 HHs	Workdays lost due to Asthma = **3.5390 (2.20)** One µgm3 fall in RSPM results in a marginal gain of **0.00007** for a representative person in a week.
Liu, et al. 2013	2006	SO_2, PM, and NOx	8,340 patients who visited the hospital at least once in the study period	Hospitalization, Hospital visit (specialist pulmonary hospital with symptoms of respiratory disease), cardiopulmonary diseases	Polluted and less polluted cluster: **1.64 (1.43, 1.89)**; Very highly polluted and polluted cluster: **1.98 (1.76, 2.22)**; Very highly polluted and highly polluted: **0.98 (0.87, 1.09)**
Maji et al. 2016	2004–2013	PM_{10}, SO_2, and NO_2	City based study (Mumbai, Pune, Nagpur, Thane, Nashik, Aurangabad, Solapur, Navi Mumbai, Kolhapur, Chandrapur)	Hospital admissions and Respiratory disease and hospital admissions cardiovascular Disease (HACD).	Mumbai: **20,955 (17,689–24,028)** Pune: **3,502 (2,939–4,040)** Nagpur: **812 (681–939)** Thane: **413 (347–478)** Nashik: **(754–1,047)** Aurangabad: **497 (419–574)** Solapur: **837 (710–960)** Navi-Mumbai: **952 (803– 1,093)** Kolhapur: **251 (211–289)** Chandrapur: **175 (147–203)**

Note: Chronic obstructive pulmonary disease (COAD); ACE = acute coronary event.

Ambient Air Pollution on hospital Visit or admissions

Pande et al. (2002) found that due to high level of outdoor pollution, the emergency room visits for asthma increased by 21.30 percent; for chronic obstructive airways disease increased by 24.90 percent and acute coronary events (ACE) increased by 24.30 percent respectively. Liu et al. (2013), explain that there is a strong correlation between visits to a hospital due to respiratory disease and emission strength in the area of residence. He further explains that the relative number of patients who visited the hospital per number of inhabitants in each pollution zone is much higher in the highly polluted regions than in the less polluted regions. The result shows that polluted and less polluted zones have 1.64 (odds ratio) risk of hospital admission (95% CI: 1.43-1.89). Similarly, very highly polluted and less polluted zone have 3.25 (odds ratio) risk of hospital admission (2.80-3.78) and very highly polluted, and highly polluted zones have 0.98 (odds ratio) risk of hospital admission (95% CI: 0.87-1.09) respectively. In the same context, Chhabra et al. (2001) explain that the higher-pollution zone has a higher chance of respiratory morbidity 2.30 (95% CI: 1.74 - 3.05); as compared to lower pollution zone 2.21 (95% CI: 1.80 - 2.71).

Another notable study by Gupta (2006) estimates the monetary benefits to individuals from health damages avoided as reductions in air pollution. In his work suggests that a 1 μgm_3 fall in RSPM results in a marginal gain of 0.00007 for a representative person in a week. He further found that the annual welfare gains to a working individual from reduced air pollution are Rs 130.39 due to the reduction in workdays lost and due to the reduced medical expenditures is Rs 34.43 to a person. This, constitute a total gain of Rs 212.82 million per annum of the study population. Indeed, hospital admissions and emergency room visits due to respiratory morbidity have been recognized as a more sensitive marker than mortality for assessment of the air pollution effects on human health (Gupta, 2008 & Liu, et al. 2013).

Long Term Effect:

Long-term exposures to air pollution have been associated with chronic bronchitis, markers of atherosclerosis, respiratory impairment, lung cancer, and mortality (Cropper et al. 1997; Kumar et al. 2010; Public Health and Air Pollution in Asia [PAPA], 2011; Balakrishnan et al. 2013; Ghosh & Mukherjee 2014; Tobollik et al. 2015; Gawande et al. 2016; & Maji et al. 2016). There is a significant number of new studies on long-term air pollution exposure, covering a wider range of the geographic region of India. These recent studies support the positive associations between ambient pollutants (PM_{10}, NO_2 & SO_2) and high risk of mortality. The pooled effect estimate that the excess risk per 10 $\mu g/m_3$ increase in PM_{10} exposure was 1.004 (1.002 to 1.007) for all-cause mortality in Tamil Nadu, and for Delhi, it was 1.0015 (1.0007 to 1.0023) [PAPA, 2011]. Overall, the available studies provide evidence that long-term exposure to ambient air pollution in India is associated with asthma cases, reduced lung function, lung cancer, non-trauma death, cardiovascular deaths, respiratory deaths and pre-mature death (Cropper et al. 1997; Pandey, et al. 2005; Sehgal et al. 2015 & Gawande, et al. 2016). In addition, case fatality also depends on age, pre-existing cardiovascular disease, obesity, low socioeconomic status smoking, and other individual factors. Individual susceptibility to the health effects of air pollution may differ, due to either biological differences or behavioral differences affecting exposure (Stockfelt, 2017).

Table. 5 Long-term effects of Ambient Air Pollution on Lung Function

Author	Follow-up period	Pollutant	Outcome measure	Population size, characteristics pollution exposure	Result & Effect (95% CI)
Kumar & Foster, 2007	2003- 2004	$PM_{2.5}$	1576 household's survey	Respiratory health and Lung function	One standard deviation increase in $PM_{2.5}$ exposure results in a **.79** point decline in lung function. A one standard deviation increase in current PM2.5 results in a **.628** point decline in lung function.
Siddique et al. (2010)	2002-2005	SPM, RSPM, NO_2 & SO_2	The exposed group consisted of 5,671 children (3,708 boys and 1,963 girls). The control group comprised of 2,245 children (1,438 boys and 807 girls)	Reduced Lung function. restrictive, obstructive, and combined type of lung functions deficits.	Level of PM (76–100 μg/m3) **RR 1.34 (1.06–1.68)** Level of PM (101–125 μg/m3) **RR 1.62 (1.40–1.87)** Level of PM (>125 3.75 μg/m3) **RR (3.50–4.60 μg/m3)**
Sehgal et al. 2015		$PM_{2.5}$, CO, NO_2 & SO_2.	153 workers respondents aged below 40 years with no smoking history.	Lung function, respiratory impairment, Asthma, and Heart attack	Difference between means of lung function duration of work 3–5 years **0.74 (0.25 - 1.33)** duration of work >5 years **0.94 (0.48- 1.40)**
Khafaie et al. (2017)	2015-2016	PM_{10}	400 exposed group (diabetic patient) and 465 non-exposed group (healthy people)	Chronic symptoms and the pulmonary function tests (PFT)	1 SD increase in PM10 was associated with a greater risk of having dyspnea by **1.50 (1.12–2.01)**. Higher exposure to PM10 was also significantly associated with lower FVC%. The size of effect for 1 SD μg/m3 increase in PM10 concentration was **3.71 (0.48–4.99)** decrease in FVC.
Arora et al. (2018)	2015	NO_2 , PM_{10}, and $PM_{2.5}$	Out of 550 adult women aged 18–59 years in 528 houses, eventually, 500 females gave consent for participation in the study.	Altered lung function	Smokers and participants with a history of respiratory disease had **4.619 (1.075–19.851)** and **3.479 (1.121–10.798)** at $P < 0.05$ higher chance of abnormal forced expiratory volume in 1 (FEV1).

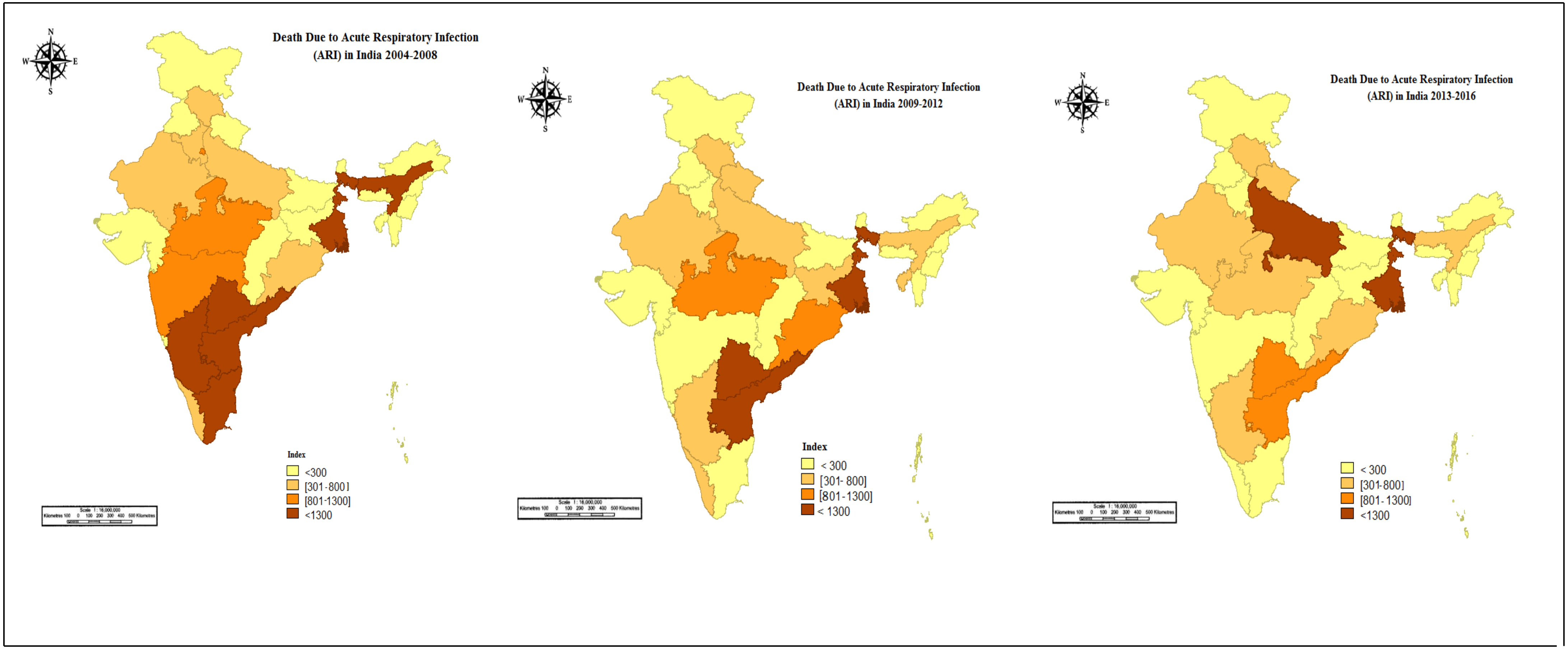
Impact on Lung Function

Lung function is an important measure of respiratory health and a predictor of cardiorespiratory morbidity and mortality (Gotschi et al. 2008). Of the most common air pollutants, particulate matter (PM) is associated with an increased risk of exacerbations and respiratory symptoms in individuals with existing lung disease, and to a lesser extent, in those without known respiratory issues (Adam et al. 2014). Over the past two decades, researchers worldwide have investigated long-term effects of ambient air pollution on lung function with most finding adverse effects (Siddiqu et al. 2017). Mehta et al. (2013) found the each 10-μg/m_3 increase in long-term ambient $PM_{2.5}$ concentrations is associated with around a 12% increased risk of acute lower respiratory infections (ALRI) incidence. Also, various studies claim that the decrease of 10-μg/m_3 of PM would be safe to Years of Life Lost (YLL). Siddiqu et al. (2017) explain that increasing levels of PM_{10} were found to be associated with increased lung function deficits of obstructive and restrictive type. The result shows that urban children are the most vulnerable group in this regard. PM10 level in ambient air was found to be associated with restrictive (OR= 1.35, 95% CI 1.07–1.58), obstructive (OR=1.45, 95% CI 1.16–1.82), and combined type of lung function deficits (OR=1.74, 95% CI 1.37–2.71) in children. Arora et al. (2018) commented that Smokers and participants with a history of respiratory disease had 4.619 (1.075–19.851) and 3.479 (1.121–10.798) at $P < 0.05$ higher chance of abnormal deficits lung function. Kumar & Foster, (2007) found that one standard deviation increase in current $PM_{2.5}$ results in a .28 standard deviation reduction in lung function. Also, one standard deviation increase in current $PM_{2.5}$ results in a .628 point decline in lung function

Table. 6 Long--term effects of Ambient Air Pollution on Mortality

Author	Follow-up period	Pollutant	Outcome measure	Population size, characteristics pollution exposure	Result & Effect (95% CI)
Cropper et al. 1997	1991-1994	TSP, SO_2, & NOx	NDMC Non-Trauma Deaths in different board Municipal Corporation of Delhi Urban: 34,455 New Delhi Municipal Committee: 1,999 Delhi Cantonment Board: 49	Non-trauma death, Cardiovascular Deaths & Respiratory Deaths	100 Microgram increase in TSP the Total Non-trauma Deaths was **2.3** increased and Cardiovascular Deaths was **4.3** increased (significance at 95% confidence level)
Kumar et al. 2010	2002–2004	RSPM, NO_x and SO2	Overall in the 3- year period, 28,007 deaths were registered, with an average of 25.4 deaths per day.	Daily death due to air pollutants	Effect of air quality on mortality **1.007 (1.002 - 1.013)** For every 1-km decrease in midday visibility (i.e., higher air pollution), the mortality increased by **2.4%.**
PAPA, 2011	2002-2004	PM_{10}, NO_2 & SO2	**Chennai:** Daily all-cause mortality ranged from 60 to 229 deaths in a year, **Delhi:** Total daily all-natural-cause mortality varied from 126 to 368 with an average of 222 deaths per day.	Daily all-cause mortality	**Tamil Nadu**: **1.004 (1.002 to 1.007)** **Delhi**: **1.0015 (1.0007 to 1.0023)**
Balakrishnan et al. 2013	2002–2004	PM_{10}	Data on daily total all-cause mortality were collected from the Chennai City Corporation office. (Daily mortality: N= 1096)	Daily all-cause mortality	**0.44 (0.17–0.71)** increase in mortality per 10 μg/m3 increase in daily average concentrations of PM10 Relative risk (RR) **1.0044 (1.002–1.007).**
Dholakia et al. 2014	2005-2012	PM_{10}	Daily all-cause mortality data were collected from the birth and death registers of the municipal corporations of Ahmedabad, Bangalore, Hyderabad, Mumbai and Shimla.	Daily all-cause mortality	Ahmedabad **0.16 (0.31 to 0.62)** Bangalore **0.22 (0.04 to 0.49)** Hyderabad **0.85 (0.06 to 1.63)** Mumbai **0.20% (0.10 to 0.30)** Shimla **1.36% (0.38 to 3.1**
Tobollik et al. 2015	2008-2011	PM	Natural Deaths per 100,000 People Male: 635, Female: 401 Cardiovascular Deaths per 100,000 People Male: 194, Female: 139	Cardiovascular Deaths, premature mortality	Life years were lost due to PM2.5: Male: **58,868 (40,003–75,094)** Women: **37,490 (25,476–47,823)**

Death due to Acute Respiratory Infection (ARI) in India during 2004-2016



Source: Data obtain from Ministry of Health and Family Welfare (MOHFW), Government of India.

Map Prepared by: Author

Ambient Air Pollution on Mortality

We found significant associations between ambient air pollution levels and mortality from respiratory infection, cardiopulmonary diseases and from lung cancer. Each 100 µg/m_3 increase in total suspended particles (TSP) is associated with only a 2.3 percent change in total non-trauma death; 4.3 percent change in cardiovascular mortality and 3.1 percent change in respiratory infection (Cropper et al. 1997). A similar result is found by Balakrishnan et al. (2013) estimated 0.44% (95% confidence interval 0.17 – 0.71) increase in mortality per 10 µg/m_3 increase in daily average concentrations of PM_{10} . Tobollik et al. (2015) found that a decrease of 10% in PM concentrations would save 15,904 (95% CI: 11,090–19,806) life years. He also found 6,108 (CI: 4150–7791) of the 81,636 total natural deaths in the urban population of Kerala due to $PM_{2.5}$. Stratified by sex and in absolute numbers, more attributable deaths were modeled for men with 3,613 (CI: 2455–4609) deaths, as compared to 2495 (CI: 1695–3183) deaths for women. Long-term exposure to $PM_{2.5}$ was more associated with mortality from cardiovascular disease (particularly ischemic heart disease) and lung cancer than from non-malignant respiratory diseases (pooled estimate 1090.4 death in India (95% UI 936.6–1254.8) [Cohen et al. 2017].

Maji et al. (2017) observed that cardiovascular death due to pollutants (PM_{10}, SO_2, and NO_2) in Agra city was 908 (95% CI: 412–1372) in 2002 followed by 1193 (95% CI: 559–1771) in 2006, 1004 (95% CI: 474–1496) in 2010 and 1095 (95% CI: 517–1632) in 2014. Overall, the available studies provide evidence that long-term exposure to ambient air pollution in India is associated with asthma cases, reduced lung function, lung cancer, non-trauma death, cardiovascular deaths, respiratory deaths and pre-mature death (Cropper et al. 1997; Pandey, et al. 2005; Sehgal et al. 2015 & Gawande, et al. 2016).

Ambient air Pollution and Premature Mortality

Over the past decades, numerous epidemiological studies and meta-analysis, estimating an increased pre-mature mortality due to short- and long-term exposure to PM (Guttikunda & Jawahar, 2012; Silva et al. 2013; Ghude et al. 2016). In India, about 0.62 million premature excess number of death cases occurred due to outdoor air pollution and became the fifth leading cause of death after high blood pressure, indoor air pollution, tobacco smoking, and poor nutrition in 2012 (Maji, 2016). Chowdhury & Dey (2016) estimate of 486,100 (73,200–1,254,800) annual premature deaths in India but it is lower than some of the recent estimates for India as part of global study (Pope et al. 2002; Cohen et al. 2006; Apte et al. 2015) because of the difference in methodology. Murray et al. (2015) in his study using a raw estimate of $PM_{2.5}$ and he calculate annual premature death of 587,000 reported for India. Even at the state level, the scenario of premature death is changing. Again, Chowdhury & Dey (2016) identified that Indian states of Uttar Pradesh, Bihar, West Bengal, Maharashtra and the Delhi metropolitan area are the most vulnerable and contribute 25%, 15%, 7.6%, 5.4% and 1.7% to total all- India premature death from ambient $PM_{2.5}$ exposure in the previous decade. Guttikunda et al. (2014) explain that due to high concentrations of $PM_{2.5}$ the premature deaths in greater Chennai and the greater Vishakhapatnam regions was 4,850 and 1,250 respectively. For comparison, Guttikunda & Jawahar, (2012) estimated 3,600 for Pune, 4,950 for Ahmedabad, 1800 for Indore, and 1250 for Surat. For cities similar in area and size, the estimated premature mortality in Guttikunda and Goel (2013) estimated 7,350 to 16,200 premature deaths for Delhi in 2010. Our systematic reviews suggest that the $PM_{2.5}$ considerably impact pre-mature mortality and life expectancy in India. In fact, the economic cost of estimated premature mortalities associated with $PM_{2.5}$ and O_3 exposure is about 640 (350–800) billion USD in 2011, which is a factor of 10 higher than total expenditure on health by the public and private expenditure (Ghude et al. 2016).

Table .7 Estimated Pre-mature Mortality due to Ambient Air Pollution in India

State/region/ City	States/Country	Study year	Pollutant	Premature mortality	Projection of Premature mortality	Study Design	Reference
National Level Estimation							
All India	National Level	1990	PM_{10}	**438000**	-	Time series	IHME, 2013
All India	National Level	2010-2011	$PM_{2.5}$	**80,000-115,000**	-	Time series	Guttikunda & Jawahar, 2014
All India	National Level	2010	$PM_{2.5}$ and O_3	**644993**	-	Cohort Study	Lelieveld et al. 2015
All India	National Level	2010	PM and Ozone	**69000**	-	Time series	OECD, 2014
All India	National Level	2011	$PM_{2.5}$	**570000**	-	Modelling Study	Ghude et al. 2016
All India	National Level	2013	$PM_{2.5}$	**397 000**	-	Cohort Study	Silva et al. 2013
All India	National Level	2016	$PM_{2.5}$	**486100**	-	Cohort Study	Chowdhury & Dey, 2016
All India	National Level	2031-2040	$PM_{2.5}$		**9100-12300 Per year**	Cohort Study	Chowdhury et al. 2018
Northern India	North India	2018	O3	**37800**	-	Cohort Study	Karambelas et al. 2018
State Level Estimation							
State Level	Uttar Pradesh	2011	$PM_{2.5}$	**85500**	-	Bottom-up Modelling Study	Ghude et al. 2016
State Level	West Bengal	2011	$PM_{2.5}$	**51300**	-	Bottom-up Modelling Study	Ghude et al. 2016
State Level	Maharashtra	2011	$PM_{2.5}$	**57000**	-	Bottom-up Modelling Study	Ghude et al. 2016
State Level	Bihar	2011	$PM_{2.5}$	**45600**	-	Bottom-up Modelling Study	Ghude et al. 2016
City Level Estimation							
Delhi	National Capital	2001	PM_{10}	**5000**	-	Time series	Nema and Goyal (2010)
Kolkata	West Bengal	2001	PM_{10}	**4300**	-	Time series	Nema and Goyal (2010)
Mumbai	Maharashtra	2001	PM_{10}	**2000**	-	Time series	Nema and Goyal (2010)
Chennai	Tamil Nadu	2001	PM_{10}	**1300**	-	Time series	Nema and Goyal (2010)
Ahmedabad	Gujarat	2001	PM_{10}	**4300**	-	Time series	Nema and Goyal (2010)
Kanpur	Uttar Pradesh	2001	PM_{10}	**3200**	-	Time series	Nema and Goyal (2010)
Surat	Gujarat	2001	PM_{10}	**1900**	-	Time series	Nema and Goyal (2010)
Pune	Maharashtra	2001	PM_{10}	**1400**	-	Time series	Nema and Goyal (2010)
Bhopal	Madhya Pradesh	2001	PM_{10}	**1800**	-	Time series	Nema and Goyal (2010)
Mumbai	Maharashtra	2000	PM_{10}	**454**	-	Case Study	Joseph et al. 2003
Kolkata	West Bengal	2010	SPM	**10000**	-	Case-Control Design	Ghose, 2009
Pune	Maharashtra	2010	PM_{10}	**3600**	**4300 (In the year of 2020)**	Intervention Study	Guttikunda & Jawahar, 2012
Chennai	Tamil Nadu	2010	PM_{10}	**3950**	**6000 (In the year of 2020)**	Intervention Study	Guttikunda & Jawahar, 2012
Indore	Madhya Pradesh	2010	PM_{10}	**1800**	**2500 (In the year of 2020)**	Intervention Study	Guttikunda & Jawahar, 2012

Continue.

City/region	States/Country	Study year	Pollutant	Premature mortality	Projection of Premature mortality	Study Design	Reference
City Level Estimation							
Ahmedabad	Gujarat	2010	PM_{10}	**4950**	7850 (In the year of 2020	Intervention Study	Guttikunda & Jawahar, 2012
Surat	Gujarat	2010	PM_{10}	**1250**	2050 (In the year of 2020)	Intervention Study	Guttikunda & Jawahar, 2012
Rajkot	Gujarat	2010	PM_{10}	**300**	670 (In the year of 2020)	Intervention Study	Guttikunda & Jawahar, 2012
Delhi	National Capital	2010	$PM_{2.5}$ & PM_{10}	**7,350–16,200**	-	Bottom-up Modelling Study	Guttikunda & Goel, 2013
Delhi	National Capital	2010	$PM_{2.5}$ & PM_{10}	**19700**	-	NA	Times of India, 2015
Mumbai	Maharashtra	2010	$PM_{2.5}$ and O_3	**10200**	-	NA	Times of India, 2015
Kolkata	West Bengal	2010	$PM_{2.5}$ and O_3	**13500**	-	NA	Times of India, 2015
Hyderabad	Telangana	2010-11	$PM_{2.5}$	**3700**	-	Modelling Study	Guttikunda & Kopakka, 2014
Varanasi	Uttar Pradesh	2011	PM_{10}	**5700**	-	Time series	Jain & Chowdhury, 2017
Chennai	Tamil Nadu	2012	$PM_{2.5}$	**4850**	-	Time series	Guttikunda et al. 2015
Vishakhapatnam	Andhra Pradesh	2012	$PM_{2.5}$	**1250**	-	Time series	Guttikunda et al. 2015
Agra	Uttar Pradesh	2016	$PM_{2.5}$	**2421**	-	Cohort Study	Dey, 2018
Allahabad	Uttar Pradesh	2016	$PM_{2.5}$	**1443**	-	Cohort Study	Dey, 2018
Gaya	Bihar	2016	$PM_{2.5}$	**710**	-	Cohort Study	Dey, 2018
Gorakhpur	Uttar Pradesh	2016	$PM_{2.5}$	**914**	-	Cohort Study	Dey, 2018
Kanpur	Uttar Pradesh	2016	$PM_{2.5}$	**4173**	-	Cohort Study	Dey, 2018
Lucknow	Uttar Pradesh	2016	$PM_{2.5}$	**4127**	-	Cohort Study	Dey, 2018
Meerut	Uttar Pradesh	2016	$PM_{2.5}$	**2044**		Cohort Study	Dey, 2018
Muzaffarpur	Bihar	2016	$PM_{2.5}$	**531**		Cohort Study	Dey, 2018
Patna	Bihar	2016	$PM_{2.5}$	**2841**	-	Cohort Study	Dey, 2018
Ranchi	Jharkhand	2016	$PM_{2.5}$	**1096**	-	Cohort Study	Dey, 2018
Varanasi	Uttar Pradesh	2016	$PM_{2.5}$	**1581**	-	Cohort Study	Dey, 2018

Table 8. Trends of Morbidity, Mortality and DALYs due to ambient air pollution in India during 1990-2015

	1990		1995		2000		2005		2010		2015	
Morbidity, Mortality and DALYs	Total Cases	Global Share (%)	Total Cases	Global Share (%)	Total Cases	Global Share (%)	Total Cases	Global Share (%)	Total Cases	Global Share (%)	Total Cases	Global Share (%)
Numbers of deaths attributable to PM2.5 exposure	7,37,400	21.21	7,95,200	21.76	8,57,300	22.60	8,95,900	22.77	9,57,000	24.26	10,90,400	25.71
Numbers of deaths from COPD attributable to exposure to ozone for all ages and sexes.	43,500	27.50	54,400	29.84	66,800	33.62	73,000	35.27	88,100	40.54	1,07,800	42.44
Age standardized DALY rates (DALYs/100,000 people) due to PM2.5 exposure	4,100	(2500 /100,000 people)	3,900	(2300/ 100,000 people)	3,700	(2100/ 100,000 people)	3,300	(1900/ 100,000 people)	3,000	(1600/ 100,000 people)	2,900	(1500/ 100,000 people)

Source: The State of Global Air, 2017

Table 9. Estimated health impact in DALYs of ambient air pollution in India, 2012

Health end-points	Total Cases	Total DALYs
Premature mortality adults	1,09,340	8,20,049
Mortality children under 5	7,513	2,55,431
Chronic bronchitis	48,483	1,06,663
Hospital admissions	3,72,331	5,957
Emergency room visits/Outpatient hospital visits	73,03,897	32,868
Restricted activity days	1,231,020,030	3,69,306
Lower respiratory illness in children	162,55,360	1,05,660
Respiratory symptoms	3,917,855,052	2,93,839
TOTAL		19,89,773

Source: The World Bank, 2012

Discussion:

In evaluating the literature, there appears to be a consistent and significant, effect of AAP on human health. There is a large number of new studies on short-term and long-term air pollution exposure, covering a wider geographic area of India. However, through our literature review, we found that direct estimation of the short-term and long-term effects of air pollution in India has rarely been attempted. We found the significant heterogeneity in AAP exposure on human health in across studies, likely related to differences in particle composition, population characteristics, and methodological differences in particular region and confounder control. Several studies have a claim that in the last two decades, due to AAP exposure the cases of respiratory and cardiovascular morbidity (including heart and brain), hospital admission/visit for respiratory causes and incidence of pre-mature mortality have increased.

The rapid growth in the industrial, power, and transportation sectors nationally, combined with growth in urbanization, both planned and unplanned, have contributed to the rapid increase in AAP levels in India. Together, the substantial growth in the number of automobiles, iron and steel and coal-based power production are expected to significantly contribute to the worsening of air quality in the next decade in India (Gordon et al. 2018). For more than half of the cities of India included in the National Air Quality Monitoring Program (NAMP), two critical measures, $PM_{2.5}$ and PM_{10} (daily and annual levels), routinely exceed Interim Target-1 levels (75 and 150 $\mu g/m_3$ for daily and 35 and 70 $\mu g/m_3$ annually, respectively), as designated by the WHO. Interestingly, the results of a recent Lancet study by Lelieveld et al. (2018) found that total global mortality attributable to air pollution is 270000 deaths per year. Out of that 6 percent were from O_3, and 4.28 million (94%) were from $PM_{2.5}$. Notably, the contribution of O_3 in India was about 10% (96000 deaths per year). From the systematic review we found that higher ambient concentrations of $PM_{2.5}$ /PM_{10}, SPM, O_3 and NO_X are responsible for an excess number of mortality and morbidity in the various megacities of India (Gupta, 2008; Ghose, 2009; Siddique et al. 2010; Guttikunda & Jawahar, 2012; Ghude et al. 2016; Gawande, et al. 2016; Arora et al. 2018). Infect the recent systematic review and meta-analysis at the global level which is also cooperated India suggested that Particulate Matter (PM) is the primary responsible for respiratory morbidity and mortality. But we also found the heterogeneity among studies and their outcome because of existed in numerous factors such as health outcome definition, length of exposure, climate of the specific city, smoking status, previous respiratory diseases, and using different study design and methodology.

In this systematic review, we found no cohort studies that reported mortality estimates for India populations exposed over the long term to high concentrations of air pollution. However, only one cohort study is explaining the maternal health risk due to ambient air pollution (Magsumbol et al. 2014). There is also evidence from time series and cross-sectional studies conducted in different cities in India of mortality from a chronic disease associated with long-term exposure to PM and other pollutants (Cropper et al. 1997; Kumar et al. 2010; Dholakia et al. 2014; & Tobollik et al. 2015). Furthermore, ambient air pollution makes a significant contribution to the variation in daily causes of mortality and pre-mature mortality, and this relation is needed to be understood in the Indian context. From the systematic review, we conclude that $PM_{2.5}$ and PM_{10} as the primarily responsible for deleterious health problems, including asthma, bronchitis, chronic obstructive pulmonary disease, pneumonia, upper respiratory tract and lower respiratory tract disorders. A recent study suggests that fine PM is a risk factor for premature mortality, cardiopulmonary and lung cancer mortality (Jayanthi et al. 2006; Kazimuddin et al. 2000; Silva et al. 2013; Lelieveld et al. 2015 & Dey, 2018).

Conclusions and Recommendations

Ambient air pollutions have one of the major impacts on human health, triggering, and inducing many diseases leading to high morbidities and mortalities, particularly in the developing countries such as India. Therefore, air pollutions control is vital and should be on the top of priority list of the governments. If India manages to meet the national air quality standard in all the cities exceeding Indian standard, annual premature death will be reduced. The policy makers and legislators must update all laws and regulations related to air pollutions. An effective environmental protection organization should have enough budgets for administration, research, development, monitoring, and full control of the environment including ambient air pollution. The pollution control authorities in India urgently need proper policies to elevate ambient air quality in terms of $PM_{2.5}$ and PM_{10} level to decrease the burden of diseases due to air pollution. Further research on the health effects of ambient air pollution should be very helpful to the researcher, public health officials, industrialists, and the general public.

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Abbreviation

PM_{10} Particulate matter ≤10 μm in aerodynamic diameter

$PM_{2.5}$ Particulate matter ≤2.5 μm in aerodynamic diameter

NO_2 Nitrogen dioxide

O_3 Ozone

SO_2 Sulfur dioxide

TSP Total suspended particles

CO Carbon monoxide

RSPM Respirable Suspended Particulate Matter

SPM suspended particulate matter

H_2S Hydrogen sulfide

DALYs The disability-adjusted life year

WHO World Health Organization

Reference:

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