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Review Article

Health Effects of Air Pollution among Residents of Delhi: A Systematic Review

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ABSTRACT

Background: Air pollution is increasingly documented as a threat to public health and recognized as an important and modifiable determinate of respiratory diseases in urban environment. Differences in vulnerability and susceptibility due to different population characteristic, may affect the risk of developing a health effect and its severity. The present study evaluates scientific literature on air pollution, and its health effects on population of Delhi to identify the risk of exposure. This comprehensive review summarizes the limitations and gaps in recent studies and recommends some suggestions for future research.
Methodology: PubMed and Google Scholar were rigorously searched for finding out research studies pertaining to air pollution and health effects in Delhi, India. All together, 13 studies from 1998 to 2017 were reviewed to understand the status of air quality and its adverse effect on human health.
Findings: Air quality of Delhi was detrimental to human health and kept on deteriorating with time. Suspended Particulate Matter (SPM), Nitrogen oxides (NO_X) and various other pollutants were above the recommended standard. Adverse health effects (coughing, wheezing, Hypertension etc.) has shown positive association with air pollutants, specifically with particulate matter. A more comprehensive research construing long term effect of air pollution on human health is thus, warranted for advocating policy or guidelines for measuring and understanding the harmful effects and also for the control of air pollution.

Keywords: Air Pollution; Public Health; Health Effects; Delhi; India

INTRODUCTION

Delhi, the capital city of India, is inhabitants of approximately 16.7 million people. [1] It is also the third largest urban agglomeration in the world. Delhi is ranked among the most polluted cities in the world. [2] The primary contributors to air pollution in Delhi are both natural and anthropogenic like industrial units, vehicular emission, road dust, tire pads, construction activities etc. [3]

Delhi has approximately nine lakh registered industrial establishments. [4] Central pollution Control Board had noted many of the establishment had idle pollution control devices and short chimney. [3] Transport sectors contributes around three fourth of pollutants in air of Delhi. [5] Vehicular sources alone generate more than 3000 metric tons of pollutants per day. [6] Delhi, with a little over 1% of India's population, is home to a 10% of the vehicular load of the country. [7] The motor vehicle fleet was 9.6 million in the year 2015. [8] The number of vehicles per kilometer of road in Delhi has gone up from

128 to 191 between 2003 and 2009. [20] Moreover, ongoing large scale construction activities contribute dust in the air. The ever increasing sources and lack of sink potential due to deforestation have also led to high ambient air pollutant concentration within the city. [6]

Climate plays an important role in determining level of pollutants at Delhi. Delhi has cool dry air and inversion in air stratification with low wind velocity during winter. Such condition prevents dispersion of air pollutants. [9] A crop residue burning of 500 million tons during winter in surroundings of Delhi causes smog formation because of inversion. [10] In summer, air quality gets deteriorated due to dust storms originating from Thar desert and middle-east Asia. [11] Dust in polluted environment become harmful because of coating of pollutants. Moreover, Delhi being a land locked city, is not able to dilute its pollutants by moderating effect of sea. [3]

Air pollution is a major environmental problem affecting the health of people in both developed and developing countries. [12] The United Nations Environment Programme (UNEP) had estimated that globally 1.1 billion people breathe unhealthy air. [13] In the past, several studies have highlighted the significant contribution of ambient air pollution in human morbidity and mortality. [14-21] In the year 2012, World Health Organization (WHO) reported that around seven million people died and one in eight of total global deaths were attributable to air pollution. Air pollution has contributed to about two-thirds of cardiac mortalities and one-third of deaths due to Chronic Obstructive Pulmonary Diseases (COPD). [14]

There is substantial and definitive evidence suggesting acute aggravation of symptoms and deterioration of pulmonary function in patients suffering from Asthma and COPD on acute exposure to air pollutants. [22-24] However, the long-term effects of several air pollutants, especially biogenic ones, on human health is till now not investigated with certainty. Various health effects that have been suggested to occur due to diverse air pollutants such as particulates, bioaerosols, ozone, carbon monoxides, VOCs, nitrogen dioxide and sulfur dioxide are summarized in the Table1.

Table 1: List of important air pollutants, their sources and health effects.

Pollutants	Sources	Health effects
Particulate matter	Biomass combustion, transportation, incinerators and manufacturing industries.	Acute change in pulmonary functions, COPD, asthma, cardiovascular diseases
Biological pollutants or Bioaerosols	Pollens, dust, mites, animals droppings and urine, pet hair, insects, fungi/mold spores, parasites, some airborne bacteria and viruses, dairy products and food processing activities	Most often responsible for triggering respiratory illness (asthma, COPD, allergies), infectious diseases & skin diseases
Sulphur dioxide	Coal and oil combustion or automobile and industrial emission	Causes chest constriction, headache, vomiting and respiratory illness
Nitrogen dioxide	Gas stoves and kerosene heater cooking or automobile and industrial exhaust	Respiratory and cardiovascular illness
Carbon monoxide	Burning of coal and gasoline or motor exhausts	Reduction in oxygen carrying capacity of blood, headaches and fatigue
VOCs	Solvents and chemicals, perfumes, sprays, polishes, air fresheners, repellents, preservatives & smoke	Respiratory illness, headaches, eyes/nose/throat irritation & cancer
Ammonia	Tobacco smoke, cleaning supplies, litter boxes or dustbins.	Eye / skin irritation, headache, nose bleeds and sinus problems
Ozone (secondary pollutant)	Formed from reaction of NOx and VOC's	Respiratory illness, eye and skin irritation

Epidemiological studies have indicated that health effects of air pollution on differ for different populations. Differences in vulnerability and susceptibility may affect the risk of developing a health effect and its severity. Population characteristics that can modify the health effects related to pollution and confer susceptibility are predominantly age, underlying disease, and potentially genetics and gender. [25-27] Thus, it is pertinent to monitor the local levels of air pollutants and determine the magnitude of its impact on the local population regarding the additional burden of morbidity and premature mortality that it inflicts on that population. The present study intends to systematically review the studies concerned with air pollution level in Delhi and corresponding health effects.

The Objective of the review are as follows:

1. To describe briefly the air pollution status in Delhi.
2. To explore risk of health outcomes with exposure to air pollution.

METHODOLOGY

A systematic review of electronic and published literature was undertaken. Electronic literature search was restricted to PubMed & Google Search and printed publications were scanned from the libraries of participating institutions on the theme of air pollution and its health effects. The study was restricted to publications from 1995 onwards.

The following terms were used for searching the PubMed and Google Scholar:

Air pollution, Health impact, Delhi (mesh term) in PubMed yielded 16 studies.

and Air pollution, Health, Delhi in abstract and title for Google Scholar yielded 22 studies.

Study Selection:

A total of 38 articles were found in search on PubMed (16 studies) and Google Scholar (22 studies) and a total of 11 articles were included for review. Only one study appeared in both searches. The remaining 27 articles did not have any substantial information about association between air pollution and health in Delhi

Original studies showing health effects of ambient air pollution in Delhi (India), irrespective of the study design, were selected for our analysis. Studies that tried to measure effect of indoor air pollution only, were excluded from the review as our aim was to study "effect of outdoor air pollution". Further, two related articles selected from cross referencing (from pre identified 11 studies) were also included in this review, so in total 13 studies were reviewed [Fig. 1].

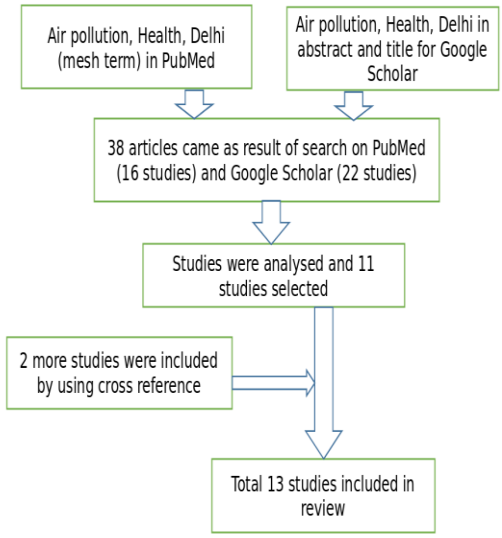

Figure 1. Algorithm for study selection in review manuscript.

Air pollution in Delhi:

Air quality monitoring in Delhi is carried out through a number of air quality monitoring stations across the territory, operated and maintained by various organizations viz. Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC), and System of Air Quality and Weather Forecasting and Research (SAFAR) of Indian Institute of Tropical Meteorology (IITM), Pune. NAAQ standard has been released by Central Pollution Control Board (CPCB) government of India in 2009. [28] NAAQ standard provides upper limit of various pollutants in air. CPCB report on air quality in Delhi provides an insight into trend of three air pollutants viz. SO_2, NO_2, and PM_{10}, level from 2009 to 2015. [3] The concentration of NO_2 and PM_{10} were above recommended level. The concentration of SO_2 was within the standard limits. However, as far as NO_2 is concerned, continuous rise in concentration was observed in past 7 years. Table 2 provides a list of air pollutants and remark on their level by various studies conducted in Delhi in last 20 years.

Globally urbanization has made a significant change in composition of air in the metropolitan cities, likely a similar trend was observed in air composition of Capital City of India. In all the studies SO_2 level was found under recommended level where as PM levels were far exceeding the prescribed standard limits. It may be due to the substantial rise in gasoline and diesel powered private vehicles. [35] NOx level remained within recommended limit from 1986 to 2007 in Delhi but a sudden steady rise was noted from the year 2001 to 2015 [33] and in year 2008 NOx surpassed NAAQ recommended level. The most abundant metals were Fe and Zn and least abundant was Cd found in Delhi air. [32] The benzene and benzo-pyrene was also reported to be above NAAQ standard as per the CPCB report. [24]

Table 2: Reviewed pollution status of Delhi.

Study Pollution data year	SO_2	NO_2	PM	CO	Benzene	Remarks
Chabbra etal. [23] 2001 1989-1998	BPL	BPL	APL	NS	NS	No clear trend observed in Air Quality (AQ). Airpollutant level remained constant with some fluctuation
Nidhi et al. [29] 2007 1998-2004	BPL	BPL	APL	NS	NS	A decrease in SO_2 concentration and an increase in NO_2 concentration was observed
Aggarwal et al. [30] 2006 2000-2003	BPL	BPL	APL	NS	NS	Maximum concentration of PMwas noted in winter month
CPCB [24] 2008 2002-2005	BPL	BPL	APL	NS	APL	NO_2 was APL at most of monitoring Stations
Pande et al. [31] 2005 2003-2004	BPL	NS	APL	NS	NS	
Jayraman et al [32] 2007 2004-2005	NS	APL	APL	APL	NS	NO_2 & CO found to be above the recommended level approx. half of the time of study duration
Khillare et al. [33] 2012 2008-2009	NS	NS	APL	NS	NS	
Guttikunda et al. [34] 2013 2001-2011	NS	APL	APL	NS	NS	2.5 times increase in PM_{10} and little less than 2 timesincrease in NO_2 was observe

(Permissible limits of various pollutants as per NAAQ standard[21] are: $NO_{2\ 24hr\ avg}$80 µg/m^3; $SO_{2\ 24hr\ avg}$80 µg/m^3; $PM_{10\ 24hr\ avg}$100 µg/m^3; $RSPM_{24hr\ avg}$60 µg/m^3;$CO_{8hr\ avg}$02 mg/m^3; Benzene $_{average}$ 05 µg/m^3; Benzo-pyrene $_{average}$ 01 ng/m^3)
BPL= below permissible limit, APL= Above permissible limit & NS=Not studied

Air quality index (AQI) adopted in India in 2014, is a six colour code developed for easy understanding of air pollution by laymen and hence, to make them aware of air quality and to involve them in strategies for control and mitigation. [36] AQI is computed by concentration of eight pollutants ((PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb). However, three out of these eight pollutants (O_3, NH_3, and Pb) were not included in any of the studies conducted in Delhi. CO levels were recorded in one study only. O_3 is one of the most consistent pollutants linked with health effects.

All reviewed studies have used air pollutant data from fixed monitoring station, which does not represent the real and exact measure of air pollution exposure at personallevel. Thus, an exact measurement of exposure to pollutant is a big hurdle to understand the multipronged pathway from exposure to development of a disease.

Health effect of air pollution:

Respiratory tract dysfunctions were most commonly investigated and reported in reviewed studies. They range from acute infections (such as pneumonia and bronchitis) to chronic conditions (such as asthma and COPD). In the reviewed studies, the adverse health outcomes were found to have a significant association with the air pollution like cough with or without Phlegm, Chest tightness, Allergic Rhinitis, Sinusitis, Bronchial Asthma, COPD, Hypertension, increased risk for cardiovascular events, Headache, Dizziness and Eye irritation [Table 3].

Table 3. Health effect of air pollutants on population of Delhi.

Parameter	Output variable	Type of study	Findings	Study
Respiratory symptoms				
Wheeze ever	Prevalence	Cross-sectional survey	OR = 1.61 for commercial complex relative to residential colony.	OR of symptoms for commercial complex, industrial area relative to residential area. Mathew et al. [37] 2015
Wheeze during activity	Prevalence	Cross-sectional survey	OR = 2.87 for commercial complex and 1.97 for industrial area	-do-
Cold and cough frequency	Prevalence	Cross-sectional survey	OR = 2.58 for commercial complex and 1.34 for industrial area	-do-
URS	Prevalence	Case control study	OR = 1.24 for more polluted Delhi than rural West Bengal	Powered with large sample size (CPCB) [24]
LRS	Prevalence	Case control study	OR = 1.66 for more polluted Delhi than rural West Bengal. Distribution highly correlated with PM	-do-
Diagnosis				
Asthma	Emergency visit	Ecological study	21.30 % of events were attributed to CO and TSP	Pande et al. [38] 2002
	Prevalence	Cross-sectional survey	No difference of prevalence in mid-high pollution zone and low pollution zone	The zone division is relative and demarcation level of 400 microgram per meter cube is 4 times higher than recommended level Chhabra et al.[23] 2001
COAD	Emergency visit	Ecological study	24.90 % of events were attributed to CO and TSP	Pande et al. [38] 2002
	prevalence	Cross-sectional survey	No difference of prevalence in mid-high pollution zone and low pollution zone	Chhabra et al. [23] 2001
	Emergency visit	Ecological study	1/3rd variability of COAD exacerbation was due to variability in the level of SPM.	Aggarwal et al. [30] 2006
Acute coronary event	Emergency visit	Ecological study	24.30 % of events were attributed to CO and TSP	Pande et al. [38] 2002
Respiratory disease	Hospitalisation	Ecological study	Relative risk for hospitalization due to air pollution is 1.07-2.82	Nidhi et al. [29] 2007
Respiratory disease	Hospitalisation	Ecological study	Ozone, NO and RSPM increased respiratory diseases related hospital visits by 24, 13 and 3% respectively.	Jairaman et al. [32] 2007
Respiratory disease	OPD attendance	Ecological study	r = 0.766; P< 0.01; r = 0.631, P< 0.05, between OPD patients and AQI at two tertiary care hospitals	Maji et al. [39] 2015
Hypertension	Prevalence	Case control study	Four times more pre-valence of Hypertension in Delhi compared to control population.	Up regulated p-selectin positive platelets, altered lymphocytes subtype Banerjee et al. [40] 2012
Physiological status				
PFT	PFT	Cross-sectional	Severe obstruction in industrial area	Mathew et al. [37] 2015
PFT	FVC, FEV1, MMEF, PEFR	Cross-sectional	Deterioration in PFT were more in medium-high polluted areas than low pollution areas. A proportion of asymptomatic with isolated reduction in MEFR in medium-high polluted zone	Chhabra et al. [23] 2001
PFT	FVC, FEV1,	Case control study	PFT was deteriorated in 40% people in Delhi (case) than 20% in West Bengal (control)	PFT more deteriorated in low SEZ than high SEZ CPCB [24] 2008
Health risk assessment				
Cancer risk	Incremental lifetime cancer risk assessment	Cross sectional study	2908 excess case of carcinoma due to presence of heavy metal in air. Cr is responsible for 80 percent of cases.	Khillare et al. [33] 2012
Health risk	Health risk	Cross-sectional Study	HR is 22.11 times higher for NO_2 and 16.13 times for SPM than due to SO_2	Health risk = dose exposure / LOAEL Pande et al. [31] 2005
Health risk	All natural cause of mortality	Time-series study	Every 10µg/m^3 rise in particulate is associated with 0.15% rise in all natural cause of mortality.	Rajarathnam et. al. [19] 2011
Health risk	morbidity due to asthma, heart disease or allergy	Cross-sectional Study	No significant difference were noted between highly polluted urban area and low polluted rural area	Joshi et al. [41] 1998

LOAEL =lowest observed adverse effect levels.

Very few studies were conducted in Delhi concerning air pollution and its association with health. During 1997, Joshi et al. [41] surveyed and determined the morbidities due to vehicular pollution in Delhi. Based on area sampling, highly polluted urban areas (SPM concentration, > 500 μg/m^3) and less polluted rural areas (assumed to be < 400 μg/m^3) were identified and numbered serially. The results of these two studies showed that exposure to vehicular pollution in the urban area was three-fold (staying in highly polluted areas) than the rural area, but interestingly, there was no significant difference between the two groups concerning morbidity due to asthma, heart disease or allergy.

Chabbra et al. [23] 2001 conducted a cross sectional study on a randomly stratified sample of 4171 permanent residents, living near each one of the nine pollution monitoring stations in Delhi. They demarcated Delhi into high, medium and low polluted zones by the level of pollution in these areas from 1989 to 1998. Respiratory symptoms were more prevalent in zones corresponding to low socio-economic zone, the reason might be prolonged outdoor pollution exposure. However, the prevalence of Bronchial Asthma, COPD, and Chronic Bronchitis was not significantly different in two zones. A proportion of asymptomatic showed an isolated reduction in Maximal Mid Expiratory Flow Rate (MEFR) suggesting early small airway disease. Subjects with such isolated reduction in maximal MEFR were more in medium- high zones.

Pande et al. [38] 2002 studied the relationship between the rate of hospitalization due to acute respiratory events (asthma and COPD exacerbations), acute coronary events and ambient air quality. Daily counts of patients visiting the emergency room of the All India Institute of Medical Sciences (AIIMS, New Delhi) for acute asthma, acute exacerbation of chronic obstructive airway disease (COAD) and acute coronary event was obtained prospectively from January 1997 to December 2000. Emergency room visits for asthma, COAD, and acute coronary events increased by 21.30%, 24.90%, and 24.30% respectively on account of higher pollutant level which was more than the permissible value.

Pande et al. [31] (2005) assessed location and age specific exposure to pollution and their health risk. They observed SO_2 as a pollutant to which exposure of subject was least, and its concentration was well within standards prescribed by NAAQ. They computed average relative “adverse health risk” for SPM and NOx taking SO_2 as the reference as 16.132 and, 22.111 respectively.

Aggarwal et al. [30] 2006 attempted to find association of respiratory ailments (COPD, Asthma, and Emphysema) with pollutants (SO_2, NO, SPM and RSPM) and meteorological factors in the year 2000-2003. They found that in winter months, the risk of exposure to pollutants increase compared to other seasons due to stability in the air stratification as pollutants get trapped in to the lower layers of the atmosphere resulting in high concentrations. A positive statistical correlation with the number of COPD cases viz., SPM ($r = 0.474$; $p < 0.01$) and RSPM ($r = 0.353$; $p < 0.05$) was observed. The two factors (SPM and Relative Humidity) had explained one-third of variability in COPD admission.

Jayaraman et al. [32] 2005 tried to determine the association between the air pollutants and daily variations in respiratory morbidity in Delhi during the years 2004–2005 by conducting data analysis based on the Generalized Additive Poisson regression model including a Lowess smoothing function for the entire patient population and subgroups defined by season. Single pollutant model showed that a 10 µg/m^{3}rise in pollutant level led to statistically significant relative risks (RR): 1.033 for O_3, 1.004 for NO_2, and 1.006 for RSPM.

Nidhi et al. [29] 2007 determined the association between environmental pollution and respiratory morbidity in Delhi for the period 1998–2004 by calculating

Relative Risk (RR) of hospitalization due to respiratory ailments caused by air pollutants in seven hospitals from different parts of Delhi. They found RR for hospitalization due to air pollution varied from 1.07 to 2.82.

A comprehensive epidemiological study to examine health risk due to air pollution in Delhi was conducted by the CPCB in 2008. [24] They identified a significant association between air pollution and all relevant adverse health outcomes. The findings were compared with a rural control population in West Bengal. It was found that Delhi had 1.7-times higher prevalence of respiratory symptoms compared with rural controls ($P < 0.001$); the odds ratio of upper respiratory symptoms in the consecutive 3 months in Delhi was 1.59 (95% CI 1.32-1.91) and for lower respiratory symptoms (dry cough, wheeze, breathlessness, chest discomfort) it was 1.67 (95% CI 1.32-1.93). Prevalence of asthma (in the last 12 months) and physician-diagnosed asthma among the residents of Delhi was significantly higher than in controls. Lung function was reduced in 40.3% individuals of Delhi compared to 20.1% in the control group.

Khillare et al. [33] 2012 studied the composition of heavy metal in suspended particulate matter and calculated Incremental lifetime cancer risk (ILCR) assessment. They estimated that up to 2908 excess cancer cases (102 for Cd, 2559 for Cr (VI) and 247 for Ni) were likely in Delhi due to lifetime inhalation exposure to these species at their current concentrations.

Rajaratnam et al. [19] 2011 studied the effect of particulate matter with the rise in all-cause mortality in Delhi. Mortality data from local municipality were taken as the output. A 0.15% rise in all natural all-cause mortality (with every $10\mu g/m^3$ increase in the particulate matter) after adjusting for meteorological parameters was reported. The rise they observed was less than what was expected from previous literature. They attributed the excess rise in mortalities to demographic characteristics, composition and toxicity of particulate matter, hence, signifying effect of the local factor on air pollution attributed mortalities.

Banerjee et al. [40] 2012 conducted a case control study comparing cardiovascular morbidity and risk factors in the population of Delhi with subjects residing in Uttarakhand as a control. Systolic and diastolic hypertensions were 2.5 and 4 times more prevalent in Delhi, respectively. Hypertension showed a positive correlation with RSPM specifically diastolic hypertension (rho = 0.350). A statistically significant abundance of target cell was observed in the population of Delhi signifying the liver problem in a substantial number of non- smoker and non-alcoholic population. Citizens of Delhi have 1.5 times more platelets than the control with an up regulated expression of platelets suggesting a hypercoagulable state, a risk factor for the cardiovascular event. The relative proportion of different subtype of lymphocytes was observed. An increase in CD8+ and the natural killer cell was observed where as CD4+ and CD19+ showed a decrease in abundance, which showed a significant correlation with particulate matter.

A cross sectional survey was conducted by Mathew et al. [37] 2015 to compare the prevalence of respiratory symptoms (wheeze, cough, phlegm) with pollution status. A statistically significant positive relationship of PM_{10} was observed with wheezing in participants. Majhi et al. [39] 2015 observed a positive correlation between AQI and OPD attendance due to respiratory morbidities.

Majority of studies were restricted to effect of air pollution on respiratory system. Studies conducted by Chhabra et al. [23] and CPCB [24] had studied comparatively large sample size and tried to search for comprehensive outcomes in study subjects. An underlying respiratory pathology even in asymptomatic and also its effect on other body systems was also observed. Banerjee et al. [40] had attributed high prevalence of hypertension, increased risk for an acute cardiac event and altered immune cell subtypes in Delhi to air pollution. Almost all of the studies conducted in Delhi were associative in nature. There is a paucity of cohort studies in Delhi. Cohort studies will help to understand the exact role of air pollution in the causation of various diseases. Thus, large cohort studies for long duration investigating comprehensive effects on the human body will provide us an insight into long-term effects of chronic pollution exposure. Such studies are especially important because changes in physiological functions are usually insidious and might take a long time to appear depending upon quantity and duration of exposure to pollutants. There are capacitation and physiological adaptation in exposure over time, which may not result in overt symptoms of the disease, although there is a concomitant reduction in the physiological capacity.

Interestingly, the studies reviewed and present review is based on assumption of homogeneity of Delhi's population. Physiological and pathological response to pollutant exposure is very heterogeneous among people of the same study area also, so studies are required to understand the genetic and physiological determinants of pathogenesis to open up windows for preventing and managing disorders due to pollution exposure. Further, models showing the quantitative association of pollutant exposure and its impact on health are developed using data from developed countries like North America and Europe where the pollutant concentrations are only one tenth to one fifth of the levels in India, and it is doubtful whether the effects at such high concentration follow the same quantitative relationship.

CONCLUSIONS

Exposure assessment and epidemiologic studies in the developing world are most important as informative database for the recent global health understanding. Despite inconsistencies, findings from Delhi based studies strongly indicate that air pollution is a major public health problem affecting health of people in an adverse manner. The air quality remained poor and kept on deteriorating in last two decades. The effect of poor air quality manifested as various health effects in the form of respiratory dysfunctions, cardiac disorders and their increased risk. The adverse health effects showed most consistent relationship with suspended particulate matter (SPM). Many of the existing epidemiologic investigations conducted in Delhi regions suffer from inaccurate exposure assessment, insufficient data and long term follow up of cohort studies. Therefore, cohort studies with larger sample size are needed to investigate the influence of air pollution on morbidity and mortality, for advocating policies and guidelines for, monitoring and control of harmful effects of air pollution.

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