Environmental Research 147 (2016) 480–496

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Review article

Exposure to particulate matter in India: A synthesis of findings and future directions

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ARTICLE INFO

Article history:
Received 20 January 2016
Received in revised form
1 March 2016
Accepted 5 March 2016

Keywords:
Air pollution
Personal exposure
PM
Microenvironment
India

ABSTRACT

Air pollution poses a critical threat to human health with ambient and household air pollution identified as key health risks in India. While there are many studies investigating concentration, composition, and health effects of air pollution, investigators are only beginning to focus on estimating or measuring personal exposure. Further, the relevance of exposures studies from the developed countries in developing countries is uncertain. This review summarizes existing research on exposure to particulate matter (PM) in India, identifies gaps and offers recommendations for future research. There are a limited number of studies focused on exposure to PM and/or associated health effects in India, but it is evident that levels of exposure are much higher than those reported in developed countries. Most studies have focused on coarse aerosols, with a few studies on fine aerosols. Additionally, most studies have focused on a handful of cities, and there are many unknowns in terms of ambient levels of PM as well as personal exposure. Given the high mortality burden associated with air pollution exposure in India, a deeper understanding of ambient pollutant levels as well as source strengths is crucial, both in urban and rural areas. Further, the attention needs to expand beyond the handful large cities that have been studied in detail.

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1. Introduction

Air pollution is a global environmental burden, and has been identified as a significant public health risk. Human exposure to ambient (outdoor) air pollution (AAP) and household air pollution (HAP) are important risk factors for morbidity and mortality, particularly in the developing countries (Lim et al. 2012). Exposure is a broadly used term that can be used to indicate both qualitative and quantitative measures of a pollutant, and can be defined in several ways, although the most generic definition takes into account the pollutant concentration and the amount of time an individual spends in contact with that pollutant (Moschandreas et al. 2002; Morawska et al. 2013). Various approaches for defining and estimating exposure are discussed by Zartarian et al.(2004). Over the last fifty years, a majority of the air pollution research efforts have focused on characterization and speciation of ambient particulate matter (PM), and its sources. While ambient PM concentrations are an important contributor to personal exposure (PE), they often do not correlate with, or are lower than levels of air pollutants individuals are exposed to (Monn et al. 1997; Huang et al. 2012).

Exposure to PM is a globally relevant topic because it has been linked to a number of deleterious health outcomes. Recent work has shown associations with exposures to generation of oxidative stress, and particle toxicity can vary based on chemical constituents (e.g. trace metals and polycyclic aromatic hydrocarbons [PAHs]), which in turn, can trigger inflammation and oxidative stress (Valavanidis et al. 2008; Shah et al. 2013; Kelly 2003). Exposure to PM has been associated with morbidity and mortality due to respiratory, cardiovascular and cerebrovascular diseases

Abbreviations: AAP, Ambient Air Pollution; AQI, Air Quality Index; BC, Black Carbon; CO, Carbon Monoxide; COPD, Chronic Obstructive Pulmonary Disease; CPCB, Central Pollution Control Board; EBC, Exhaled Breath Condensate; ETS, Environmental Tobacco Smoke; FEV, Forced Expiratory Volume; GBD, Global Burden of Disease; HAP, Household Air Pollution; HIA, Health Impact Assessment; I/O, Indoor/Outdoor; LPG, Liquefied Petroleum Gas; LUR, Land Use Regression; NAAQS, National Ambient Air Quality Standards; NCR, National Capital Region; OC, Organic Carbon; PAH, Polycyclic Aromatic Hydrocarbon; PE, Personal Exposure; PM, Particulate Matter; PNC, Particle Number Concentration; PSD, Particle Size Distribution; ROS, Reactive Oxygen Species; RSPM, Respirable Suspended Particulate Matter; SAFAR, System of Air Quality Weather Forecasting and Research; SPM, Suspended Particulate Matter; VOC, Volatile Organic Compound; WHO, World Health Organization

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http://dx.doi.org/10.1016/j.envres.2016.03.011
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(Harrison and Yin 2000; Chen and Lippmann 2009; Raaschou-Nielsen et al. 2016). In 2012, outdoor air pollution was classified as a group 1 carcinogen (i.e. carcinogenic to humans) (Benbrahim-Tallaa et al. 2012), and a recent World Health Organization (WHO) estimate suggests that in the same year, more than seven million premature deaths were due to air pollution exposure, with more than 80% being in the Pacific and South Asian regions (WHO 2014).

Several studies have concluded that use of fixed outdoor monitoring stations to estimate PE can lead to exposure misclassification (Huang et al. 2012; Dons et al. 2011; Koistinen et al. 2004), and as a result, the focus is rapidly shifting to direct characterization and quantification of PE to various air pollutants. For example, Hsu et al. (2012) reported personal PM exposures in the United States to be higher than indoor levels and studies in Europe have reported similar results (Broich et al. 2012; Johannesson et al. 2007). However, it is important to note that this may not be true in developing countries where ambient pollution levels are often very high. A recent global study on ambient PM concentrations reported a twofold difference between average population weighted $PM_{2.5}$ (PM with aerodynamic diameter less than 2.5 μm) concentrations in North America (12 μg/m^3) and Asia (38 μg/m^3) with the highest levels of $PM_{2.5}$-associated mortality in Asia due to high population densities (Apte et al. 2015). Similarly, intake fractions are also reported to be higher for Asian and Pacific countries compared with developed countries (Apte et al. 2012). Further, the population density levels in the developing countries are higher, which can contribute to higher overall exposure levels. A case in point is India where more than 50% of the population lives in areas where ambient $PM_{2.5}$ levels exceed the annual $PM_{2.5}$ (40 μg/m^3) Indian National Ambient Air Quality Standard (NAAQS) and less than 0.01% of the population lives in areas that meet the WHO $PM_{2.5}$ guideline of 10 μg/m^3 (Brauer et al. 2015). This is in stark contrast to Europe, where only 10-14% of the population lives in areas that exceed the European $PM_{2.5}$ guideline value (25 μg/m^3) (EEA 2014).

Very little is known about exposure to air pollutants in developing countries in Asia, Africa and Latin America where communities are saddled with burgeoning population levels and face rapid growth in urbanization and industrialization. There are several factors that can affect the exposure to PM in developing countries. First, there are several unique sources that are not found in developed countries (e.g. open waste burning, open cooking, use of animal dung as a fuel, use of diesel generator sets), and these sources have not been characterized well. Secondly, there are sources such as solid fuel burning which are significant in terms of indoor as well as ambient air pollution in developing countries, but do not contribute much to exposures in developed countries. Third, humans spend the largest proportion of their time in indoor microenvironments in the developed countries (Ott 1995; Diapouli et al. 2013) but this may not be true for developing countries. Finally, due to high poverty (especially energy poverty) levels and lower quality of life, certain sections of the population have higher susceptibility to negative health effects linked with air pollution. Thus, there is a need for a concerted global effort to generate exposure estimates for developing countries, yet most of our understand of health effects and air pollution are derived from communities that are cleaner and more developed.

The Global Burden of Disease (GBD) study in 2010 was a significant step forward in estimating exposures, and characterizing health risks associated with exposure to air pollution. In India, the GBD study identified both AAP and HAP as key risk factors in terms of disease for the Indian population (Lim et al. 2012), and air pollution, both AAP and HAP has been identified as one of the critical social determinants of health in India (Cowling et al. 2014). Nearly 100,000 premature deaths in India are linked to air pollution exposure (PHFI 2014) and in Delhi (Fig. 1) alone, between 7,350 and 16,200 premature deaths have been attributed to PM exposure (Guttikunda and Goel 2013). For a rapidly developing

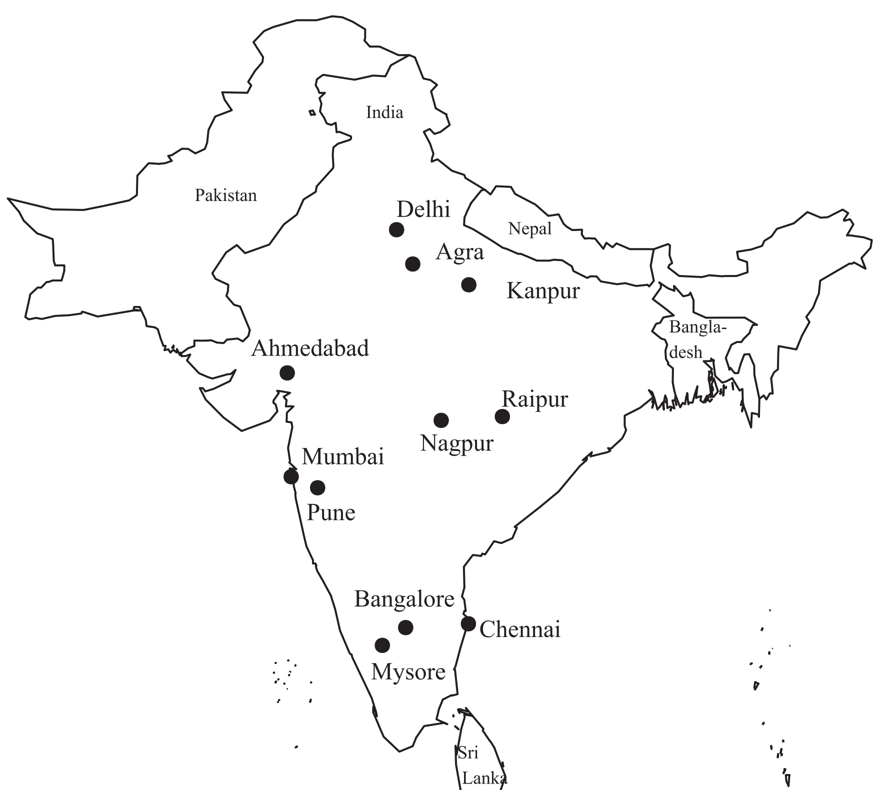

Fig. 1. Location of major Indian cities where indoor and/or personal exposure studies have been conducted, with results published in the literature.

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