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Mass distribution and health risk assessment of size segregated particulate in varied indoor microenvironments of Agra, India - A case study

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A B S T R A C T

Present study attempted to pave the way in study of indoor air pollution by Particulate Matter (PM) and picturesque a negative association of PM mass concentration levels with income (exposure determinant) at household level in Agra, India. Size resolved composition of PM (> 2.5 μm, 2.5–1.0 μm, 1.0–0.5 μm and 0.5–0.25 μm) was sampled through a cascade impactor that examined mass distribution of 11 metals i.e. Fe, K, Mg, Ni, Mn, Pb, Zn, Ca, Cr, Cu and Al; subsequently determined with ICP-AES. Results revealed the prime association of Fe, Ca, K, Cr and Cu with coarse sized particulates while the remaining metals were associated with fine PM. Their source identification was confirmed through enrichment factor calculation and correlational analysis. Calculated bioavailability index revealed higher value for smaller size fraction (0.5–0.25 μm) inferring higher chances of getting adsorbed into the body. Assessed health hazard for individual metals identified greater risk posed to adults than children by different size fractionated particles. Moreover, the study made a newer attempt by elucidating the fact that people residing in low income households relying on solid fuels (and/or *chulha*) are subjected to higher cancerous (2.3–14.8 fold) and non-cancerous (1.5–2.3 fold) risk than those living in safer environment.

1. Introduction

The most dysfunctional parts of the nation's growth system include the current state of outdoor air pollution that has somehow managed to turn down the curtains and the environmental concern of climate change that has developed a complex challenge to sustainable development in India. Both are worrying. But if home is one's yardstick, nothing beats the perilous impact of air pollution in the indoor environment. It encompasses its wings in being the world's single most environmental health risk feature, besides sharing a widespread hand in contributing to outdoor pollution related deaths (0.4 million) as a direct link of releasing emissions into the ambient atmosphere (WHO, 2014). The research indicates that people spend about 80% of time indoors among which the elderly and infants share a wider ratio of time inside their homes and are thus susceptible soundly to this hazard (Satsangi et al., 2014).

Of all the known indoor air pollutants, Particulate Matter (PM) study takes a unique place as per the growing scientific interest perspective and carries a large weightage from the research point of view as almost 1500–2000 annually published papers address only to the concerned subject (Fuzzi et al., 2015). The composition of PM includes a concoction of constituents including trace metals, water soluble ions and organic compounds like polycyclic aromatic hydrocarbons, polychloro-biphenyls etc. (Pipal et al., 2016). Trace metals, specifically make up a significant portion of particle mass as they are found in almost all atmospheric particle size

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fractions (Samara and Voutsa, 2005). A spectrum of anthropogenic and natural activities including biomass burning, tobacco emissions and smoking etc. have been known that drive the emissions of trace metals into the indoor atmosphere and thus play a crucial role in defining size distribution; with each reflective of its source profile (Sharma et al., 2014).

The application of cascade impactor technology in particle size exposure assessment provides a basis for precise examination of the relative contribution of fractionated PM as well as chemical components within each size fraction (Ambade, 2014). Various studies in literature have reported size distribution of particulate chemical constituents in indoor and outdoor atmosphere (Allen et al., 2001; Malandrino et al., 2016; Segalin et al., 2017; Slezakova et al., 2014; Viana et al., 2015; Waheed et al., 2011). In Indian context, a former study by Lakhani et al. (2008) published the size distributional data of trace metals in ambient air of a suburban site in Agra. Kumar et al. (2009) deployed a ten-channel QCM cascade impactor to study the aerosol size segregated characteristics over Indian semi-arid region. A study at Raipur explored PM concentrations as a function of particle size distribution (Deshmukh et al., 2013) whereas the abundance of size segregated ionic species in ambient atmosphere of Patiala has been reported by Singh et al. (2016). A recent study explored the size distribution of PM mass and associated elements using a ten-stage MOUDI impactor along a traffic site in New Delhi (Pant et al., 2016). However, none of these studies in India have compared the size distribution of indoor PM and its metal constituents collected at both urban and roadside sites and diverging with the socio-economic parameter that occupies the list of distal determinants of exposure parameters (Rohra and Taneja, 2016). Moreover, studies specifically relating to fractionation of bioavailable elements that leads to identification of comparable toxicity in varied sizes of PM too lack behind.

The present study has sought to bridge this gap by providing information on the concentration levels of PM at different microenvironments of world heritage site, Agra, India. The main objectives of the study are (i) to investigate the size distribution and related metal constituent concentration in coarse ($PM_{>2.5}$) and fine ($PM_{2.5–1.0}$, $PM_{1.0–0.5}$ and $PM_{0.5–0.25}$) particle fractions in residential homes diverging with location (urban and roadside) and socio-economic strata (low-, middle- and high-income groups), (ii) to assess the particle size effect on elemental bioavailability and (iii) to evaluate the carcinogenic and non-carcinogenic risk of particle size-segregated metal constituents through inhalation pathway. Notably, the risk assessment performed in the present study is one of its kinds as other health studies of PM have by far investigated the risk till particle size of 1.0 μm (Izhar et al., 2016) and thus have not gone beyond that. Thus, the results of this study will give a better view of the indoor air quality with reference to size resolved particulate concentrations in residential microenvironments that could help the health officials and general public to gain insight into the toxicity of metal bound particles with a better understanding to control them.

2. Materials and methods

2.1. Site description

Agra, the city of inimitable Taj Mahal, is situated in Uttar Pradesh, the North Central part of India (27°10′N, 78°20′E), approximately 200 km of south of New Delhi. The city has about 4,418,797 total population, and the population density is about 1084 persons/km^2 (http://www.census2011.co.in/census/city/115-agra.html; accessed on 6/10/16). As being one of the most populous city in the state, vehicular traffic accounts as major pollution source. Four major national highways NH–2, 3, 11 and 93 are passing all the way through the city aiding serious traffic. Besides, Mathura oil refinery and Firozabad glass industry with a number of industrial units situated within radius of the city also serves as a local pollution source (Kulshrestha et al., 2009).

2.2. Sampling design

In the present study, a couple of houses were selected in urban and roadside areas of Agra region (Fig. 1) for sampling and questionnaires were made to fill by the occupants to avail existing information of their daily activities and the sampled house characteristics. The houses in the urban microenvironment were old; closely build in a narrow street with houses at both the side of the street. The homes in the roadside microenvironment were adjacent to a road in the posh area of the inner city experiencing moderate traffic in the morning and evening hours. These houses were multi-storied unlike urban houses and were modern type with greenery in the surrounding areas. Moreover, to assess the effect of socio-economic status on the indoor particulate pollution, the urban houses were classified into three categories: Low income Groups (LIG) (INR < 5000) Middle Income Groups (MIG) (INR 60,000) and High-Income Groups (HIG) (INR > 70,000) after the approximate estimation of the monthly income earned by household member (Kulshreshtha and Khare, 2011). Their individual characteristics have been illustrated in Table 1.

2.3. Instrumentation and sample collection

Indoor PM samples were collected in the month of April 2016 using the Leland Legacy pump (at selected air flux of 9 L/min) in combination with a five-stage Sioutas cascade impactor (SKC Inc. Eighty-Four PA USA) with particle size cut points of 2.5 μm, 1 μm, 0.5 μm and 0.25 μm. It collects five particle fractions viz. $PM_{>2.5}$, $PM_{2.5–1.0}$, $PM_{1.0–0.5}$, $PM_{0.5}–_{0.25}$ and $PM_{<0.25.}$ In our study, PM in the fifth i.e. back-up stage could not be collected due to some unavoidable circumstances. Notably, the term 'coarse' used in further sections of manuscript denotes the particles of the first stage ($PM_{>2.5}$) and the term 'fine' (interchangeably mentioned as $PM_{2.5}$) refers to the sum of last three stages.

Calibration of the instrument was performed using a DryCal DC-2 calibrator (Bios International Corporation, NJ USA). The sampling device was placed on a tripod photographic stand at an average inhalation height of a person i.e. 1.6 m in the living area of the home where it is assumed that people spend most of their time (Taneja et al., 2008). Sampling was conducted for 18–20 h for two