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Chemical and morphological characteristics of indoor and outdoor particulate matter in an urban environment

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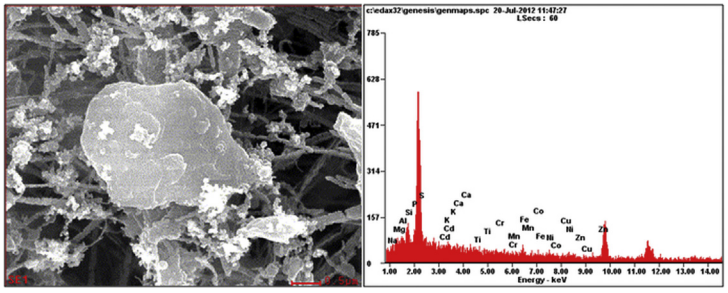
HIGHLIGHTS

- Characteristics of Indoor–outdoor particulate elemental and ionic composition.
- Seasonal variation of indoor particulate elemental and ionic concentration.
- Particle characterization confirms vehicular emissions contribution in indoor SPM.

GRAPHICAL ABSTRACT



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ABSTRACT

Chemical characterization of suspended particulate matter (SPM) measured inside a naturally ventilated school building (indoor) and at an adjacent roadway (outdoor) in Chennai city was performed during monsoon, winter and summer seasons. The daily average indoor SPM concentrations in monsoon, winter and summer seasons were 158.18, 170.08 and 149.63 μg m^{-3}, respectively. Indoor and outdoor samples were analyzed for 11 inorganic ions using ion chromatography and 28 elements by inductively coupled plasma optical emission spectrometry. Results indicated the dominance of SO_4^{2-} (10.89 μg m^{-3}) followed by NH_4^+ (5.62 μg m^{-3}), NO_3^- (5.35 μg m^{-3}), Na^+ (4.35 μg m^{-3}) Ca^{2+} (4.08 μg m^{-3}) and Cl^- (3.47 μg m^{-3}) ions in the indoor SPM. In the outdoor SPM, SO_4^{2-}, NO_3^- and NH_4^+ ions concentration were slightly higher while Ca^{2+}, K^+ and Mg^{2+} ions concentrations were higher in indoors. Among the elements, crustal element (Al, Fe, Ca, K, Mg and Na) concentrations were much higher (92.7% of the total elemental concentration) in indoor environment than those of toxic elements (Ba, Cr, Cu, Mn, Mo, Ni, Sr, Ti, V and Zn) emitted from vehicles. Analysis of elemental carbon (EC) and organic carbon (OC) components in indoor and outdoor PM indicated the predominance of OC. The indoor/outdoor (I/O) ratios for EC = 0.70 and OC = 0.82, indicating no significant indoor emission sources of OC and EC. To characterize the morphology, indoor and outdoor filters were examined by Scanning Electron Microscopy coupled with energy dispersive X-ray spectrometry. Soot and Al–Si rich particles were mostly found in indoor and outdoor SPM. The presence of toxic elements and soot particles in the indoor PM confirms the contributions of vehicular emissions from the adjacent motorway.

1. Introduction

Indoor air pollution (IAP) is one of the major problems in developing countries, especially in India. The contribution of IAP to disease in India is about 4.2–6.1% (Smith, 2000). Particulate matter (PM) is

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one of the critical pollutants in the indoor environment. Exposure to PM has been linked to adverse health effects, including acute and chronic respiratory disorders, lung cancer, morbidity and mortality in children and adults (Pearce and Crowards, 1996; Pope et al., 2002; WHO, 2003; Neubergera et al., 2004; Wallenborn et al., 2009; Maté et al., 2010). The health effects of PM strongly depend on its composition, which consists of inorganic ions, organic carbon (OC), elemental carbon (EC), crustal elements and toxic metals. The PM composition and concentration are extremely variable and depend on many factors such as climatic conditions, emission sources and geographical location. Indoor PM concentrations are affected by indoor sources and sinks, ambient concentrations, outdoor meteorology, air exchange rates, penetration factors, as well as deposition and re-suspension mechanisms. So to identify the prominent IAP sources, it is essential to know the chemical composition of particulate matter in the indoor environment.

In the past, several researchers reported that levels of indoor particulate matter in school building are exceeding the WHO air quality guidelines and air quality standards of various nations. It is also documented that a large number of children are regularly exposed to elevated levels of traffic-related emissions because of the proximity of urban schools to motorways (Lee and Chang, 2000; Janssen et al., 2001; Goyal and Khare, 2009; Chithra and Nagendra, 2012; Tran et al., 2012). Another reason for elevated PM concentrations in classrooms is due to intense occupant activities (Janssen et al., 1999; Branis et al., 2005; Poupard et al., 2005; Fromme et al., 2007; Diapouli et al., 2008; Stranger et al., 2008). So the analysis of PM chemical composition will help identify the IAP sources in classrooms. John et al. (2007) analyzed trace elements and ions in the ambient fine PM at three elementary schools in Ohio and observed strong seasonal and regional variations in indoor PM. Source apportionment using the principal component analysis (PCA) technique indicated that the study region was primarily impacted by industrial, fossil fuel combustion and geological sources. A recent study conducted in French classrooms reported that re-suspension dust, traffic and marine aerosols are the major sources of PM in classrooms (Tran et al., 2012). Most of the researchers observed that sulfate and calcium (caused by the use of chalk) are the major components of indoor PM in school building (John et al., 2007; Fromme et al., 2008; Diapouli et al., 2008; Stranger et al., 2008; Pegas et al., 2012; Tran et al., 2012).

In India, literature on PM chemical characterization inside classrooms is very scanty. Gadkari and Pervez (2008) analyzed the elemental composition of indoor PM among school communities in central India. Source apportionment of personal exposure shows that industrial emissions and road traffic dust are the major sources of personal exposure of fine particulates. The aim of the present study is to characterize the chemical and morphological properties of suspended particulate matter (SPM) in classrooms and its corresponding outdoor air. In this research work, the chemical characterization of PM2.5 and PM1was not carried out due of limitation of resources.

2. Materials and methods

2.1. Description of the site

Chennai, formerly known as Madras, is situated on the south eastern coast of India. The Chennai Metropolis lies in the latitude between 12°50′49″ and 13°17′24″ and longitude between 79°59′53″ and 80°20′12″ and covers about 1189 km^2. It has a tropical wet and dry climate and is highly influenced by sea–land breeze phenomena. The Indian Meteorological Department (IMD) has categorized the months of January and February as winter season, March–May as summer season, June–September as southwest monsoon and October–December as northeast monsoon. Chennai gets most of the rainfall during northeast monsoon and less rainfall during the southwest monsoon. According to the 2011 census, the city has 4.68 million residents, making it the sixth most populous city in India; the urban agglomeration of approximately 8.9 million, making it the fourth most populous metropolitan area in the country and 31st largest urban area in the world. Chennai is growing as a major export hub for vehicles in the Southeast Asian markets. It has a 30% share in the Indian automotive industry and is often called "Detroit of India" (Devonshire-Ellis et al., 2012). Chennai is home to many educational and research institutions and has a mix of public and private schools. The public school system is managed by the Chennai Corporation, with an enrollment of 142,387 students in over 330 schools (Corporation of Chennai, 2012). For the present study, a naturally ventilated school building located adjacent to an urban road (Sardar Patel road) having an average traffic flow of about 1,74,000 vehicles per weekday and 1,36,000 vehicles per weekend was selected (Fig. 1). The study room is on the primary wing of the school building with occupancy of 43 students in the age group of 8–9 years. A detailed description of classroom characteristics can be found in Chithra and Nagendra (2012).

2.2. Sampling

Indoor and outdoor SPM levels were measured using low volume handy air samplers (Model APM 821, Envirotech Instruments Private Limited, India) with a flow rate of 1.5 L per minute for 24 h. Handy samplers are portable instruments designed for measuring particulates and gaseous pollutants in work places, which has been used in many studies previously (Kumar et al., 2008; Masiha et al., 2010). The instrument was placed in the classroom, with the inlet approximately 1 m above the floor corresponding to breathing level of the children. Indoor SPM was monitored for 20 days each during monsoon (October–November) of 2011, winter (January–February) and summer (April–May) of 2012. Outdoor sampler was kept on kerbside and monitoring was done for 25 days including all the three seasons (9 days in monsoon, 8 days in winter and 8 days in summer). Samples were collected on 25-mm diameter PTFE filters of pore size 0.2 μm (Whatman International Limited, USA). A TSI IAQ-CALC Model 7545 Indoor Air Quality Meter (TSI Incorporated, USA) was used to measure the indoor and outdoor temperature, relative humidity, CO_2 and CO concentrations. The outdoor meteorological parameters like wind speed, wind direction and temperature were collected using wind monitor (WM 25, Envirotech Instruments Private Limited, India) mounted on the building rooftop, which is about 10 m above ground level.

2.3. Analytical methods

After the gravimetric analysis, the filter papers were divided into two halves. One half was used for the analysis of ions and the other half was used for the elemental analysis. Elements were extracted using hot acid digestion procedure (IO-3.1) and were analyzed (IO-3.5) based on EPA methods (USEPA, 1999a, 1999b). Filters were placed in beakers and 10 mL of acid solution (55% HNO_3/16.75% HCl) was added and heated at nearly 100 °C for 1 h. Then the volume of the extracts was adjusted to 20 mL by distilled water and analyzed for elements. A total of 28 elements (Ag, Al, As, Ba, Be, Bi, Ca, Cd, Co, Cr, Cu, Fe, Ga, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Rb, Se, Sr, Te, Ti, V and Zn) were analyzed quantitatively by ICP-OES (Perkin Elmer Optima 5300 DV). Extraction and analysis of ions were carried out as per the standard operating procedures (SOPs) suggested by Central Pollution Control Board (CPCB), Ministry of Environment and Forests, Government of India, New Delhi. Water-soluble anions (F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-} and PO_4^{3-}) and cations (Na^+, NH_4^+, K^+,