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Exposure from particle and ionic contamination to children in schools of India

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ABSTRACT

The high levels of indoor particulate matter in developing countries and the apparent scale of its impact on the global burden of disease underline the importance of particulate matter as an environmental health risk and the consequent need for monitoring them particularly in indoor school microenvironments. The concentrations of PM_{10}, $PM_{2.5}$, and $PM_{1.0}$, were measured along with ionic concentrations K^+, Ca^{2+}, Na^+, Mg^{2+}, SO_4^{2-}, NO_3^-, Cl^- and F^- collected from settled dust in the indoor–outdoor environment of roadside and residentially located schools in Agra City, from January to May 2008–09. Along with PM concentrations at the roadside and residentially located schools meteorological parameters like temperature, humidity, and wind speed and air exchange rate was also calculated during the study period. The enrichment factor was calculated using Ca as a reference to the trace ionic species to identify the sources. Principle component analysis showed three to two factors inside and three factors outside the classrooms of the roadside and residentially located schools. These factors reflected sources like soil dust, road dust, vehicle emissions, anthropogenic sources, industrial emissions, metal processes, and incineration activities and their contributions were estimated using principal component analysis. Symptoms like asthma, dizziness, coughing, itching, eye irritation, shortness of breath, headache, cold and flu were observed. Measurements of such exposure levels would be helpful in the prevention of environmental risks to school children.

Keywords: *PM and ionic contamination, children exposure, enrichment, source apportionment*

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1. Introduction

Indoor air pollution has become increasingly clear and indicates that the exposure to contaminated indoor air may not only be unpleasant, but can have serious adverse health effects on all mankind (Smith and Mehta, 2003; Schwartz, 2004), especially in developing countries such as India are higher than those in developed countries and hence this problem is often severe in cities of developing countries all over the world (Mage et al., 1996; Bhaskar and Mehta, 2010). Since children are the most sensitive subgroup of the population, schools are considered as the important places in health work where children spend about half of their wakening hours. Their susceptibility is due the continuing process of lungs growth and development, incomplete metabolic systems, immature host defenses, high rates of infection with respiratory pathogens, and activity patterns that heighten exposure to air pollution and to lung doses of pollutants (Spengler et al., 2001).

The Earth's crust is the persistent source for all natural constituents, i.e. ions, metals, etc. Many studies have shown geological sources such as fugitive dust from tilling, roadways, traffic emissions, construction, unimproved roads, (Amato et al., 2009) soil dust and industrial emissions as the main contributors of the coarse and fine particulates. Apart from this, indoor activities in school buildings like paint chipping, inadequate cleanliness in classrooms, large number of occupants with less surface area of classrooms, frequent rubbing of chalk dust on blackboards contribute to indoor pollution levels (Habil et al., 2013).

On an average, long–term indoor exposure to coarse and fine particle concentrations accounts for three times higher than that observed by outdoor measurements alone (Janssen et al., 1999). Their toxicity tends to increase as these particle size decreases (Gadkari, 2010; Massey et al., 2012). Prolonged exposure to dust may lead to respiratory problems (Ingle et al., 2005). Nature of particulate matter in the atmosphere and within the human respiratory system is determined by various physical and chemical properties of particulates (Andrade et al., 1993). Particles, especially $PM_{2.5}$ penetrates deep into the lungs and in the alveoli, which provoke inflammation in response, throughout the body, producing upper respiratory and mucous membrane irritation to nose, throat, eyes and skin, headaches, dizziness etc. Their continuous inhalation can lead to the symptoms of lower respiratory tract such as cough, shortness of breath and pain with inspiration and neuropsychological effects (Majumdar and William, 2009; Habil and Taneja, 2011).

In India, mostly, schools are naturally ventilated, where air moves through opened doors and windows allowing outdoor polluted air to flow indoors. The unavailability to provide good air quality in schools can have health related consequences, both for the pupils and staff, which indirectly affects children's learning environment, productivity of teachers (Janssen et al., 1999; Mendel and Heath, 2004). Thus, indoor air pollution not only has immediate localized impacts on human health, but also contributes to regional and global air pollution problem, especially in developing countries like India. This paper presents a study on particulate matter

pollution carried out in Agra City, Uttar Pradesh, India. Particulate matter sizes, coarse particle PM_{10} and fine $PM_{2.5}$ and $PM_{1.0}$ were collected to detect air quality, while, ionic content in settled dust was detected to view dust contamination. Furthermore, data derived from the study have been utilized for Enrichment Factor Analysis and statistical analysis using Pearson correlation and Principal Component analysis, to identify the possible sources contributing in and around the school premises. Results, obtained by this study can provide useful information on the sources contributing to health risk in sensitive environments, i.e., schools, of this region. The metallic part of this data has already been discussed in detail in one of our previous studies (Habil et al., 2013).

2. Materials and Methods

2.1. Site description

Sampling was carried out in Agra, the city of Taj Mahal (27°10′ N, 78°02′ E), located in Central Northern India. Being a tourist spot, a large economy draws daily in and out, from within and outside the country. This region consists of three major national highways connecting to Delhi (NH2) with Mumbai (NH3) and with Jaipur (NH11) which cross the city. Vehicular traffic on these highways is high as 10^5 vehicles per day (RTO, 2009). Agra has about 4 418 797 of the total population inhabits in a 4 041 km^2 area with a density of 1 084 km^2, out of which, 62.6% are school–going children (Habil and Taneja, 2013). In summers the temperature ranges from 30.1 °C to 46 °C with hot dry winds and 7.2 °C to 25 °C in winters, experiencing cold and chilly winds in the morning and evening. Relative humidity ranges from 19% to 71%. The wind speeds vary from 5.1 km/h to 10.5 km/h, which is highest during the summers followed by winters and monsoons (Habil et al., 2013). Figure 1 shows ten schools chosen for sampling in different areas of the city, i.e. at roadside (RD, five schools), and residential areas (RN, five schools). Roadside schools were defined as one adjacent to a major road (at a distance of 2 to 5 m) experiencing heavy traffic, especially; during morning rush hours (7 AM to 10 AM, when children and adults go to schools and offices) and noon to evening rush hours (between 1 AM to 3 PM, when people go back home), as observed during school days during 2008–2009. Residentially located schools were those with lower traffic zone, i.e. surrounded by streets. In addition, one of the schools with less pollution in residential area was considered as a background site, for other schools, which was used to view the exceedance of the concentration obtained at schools located at roadside and residential areas. All schools practiced cleaning such as sweeping, mopping and occasional dusting of student's furniture's. Sweeping was done two to three times (before school, after recess and after school), while mopping was done once during the school hours.

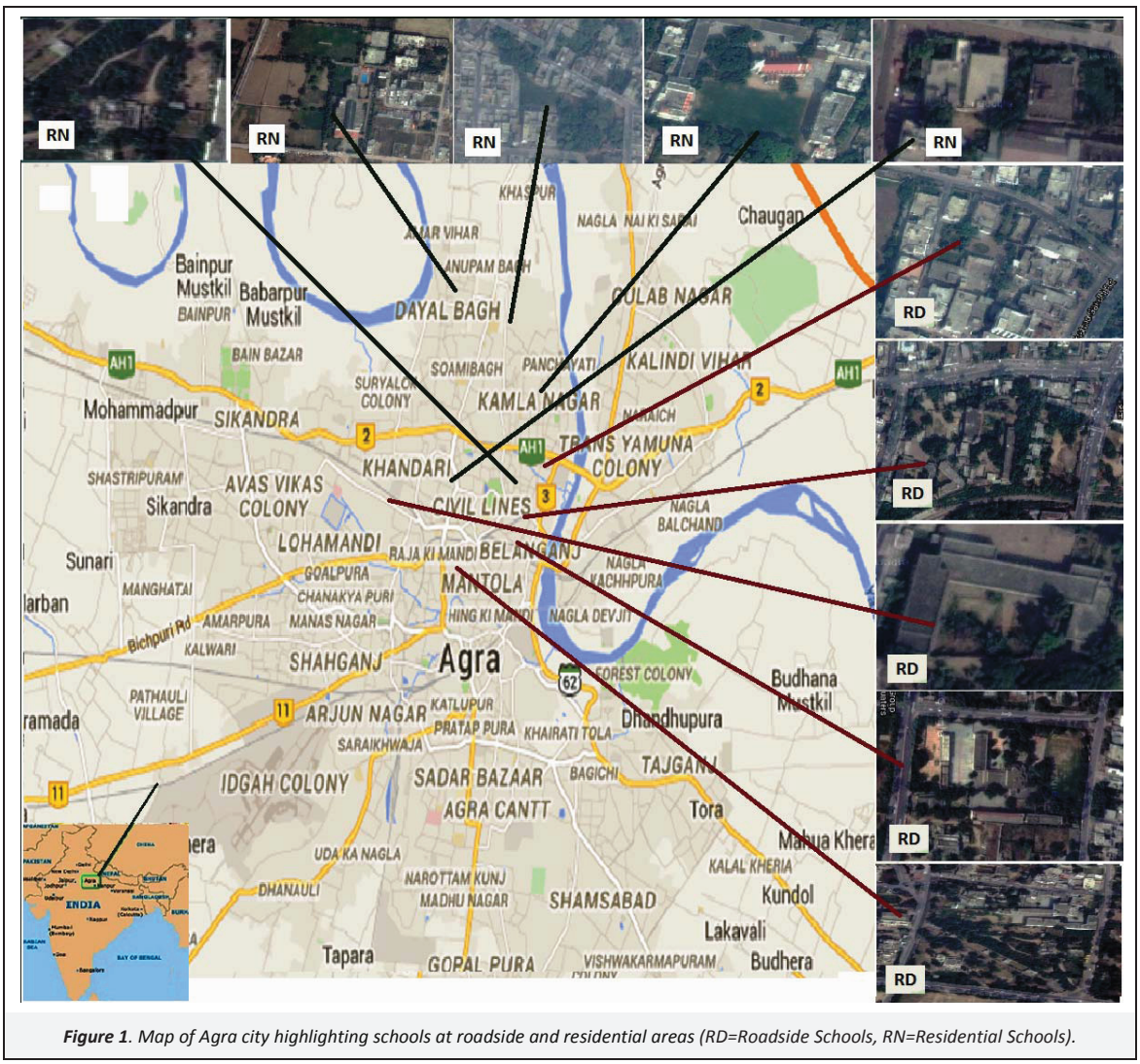

Figure 1. *Map of Agra city highlighting schools at roadside and residential areas (RD=Roadside Schools, RN=Residential Schools).*

2.2. Sample collection

Sampling was conducted both inside and outside the class-rooms of schools located near roadside and those located in residential areas. Sampling time was restricted to 5–6 h of lecturing during school days only. Therefore, in order to measure the PM levels, in classrooms with occupants and without occupants, sampling time was extended, i.e., 30 min before (in the morning, when school is going to start) and 30 min after the school (in the afternoon, when school gets over) to get the overall effect. Classrooms starting from third to ninth standard were chosen for monitoring in each school. Schedule for sampling was carried from January 2008 to May 2009, in all the three seasons, i.e., winter, summer, and monsoon. However, due to unavailability of students during summer vacations (in June) and restriction for sampling during examinations (in March), the respective 2 months were not included in the sampling schedule, along with weekends and government holidays. Therefore, students' occupancy was observed around 200 days out of the 365 days of a year. Thus, the total number of samples collected during the monitoring was 210 in number from all the sampling locations. For a collection of particulate matter, the sampling unit was placed in the classroom, opposite to the blackboard, about 1 m above the floor level, the level at which children normally inhale, and away from doors and windows. Outdoor measurements were taken outside the sampled classroom in open areas (about 10 m away).

Due to a lack of multiple samplers, a methodology was adopted, in which the indoor and outdoor measurements were taken by placing the sampler at any one location (indoor/outdoor) for the first 30 min and for the other location (indoor/outdoor) for the next 30 min until the stated sampling duration (school hours). In order to obtain a continuous data of a day, the instrument was placed the next day to monitor those locations that lacked intervals of the previous day in the same order. Then, these measured values were merged together to obtain the full day data variation in indoor and outdoor environments of the schools. This methodology is also adopted by earlier studies (Habil and Taneja, 2011; Habil and Taneja 2013; Habil et al., 2013; Massey et al., 2013). Though, the measurements were conducted from one school at a time to other throughout the sampling duration. Along with this, meteorological parameters like temperature, wind speed, humidity, and ventilation rate was also measured, to know their influence on the measurements.

Grimm 31–Channel Portable Aerosol Spectrometer model No.1.109 was selected for monitoring the indoor and the outdoor mass concentration of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ at a constant flow rate of ±1.2 L/min ±5% with a controller for continuous measurement during the sampling period. The instrument works on dual technology, i.e. the principle of scattering of light at 90° to give the real–time measurements and total particles can be collected on 47–mm PTFE filters for chemical analysis (Habil and Taneja, 2011; Massey et al., 2013). Its real time measuring range is from 0.25 to 32 µm in 31 channel sizes, each unit is with NIST (National Institute of Standards and Technology) certified, monodisperse latex on the size of channels calibrated (www.dustmonitor.com/Research/1109.htm). Environmental parameters like temperature (°C), relative humidity (RH%), and ventilation rate (cubic meter per hour) were also monitored simultaneously by using Young Environmental Systems, Canada (YES 205 and YES 206) multi–gas monitors, while wind speed was obtained by the meteorological station (WM251, Envirotech), installed at a 10–m height from the ground level on the rooftop of the chemistry department of St. John's College, Agra which is located in the center of the city and close to all the sampling locations.

Moreover, settled dust was collected from 0.5 m of area of shelves inside the classrooms, as indoor dust samples, and outdoor samples from outside the school premises adjacent to a nearby road/street. Each dust samples were collected separately for each school, by using a brush and a tray, and kept in zip–lock bags as dust samples. The collected dust samples were sieved and were extracted for 90 min in ultrasonic extractor for the determination of water–soluble ions. Then extract was filtered through Whatman filter paper and transferred to polypropylene sample bottles dipped in 2% HNO_3 overnight before storage and then again dipped in deionized distilled water overnight to remove any impurities on these bottles). Ionic concentrations of F^-, Cl^-, NO_3^- and SO_4^{2-} were analyzed by an Ion Chromatograph (DIONEX–2000, USA) using an analytical column (Ion Pac–ASI5), anion micro–membrane suppressor (ASRS–II 2 mm), 38 mM KOH/1.7 mM sodium bicarbonate as eluent and triple–distilled water as regenerator at the Institute of Tropical Metrology, environmental laboratory in Delhi. While, cations Ca^{2+}, K^+, Na^+ and Mg^{2+}, were determined by ICP–AES, Model No. ARCOS from M/s. Spectro, Germany, at IIT, Mumbai. To assure the quality of samples, blanks were determined by carrying full chemical extraction without taking the dust sample. These blank values were very low, typically below or around the method detection limits. Certified analytical grade (Merck) chemicals were used along with high purity standards, for linear calibration curves, which were checked after each four to five analytical runs and a visual check was also made for linearity and replication. PM indoor/outdoor ratios, associating with meteorological parameters, were also calculated, along with descriptive data, to view the more dominant area (indoor–outdoor) of ionic content. The enrichment factors (EFs) (Figure 2) for ionic data were calculated to evaluate and identify if a determined metal is contaminant or constituent, frequently found in soil and dust samples (Habil et al., 2013). Ca was used as a reference element because of its exceptional abundance in regional soil dust (Kothai et al., 2011), using the following equation:

$$refEF_{el} = \frac{C_{el,dust\ (indoor)} \times C_{Ca,dust\ (outdoor)}}{C_{Ca,dust\ (indoor)} \times C_{el,dust\ (outdoor)}} \quad (1)$$

where Ca is calcium, refEF is the enrichment factor (ratio) of a metal in indoor dust, according to outdoor dust at the reference point, C is the concentration of a metal in dust, and el is the observed metal. Principle component analysis (PCA) was also conducted to view similar metal sources, in indoor and outdoor samples along with the inter–metal relationships. It was applied to the correlation matrix for the present study, and each variable was normalized to unit variance and therefore contributes equally (Salvador et al., 2004).

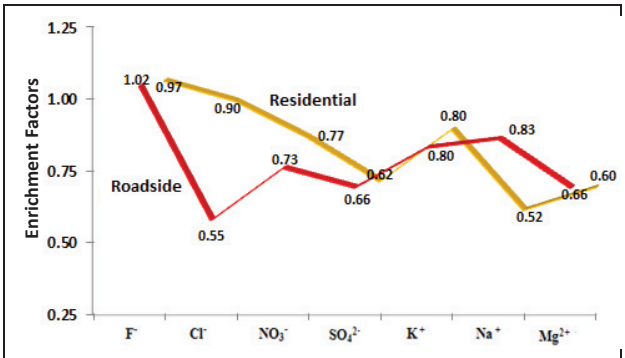

Figure 2. *Enrichment factors of ions in classroom dust at schools at roadside and residential areas.*

Furthermore, symptoms related to health effects were evaluated by help of questionnaires that were distributed, which reflected the impact of indoor and outdoor surroundings. A total of 350 questionnaires were distributed to the pupils being monitored in classrooms at both roadside and residential schools (175 and 175, respectively), where 300 questionnaires were returned from all

schools. However, one questionnaire was completed by one pupil such that the response rate of the reported symptoms is the number of received questionnaire with that symptom, divided by the number of distributed questionnaires. This consisted of three parts: questions regarding the school area, classroom condition and health effects or symptoms experienced by the children due to the school environment. The questionnaire was also used to record occurrences of acute respiratory symptoms, which would provide a powerful method for assessing the impact of short–term changes in human health due to environment. Symptoms included were: asthma, dizziness, coughing, itching, irritation in the eyes, shortness of breath, headache, cold and flu.

3. Results

3.1. Particulate matter and chemical constituents

PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ mass concentrations along with CO_2, temperature, relative humidity and air exchange rate was measured inside and outside the classrooms of schools located at the roadside and residential areas of the city of Agra from January 2008 to May 2009, during three seasons i.e., winter, summer and monsoon, as indicated in Table 1. The PM concentrations in indoor and outdoor during sampling duration were 264.91±33.73 μg/m^3 and 240.96±38.08 μg/m^3 (for PM_{10}), 81.85±13.06 μg/m^3 and 75.14± 16.37 μg/m^3 (for $PM_{2.5}$), 55.43±11.12 μg/m^3 and 51.48±12.19 μg/m^3 (for $PM_{1.0}$) at roadside schools while at residentially located schools PM_{10} accounted as 261.11±45.48 μg/m^3 and 235.51±34.48 μg/m^3, $PM_{2.5}$ as 78.33±12.44 μg/m^3 and 71.95± 14.55 μg/m^3 and $PM_{1.0}$ as 53.20±9.59 μg/m^3 and 48.62± 11.97 μg/m^3 respectively. These reported values are the sum of each five schools located near roadside and the other five at residential area in their indoor and outdoor environments, during the three seasons. The trends of particulate mass concentrations for all the particle sizes were similar but greater in roadside schools than residentially located schools for outdoors as well as indoors environments. This indicates that air quality in roadside schools is affected more by particulate matter than in comparison to residentially located schools, but with negligible difference, which might be due to the factor of natural ventilation at both roadside and residentially located schools. On comparison with National Ambient Air Quality Standard (60 μg/m^3 annual average for PM_{10} and 40 μg/m^3 annual average for $PM_{2.5}$) (NAAQS, 2009), PM_{10} was found to be 4 times and $PM_{2.5}$ 6 times higher in indoors and outdoors and on comparison with World Health Organization (WHO, 2005) standards (20 μg/m^3 for PM_{10} and 10 μg/m^3 for $PM_{2.5}$ annual mean). Our results exceeded 4–13 and 8–26 times for PM_{10} and $PM_{2.5}$ indoor whereas outdoor concentration ranged between 4–12 and 7–23 times (for PM_{10} and $PM_{2.5}$ respectively).

Water soluble species were also analyzed in this study, which include anions (SO_4^{2-}, NO_3^-, Cl^-, F^-) and cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+). The mean concentration of anions and cations are shown in the Tables 2a and 2b. Table 2a and 2b depicts that cations reigns both in indoor and outdoor at roadside and residential schools. Mg^{2+} was found to highly contribute (40%), followed by Ca^{2+} (10 to 20%)>K^+(10%)>NO_3^-(10 to 15%)>SO_4^{2-}(5 to10%)>Na^+(5 to10%)>Cl^- (2%), while, F^- was observed in negligible amounts, at roadsides and residential schools. Thus, the trend indicates that the contaminating soil consist major parts of regional soil dust which gets influenced by nearby anthropogenic sources. Cation Mg^{2+} (ranged 29.61–41.28 mg/kg) and Ca^{+2} (ranged 16.75–20.33 mg/kg) dominated with higher concentration levels in indoor and outdoor at roadside and residential schools. While, ions K^+, Na^+, SO_4^{2-}, NO_3^-, Cl^- and F^- ranged from to 0.07–10.67 mg/kg at both roadside and residential areas.

Table 1. *PM concentrations (μg/m^3) and meteorological parameters during the study period*

Parameters	Roadside Schools						Residential Schools						Temperature, °C	Relative Humidity, %	Wind Speed, m/h	Ventilation Rate, m^3/h
	PM_{10} In	PM_{10} Out	$PM_{2.5}$ In	$PM_{2.5}$ Out	PM_{10} In	PM_{10} Out	PM_{10} In	PM_{10} Out	$PM_{2.5}$ In	$PM_{2.5}$ Out	$PM_{1.0}$ In	$PM_{1.0}$ Out				
Mean	264.91	240.96	81.85	75.14	55.43	51.48	261.11	235.51	78.33	71.95	53.20	48.62	28.32	41.57	7.75	61.78
SD	33.78	38.08	13.06	16.37	11.12	12.19	45.48	34.48	12.44	14.55	9.59	11.97	8.65	18.29	1.95	28.14
Maximum	324.32	310.29	106.41	102.73	73.96	70.37	302.03	292.42	105.11	100.11	68.47	65.73	46.00	71.00	10.50	100.00
Minimum	215.99	198.54	70.42	52.00	40.16	35.04	212.73	194.89	65.44	50.16	40.02	28.79	7.25	19.00	5.10	27.00
Skewness	0.27	0.56	1.02	0.44	0.59	0.37	1.19	0.44	1.03	0.50	0.57	0.09	–0.25	0.34	–0.03	0.32

Table 2. *Statistical analysis of ionic constituents in indoor and outdoor environments at* ***(a)*** *roadside located,* ***(b)*** *residentially located schools in mg/kg*

	F^-		Cl^-		NO_3^-		SO_4^{2-}		Ca^{2+}		K^+		Na^+		Mg^+	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
								(a)								
Mean	0.08	0.07	1.48	1.36	9.11	9.96	4.52	7.25	20.33	20.33	10.54	10.67	6.91	6.52	29.61	41.28
Median	0.08	1.44	1.36	9.23	10.06	4.26	7.25	21.18	21.18	21.63	10.68	10.99	6.43	6.71	29.71	41.43
SD	0.01	0.01	0.08	0.06	0.50	0.84	0.63	0.03	2.75	3.43	0.36	0.31	0.28	2.42	1.08	2.45
VC	0.15	0.12	0.05	0.05	0.05	0.08	0.14	0.00	0.14	0.14	0.03	0.03	0.04	0.06	0.04	0.06
Skew.	1.59	0.86	0.84	0.84	0.34	–1.32	–1.28	0.68	–0.20	–1.91	–0.61	–0.03	–0.56	0.64	–0.65	0.22
								(b)								
Mean	0.07	0.06	1.23	1.19	7.90	8.79	4.56	7.11	17.84	16.75	9.42	9.83	5.32	5.32	29.86	40.36
Median	0.08	0.06	1.44	1.33	9.57	10.11	4.15	7.35	20.22	16.87	10.42	10.78	6.50	6.41	30.89	41.67
SD	0.02	0.02	0.54	0.37	2.96	2.84	0.63	0.50	5.86	7.80	2.51	2.29	2.51	2.50	3.98	6.09
VC	0.28	0.33	0.43	0.31	0.37	0.32	0.14	0.07	0.34	0.46	0.27	0.23	0.47	0.46	0.13	0.15
Skew.	–1.06	–0.54	–1.38	–1.43	–1.34	–1.13	0.84	–1.89	–0.93	–0.94	–1.38	–1.38	–1.42	–1.36	–1.37	–1.15

Table 3 shows ionic indoor/outdoor ratios during the sampling duration. The trends showed similar results at both roadside and residentially located schools i.e. close to 1 (0.94 and 0.93 respectively). The average I/O ratio for anions F^- was 1.14 and 1.16 and Cl^- was 1.08 and 1.03 and for cations Ca^{+2} was 1.00 and 1.06 and Na^+ was 1.05 and 1.00 for roadside and residentially located schools respectively, indicating equal contribution by indoor and outdoor sources. Whereas for anions NO_3^-, SO_4^{2-} and cations K^+, Mg^+ was less than 1, depicting outdoor sources to be more dominant.

Table 3. *Indoor/outdoor ratios of ionic concentrations at roadside and residential schools*

Sites Indoor/Outdoor Ratios	Roadside Schools	Residential Schools
F^-	1.14	1.16
Cl^-	1.08	1.03
NO_3^-	0.91	0.89
SO_4^{2-}	0.62	0.64
Ca^{2+}	1.00	1.06
K^+	0.98	0.95
Na^+	1.05	1.00
Mg^+	0.71	0.73
Average	0.94	0.93

In addition to this enrichment factors were calculated using Ca ion as the reference element due to its regional abundance in soil and chalk dust in classrooms. F^- ions showed greatest enrichment EF≥1 (1.02), at roadside schools (Figure 2). The lowest enrichment was seen by Cl^- ion at schools near roads, followed by others ions, NO_3^-, SO_4^{2-}, K^+, Na^+ and Mg^{2+} i.e. crustal source of emission. In this region, Ca^{2+} ion in dust is found to originate as carbonates and sulfates from the soil while Mg is present in soil as dolomite [$(CaMg(CO_3)_2)$]. These ions also exceeded their background values at the roadside and residentially located schools. K^+ ion, as a trace ion occurs due to biomass burning (Habil and Taneja, 2013). SO_4^{2-} is mostly considered as anthropogenic formed by the reaction of SO_2 on particles, which has been associated persistently with health, especially cardiopulmonary effects. NO_3 in atmosphere occur as ammonium nitrate which dissociates to HNO_3 and NH_3 and occur as NH_4^+, NO_3^- charge particles on the vaporization of nitrate. Na^+ and Cl^- are found to be present abundantly in soil as NaCl and Na_2SO_4. Cl^- also shows some anthropogenic sources of emission, and F^- of coal and wood burning. The highest enrichment was seen by F^- ions which may be attributed to burning activities of coal in food shops and vehicle repair shops near roadside. The lowest enrichment is shown by Cl^- ions which may be due to anthropogenic activities like wood burning and tobacco smoking, which may be carried indoors (Li, 1994).

3.2. Correlation and factor analysis

Correlation analysis was performed to determine the relationship between indoor and outdoor sources among ionic species. Inter correlations between ionic species in school dust at the roadside and residential areas were performed. At roadside indoor F^-, Cl^-, NO_3^-, SO_4^{2-}, Ca^{+2}, K^+, Na^+, Mg^{2+} significantly correlated with their corresponding outdoors (R^2=0.92, 0.96, 0.98, 0.69, 0.95, 0.99, 0.99, 0.90 respectively), indicating similar soilborne and anthropogenic sources. Most of the ions showed good correlation with Mg^{2+}. Cl^- is strongly correlated with K^+, Na^+ and Mg^{2+} as R^2=0.97, 0.96, 0.96 (outdoor), followed by NO_3^-, R^2=0.94 (indoor) 0.92 (outdoor), K^+ is strongly correlated with Na^+ R^2=0.99 (indoor) 0.98 (outdoor) and Mg^{2+} 0.99 (outdoor), respectively. Such strong correlations indicate the influence of roadside vehicular emissions in regional soil and oil combustion in motor vehicles (Kulshrestha et al., 2010). However, at residential area, similar but lower range of correlations was observed. The indoor F^-, Cl^-, NO_3^-, SO_4^-, Ca^{+2}, K^+, Mg^{2+} showed good correlations as R^2=0.88, 0.98, 0.99, 0.68, 0.95, 0.99, 0.88, respectively. Instead of soil originated Mg^{2+}, K^+ played a significant role showing maximum strong correlations with Cl^- indoor and outdoor (0.98–0.97 and 0.98–0.98), NO_3^- (0.97 and 0.98–0.96), Ca^{+2} (0.93 and 0.93), Na^+ (0.90–0.93) and Mg^{2+} (0.75–0.80 and 0.88–0.95). Biomass burning, activities like garbage burning and wood burning are quite common in residential areas, indicating K^+ as a significant source.

In order to obtain a reliable estimation of different sources contributing to ionic species in indoor and outdoor environments at the roadside and residential sites, Principal Component Analysis (PCA) was used. Varimax rotated factor analysis was carried out by using the software SPSS 10.0. Using factor extraction with an eigenvalue larger than 1, after Varimax rotation leads to more accuracy. According to some studies, the factor loadings >0.71are very much responsible for the sources and that <0.32 are less responsible for the sources (Nowak, 1998; Garcia et al., 2004). In roadside ionic dust (Table 4a), factor 1 explains 43% of the total variance of the ions (F^-, Cl^-, NO_3^-, Ca^{2+}, K^+, Na^+ and Mg^{2+}). These high loadings clearly indicate the influence of vehicular emissions on the roadside dust, which usually blow to indoor spaces of schools near the roadside (Meza–Figueroa et al., 2007). Factor 2 is represented 21% of variance composed of Cl^- which is due to anthropogenic emissions, might be from wood burning (Naira et al., 2006). Factor 3 represented 19% of variance composed of SO_4^- loadings which are due to aerosols those deposits in the soil, causing high loadings (Pitts and Pitts, 1986). Ca^{2+} and Na^+ indicate crustal origin (Pitts and Pitts, 1986; Parmar et al., 2001; Naira et al., 2006). In outdoors factor 1 dominates by soilborne and by vehicular emissions contamination in soil with 38% of the variance. The second factor indicated the soil origin with 23% of contamination. SO_4^- dominates third factor with 18% variance, which might be due to aerosol contamination in the roadside dust (Pitts and Pitts, 1986). Table 4b represents factors at residential areas. Similar to roadside, residential dust dominated with ions of higher variance of 46%. This factor shows combination of crustal and anthropogenic sources. Cl^-, SO_4^-, Ca^{+2}, Na^+ presents second factor with 21% variance. This indicates sources like coal burning, (Kulshrestha et al., 2010). Outdoor dust shows three factors, with similar sources like soilborn and aerosol contamination having variance of 38% and vehicular contamination in soil with 13%. The third factor, Ca^{2+} dominates with 12% variance, suggesting the influence of regional soil enriched with Ca_2^+.

During the time of the indoor sampling, a questionnaire was also filled by the students. According to the responses by the students in our survey, the most frequently occurring symptoms were irritation of the eyes, headaches, coughing, cold, dizziness and asthma as shown in Table 5. The symptoms linked to particles like asthma or respiratory problem, cold, itching and dizziness were more in common in the children of the roadside schools in comparison to residentially located schools. It was found that the occupants of the roadside schools with a mean concentration of coarse particles (i.e. PM_{10}) varied from 264.91 μg/m^3 to 260.44 μg/m^3 and for fine particles (i.e. $PM_{2.5}$ to $PM_{0.25}$) 73.15 μg/m^3 to 68.27 μg/m^3 suffered more from these symptoms. While in the residentially located schools where the mean concentration of coarse particle varied below from 256.02 μg/m^3 to 253.75 μg/m^3 with a difference of p=0.45 and p=0.41 and for fine particles varied below from 60.19 μg/m^3 to 56.87 μg/m^3 with a difference of p=0.50 and p=0.45 the symptoms were less reported. Other symptoms like irritation of the eyes, headache and coughing were also more commonly reported by the students of the roadside schools in comparison to residentially located schools (Table 5). The reported health symptoms can be associated with outdoor locations in highly polluted areas with high diesel emissions, mechanical repair and commercial shops, and work activities could affect air quality in classrooms of schools located near major roads, roads crossings located near schools. While, schools located in a residential locality might be much more beneficial in this way as they would be far away from the main roads and covered with green surrounding areas. Studies have shown that occupants experiencing such symptoms

begin to perceive a reduction in their own performances. Such reduction increases as the number of symptoms increases, averaging a 3% loss with three symptoms, and an 8% loss with five symptoms, which leads to school absenteeism. Studies have shown accounts for 14 million missed school days per year (Habil and Taneja, 2011).

4. Conclusions

Particle mass and ionic contents were observed separately in the air and settled dust, at schools located at the roadside and residential areas. Values were generally higher at the roadside than residential schools and higher in indoor than at outdoor. The results obtained exceeded 4–13 and 8–26 times for PM_{10} and $PM_{2.5}$ for indoor whereas outdoor concentration ranged from 4–12 and 7–23 times (for PM_{10} and $PM_{2.5}$ respectively), when compared with (NAAQS, 2009) standards, and 4 times and 6 times higher for PM_{10} and $PM_{2.5}$, respectively by World Health Organization (WHO, 2005), which suggested contamination from outdoors to indoors. Mixed forms of crustal and anthropogenic sources were observed, where natural ventilation acted as a pathway to a variety of sources. Traffic emissions from nearby roads, dust carried away by wind and by shoes, some occasional burning activities from outdoors, chalk dust, particle resuspension due to children activities in indoors during the morning and afternoon rush hours were the main contributing sources. Our investigation, which covered teaching hours only, gives a more realistic duration of estimation of the PM and ionic concentrations of students being exposed to at the respective schools. Therefore, by applying simple, useful measures of cleanliness, less and comfortable occupancy, more paved areas rather than dusty, except playgrounds and building schools in areas with low pollutant levels and high greenery levels will surely help in future to reduce the indoor contaminant levels. This study illustrates that PM and ionic exposure levels could exhibit important role in exposure studies, especially in sensitive environments like schools in developing countries like India, at a global level for better and healthy mind of children studying at schools.

Table 4a. *Principal component loadings of ions at schools at roadside areas*

	Indoor				Outdoor			
Component	1	2	3	Communalities	1	2	3	Communalities
F^-	0.792	0.462	0.000	0.841	0.870	0.000	0.214	0.889
Cl^-	0.638	0.748	0.124	0.967	0.690	0.704	0.349	0.994
NO_3^-	0.930	0.299	0.058	0.954	0.609	0.678	0.000	0.993
SO_4^{2-}	0.000	0.348	0.964	0.938	0.089	0.000	0.975	1.000
Ca^{2+}	0.721	0.412	0.652	0.945	0.548	0.765	0.152	0.935
K^+	0.876	0.471	0.214	0.989	0.603	0.249	0.174	0.990
Na^+	0.679	0.348	0.687	0.934	0.817	0.410	0.196	0.984
Mg^{2+}	0.952	0.000	0.000	0.906	0.770	0.537	0.000	0.946
Eigen Value	4.859	2.615	1.245		4.822	1.627	1.221	
% Variance	43.125	21.348	19.257		38.378	22.647	18.237	
% Cumulative	43.125	64.473	83.730		38.378	61.025	79.262	

Table 4b. *Principal component loadings of ions at schools in residential areas*

	Indoor			Outdoor			
Component	1	2	Communalities	1	2	3	Communalities
F^-	0.860	0.414	0.912	0.919	0.197	0.175	0.914
Cl^-	0.883	0.420	0.956	0.911	0.352	0.000	0.992
NO_3^-	0.963	0.212	0.971	0.942	0.103	0.000	1.000
SO_4^{2-}	0.233	0.965	0.987	0.214	0.972	0.000	0.933
Ca^{2+}	0.762	0.573	0.908	0.934	0.159	0.976	0.986
K^+	0.924	0.370	0.990	0.962	0.178	0.000	0.989
Na^+	0.941	0.323	0.990	0.000	0.000	0.000	0.949
Mg^{2+}	0.942	0.164	0.915	0.951	0.000	0.000	0.951
Eigen Value	5.708	1.921		5.340	1.185	1.161	
% Variance	46.138	21.028		37.158	13.158	12.297	
% Cumulative	46.138	67.166		37.158	50.316	62.613	

Table 5. *Relationship between health related problems and PM concentrations in different schools of Agra*

Health Effects	Microenvironment	Type	Mean Coarse PM_{10} ($\mu g/m^3$)	*p* Value	Mean Fine $PM_{2.5-1.0}$ ($\mu g/m^3$)	*p* Value
Asthma and related respiratory problem	Roadside	5	264.91	0.45	73.15	0.50
	Residential	4	256.02		60.19	
Headache and Coughing	Roadside	3	253.16	0.31	63.18	0.33
	Residential	2	240.87		50.19	
Cold, Itching and Dizziness	Roadside	4	260.44	0.41	68.27	0.45
	Residential	3	253.75		56.87	
Irritation in eyes	Roadside	3	255.71	0.32	62.33	0.34
	Residential	2	242.23		51.84	

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Supporting Material Available

Ionic correlation matrix at roadside schools (Table S1), Ionic correlation matrix at residential schools (Table S2). This information is available free of charge via the Internet at http://www.atmospolres.com.

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