



Physicochemical characteristics of PM_{2.5}: Low, middle, and high-income group homes in Agra, India—a case study

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ABSTRACT

The present study shows the current scenario of the aggregate relation between income and pollution at the household level. The indoor sampling of fine particulate matter was conducted in low– middle– and high-income group homes in Agra City, the North Central region of India. The mean indoor concentrations of PM_{2.5} were 46.7 µg/m³, 39.2 µg/m³ and 25.6 µg/m³ in low– middle– and high-income group homes respectively. The full-day variation revealed that the concentrations of fine particles were higher during morning and evening hours in all the three income group homes. The indoor meteorological parameters were also monitored. Using scanning electron microscopy coupled with energy dispersive x-ray spectrometer (SEM–EDS) chemical and elemental analysis of fine particles and their probable sources has been conducted in low– middle– high-income group homes. EDS spectra indicates the elemental composition of PM_{2.5} which can be distributed into following groups of particles i.e. C–O rich (54%), F rich (42%) and other (4%) in low– income group homes. In middle– and high-income group homes F rich (59–65%), C–O rich (32–37%) and other (3–4%) were observed in PM_{2.5}. The SEM images of fine particles indicates that the particles are clustered into following groups i.e. aluminosilicates/silica particles, spherical carbon rich particles, nearly spherical fluorine rich particles, Mg–Si or Mg–Si–Al particles.

Keywords: Indoor Air Quality (IAQ), Socioeconomic Status (SES), fine particulate matter, physical–chemical characteristics, meteorological parameters



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1. Introduction

In urban areas industrialization and economic growth have resulted a dramatic increase in the number of office buildings, manufacturing units, and residences simultaneously with the rise in both the number and density of motor vehicles. This has resulted in a profound deterioration of air quality (Chan and Yao, 2008). Increasing anthropogenic activities linked to socioeconomic status have significant bearing on the air quality scenarios (Kim, 1992; Mitra and Sharma, 2002; Branis and Linhartova, 2012). In India, air pollution has turned out to be a major worry in recent years. The huge parts of the Indian urban population are exposed to the utmost pollutant levels throughout the world (Smith, 1993; Schwela, 1999; Yale CELP, 2007). Interest in indoor air quality is primarily fueled by the fact that individuals spend the majority of their time indoors. It is projected that people spend more than around 80–90% of their time indoors (Branis et al., 2005; Schweizer et al., 2007; Taneja et al., 2008). During this period, they are exposed to an ample range of pollutants of indoor and outdoor origin. Indoor emission sources and formation processes consist of out gassing from furniture, textiles, carpets, building materials, processes like cooking, heating, smoking, residues from personal care, pesticides and specific indoor physical activities such as cleaning, and walking (Fan et al., 2003; Smolik et al., 2005; Morawska and Salthammer, 2006; Zdimal et al., 2011). Outdoor pollutants also infiltrate readily into interior spaces through open windows, doors, and ventilation systems of the buildings. Pollutants in indoor spaces have mixture of both outdoor and indoor sources (Massey et al., 2009; Nasir et al., 2013).

It was made known that aerosols are common class of indoor air pollutants, and that they represent serious health risks from air pollution indoors (Salma et al., 2013). Array of the factors affecting the physical–chemical characteristics of indoor fine particles have also caused a large deviation in their properties and; for that reason, it seems to be more useful to be aware of the nature and relative significance of the dominant factors and their implications in indoor environment (Lee and Chang, 2000; Patterson and Eatough, 2000; Lee et al., 2002; Guo et al., 2010; Branis et al., 2011; Hovorka and Branis, 2011; Szoboszlai et al., 2011; Salma et al., 2013).

In India, a large amount of effort has been made to study the pollution level in low income classes (Kulshreshtha and Khare, 2011; Singh and Jamal, 2012). Though, not much study has been done about the middle– and high-income class, who can actually offer the necessary resource inputs to stimulate economic growth and pollution level. This paper intends to define and present the concentration of fine particles and their physical–chemical characteristics in the indoor environment of low– middle– and high-income group homes in Agra City. Our key objectives were:

- Determination of PM_{2.5} mass concentration,
- Characterization of chemical and morphological composition of fine particles,
- Evaluation of PM_{2.5} concentration together with indoor meteorological variables in order to identify the possible sources of fine particles, as well as the effect of various indoor activities on their properties.

2. 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 kilometers of south of New Delhi. The city lies in a semi-arid region, on the south and west neighboring to the Thar Desert of Rajasthan with a tropical climate and strongly affected by the Aeolian dust blown from the Thar Desert. Mathura is situated towards the north, and on the east it is bounded by Firozabad District, which is famous for its glass manufacturing industries. Four major national highways namely NH-2, 3, 11 and 93 are passing all the way through the city and serving very serious load of traffic (10^5 vehicles per day) (Saini et al., 2009; ADA, 2013). Agra is generally a commercial city, known for carpets, leather goods, handicrafts, stone carving, zari zardozi, inlay work, and sweets (petha and gajak). These are mostly positioned in the old mogul city, particularly Rakabganj, Lohamandi, Tajganj, and Kotwali areas. The large-scale industrial units are located near to Kanpur–Delhi national highway (NH-2), and in Chatta and Hariparvat areas. Agra City has about 2 009 497 total population, and the population density is about 1 084 persons/km² (Census, 2011).

2.2. Socioeconomic conditions of the sampled households

Socioeconomic status determines man's way of living, type of house, location of residence, and access to various services and facilities. Using the income limits (Census, 2011), the low- middle- and high-income group homes were chosen in Agra City (Figure 1) in which indoor sampling was done. This includes two high-income group homes (earning >INR 70 000 ~ USD 1 100 per month) with commercial areas and big industries in the vicinity. Most of the members of this category had professional degrees and were engaged in white collar jobs or were industrialists. They owned palatial houses and had almost all the modern household

appliances like color televisions, videos, refrigerators, liquid petroleum gas, coolers, washing machines, generators, telephones and vehicles. Two middle-income group homes (earning <INR 60 000 ~ USD 900–1 000 per month) with a heavy traffic density. The members of the medium-income households were also educated and some of them had professional degrees. They were employed as junior engineers and office workers. Two low income group homes made up of mud and grasses with little traffic but high population density. The sampled low-income households belong to the lower socioeconomic strata (earning <INR 5 000 ~ USD 90–100 per month). The low-income household members were poorly educated. Most of them were employed as skilled and unskilled laborers. As household income decreases, there is a decrease in the number of household appliances, a decrease in the level of education and a change in the job status.

2.3. Questionnaire survey

In this study, survey data were collected from 50 houses out of which six houses were selected in Agra City for indoor sampling. Questionnaires were made to fill by the occupants to know the daily indoor activity pattern, along with the survey of the houses to know the sources responsible for the particulate emission. The questionnaire included daily time/activity diary to know about the house characteristics and different activities such as cooking, cleaning, heating, the number of occupants, surroundings of homes, other activities carried in the indoor environment of the homes. The questionnaire survey filled by the occupants of the houses is provided with the work as supplementary information for better understanding of the data collected. This sampling time covered the activities for the entire day inside the houses, such as prayer time (burning candles and incense sticks), cleaning, sweeping, making food. It also accounted for the times when the traffic was low and high and also for the use of generators in case of power failures (Table 1).

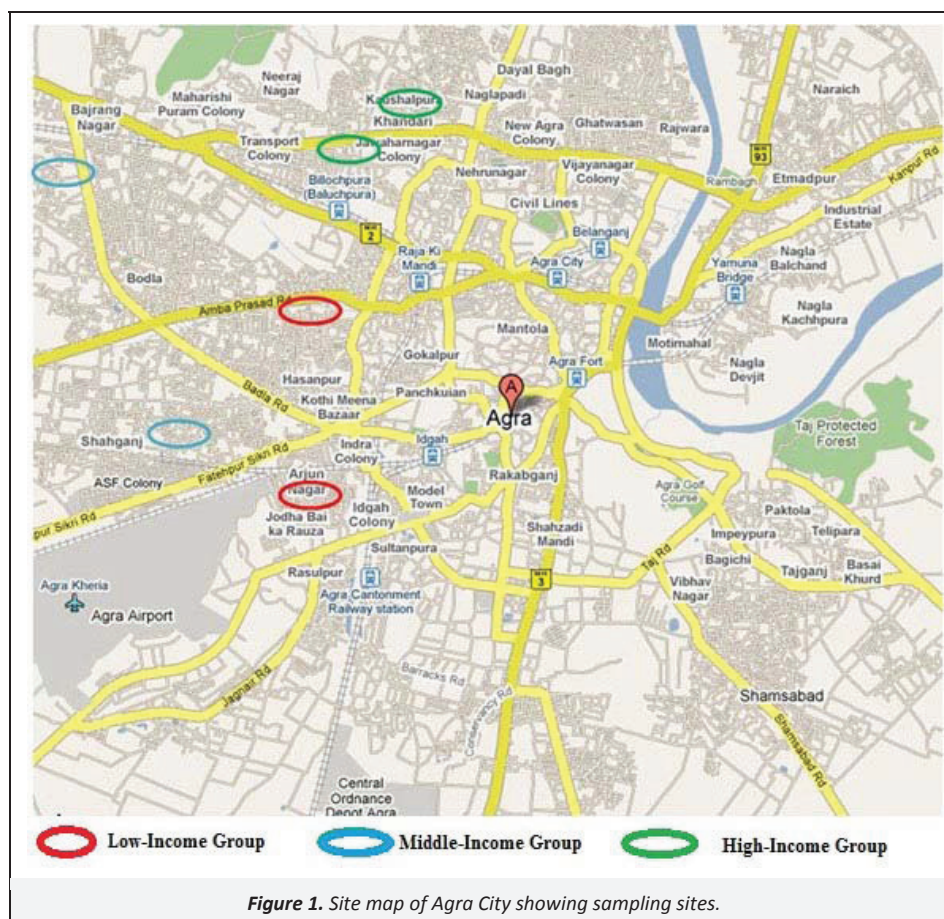


Figure 1. Site map of Agra City showing sampling sites.

Table 1. General characteristic of the residential homes

	Low-Income Group	Middle-Income Group	High-Income Group
Area of Living Room (m ²)	5–8	12–15	20–25
Surfaces (A—m ²)	24.8–39.7	54.1–67.5	82.4–103.0
Total volume (V—m ³)	11.7–18.8	29.4–36.7	60.5–75.6
A/V (1/m)	2.1	1.8	1.3
Home Age (Years)	10–15	5–6	6–7
Conditions	Highly Populated, Less Cemented Area, Use of Mud Stoves, Coal and Biomass Combustion	Less Populated, Marble Flooring, L.P.G. Stoves	Less Populated, Tile Flooring, Microwave, Modern and efficient Hobs, Close to a major traffic route

2.4. Sample collection

In the month of July 2012, from 6 low– middle– and high– income group homes, a total of 24 indoor samples (4 samples from each house) of fine particles were collected for 24 h on PTFE filters by a medium–volume sampler (model: APM 550, Envirotech, New Delhi flow rate: 16.6 L/min). Grimm 31– Channel Portable Aerosol Spectrometer model No.1.109 was used for the monitoring of particulate mass concentration, which runs at a flow rate of 1.2 L/min \pm 5% constant with controller for continuous measurement during the sampling period. The instrument was generally positioned in a living room area where occupants of the homes spend most of their time. Living rooms are equipped with amenities for sitting, and can have room for a larger number of people for a substantial time interval. Inlet head was positioned as close as possible to the breathing zone for the occupants. The air exchange rate was measured on sampling site by using (YES–206) Falcon indoor air quality monitor from (Young Environment Systems, Inc., Canada). Sampling of fine particles with medium volume sampler and sampling with Grimm aerosol spectrometer were compared. Average fine particle concentrations recorded by Grimm aerosol spectrometer were found to be 1.2–1.4 times higher than medium volume sampler at all the sampling sites. It may be because of its sensitivity and no loss in PM mass due to loading and unloading of the filter papers which occurs in other sampler. To compare the PM_{2.5} mass concentration data collected by two instruments (APM 550 and Grimm), concentrations sampling was done simultaneously by placing the two instruments together at each sampling house. We found that there is correlation of $R^2=0.872$ for PM_{2.5} between medium volume sampler and Grimm aerosol spectrometer.

2.5. Gravimetric analysis

Filter papers were weighed thrice before and after sampling using four digit balance (Wensar model– MABI 20) with sensitivity of ± 0.2 mg. Before weighing the samples were equilibrated in desiccators at 20–30 °C and relative humidity of 30–40% in humidity controlled room for 24 h. Field blank filters were collected to reduce the gravimetric bias due to filter handling during and after sampling. Filters were handled only with tweezers coated with Teflon tape to reduce the possibility of contamination. PM mass was determined gravimetrically by subtracting the initial average mass of the blank filter from the final average of the sampled filter dividing by air volume passed.

2.6. Quality control in monitoring

- The sampler is designed to work at a constant flow rate of 16.67 ± 0.83 L/min. Daily flow rate calculations (gas meter reading / timer reading) was made to make sure that the fluctuation in flow rate was within the range.
- Filter in the wins impactor needs to be changed after 72 h of sampling (Chow and Watson, 1998) or when the filter gets clogged as per the operator's judgment.

- Periodic cleaning of the sampler was done to make the sampler dust free so that the dust on the sampler may not be counted with the mass concentration of the sample.

2.7. Sample analysis

The characterization of particles in PM_{2.5} samples were performed using electron scanning microscopy (SEM, JEOL Model JSM–6390LV) coupled with energy dispersive spectrometer (EDS, JEOL Model JED–2300) for determination of morphology (shapes and sizes) and chemical composition of airborne particles. SEM is a method for high resolution surface imaging. It uses an electron beam for surface imaging. Its advantages over light microscopy are greater magnification and much larger depth of field. Different elements with different surface topographies emit different quantity of electrons due to which the contrast in a SEM micrograph is representative of the surface topography and distribution of elemental composition on the surface. Approximately one fourth filter paper of PTFE filter paper was cut and coated with gold. Gold – coated SEM stubs were prepared for each sample. Stubs were gold– coated to a thickness of 20 nm using a sputter coater and then put into the SEM chamber for obtaining morphologies of individual particles (Pipal et al., 2011). Three images of one sample were taken at a magnification of x250, x500, x2 000 and EDS spectra of individual particles were obtained after scanning an electron beam with an accelerating voltage of 10–15 kV.

2.8. Statistical analysis

Using the IBM SPSS software version Portable PASW Statistics 18 and some statistical tools were applied to support the results. The continuous fine particle (PM_{2.5}) concentration data and other environmental parameters were initially investigated by descriptive statistics. Further, the elemental composition of PM_{2.5}, the bivariate Pearson correlation was used to know the strength of linear relationship all the elements.

3. Results and Discussion

3.1. Indoor characterizations and PM_{2.5} concentrations

The average mass concentration of PM_{2.5} in low–income group homes was $46.7 \mu\text{g}/\text{m}^3$ (C.I.=38.1–55.5) which was 19.3% higher than middle–income group homes [$39.1 \mu\text{g}/\text{m}^3$ (C.I.=31.1–47.3)] and 82.6% higher than high–income group homes [$25.6 \mu\text{g}/\text{m}^3$ (C.I.=20.9–30.2)] (Table 2). In low–income group homes, the highest average fine particulate matter (PM_{2.5}) concentration was recorded in the evening hours (18:00–21:00 hours) (18.7% higher than morning hours) followed by morning hours (07:00–10:00 hours), this may be attributed to activities like cooking, cleaning and maximum number of occupants in the evening and morning hours (Taneja et al., 2008). In middle–income group homes, evening concentration was 46.2% higher than morning hours. In high–income group homes the evening concentration was 139.5% higher than morning hours and 211.3% higher than afternoon hours (12:00–14:00 hours). In low– middle– and high– income group homes cooking may be the major contributing factor in variation of PM_{2.5} concentration in evening and morning hours

(Massey et al., 2009). The maximum values for $PM_{2.5}$, exceeding the $349.8 \mu\text{g}/\text{m}^3$ for low-income group homes, $204.9 \mu\text{g}/\text{m}^3$ for middle-income group homes, and $145.1 \mu\text{g}/\text{m}^3$ for high-income group homes. These results reveal the existence of peaks, although with a low frequency. Its origin can be due to tobacco smoking, wood burning, resuspension of dust and occupant activities during the different times in a day (Tuckett et al., 1998; Long et al., 2000; Tucker, 2000).

3.2. Meteorological parameters

Meteorological conditions have also been identified as one of the predominant factors responsible for variation of $PM_{2.5}$ concentration (Massey et al., 2012). Along with the measurement of particulate matter concentration during sampling days, the meteorological parameters were also monitored and are given in Table 3. The average concentrations of CO_2 were 584.1 ppm, 569.7 ppm and 555.1 ppm in low- middle- and high-income group homes. The highest CO_2 concentration was recorded in low-income group homes. This may be due to the use of solid fuels as a primary source of energy. As this is one month study, the average temperatures were 34.5°C in low- 32.1°C in middle- and 31.3°C in high-income group homes. The average relative humidity were found to be 55.1% in low- 66.1% in middle- 69.8% in high-income group homes, and average ventilation rate were 29.7 L/s, 33.1 L/s and 31.9 L/s in low- middle- and high-income group homes respectively.

3.3. Elemental and morphological analysis

$PM_{2.5}$ in low-income group homes. As shown in the SEM micrographs and EDS spectrum of $PM_{2.5}$ (Figure 2), the particles were irregular, spherical, reticular, cluster, and flaky shaped and C, F and O-rich particles dominate over other elements. Apart from C, F, and O rich particles, Na, Al, Mg, and Si rich particles were also present in this size range, which follow the trend: $C > F > O > Na > Al > Si > Mg$. The morphology of carbonaceous particle varies depending

on the fuels, burning conditions and atmospheric processes (Berube et al., 1999; Posfai and Buseck, 2010; Tumolva et al., 2010). In our study, we find branched clusters resulting in spheres of carbon occurring at high-temperature processes like combustion (Murr and Bang, 2003; Cyrys et al., 2004; Gotschi et al., 2005). In the low-income group homes incomplete combustion of fossil and bio-fuels by cooking on unvented mud stoves and smoking are the major source of carbon and oxygen (Hand et al., 2005; Alexander et al., 2008; Cong et al., 2009). Nearly spherical particles of F were also observed. People living in low-income group communities commonly use coal as the primary source of energy. Coal naturally contains F as impurity during combustion. Other than coal combustion, some other sources may also contribute to rise up the F in the air, i.e. incense burning, pesticides, insecticides, brick kilns, floor polishes, and some industrialization processes (Huynh et al., 1991; Schauer, 2003; Lonati and Giugliano, 2006; Ikezawa et al., 2011). While soil also contains F, and soil resuspension by the wind also play an important role to the atmospheric burden of F in the form of soil minerals (Dudragne and Amouroux, 1998). The major type of chemical compound in the earth's crust is composed of about 72% of the aluminosilicate group in terms of weight (Van Malderen et al., 1996; Cong et al., 2009). In low-income group homes some aluminosilicates were also identified, which were made up of Al-Si-O along with other elements like Na and Mg. Si associated with O, Al and Na showed the presence of clay, mineral, and feldspar particles (Shao et al., 2007). Si-Na particles could be the mixture of sea salt and mineral dust. Mineral particles have irregular shapes, and they were mainly derived from natural sources such as soil dust, resuspension of dust from the road and some other anthropogenic activities such as construction and vehicles (Li et al., 2010a). The presence of Mg-Si or Mg-Al-Si in indoor environment shows talc like composition (Conner et al., 2001). Some particles were skin flakes shaped. Based on these results, the observations suggest powders and cosmetics are also of one of the possible indoor sources of fine particles.

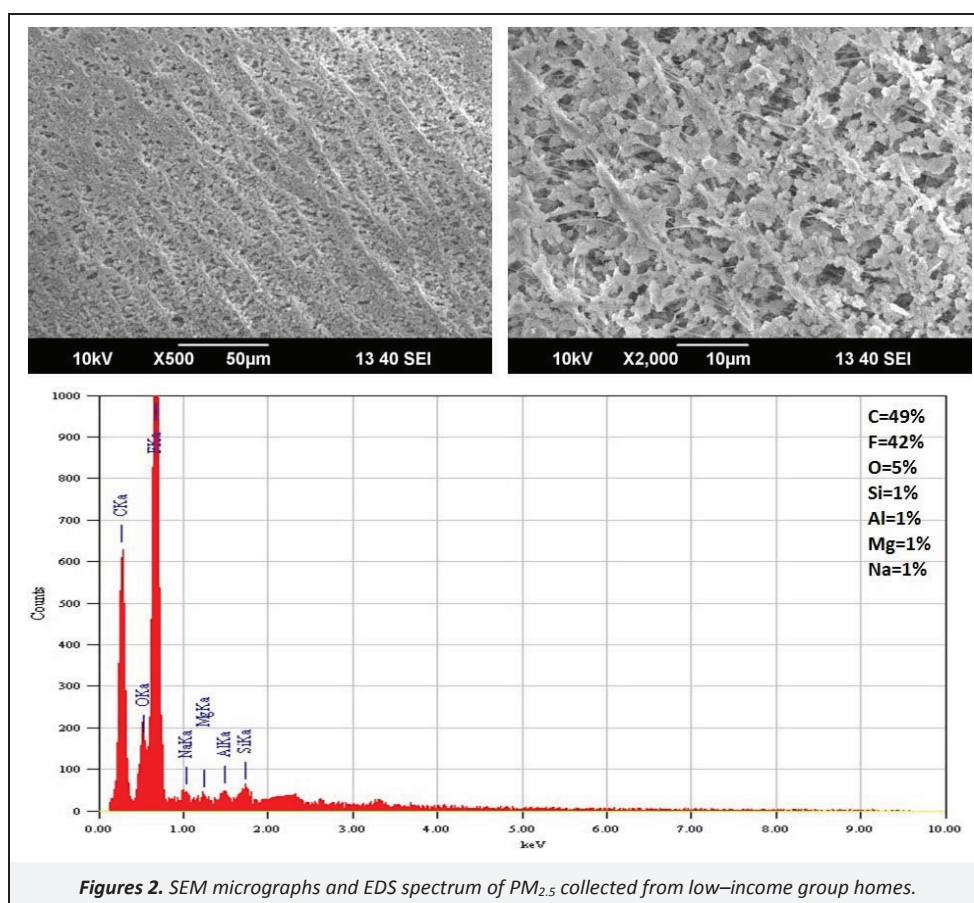


Table 2. Explorative statistical parameters of indoor concentrations for PM_{2.5} collected from Grimm PAS 1.109 in low– middle– and high–income group homes

Variable	Parameter	Low–Income Group	Middle–Income Group	High–Income Group
PM _{2.5} (µg/m ³)	Mean	46.7	39.2	25.6
	Median	32.9	25.0	21.8
	Standard Error	4.4	4.1	2.3
	Skewness	3.3	2.6	3.1
	95% Confidence Interval	38.1–55.5	31.1–47.3	20.9–30.2

Table 3. Measurement of meteorological parameters measured during the study period in low– middle– and high–income group homes

		CO ₂	Temp.	RH	VR
Low–Income Group Homes	M	584.1	34.5	55.1	29.7
	S.E.	7.8	0.2	0.9	1.9
	Skew	1.7	0.5	–0.3	0.4
	Min	500.1	31.1	39.0	4.2
	Max	827.3	39.4	70.0	62.7
Middle–Income Group Homes	M	569.7	32.1	66.1	33.1
	S.E.	13.7	0.2	1.4	2.1
	Skew	1.1	0.6	0.2	0.3
	Min	453.1	29.1	49.0	10.9
	Max	838.5	39.2	81.0	66.7
High–Income Group Homes	M	555.1	31.3	69.8	31.9
	S.E.	10.2	0.1	1.2	1.7
	Skew	1.7	0.3	0.1	0.7
	Min	464.1	29.8	55.1	50.4
	Max	818.1	33.6	81.1	61.8

CO₂: Carbon dioxide (ppm), Temp.: Temperature (°C), RH: Relative Humidity (%), VR: Ventilation Rate (Lps), M: Mean, S.E.: Standard Error, Skew: Skewness, Min: Minimum, Max: Maximum.

PM_{2.5} in middle–income group homes. In middle–income group homes the SEM micrographs and EDS spectrum of PM_{2.5} (Figure 3) show the presence of spheres, cluster, plates and reticular shaped particles of F>C>O>Al>Si>Na. In the present study, we could spot the branched clusters resulting from the interconnection of often hundred of carbonaceous spherules, which stick together through mingle of adhesive surface forces and partial coalescence occurring at high–temperature common during combustion (Murr and Bang, 2003). A blend of carbonaceous particle and inorganic with varying amount of soil–related component like Na, Si, and Al are forming complex aggregates were also observed. During the study period incense burning at the time of prayer and heavy use of insecticides like mosquito repellent spray or coils show the presence of nearly spherical shaped particles of F in SEM micrographs of middle–income group homes (Lonati and Giugliano, 2006; Ikezawa et al., 2011). Silica particles are generally characterized by the presence of Si and O particles. Silica particles are tubular in shape. Generally, these particles are natural and anthropogenic in origins (Li et al., 2010b). This is the most abundant chemical constituent of the earth's crust, cement, bricks, glass, ceramics, and clays, etc.; therefore, these particles also likely to be originated from building materials. Other major contributors of the earth's crust are aluminosilicates. Most of the particles are irregular in shape (Cong et al., 2009). In middle–income group homes soil delivered aluminosilicates particles were mainly composed of oxides of Al and Si with varying amounts of Na like Na–feldspar (Pachauri et al., 2013).

PM_{2.5} in high–income group homes. The SEM micrographs and EDS spectrum of PM_{2.5} (Figure 4) indicates that the particles are flaky, cluster, reticular and irregular shaped in high–income group homes. Apart from the dominance of F, C and O rich particles, Al and Si were also observed. The trend of these elements was F>C>O>Si>Al. Agra is famous for “Petha” (a delicacy prepared from a vegetable of the gourd family). There are approximately 400 petha industry units in Agra City. The situation is worst in the petha industry area, as the petha waste attracts flies, mosquitoes and strays too. In some areas, the trash waste was recklessly burnt in open dump yards positioned on the major national highways of Agra City (Agra Nagar Nigam, 2006). High–income group homes of the Lawyer's colony and Lajpatkunj, Khandari, Agra was located near to NH–2, hence garbage and coal burning due to petha industry units of Agra City and use of heavy diesel generators may attribute to increase in the percentage of F in high–income group homes (Webber, 2009). SEM micrographs show the presence of nearly spherical shaped particles of F. In addition presence of F in high–income group homes may also be due to the pest control performed few days before the study and regular floor polishing done during the study period (Safai et al., 2005). People living in high–income group homes do not use solid fuel for cooking and heating, they use better modes of cooking like cooking on modern and efficient hobs, use of microwave oven, use of electric chimneys, and better cooking oil, so C was not the major element found in high–income group homes. PM_{2.5} particle also seems to be constituted by aluminosilicates having oxides of Al and Si as its contents. These particles probably originate from crustal sources (Slezakova et al., 2008).

Besides all these sources in all the three income group homes (i.e., low– middle– and high–income group homes) presence of large concentration of carbon and fluorine particles may be attributed to matrix effect and coming from PTFE filter paper (Ikezawa et al., 2011).

3.4. Correlation matrix

By evaluating the bivariate Pearson correlation coefficient for all the elements present in PM_{2.5} collected in low– middle– and high–income group homes, the degree of linear relationship can be measured between two variables. The *r* value ≥0.5 shows the strong correlation. Table 4 shows the correlation coefficients between particulate matter and elements in low– middle– and high–income group homes. Highly significant correlation (*r*>0.9) was observed between Al–Si, Mg–Al. Moreover, the positive correlation of F, Mg and Al with O; Al and Si with Na and Na with PM_{2.5} were also found in low–income group homes (*r*>0.6–0.8). In middle–income group homes the highest correlation (*r*>0.9) was observed between Na with Al, Si with Na and Al and O with Na, Al and Si. O, Na, Al show positive correlation with C (*r*>0.5–0.6) and Si shows positive correlation with F (*r*>0.8) in middle–income group homes. Highly significant correlation (*r*>0.9) was shown between Al–O, Si–O and Al–Si in high–income group homes. PM_{2.5} concentration shows positive correlation only with C in middle–income group (*r*>0.5) and high–income group homes (*r*>0.6).

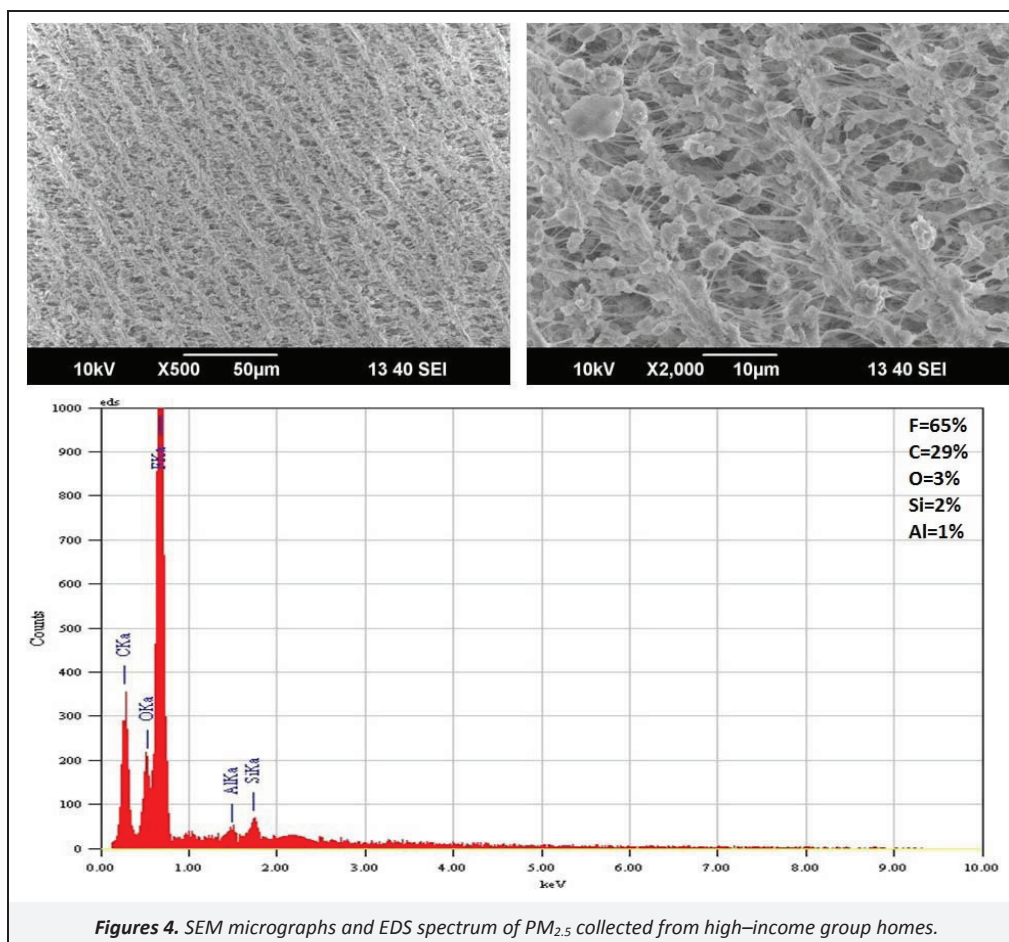
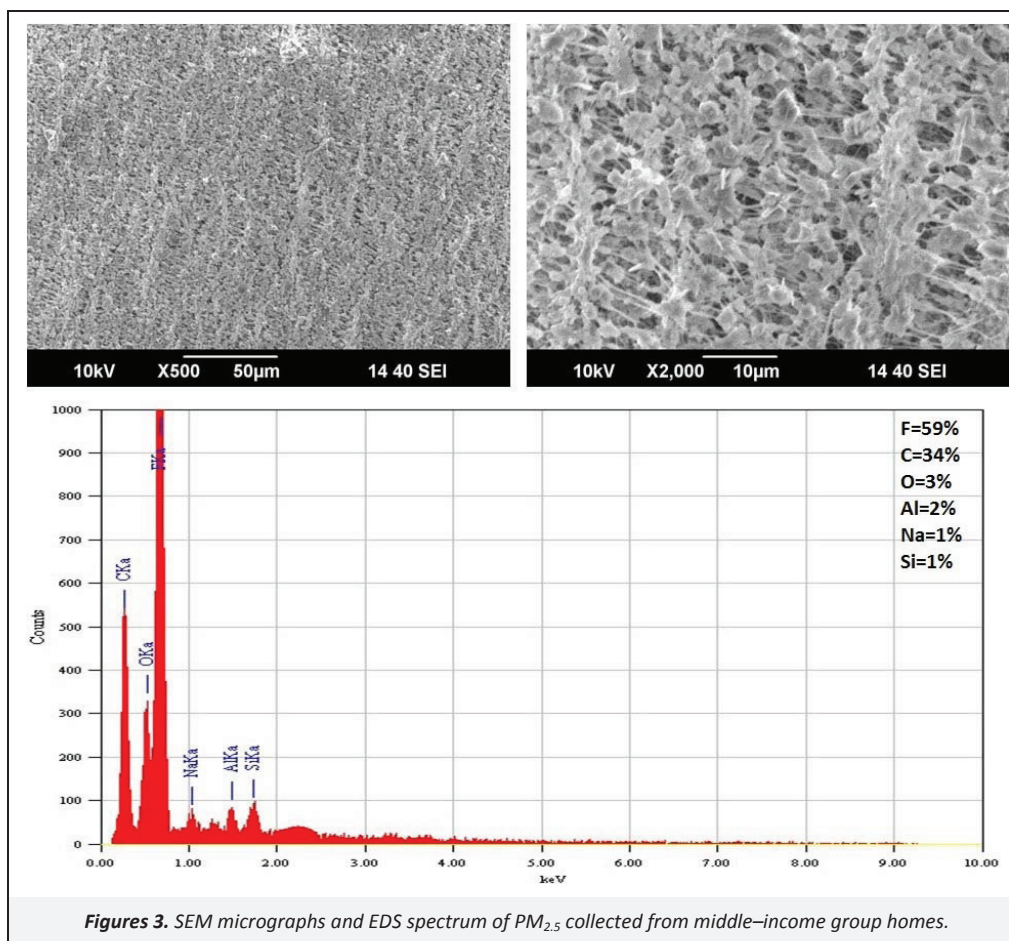


Table 4. Correlation coefficient between PM_{2.5} and elements found in low–middle– and high–income group homes

		C	O	F	Na	Mg	Al	Si	PM _{2.5}
Low–Income Group Homes	C	1							
	O	–0.8	1						
	F	–0.9	0.8 ^a	1					
	Na	–0.3	0.3	0.2	1				
	Mg	–0.2	0.6 ^a	0.1	0.411	1			
	Al	–0.4	0.7 ^a	0.3	0.6 ^a	0.9 ^a	1		
	Si	–0.4	0.7 ^a	0.3	0.6 ^a	0.9 ^a	0.9 ^a	1	
	PM _{2.5}	0.4	0.1	0.4	0.7 ^a	–0.2	0.1	0.1	1
		C	O	F	Na	Al	Si	PM _{2.5}	
Middle–Income Group Homes	C	1							
	O	0.5 ^a	1						
	F	–0.9	–0.8	1					
	Na	0.6 ^a	0.9 ^a	0.1	1				
	Al	0.6 ^a	0.9 ^a	0.2	0.9 ^a	1			
	Si	0.3	0.9 ^a	0.8 ^a	0.9 ^a	0.9 ^a	1		
	PM _{2.5}	0.5 ^a	–0.4	–0.7	0.5	–0.2	–0.9	1	
		C	O	F	Al	Si	PM _{2.5}		
High–Income Group Homes	C	1							
	O	0.1	1						
	F	–0.6	–0.8	1					
	Al	0.3	0.9 ^a	–0.5	1				
	Si	0.3	0.9 ^a	–0.4	0.9 ^a	1			
	PM _{2.5}	0.6 ^a	0.1	0.2	0.3	0.1	1		

^a Significant at the 0.05 level (2–tailed)

4. Conclusions

This initial study provides one of the first systematic measurements of indoor air quality in different income neighborhoods in Agra. The study showed that indoor activities and disparity in lifestyle between poorer residents and privileged residents affect indoor fine particle concentration levels, with the degree of effect depending upon the type of the source and on house characteristics. The results show that PM_{2.5} at indoor in these three neighborhoods ranged from 9.5 to 349.8 µg/m³ in low–income group homes, 12.3 to 204.9 µg/m³ in middle–income group homes and 7.2 to 145.1 µg/m³ in high–income group homes. PM_{2.5} level was quite high in low–income group homes than middle– and high–income group homes. In comparison with World Health Organization (WHO) standards (25 µg/m³ 24 hours mean for PM_{2.5} respectively) (WHO, 2005) the concentration of PM_{2.5} was found to be approximately two times higher in low– and middle–income group homes whereas in case of high–income group homes, it is slightly above the threshold limit. There are a number of diverse indoor as well as outdoor sources, which make particles greatly vary in their concentration, morphologies and chemical compositions. The composition of PM_{2.5} in low–middle and high–income group homes and findings from SEM–EDS suggest that the indoor PM_{2.5} consist mainly of natural and anthropogenic origin. Among the indoor sources, cooking, stove and fuel use, smoking, cleaning, incense burning, cosmetic products and use of insecticides/pesticide and some outdoors sources like soil resuspension, garbage and vegetation burning were shown to augment the indoor fine particle mass concentrations. The study concluded that there is a need to address the issue of PM_{2.5} monitoring and examine the range and various health effects linked with this indoor air pollutant.

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