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Mass and Number and Its Chemical Composition Distribution of Particulate Matter in Different Microenvironments

Mahima Habil, David D. Massey and Ajay Taneja

Abstract

Adverse health effects from exposure to air pollution are a global challenge and of widespread concern. Therefore, the present study attempted to pave the way in the study of indoor air pollution by coarse and fine particulate matter and picturesque its relation with the different indoor microenvironment. A campaign study was conducted in the city of Taj “Agra,” India in which different microenvironments were selected (i.e., offices, shops, and commercial centers). For each site, two different locations were chosen to examine the coarse particles (PM_{10} and $PM_{5.0}$) and fine particles ($PM_{2.5}$, $PM_{1.0}$, $PM_{0.5}$ and $PM_{0.25}$) concentrations and metal concentration of Zn, Pb, Ni, Fe, Cr, Cd, Mg and Cu in $PM_{2.5}$ and for their related health effects. The exposure factor and health risk assessment for carcinogenic effects due to heavy metal contaminants have also been calculated for adults working in different micro-environment by following the methodology prescribed by US EPA.

Keywords: indoor microenvironment, particulate matter, multivariate statistical analysis, carcinogenic and related health effects

1. Introduction

World Health Organization explains a healthy city is one that is continually creating and improving those corporal and communal environments and expanding those community assets that enable people to mutually support each other in achieving all the purposes of life and in developing to their maximum potential. While the basic tasks of the urban environment are climate change, the wasteful use of natural resources, the health impacts of airborne pollutants and exposure to vast arrays of hazardous chemicals. These problems are bound up with the modern lifestyles and at the same time require attention and action of many different parts of society. Environmental awareness to people is at rise, as more and more individuals are search for higher living standards and a better living surroundings. Thus the development of sound environmental policy requires both scientific information about the linkages between pollutant emissions and human health effects and value judgments about the importance of these effects relative to other social concerns.

Asia is one of the significant part of the world in the view of atmospheric aerosol loading because of the presence of growing economies like India, China and other

developed and developing countries. Mechanization, expansion, financial growth and connected increase of energy demands have resulted in profound deterioration of urban air quality [1, 2]. The developing countries like India have shifted their economics from manufacturing toward services that involve information technologies. Growth in information technology have amplified the quantity and extended the use of equipment used in proximity to office worker due to which electronic media used for entertainment, telecommunications and data processing have become widespread in daily life [3, 4]. Typical examples are television, audio-visual recorders, stereo systems, and CPUs with their peripherals such as monitors and printers, scanners and copiers. There is growing concern about the levels of potentially harmful pollutants that may be emitted from office and other commercial centers equipment. Office equipment has been found to be a source of ozone, particulate matter, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) [5]. Several studies have revealed more consistent correlation for the concentration of fine ($PM_{2.5}$) and inhalable (PM_{10}) particles with health than any other air pollutant [6, 7]. In cities, a major fraction of ultrafine aerosol particles (particle diameter, $D_p < 100$ nm) cause adverse health effects in sensitive human beings more than larger particles due to their increased lung deposition efficiency [8]. With possible adverse health effects, the question of the chemical characterization of the fine particles released by such devices is of special importance [9]. Trace elements associated with $PM_{2.5}$ and below are nonvolatile in nature; they are less vulnerable to chemical alterations and remain in the form as they were emitted, even though they tend to undergo long range atmospheric transport [2, 10, 11]. Particulate metal components can have severe carcinogenic and toxic effects on occupants when inhaled in higher concentration. Short-term differences of atmospheric metal concentration have been observed in a day-to-day or even an hour-to-hour basis [1, 12]. Epidemiological studies show that these ultrafine particles cause more adverse health effects in sensitive human beings more than larger particles due to their increased lung deposition efficiency. Therefore the reduction of particulate and associated metal pollution to some acceptable levels is an important environmental issue. The objective of this study helps in pinpointing the integrated actions essential to reduce the particulate pollutant and eliminate the toxicological environment impacts of Indian urban environment. This can enhance the capacity of national environment within the city and which can be implemented to other towns and cities of India that can benefit health, quality of life and the economy.

2. Experimental setup

2.1 Site description

The city of Taj, Agra ($27^{\circ}10'N$, $78^{\circ}02'E$) is located in the central part of northern India, about 204 km of south of Delhi in the Indian state of Uttar Pradesh. Agra is one of the most famous tourist spots of the country. The city is situated on the west bank of the river Yamuna 169 m above sea level. A part of the great northern Indian plains, Agra region experience a tropical climate. In winter the temperature ranges from 3.5 to $30.5^{\circ}C$ and during summers which are hot and dry the temperature ranging from 32 to $48^{\circ}C$. The downward wind is south-southeast 29% and northeast 6% of the time in summer, and it is west-northwest 9.4% and north-northwest 11.8% of the time in winter. Agra has about 1.586 million population and the population density is about 1084 persons per square km (ORG, office of the registrar New Delhi, India: Ministry of Home Affairs, 2011). In this study real time series data for mass and number of coarse and fine particles were monitored in indoor

environment of three different location (two shops, two commercial buildings and two offices) in different parts of Agra city (**Figure 1A** and **B**). Indoor PM₅ was also collected from these sites for chemical characterization. The detailed description of these sites is shown in **Table 1**.

2.2 Sample collection

A short term study was conducted from September 2011 to November 2011 to determine number and mass concentration of coarse and fine particles, i.e., PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5}, and PM_{0.25} in indoors of commercial centers, shops and offices in of Agra city. Chemical characterization in PM₅ was also carried for heavy metal detection. A total of 36 samples (i.e., 18 samples each for PM mass and

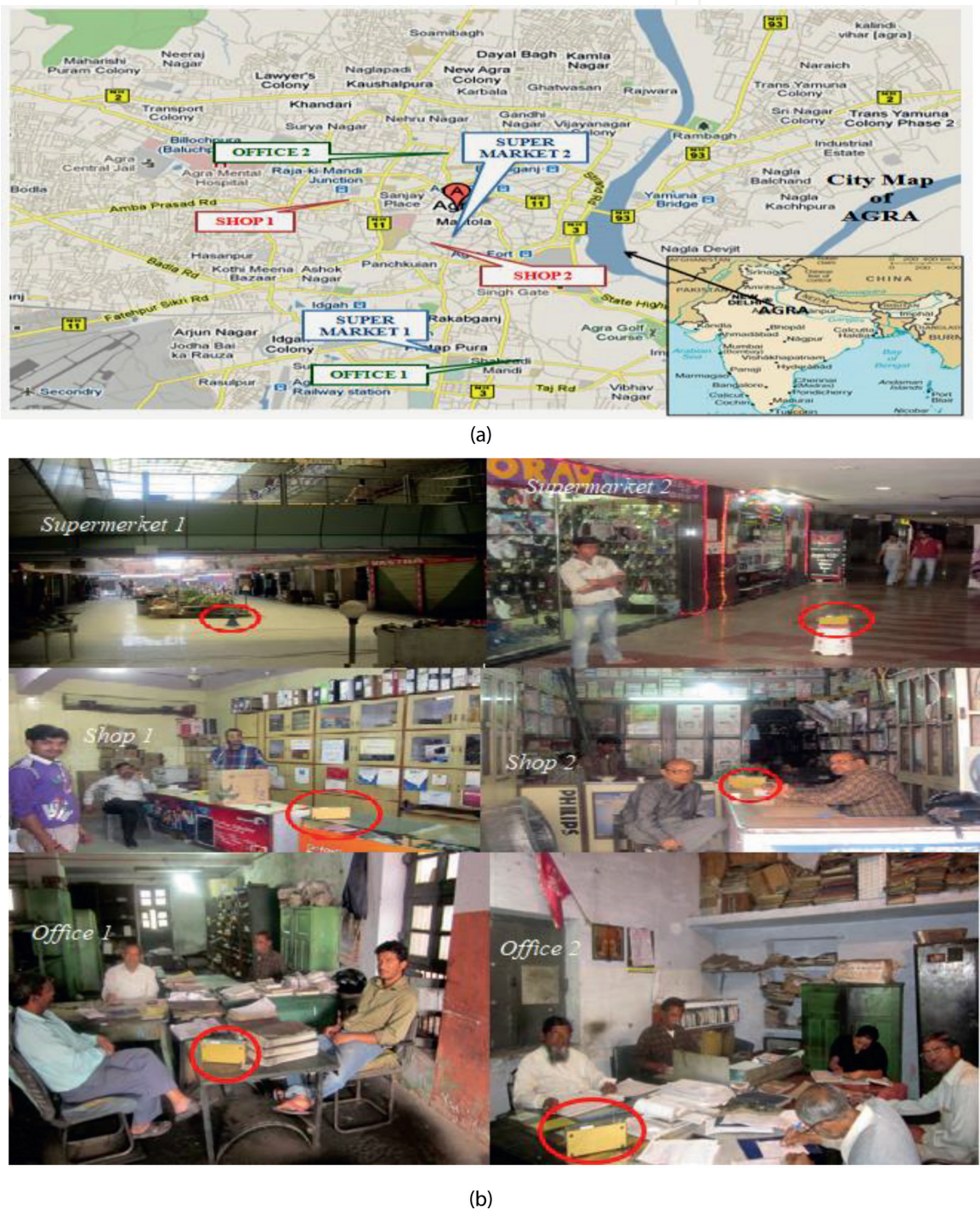


Figure 1.
(A) Map of Agra city showing different sampling sites and (B) different sampling sites.

Sampling site/type	Conditions	Building age (years)	Height	Working area (m ²)	Traffic/greenery/trees	Ventilation
Supermarket 1	High population area, congested, made of iron, brick and cement	2	5–10	600	High traffic with no greenery around, situated in congested commercial area	Air cooling system but mostly kept close
Supermarket 2	High population area, made of iron, brick and cement	3	5–10	550	High traffic with no greenery around, situated in congested old market area	Improper ventilation system with no use of exhaust
Shop 1	Congested and very populated area of the city, made of bricks and cement	20	5	181	Heavy traffic throughout the day with no greenery around, situated in congested commercial area	Improper ventilation
Shop 2	Congested and very populated area of the city, made of bricks and cement	20	5.5	192	Heavy traffic throughout the day with no greenery around, situated in congested old market area	Improper ventilation
Office 1	Congested and very populated area of the city, made of bricks and cement	12	6	287	High traffic with less greenery, situated in congested residential area	Improper ventilation with no use of exhaust
Office 2	Congested and very populated area of the city, made of bricks and cement	40	5	250	High traffic with no greenery, situated in congested commercial area	Improper ventilation with no use of exhaust

Table 1.
Detail description of sampling sites.

number concentration) and 36 samples for chemical characterization were collected from these sites at the same time. Grimm Aerosol Spectrometer model (1.109) (**Figure 2**) was selected for the monitoring of coarse and fine particles, it runs at a flow rate of 1.2 L/min \pm 5% constant with controller for continuous measurement during the sampling period. It measures mass in ($\mu\text{g m}^{-3}$) and number in (particles/ m^3). The sampler measures particles from 0.25 to 32 μm range in 31 channel sizes, each unit is certified by National Institute of Standards and Technology, monodisperse latex on the size of channels calibrated by [www. GRIMM Aerosols.c om](http://www.GRIMM-Aerosols.com). To improve the time resolution, the range was limited to 0.25–10 μm . The sampling equipment was housed such that it was as compact as possible and positioned indoors to cause minimal intrusion to the occupants. The instrument was generally positioned in the center of the rooms where people spent most of their time. Inlet heads were positioned as close as possible to head height. The instrument was set to average the data over 15 min to reduce the response time and to enable the identification of individual sources. The GRIMM particle measuring system is equipped with GRIMM 1174 Software for data acquisition.



Figure 2.
 GRIMM aerosol spectrometer (model: 1.109).



Figure 3.
 Handy sampler APM 821.

After sampling the filters were thrice weighted before and after sampling using four digit (Wensler, Model No. MAB 120) with sensitivity of $2 \pm \text{mg}$ and in the 220–20 mg range. Before the samples were equilibrated in desiccators at 20–30°C and relative humidity of 30–40% in humidity controlled room for 24 h. Filters cassettes were used to carry weight filter papers to the sampling sites, there filters were transferred to filter holders and placed on the sampling plates. Exposed filters along with the holders were then wrapped with aluminum foil, and taken back to the laboratory and placed in the desiccators. Field blanks were collected with exposed filters, they were latter weighted and were stored in refrigerator at 4°C to prevent the evaporation of volatile components [13]. Handy sampler Model No. 821 (Envirotech, New Delhi make) (**Figure 3**) was used for PM₅ chemical characterization which was maintained at a flow rate of 2 L/min and YES-IAQ monitor model No.206 (**Figure 4**) for recording the air exchange rate.

2.3 Chemical analysis

The exposed filter papers were digested in analytical grade (Merk) HNO₃ and kept on hot plate at the temperature of 4–60°C for 90 min. The solution was diluted up to 50 ml with distilled deionized water and stored in polypropylene bottles at 4°C till analysis. Analysis for metals (Fe, Br, Pb, Ba, Zn, Sb, Cu, Cd, Hg) was done on AAS (AAnalyst 100, Perkin Elmer) (**Figure 5**) present in our departmental analytical lab. The tested suites of elements were related to specific combustion sources using Principal component analysis statistical techniques.



Figure 4.
Handy sampler YES-206.

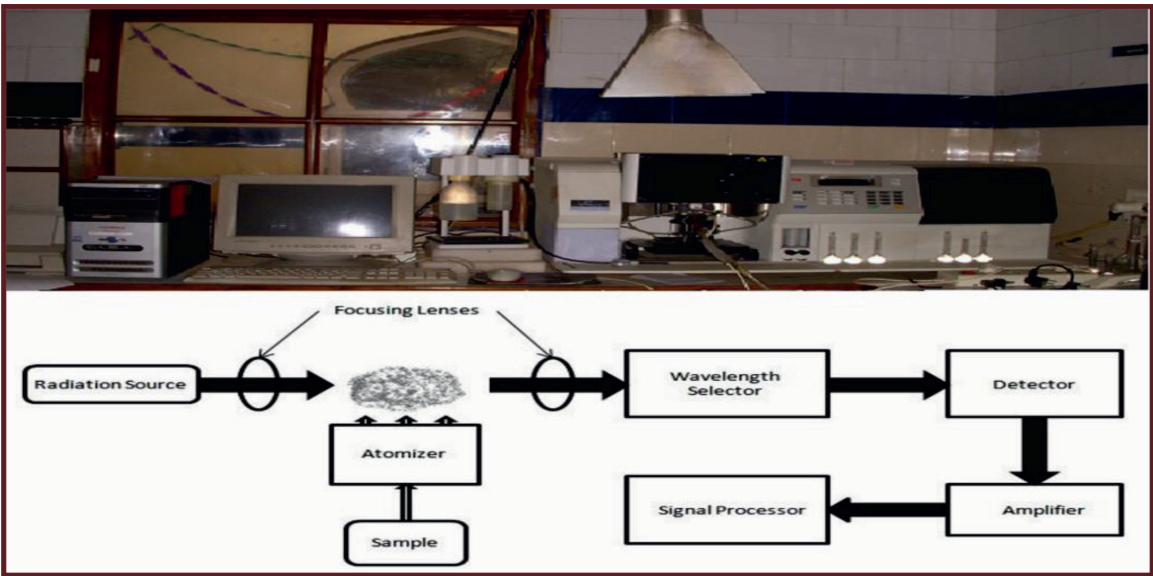


Figure 5.
Atomic absorption spectrophotometer (Perkin Elmer, AAnalyst 100), with schematic diagram.

3. Result and discussion

3.1 Particulate concentration

A total of 12 samples per month (i.e., six for mass concentration and six for number concentration) for PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5}, and PM_{0.25} were collected from three different indoor microenvironments. **Tables 2 and 3** gives the statistical summary of particulate mass and number concentrations along with temperature, CO₂, humidity and air exchange rate during the total sampling days. During the campaign study the mean PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5} and PM_{0.25} mass concentration and standard deviation (SD) was 324.17 ± 46.70, 270.27 ± 42.66, 223.41 ± 48.19, 137.47 ± 23.43, 99.84 ± 20.39 and 52.34 ± 11.45 µg m⁻³ at supermarket sites, 324.57 ± 47.13, 271.30 ± 40.63, 225.44 ± 49.79, 137.89 ± 23.86, 99.41 ± 20.72 and 53.07 ± 11.36 µg m⁻³ at shop sites respectively and 327.00 ± 47.03, 272.98 ± 40.03, 227.44 ± 50.54, 139.17 ± 23.75, 101.33 ± 20.75 and 56.13 ± 11.58 µg m⁻³ at office sites respectively and for number concentrations for coarse and fine particles, mean values of PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5} and PM_{0.25} was 564,050 ± 915,78.43, 320,394 ± 393,85.52, 193,678 ± 17,880.25, 174,101 ± 23,865, 158,428 ± 29,089.22 and 73,378 ± 22,638

SUPERMARKETS	PM ₁₀ μgm ³	PM _{5.0} μgm ³	PM _{2.5} μgm ³	PM _{1.0} μgm ³	PM _{0.5} μgm ³	PM _{0.25} μgm ³	CO ₂ PPM	TEMP °C	HUMIDITY %	AIR EXCHANGE RATE h ⁻¹
AVERAGE	324.17	270.27	223.41	137.47	99.84	52.34	545.97	30.96	49.31	2.45
SD	46.70	42.66	48.19	23.43	20.39	11.45	10.78	2.01	1.03	0.37
MAXIMUM	329.00	281.11	243.27	154.55	110.54	57.79	555.49	32.45	50.39	2.86
MINIMUM	320.31	249.48	188.58	107.25	83.71	46.04	534.27	28.67	48.34	2.14
SKEWNESS	0.93	-1.73	-1.68	-1.69	-1.47	-0.63	-0.87	-1.50	0.45	1.13
SHOPS										
AVERAGE	324.57	271.30	225.44	137.89	99.41	53.07	373.37	33.86	58.76	5.24
SD	47.13	40.63	49.79	23.86	20.72	11.36	19.18	3.04	3.39	0.10
MAXIMUM	330.41	283.64	238.17	156.69	112.05	59.51	389.45	36.48	62.15	5.36
MINIMUM	319.99	251.06	192.93	106.56	82.36	46.48	352.15	30.52	55.37	5.17
SKEWNESS	0.94	-1.61	-1.61	-1.63	-1.19	-0.10	-1.12	-1.00	0.01	1.57
OFFICES										
AVERAGE	327.00	272.98	227.44	139.17	101.33	56.13	423.53	33.63	58.25	4.57
SD	47.03	40.03	50.54	23.75	20.75	11.58	8.41	2.71	3.59	0.27
MAXIMUM	333.87	283.04	245.65	157.69	113.81	62.27	432.78	36.42	62.01	4.86
MINIMUM	319.91	253.03	194.00	105.60	82.63	48.29	416.35	31.01	54.85	4.32
SKEWNESS	-0.14	-1.73	-1.71	-1.70	-1.46	-1.01	1.04	0.29	0.45	0.75

Table 2.
Statistical summary of mass concentration during the sampling duration at sampling sites.

SUPERMARKETS	PM ₁₀ μgm ³	PM _{5.0} μgm ³	PM _{2.5} μgm ³	PM _{1.0} μgm ³	PM _{0.5} μgm ³	PM _{0.25} μgm ³	CO ₂ PPM	TEMP °C	HUMIDITY %	AIR EXCHANGE RATE h ⁻¹
AVERAGE	564050	320394	193678	174101	158428	73378	546.89	31.15	49.31	2.48
SD	91578.34	39385.52	17880.25	23865.87	29089.22	22638.62	10.55	1.89	1.05	0.37
MAXIMUM	708054	387299	239159	229203	198148	98297	556.23	32.56	50.40	2.88
MINIMUM	385325	240431	169085	132835	97426	25012	535.45	29.00	48.30	2.15
SKEWNESS	-0.30	-0.37	1.20	0.47	-0.76	-0.66	-0.86	-1.48	0.31	0.89
SHOPS										
AVERAGE	589882	349888	206648	181495	166050	77619	364.92	33.86	58.76	5.26
SD	98489.67	39072.42	25422.77	24131.06	28853.73	22858.65	22.08	3.10	3.46	0.09
MAXIMUM	723225	417693	255400	236318	203617	105994	390.25	36.58	62.22	5.37
MINIMUM	393102	263745	170290	141152	104224	29445	349.75	30.48	55.30	5.20
SKEWNESS	-0.72	-0.49	0.57	0.30	-0.73	-0.64	1.63	-0.91	-0.01	1.64
OFFICES										
AVERAGE	622352	352319	232186	193769	178172	85121	423.59	33.65	58.31	4.64
SD	77730.91	38052.23	35323.51	28899.68	24245.03	24879.46	7.63	2.71	3.62	0.31
MAXIMUM	728091	416462	293039	250985	212192	116927	432.26	36.44	62.10	4.99
MINIMUM	479345	264499	164632	142149	127194	33026	417.85	31.01	54.90	4.38
SKEWNESS	-0.60	-0.72	-0.23	0.13	-0.70	-0.56	1.47	0.25	0.48	1.11

Table 3.
Statistical summary of Number concentration during the sampling duration at sampling sites.

particles/L at supermarket sites, $589,882 \pm 98,489.67$, $349,888 \pm 39,072.42$, $206,648 \pm 25,422.77$, $181,495 \pm 24,131.06$, $166,050 \pm 28,853.73$ and $77,619 \pm 22,858.65$ particles/L at shop sites respectively and $622,352 \pm 77,730.91$, $352,319 \pm 38,052.23$, $232,186 \pm 35,323.51$, $193,769 \pm 28,899.68$, $178,172 \pm 24,245.03$ and $85,121 \pm 24,879.46$ particles/L at office sites respectively.

On applying the one way ANOVA (SPSS 10.0) to the mean values of particulate concentrations at all the sites for each location significant values found for PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5} and PM_{0.25} were close to 1 or were approximately 1. For the supermarkets it varied from 0.931 to 0.997, for shops it varied from 0.942 to 0.998 and for offices they varied from 0.938 to 0.999, indicating that there is no significant difference between the concentrations of two types of similar microenvironment and thus have similar kind of sources which lead to the generation of particulate pollutant in their indoor environment. Due to the above reason, the discussion made in this report is explained on the basis of average concentration of two types of similar microenvironment rather than six places individually. The study period for mass and number concentration trend of PM₁₀, PM_{5.0}, PM_{2.5}, PM_{1.0}, PM_{0.5} and PM_{0.25} from September 2011 to November 2011 in supermarket, shops and offices are given in **Figure 6A** and **B**. On comparing with the standards

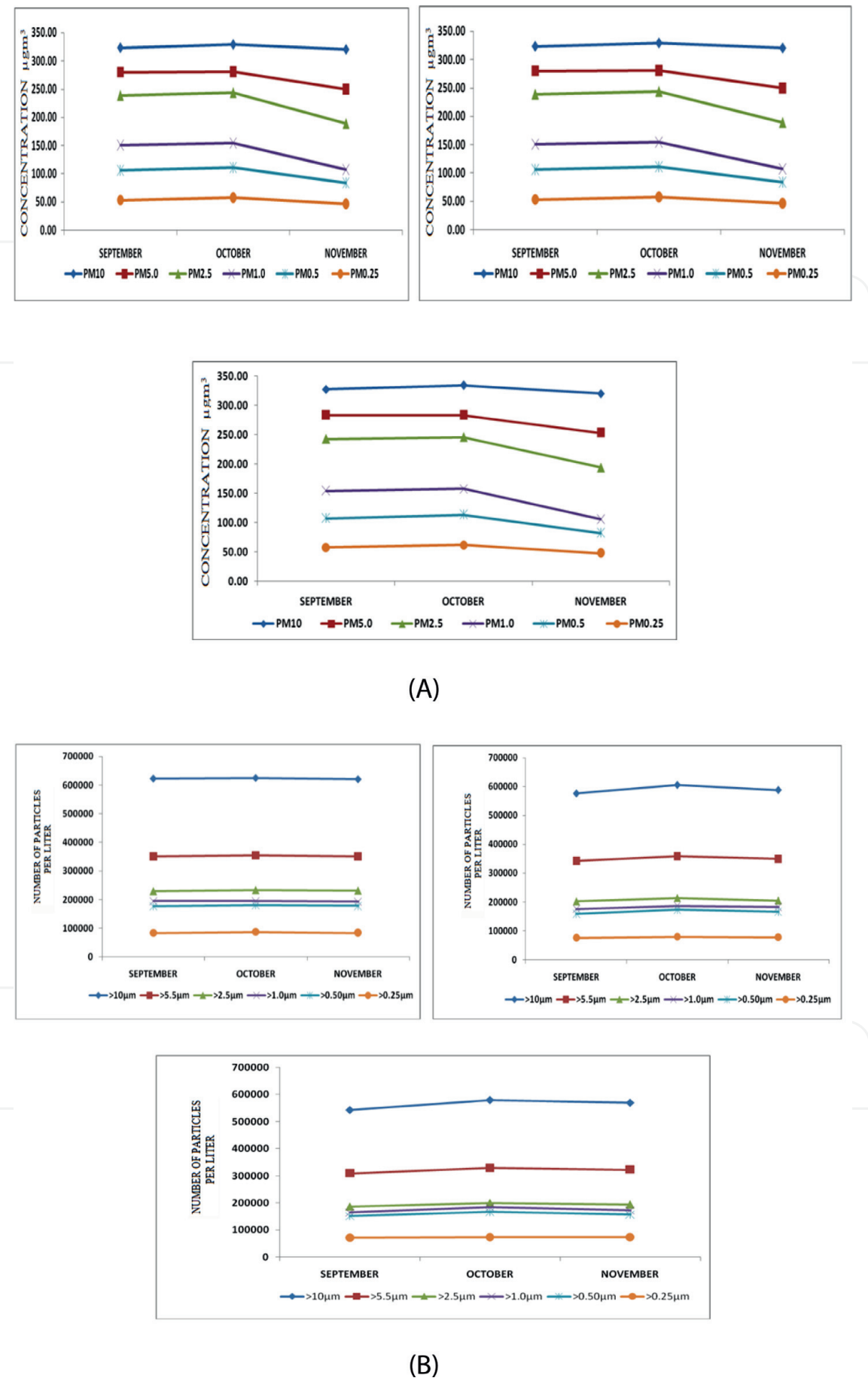


Figure 6. (A) Mass concentration of PM_{10} , $\text{PM}_{5.0}$, $\text{PM}_{2.5}$, $\text{PM}_{1.0}$, $\text{PM}_{0.5}$ and $\text{PM}_{0.25}$ at supermarkets, shops and offices from September 2011 to November 2011, and (B) number concentration of PM_{10} , $\text{PM}_{5.0}$, $\text{PM}_{2.5}$, $\text{PM}_{1.0}$, $\text{PM}_{0.5}$ and $\text{PM}_{0.25}$ at supermarkets, shops, and offices from September 2011 to November 2011.

given by WHO guidelines (24 h mean = $25 \mu\text{g m}^{-3}$, $50 \mu\text{g m}^{-3}$ for $\text{PM}_{2.5}$ and PM_{10}), $\text{PM}_{2.5}$ exceeded 9 times and PM_{10} exceeded 6.5 times in all the indoor microenvironment (i.e., supermarkets, shops, and offices). On comparing with NAAQS standards (24 h mean = $60 \mu\text{g m}^{-3}$, $100 \mu\text{g m}^{-3}$ for $\text{PM}_{2.5}$ and PM_{10}), Coarse to fine particles exceeded 6 to 4 times at all the sampling locations. For coarse and fine particles similar kind of trend was obtained at all the different microenvironments. However, the mass and number concentration trends for coarse and fine particles were somewhat higher for all the particle sizes in the offices in comparison to shops and supermarkets. The higher concentration trend in the offices can be due to particle resuspension from vacuum cleaning, sweeping, low air exchange rate as or due to the movements of office workers [14, 15]. PM concentrations are also greatly affected in the offices by the use of printers and multitask devices [16]. During the campaign study a slight increase was noticed in the PM concentrations during month of October in comparison to September and November. On applying the one way ANOVA (SPSS 10.0) to the mean values of particulate concentrations at all the working environment; significance values were found for PM_{10} , $\text{PM}_{5.0}$, $\text{PM}_{2.5}$, $\text{PM}_{1.0}$, $\text{PM}_{0.5}$ and $\text{PM}_{0.25}$ were close to 1 or approximately 1. They varied from 0.923 to 0.998 at two offices site, 0.918 to 0.993 at two shop sites and 0.920 to 0.987 at two commercial center sites indicating that there is no significant difference between the concentrations of same type of working environment and thus have similar kind of sources which lead to the generation of particulate pollutant in their environment.

3.2 Full day variation trend

The diurnal trend of particulate number and mass concentration during the sampling duration has been monitored continuously throughout the night and day in indoors at the supermarket, shop and office (**Figure 7A and B**). Full-day variation trend of particulate pollutant around the clock covers all the indoor activities taking place. The highest mass and number concentration peaks were observed basically during the morning hours from 9:00 to 10:00 AM and late in the evening hours from 18:00 to 19:00 PM. The maximum concentrations of the particulate matter during this time can be due to resuspension generated by traffic and other human activities, as these sites are mostly adjacent to busy traffic roads of the city (**Figure 1A**). As a result concentrations reaches maximum during the rush hours in the evening and morning [17]. The low concentrations for all the particles are observed during 3:00–4:00 AM in the early morning hours. Whereas, during the working hours low concentrations were reported between 14:00 and 15:00 PM in the afternoon hours at all the microenvironments. All the coarse and fine particulate sizes showed similar trends.

3.3 Inter particulate ratios

For better understanding of these particles in the different indoor environment, inter particulate ratios have also been evaluated and reported in **Table 4**. The average contribution of finer particles (i.e., $\text{PM}_{0.25}$, $\text{PM}_{0.50}$, $\text{PM}_{1.0}$, and $\text{PM}_{2.5}$) to coarse particles (i.e., $\text{PM}_{5.0}$ and PM_{10}) in indoors during the study period for September was around 44.7% at supermarket sites, 44.8% at shops sites and 47% at office sites. In October it was 45.7% at supermarket sites, 46.2% at shops sites and 47.9% at office sites. In November it was 37.1% at supermarket sites, 37.5% at shops sites and 38.0% at office sites. Particles especially $\text{PM}_{2.5}$ and below are resuspended in air with high intensive activities during indoor activities when there is low

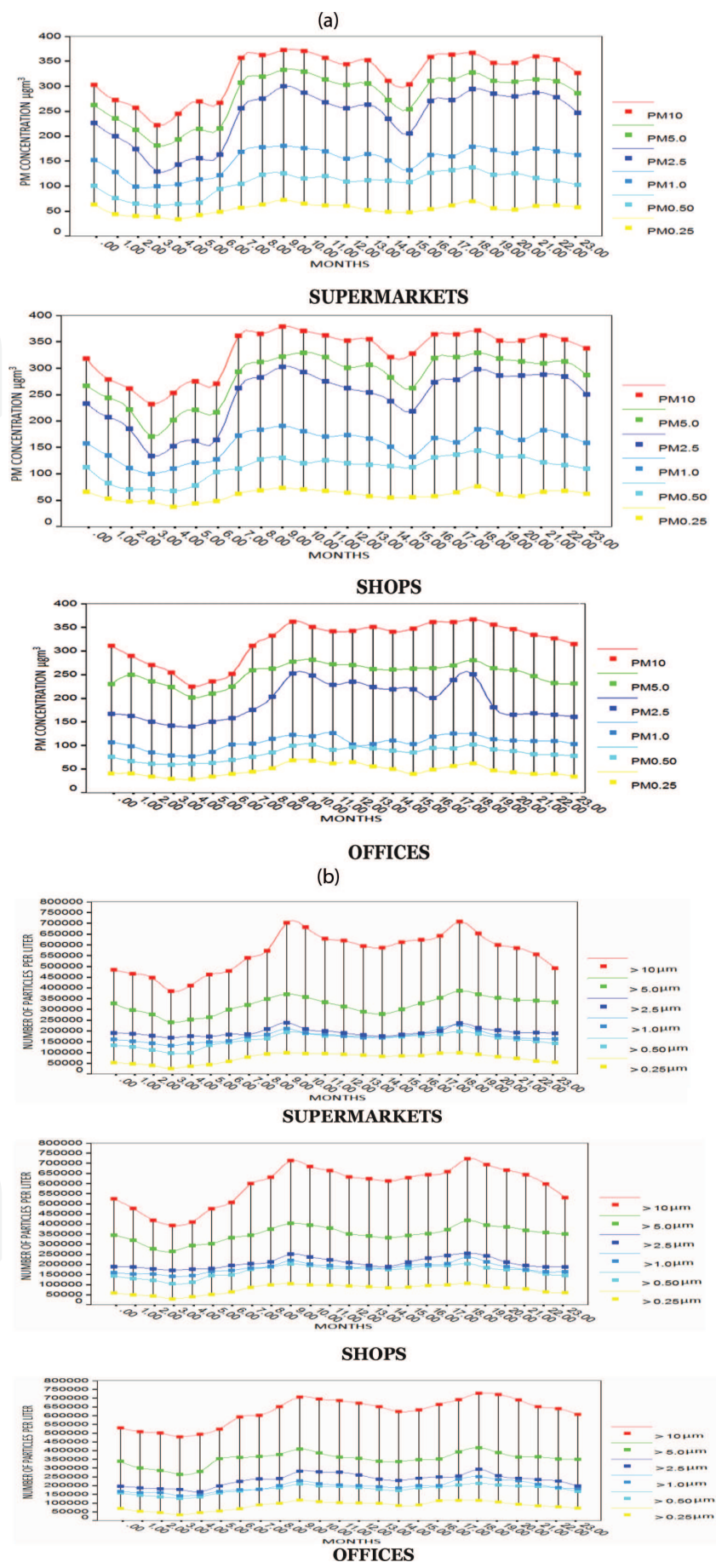


Figure 7.
(A) Full day variation in $\mu\text{g}/\text{m}^3$ in different indoor microenvironment and (B) full day variation in particles/L in different indoor microenvironment.

SUPERMARKET	PM 5/10	PM 2.5/10	PM 1.0/10	PM 0.5/10	PM 0.25/10	PM 2.5/5	PM 1/5	PM 0.5/5	PM 0.25/5	PM 1/2.5	PM 0.5/2.5	PM 0.25/2.5	PM 0.5/1	PM 0.25/1	PM 0.25/0.5
SEPTEMBER	0.87	0.74	0.47	0.33	0.16	0.85	0.54	0.38	0.19	0.63	0.44	0.22	0.70	0.35	0.51
OCTOBER	0.85	0.74	0.47	0.34	0.18	0.87	0.55	0.39	0.21	0.64	0.45	0.24	0.72	0.37	0.52
NOVEMBER	0.78	0.59	0.33	0.26	0.14	0.76	0.43	0.34	0.18	0.57	0.44	0.24	0.78	0.43	0.55
SHOP															
SEPTEMBER	0.86	0.74	0.47	0.32	0.16	0.85	0.54	0.37	0.19	0.63	0.44	0.22	0.69	0.35	0.51
OCTOBER	0.86	0.74	0.47	0.34	0.18	0.86	0.55	0.40	0.21	0.64	0.46	0.24	0.72	0.38	0.53
NOVEMBER	0.78	0.60	0.33	0.26	0.15	0.77	0.42	0.33	0.19	0.55	0.43	0.24	0.77	0.44	0.56
OFFICE															
SEPTEMBER	0.86	0.74	0.47	0.33	0.18	0.86	0.55	0.38	0.20	0.64	0.44	0.24	0.70	0.38	0.54
OCTOBER	0.85	0.74	0.47	0.34	0.19	0.87	0.56	0.40	0.22	0.64	0.46	0.25	0.72	0.39	0.55
NOVEMBER	0.79	0.61	0.33	0.26	0.15	0.77	0.42	0.33	0.19	0.54	0.43	0.25	0.78	0.46	0.58

Table 4.
Inter Particulate Ratios at sampling sites.

ventilation rates due to closed doors and windows, which get reduced to some level during the infiltration from higher air exchange rates [18]. The shops are more ventilated in comparison to offices and supermarkets (**Tables 2 and 3**).

At offices contribution of finer particles to coarse particles is 44% while at the shops and supermarket is around 42%. This suggests that office sites are more exposed to finer particles then in comparison to shops or supermarkets.

3.4 Metal concentrations

Characterization of PM components, including inorganic elements, is of central importance in proposing mechanisms for health effects and in source apportionment studies [19, 20]. Data obtained by chemical analysis for seven metals in PM_{2.5} particulate size collected from 36 samples of different indoor environment of supermarkets, shops and offices sites is shown in **Table 5**. Observations on the basis of these tables are as follows:

Metal concentration ($\mu\text{g m}^{-3}$)	Zn	Ni	Cr	Mn	Cu	Fe	Pb
<i>Supermarket</i>							
Average	0.60	0.04	0.09	1.36	0.07	0.38	0.17
SD	0.02	0.02	0.01	0.13	0.01	0.04	0.03
Maximum	0.62	0.06	0.10	1.50	0.08	0.42	0.20
Minimum	0.58	0.03	0.08	1.24	0.06	0.35	0.15
<i>Shops</i>							
Average	0.62	0.07	0.10	1.52	0.09	0.42	0.21
SD	0.03	0.02	0.02	0.13	0.01	0.03	0.03
Maximum	0.65	0.09	0.12	1.65	0.10	0.45	0.25
Minimum	0.60	0.06	0.09	1.40	0.08	0.40	0.19
<i>Offices</i>							
Average	0.67	0.08	0.12	1.78	0.13	0.45	0.25
SD	0.03	0.02	0.03	0.15	0.02	0.03	0.04
Maximum	0.70	0.10	0.15	1.95	0.15	0.48	0.29
Minimum	0.65	0.07	0.10	1.66	0.11	0.42	0.22

Table 5.
Statistical profile of metal concentrations in PM_{2.5} (N = 36).

3.4.1 Metal concentrate particles

At supermarket sites the sum of the average concentrations for fine particles were found to be $223.41\text{ }\mu\text{g m}^{-3}$ and ranged from 243.27 to $188.85\text{ }\mu\text{g m}^{-3}$ in indoors, at shops site the concentration was $225.44\text{ }\mu\text{g m}^{-3}$ and ranged from 238.17 – $192.93\text{ }\mu\text{g m}^{-3}$ in indoors and whereas at offices sites the concentration was found to be $227.44\text{ }\mu\text{g m}^{-3}$ and the range from 245.65 to $194.00\text{ }\mu\text{g m}^{-3}$ in indoor environment respectively. The total analyzed parameters contributed 65% at supermarket sites, 70% at shop sites while 75% at the offices site of the particulate concentration respectively. The trends in increasing order of metal concentrations at supermarket, shop and office sites are as follows:

$$\text{Ni} < \text{Cu} < \text{Cr} < \text{Pb} < \text{Fe} < \text{Zn} < \text{Mn} \tag{1}$$

A similar kind of trends were found for metal concentrations in all the three microenvironment, indicating one or more similar kind of sources contributing to these microenvironment, being present in similar kind of commercial areas of the city. Out of 0.14% contribution of analyzed metals in PM_5 at supermarket percentage contribution of each metal is shown in **Figure 8A** while from the total contribution of 0.16% at shop sites and 0.20% at office sites percentage contribution of each metal is shown in **Figure 8B** and **C**. Global emissions reported shows that natural and anthropogenic sources can contribute to the principal aerosol classes, but values change according the local scenario (coarse and fine) of atmospheric particulate matter (PM). About 10–20% of the aerosols can be characterized as anthropogenic on a global scale [21], but these values may drastically change due to local scenarios, human activities, and the prevailing particle cutoff. The principal component analysis is the most common multivariate statistical methods applied in environmental studies. The SPSS software package version 10.0 was used for the multivariate analysis. The levels of various elements vary by different orders of magnitude and hence the principal component analysis was applied to the correlation matrix.

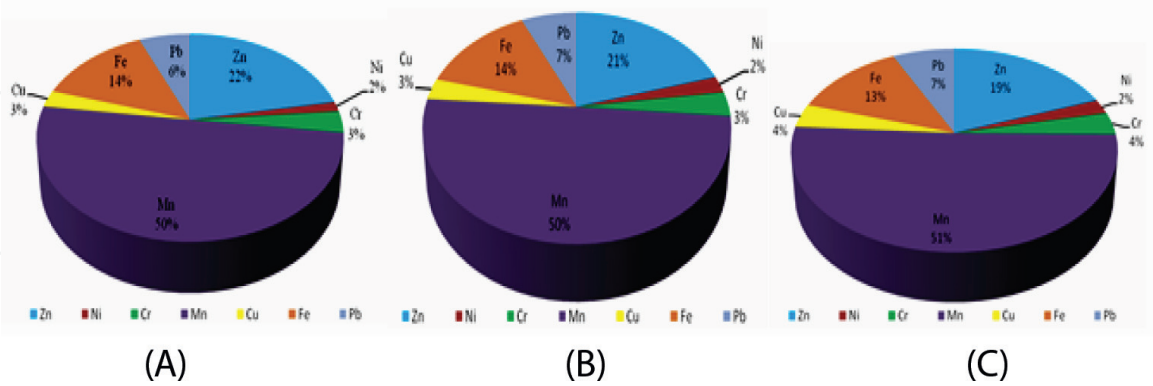


Figure 8.
(A–C) Percent contribution of each metal at supermarket, shop, and office sites.

3.5 Multivariate principal component analysis

Principal component analysis (PCA) is a well-established tool for analyzing structure in multivariate data sets [22]. A varimax rotated factor analysis was performed to identify the major sources responsible for the particulate pollutants and the sampling sites. It is a statistical method; in which a set of multiple

intercorrelated variables are replaced by small number of independent variables or factors by orthogonal transformations also called as rotations. This is achieved by analyzing the correlation matrix of the variable, i.e., by computing their Eigen values and the Eigen vectors. “Factor loadings” obtained after the varimax rotation give the correlation between the variables and the factors. Data which is included in the matrix only if their Eigen values of tat factor is bigger than 1. The varimax technique was adopted for rotation of the factor matrix to allocate the initial matrix into one that was easier to understand. For this SPSS version 10.0 was used to perform factor analysis. At supermarket, shop and offices sites we have mostly multistory modern types of construction, as they have been built recently; usually their outside environment is of high traffic during the day with both heavy and light motor vehicles. These are in the busy commercial places of the city with many kinds of other activities like major hospitals, hotels, railway station, big or small restaurants and banks etc.

3.5.1 Supermarket

At supermarket sites indoors three sources identifying 90% of metal concentration were identified (**Table 6**). Zn, Ni, Cr and Mn represent the factor 1 with 36% variance. The common source attributed to the smoking of the occupants in the indoor environment [23]. Factor two is represented by Cu and Fe with 31% variance and was attributed to resuspension of dust due to indoor human activities [23]. Third factor is comprised of Pb with 24% and is attributed to emission of paints from wall, ceiling and furniture [24].

Rotated component matrix at office sites			
	1	2	3
Zn	0.71	0.29	0.43
Ni	0.78	0.44	0.30
Cr	0.74	0.43	0.19
Mn	0.79	0.29	0.48
Cu	0.23	0.75	0.22
Fe	0.38	0.62	0.45
Pb	0.44	0.31	0.76
Total	2.51	2.16	2.14
% of variance	35.88	30.79	23.62
Cumulative %	35.88	66.67	82.29

Table 6.
Factor analysis at supermarket sites.

3.5.2 Shops

At shop sites indoors three sources identifying 93% of metal concentration were identified (**Table 7**). Zn, Cr and Mn represent the factor 1 with 37% variance. The common source attributed to the smoking of the occupants in the indoor environment [25]. Factor two is represented by Ni, Cu and Fe with 28% variance

Rotated component matrix at office sites			
	1	2	3
Zn	0.62	0.47	0.46
Ni	0.48	0.68	0.42
Cr	0.70	0.33	0.26
Mn	0.83	0.34	0.41
Cu	0.44	0.89	0.38
Fe	0.39	0.76	0.30
Pb	0.42	0.34	0.87
Total	2.89	1.99	1.89
% of variance	37.28	28.45	26.99
Cumulative %	37.28	69.73	96.72

Table 7.
Factor analysis at shop sites.

and was attributed to electrical wiring or appliances [1]. Third factor is comprised of Pb with 27% and is attributed to emission of paints from wall, ceiling and furniture [24].

3.5.3 Offices

At office sites indoors three sources identifying 92% of metal concentration were identified (**Table 8**). Zn, Ni, Cr and Mn represent the factor 1 with 30% variance. The common source attributed to the smoking of the occupants in the indoor environment [25]. Factor two is represented by Cu and Fe with 32% variance and was attributed to resuspension of dust due to indoor human activities [23]. Third factor is comprised of Pb with 30% and is attributed to emission of paints from wall, ceiling, and furniture [24].

Rotated component matrix at office sites			
	1	2	3
Zn	0.57	0.47	0.46
Ni	0.55	0.38	0.47
Cr	0.54	0.62	0.48
Mn	0.62	0.47	0.32
Cu	0.41	0.82	0.40
Fe	0.39	0.84	0.34
Pb	0.32	0.47	0.87
Total	2.40	2.24	2.10
% of variance	30.22	32.03	29.99
Cumulative %	30.22	66.25	96.24

Table 8.
Factor analysis at office sites.

3.6 Risk assessment from carcinogenic metals in different working environment

Excess cancer risks (ECRs) were calculated using the unit risk and the PM-bound concentration of the metals which represents the total concentration of the metals. ECRs can be calculated simply by using the formula given below [26, 27]:

Excess cancer risk (inhalation) = concentration of pollutant ($\mu\text{g m}^{-3}$) \times unit risk ($\mu\text{g m}^{-3}$)⁻¹ (2)

The information on the carcinogenic types and the unit risks of the metals was obtained from the US EPA database for IRIS (Integrated Risk Information System) [28]. Fine particles, PM_{2.5}-bound metals such as Cd, Cr, Ni and Pb are the known carcinogenic metals which can cause serious health risks to occupants in these microenvironments. They are introduced to the occupants by exposure through the inhalation pathway [27]. Cadmium have been categorized as the B1 carcinogen, while Cr (VI) is classified as group A which indicates that it is a known human carcinogen by the inhalation route of exposure. Therefore, the concentration of Cr (VI) used for the carcinogenic risk assessment was calculated as one seventh of the total Cr concentration. Nickel also has been classified as group A materials, known human carcinogens. From the research findings it is evident that Ni was mainly emitted from tobacco or cigarette smoke and outdoor sources like the industrial or refinery emissions can contribute to it in an indoor environment [29]. Lead on the other hand is also a probable human carcinogen (group B2), but human evidence is inadequate and its unit risk is currently being amended by the US EPA.

PM_{2.5}-bound metals such as Cd, Cr and Ni, respectively, based on PM concentrations. The particles whose diameters are less than 4 mm can penetrate into the trachea, bronchi and the alveoli [28, 29]. In **Table 9**, the estimated ECR of

Elements	Concentration (ng m ⁻³)		Inhalation unit risk (μg m ⁻³) ⁻¹	Excess cancer risk (μg m ⁻³) ⁻¹	
Offices	Average	95th percentile		Average	95th percentile
Cd	0.08	1.05	1.8×10^{-3}	0.14	2.51
Cr ^(VI) (=ΣCr/7)	0.11	2.01	1.2×10^{-2}	0.13	2.43
Ni	0.07	1.03	2.4×10^{-4}	0.16	2.76
Shops	Average	95th percentile		Average	95th percentile
Cd	0.08	1.04	1.8×10^{-3}	0.14	2.40
Cr ^(VI) (=ΣCr/7)	0.10	1.95	1.2×10^{-2}	0.12	2.37
Ni	0.06	1.02	2.4×10^{-4}	0.14	2.58
Commercial centers	Average	95th percentile		Average	95th percentile
Cd	0.05	1.01	1.8×10^{-3}	0.09	1.97
Cr ^(VI) (=ΣCr/7)	0.09	1.82	1.2×10^{-2}	0.10	2.20
Ni	0.04	1.00	2.4×10^{-4}	0.09	2.36

Table 9.
Excess cancer risks of carcinogenic elements in PM_{2.5} in different indoor environment.

PM_{2.5}-bound carcinogenic elements in the indoor environment for the average values and the 95th percentile values of Cd, Cr and Ni. The total ECRs based on the average values of Cd, Cr (VI) and Ni in PM_{2.5} in different indoor environment varied from 0.47 to 0.32×10^{-6} , respectively. Ni had the highest ECRs followed by Cd and Cr in the different indoor environment. The results indicates that occupant exposure to toxic trace metals in indoor environments can easily get cancer in different indoor working environments. Thus, trace metals in airborne fine and ultrafine particles be used in order to more accurately assess environmental and health risks. Thus chemical speciation of metal is important and should become a routine analysis in future study of air pollution.

4. Conclusion

Indoor air pollution in developing countries is recognized as a major source of health risk to the exposed population, thus there is a need to address the issue of particles, especially fine particles and their related toxicity in different indoor microenvironments. On comparing with the standards given by WHO and national standards, PM₁₀ and PM_{2.5} concentrations exceeded many folds at all the sampling sites. These high values indicate the need to find strategies to control particulate pollution. Metal concentrations were determined using the positive matrix factorization in PM_{2.5} in different indoor working environments. The sources responsible for PM_{2.5} emissions are smoking, incense burning, anthropogenic activities and use of different mechanical and electrical apparatus like computers, printers and photocopiers, etc. in the work environment. Risk assessment related to particulate pollutant was evaluated on the basis of metal contamination. The values summarized in this study represent initial estimates of emissions and their implications, which can be a useful addition to the existing literature, in particularly for the developing countries like India; where such measurements are yet under represented.

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