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Seasonal Trends of $PM_{2.5}$ and PM_{10} in Ambient Air and Their Correlation in Ambient Air of Lucknow City, India

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Abstract The PM_{10} concentration (μg/m^3) in Lucknow city at 4 locations in three different seasons ranged between 148.6–210.8 (avg. 187.2 ± 17.1) during summer, 111.8–187.6 (avg. 155.7 ± 22.7) during monsoon and 199.3–308.8 (avg. 269.3 ± 42.9) during winter while $PM_{2.5}$ ranged between 32.4–67.2 (avg. 45.6 ± 10.9), 25.6–68.9 (avg. 39.8 ± 4.6) and 99.3–299.3 (avg. 212.4 ± 55.0) during respective seasons. The mass fraction ratio of $PM_{2.5}$ ranged between 0.22–0.92 (avg. 0.42 ± 0.26) and was significantly high during winter season indicating their composition.

Keywords PM_{10} · $PM_{2.5}$ · Mass ratio · Exceedance factor

Respirable particulates having aerodynamic diameter ≤10 μm (PM_{10}) and ≤2.5 μm ($PM_{2.5}$ and fine particles) are an important part of the atmosphere. The particle size is very important both in terms of deeper penetration into the lungs and are carriers of toxic air pollutants including heavy metals and organic compounds. The main components of $PM_{2.5}$ are organic matter (30–60%), metals (1%), nitrates and sulfates (25–35%), elemental carbon (5%) and rest others (USEPA 1995).The sources, characteristics, and potential health effects of PM_{10} and $PM_{2.5}$ are different; various health effects of PM, are associated with its specific chemical and physical components (Dockery et al. 1993). PM_{10}, when present in excess of 50 μg/m^3 are known to adversely affect human health (WHO 2006). Fine particles in the atmosphere are responsible for visibility impairment (Eldering and Cass 1996; Reddy and Venkataraman 2000) and adverse health effects linked to chronic respiratory illness, cancer and premature death (Dockery et al. 1993; Dockery and Pope 1994; Pope et al. 1995). Epidemiological evidence indicate that even a low level of exposure leads to an increase in the risk factors for cardiopulmonary diseases, stressed respiratory physiology, mortality and morbidity (Pope 2000).

Most of the studies in Indian cities reported the total particulate matter and PM_{10} only. Very few studies have reported for $PM_{2.5}$ concentrations. The present study was planned and conducted during 2007–2008 when the standards for $PM_{2.5}$ in ambient air in India were under formulation stage. The introduction of new cars fitted with efficient engines (Bharat-II compliant) and CNG in Lucknow for public transport vehicles has resulted in the increased emission of finer particulates. Air monitoring was carried out in three seasons, winter (November–Feburary), summer (March–June) and monsoon (July–October) in order to assess the air quality with respect to $PM_{2.5}$ and PM_{10}.

Lucknow, the capital of the one of the most populous state of India, is situated between 26°52′N latitude and 80°56′E longitude and 120 m above sea level in the central plain of the Indian subcontinent. The year is divided into three distinct seasons i.e. summer (March–June), monsoon (July–October) and winter (November–Feburary). The temperature ranges from 5°C in winter to 45°C in summer.

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The mean average relative humidity is 60% and rainfall 1,006.8 mm (Barman et al. 2008). In 1981 population of Lucknow city was 1.0 million which reached to 1.7 million in 1991 and more than 2.25 million in 2001. To meet the requirement of growing population city has marked substantial growth its infrastructure facilities and vehicular population. Since 2005 every year 70–80 thousands vehicles were registered in Lucknow. As per Road Transport Office (RTO) Lucknow records 9,69,915 vehicles were registered till 31st March, 2008. Monitoring of $PM_{2.5}$ and PM_{10} was carried out across the city of Lucknow at following four locations, Aliganj (Residential), Chowk (Commercial), Charbagh (Commercial) and Talkatora (Commercial/Industrial).

Materials and Methods

Sampling of respirable particulates was conducted continuously on 24 hourly basis in three distinct seasons i.e. summer (March–June), monsoon (July–October) and winter (November–Feburary). Fine particles $PM_{2.5}$ were sampled using Fine Particulate Sampler (FPS, Envirotech, APM 550) which runs at a constant flow rate of 16.6 L/min. It has a portable Wins-Anderson impactor for the sampling of $PM_{2.5}$. Respirable Dust Sampler (RDS, Envirotech, APM 460) was used for PM_{10} sampling which has a flow rate of 1.1 m^3/min. The samplers were installed at a height of 4 feet at each sampling site. Glass fiber filter of 8 × 10 inches and Teflon filter paper of 47 mm diameter were used for sampling of PM_{10} and $PM_{2.5}$, respectively.

The filters were equilibrated in desiccators containing silica gel for 24 h before and after sample collection and weighed on pre-calibrated electronic balance (capable to weigh up to 0.01 mg) before and after the sampling to know the weight of collected dust. The ambient air mass concentration was calculated by dividing the weight of collected dust by volume of air sampled.

Results and Discussion

Results of respirable particulates; $PM_{2.5}$ and PM_{10} during study period are summarized in Table 1 and Fig. 1. Arithmetic average concentration of $PM_{2.5}$, PM_{10} and $PM_{10-2.5}$ was found 101.05 ± 22.5, 204.0 ± 26.7 and 103.6 ± 16.9 μg/m^3, respectively. The average levels of $PM_{2.5}$ and PM_{10} were lowest in Aliganj i.e. 75.8 and 163.9 μg/m^3, respectively. $PM_{2.5}$ and PM_{10} levels at Chowk were highest i.e. 129.8 μg/m^3 and 218.4 μg/m^3, while the values at Charbagh and Talkatora exits in between Aliganj and Chowk. The concentration of PM_{10} at Charbagh and Talkatora i.e. 216.6 and 217.2 μg/m^3, respectively were very close to the average highest level at Chowk. Aliganj, predominantly a residential area has least commercial activities and lower traffic density thus has shown lower concentrations of $PM_{2.5}$ and PM_{10}. Talkatora being an industrial cum commercial area, Chowk and Charbagh also have high commercial activities and heavy traffic density, which has resulted in higher $PM_{2.5}$ and PM_{10} levels at these locations as compared to Aliganj.

Seasonal values of $PM_{2.5}$ and PM_{10} during study period are summarized in Table 2. Arithmetic average concentration of $PM_{2.5}$ was found 39.83 ± 4.6, 212.35 ± 55.0 and 45.65 ± 1.4 μg/m^3 and that of and PM_{10} 155.72 ± 22.7, 269.32 ± 42.9 and 187.17 ± 17.1 μg/m^3 in monsoon, winter and summer respectively, (Table 2).

The levels of $PM_{2.5}$ in a winter study in two commercial areas of Kanpur were reported as 186 and 195 μg/m^3. The corresponding values of PM_{10} in these locations were 272 and 282 μg/m^3 (Sharma and Maloo 2005). The average levels of $PM_{2.5}$ and PM_{10} were lower in monsoon and summer as compared to winter. In an integrated continuous ambient air quality monitoring study carried out at Bahadur Shah Zafar Marg, Delhi, during 2006–2007 reported concentration of $PM_{2.5}$ as 214.8, 78.2, 70.5 μg/m^3 in winter, summer and monsoon (http://164.100.43.188/cpcbnew/movie.html). The concentration of RSPM was found at all locations was almost double from National Ambient Air

Table 1 Concentration (μg/m^3) of respirable particulate matter

Monitoring station	$PM_{2.5}$	PM_{10}	$PM_{10-2.5}$	$PM_{2.5}/PM_{10}$	$PM_{(10-2.5)}/PM_{10}$
Aliganj	75.8 (34.8–175.24)	163.96 (111.8–215.7)	88.09 (26.6–130.7)	0.42 (0.20–0.87)	0.58 (0.13–0.79)
Chowk	129.85 (25.6–289.3)	218.43 (148.7–308.7)	91.03 (16.5–173.1)	0.47 (0.16–0.94)	0.51 (0.05–0.83)
Charbagh	104.5 (37.2–299.3)	216.65 (169.76–303.4)	112.11 (4.0–158.6)	0.42 (0.20–0.98)	0.58 (0.01–0.79)
Talkatora	93.94 (29.2–299.4)	217.23 (157.8–315.6)	123.3 (16.2–170.4)	0.37 (0.17–0.94)	0.63 (0.05–0.82)
Average	101.05	204.07	103.63	0.43	0.57
SD	22.55	26.75	16.92	0.049	0.049
Minimum	75.87	163.96	88.09	0.37	0.5
Maximum	129.85	218.43	123.3	0.49	62

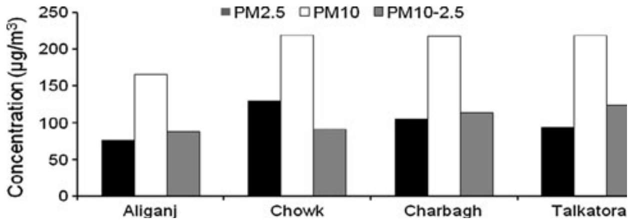

Fig. 1 Distribution of $PM_{2.5}$ and PM_{10}–$PM_{2.5}$ in PM_{10}

Quality Standards (NAAQS), India. $PM_{2.5}$ data confirms the pronounced seasonal peaks coinciding with lower mixing heights of the winter months. The measured PM pollution in the winter is at least double the concentrations measured during the rest of the season (Guttikunda, 2009). In a study done by Sharma et al. (2006) on RSPM concentration and its associated trace metals concentration in Lucknow city, during summer, he found concentration of PM_{10} ranged between 107.6 and 237.8 µg/m^3 which is in the same range of our study i.e. 187.17 µg/m^3. In another study of Lucknow done by Barman et al. (2008) revealed that, urban populations are exposed to a high level of fine and ultrafine particles from motor vehicle emissions which affect human health. The level of $PM_{2.5}$ reported in two residential locations of Lucknow during November 2005, during beginning of winter was 142.74 µg/m^3. In the present study during winter the observed $PM_{2.5}$ was 212.35 ± 55.0 (147.38–280.08) µg/m^3, which clearly indicated the progressive increase in the concentration as winter progresses.

The overall value of mass ratio of $PM_{2.5}$–PM_{10} during study period was 0.42 i.e. 42% particles are in $PM_{2.5}$ size range with minimum 0.38 at Talkatora and maximum 0.47 in Chowk area. The average seasonal mass ratio of $PM_{2.5}$–PM_{10} during study period is summarized in Table 3. The average mass ration during monsoon and summer, 0.25 and 0.24 was in the same range, indicating that about a fourth of the dust is in the size range of $PM_{2.5}$. Whereas during winter the ratio has increased three fold and gone up to 0.76, which is a clear indication of increase in finer particulate fraction. $PM_{2.5}$ emitted from CNG driven vehicles and local biomass burning in winter season for heating purpose along with domestic heating may be the possible sources of finer particulates. High concentration built up of $PM_{2.5}$ in winter season is mainly due to low wind speed and high humidity during the winter in comparison to other seasons so the removal of aerosol particles by wet scavenging is reduced (Kulshreshtha et al. 2009). Studies conducted in Kolkata, India reported that about 55%–63% of the PM_{10} was made of $PM_{2.5}$ (Das et al. 2006). A recent study of Agra reported 38%–77% $PM_{2.5}$ fraction in PM_{10} (Kulshreshtha et al. 2009), while in Birmingham, UK it is reported that $PM_{2.5}$ comprises about 80% of PM_{10} during

Table 2 Average Concentration (µg/m^3) of particulates at all locations in different seasons during study period

	Monsoon		Winter		Summer	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Aliganj	34.84 (29.4–49.3)	123.46 (111.8–138.0)	147.38 (128.2–175.2)	206.91 (199.34–215.72)	45.39 (38.74–51.24)	161.52 (148.6–173.9)
Charbagh	43.65 (37.2–49.6)	175.92 (172.0–187.63)	222.44 (147.8–299.3)	277.39 (219.87–303.45)	47.54 (37.24–67.21)	196.63 (184.5–210.7)
Chowk	43.96 (25.6–68.9)	157.8 (148.72–169.6)	280.08 (270.3–289.3)	303.07 (298.67–308.76)	44.21 (32.41–65.97)	194.43 (187.5–207.4)
Talkatora	36.86 (29.2–52.2)	165.69 (157.8–178.5)	199.5 (99.3–299.3)	289.91 (269.82–315.63)	45.46 (35.47–58.28)	196.11 (189.6–203.8)
Average	39.83 ± 4.6	155.72 ± 22.7	212.35 ± 55.0	269.32 ± 42.9	45.65 ± 1.4	187.17 ± 17.1

Table 3 Average seasonal mass ratio of $PM_{2.5}/PM_{10}$ during the sampling period

	Monsoon	Winter	Summer	Average
Aliganj	0.2 (0.20–0.39)	0.71 (0.60–0.86)	0.28 (0.24–0.34)	0.43
Charbagh	0.24 (0.21–0.29)	0.8 (0.67–0.98)	0.24 (0.20–0.32)	0.43
Chowk	0.27 (0.17–0.45)	0.92 (0.90–0.94)	0.22 (0.16–0.35)	0.47
Talkatora	0.22 (0.18–0.29)	0.68 (0.37–0.95)	0.23 (0.20–0.30)	0.38
Average	0.25	0.76	0.24	0.42

the winter months and 50% of in summer months (Harrison et al. 1997).

Results with respect to $PM_{2.5}$ and PM_{10} relationship reported in some more studies conducted in different countries have been compared with the present study (Table 4). The particulates concentrations are higher in winter season and are lower during monsoon months. During the winter season, average mixing height is lower as compared to other seasons and atmospheric dispersion is typically at a minimum and therefore the pollutants will not be as widely dispersed. Lower average mixing height in winter season results in less volume of troposphere available for mixing and hence higher concentrations. The monsoons results in large amount of precipitation, high wind velocities and changes in general wind direction which reduces atmospheric pollution via associated wet deposition processes.

Relationship between Average PM_{10} and $PM_{2.5}$ during study period of Lucknow (all areas combined) exhibits a high degree of correlation (r = 0.90) (Fig. 2). The PM_{10} concentrations was strongly associated with $PM_{2.5}$ in all locations i.e. Chowk (r = 0.96), Charbagh (r = 0.94), Talkatora (r = 0.93) and Aliganj (r = 0.86) (Fig. 3). Das et al. (2006) reported strong association of PM_{10} with $PM_{2.5}$ (r = 0.95) in Kolkata. In a study of Mumbai $PM_{2.5}$ with PM_{10} showed a high correlation coefficients of 0.83 (Kumar and Joseph 2006).

The study was planned when the standards for $PM_{2.5}$ were under the formulation stage in India. Observed $PM_{2.5}$ and PM_{10} values were exceeding from NAAQS at all locations. The lowest exceedance factor respectively, for $PM_{2.5}$ and PM_{10} i.e. 1.3 and 1.6 was observed at Aliganj, while highest (2.2) was found at Chowk (Table 5; Fig. 4). In a study conducted by Sharma et al. (2006) during summer reported an excedance factor (1.3) for PM_{10} Aliganj and Chowk and 1.7 at Charbagh in Lucknow city. The average concentrations PM_{10} and $PM_{2.5}$ were 4.1 times and 4.0 times higher than the World Health Organization (WHO) air-quality guidelines (WHO 2006) of 50 and 25 μg/m^3 24 h basis for PM_{10} and $PM_{2.5}$, respectively.

The results found in this study show that 24-h mean Respirable particulate ($PM_{2.5}$ and PM_{10}) were higher than the respective NAAQS 24 hourly standards of 60 and 100 μg/m^3 respectively and may lead to the substantial

Table 4 Reported values of mass ratio

Country	$PM_{2.5}/PM_{10}$	$PM_{10\text{-}2.5}/PM_{10}$	References
Austria	0.70		Hauck et al. (2004)
Birmingham, UK	0.80 winter, 0.50 summer		Harrison et al. (1997)
Germany	0.61 winter, 0.42 summer		Spindler et al. (2004)
Kolkata, India	0.59 winter	0.41 in winter	Das et al. (2006)
Agra, India	0.77 winter, 0.38 summer		Kulshreshtha et al. (2009)
Present study	0.76 in winter	0.24 in winter	

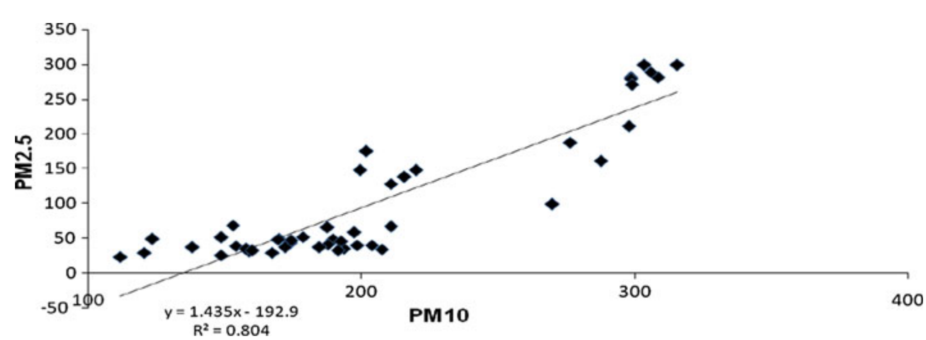

Fig. 2 Relationship between Average $PM_{2.5}$ and PM_{10} (overall)

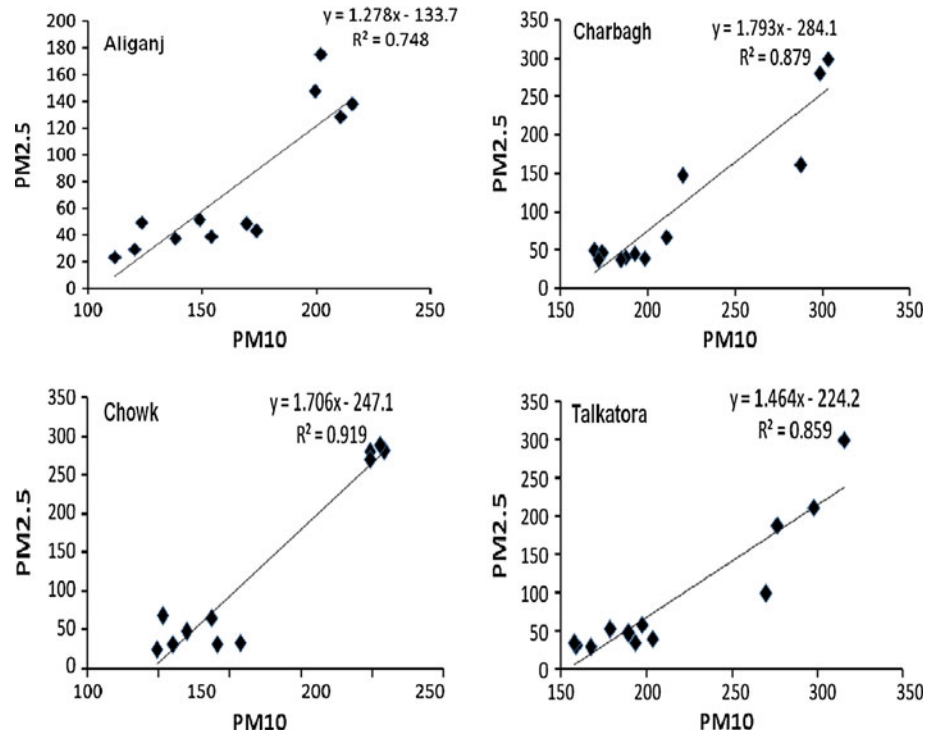

Fig. 3 Relationship between $PM_{2.5}$ and PM_{10} at different locations

Table 5 Comparison of $PM_{2.5}$ and PM_{10} with NAAQS

Location	$PM_{2.5}$	NAAQS[a]	Exceedance factor	PM_{10}	NAAQS[a]	Exceedance factor
Aliganj	75.8	60	1.3	164.0	100	1.6
Charbagh	104.5		1.7	216.7		2.2
Chowk	129.8		2.2	218.4		2.2
Talkatora	93.9		1.6	217.2		2.2

[a] NAAQS 24 hourly average, exceedance factor = ratio of observed value to standards

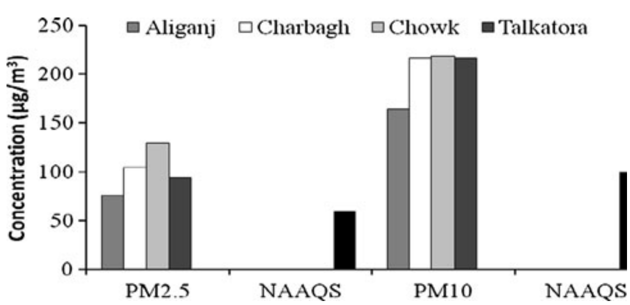

Fig. 4 Comparison of particulates with their standards

burden of disease and premature death. This confirms the inclusion of Lucknow by CPCB's in the list of polluted cities of India (CPCB Annual Report 2006–2007). Although various measures such as implementation of Bharat Stage-III norms etc. have been under taken to mitigate ambient RSPM levels but at the same time number of vehicles have increased exponentially in Lucknow. During monsoon and summer $PM_{2.5}$ is about one-fourth of PM_{10}, while in winter the ratio increases up to 75%. Stronger relationship between $PM_{2.5}$ and PM_{10} at all locations is an indication of direct emissions, most likely transport and burning of biofuels. Proper implementation of action plans formulated by the government to control air pollution and public awareness about dangers of particulate matter in ambient air will help in the improvement of urban air quality.

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