Bull Environ Contam Toxicol (2012) 89:1098–1104
DOI 10.1007/s00128-012-0834-1

Aerosol Size Distribution and Seasonal Variation in an Urban Area of an Industrial City in Central India

Dhananjay K. Deshmukh · Manas K. Deb · Devsharan Verma · Santosh K. Verma · Jayant Nirmalkar

Received: 9 May 2012 / Accepted: 12 September 2012 / Published online: 19 September 2012

Abstract To study the size distribution and seasonal variations of atmospheric aerosols, size-segregated aerosol samples were collected from July 2009 to June 2010 using the nine-stage cascade impactor aerosol sampler in Durg City, India. The aerosol particles exhibited bimodal size distribution on mass concentration with a peak at 2.5–4.4 μm size ranges in the coarse mode and 2.1–2.5 μm size ranges in the fine mode. The aerosol mass and size distribution during monsoon were found unimodal distribution with a peak in the coarse mode, while they showed trimodal distributions during winter with all three peaks appearing in the fine mode. The annual mean concentration of PM_{10} aerosol was found to be 253.5 ± 99.4 μg/m^3, which is four times higher as compared to the annual guideline of National Ambient Air Quality Standards (NAAQS) of India prescribed by the Central Pollution Control Board (CPCB), India. The highest aerosol mass concentrations were found during winter due to enormous biomass burning, while the lowest concentrations were observed during monsoon due to heavy rainfall. Air quality index values calculated in this study showed that 35 % of the days were unhealthy for sensitive people, 35 % were unhealthy or very unhealthy, while 3.3 % were found as hazardous in Durg City, India.

D. K. Deshmukh · M. K. Deb (✉) · D. Verma · J. Nirmalkar
School of Studies in Chemistry, Pt. Ravishankar Shukla University, Raipur 492010, Chhattisgarh, India
e-mail: debmanas@yahoo.com

D. K. Deshmukh
e-mail: dhananjaychem@yahoo.in

S. K. Verma
State Forensic Science Laboratory, Raipur 492001, Chhattisgarh, India

Keywords Atmospheric aerosols · Size distribution · Mass concentration · Air quality index

Aerosol particles suspended in air from anthropogenic and natural sources have been estimated to account for a large fraction of air pollutants in Indian cities (Bhaskar et al. 2010; Pandey et al. 2012). In India, major sources of urban air pollution include soil-derived aerosols, automobile emissions, industrial processes, biomass and coal burning (Pipalatkar et al. 2012). The effects of atmospheric aerosols upon human health are fundamentally depending on particle size (Mohanraj et al. 2011). The results of the long-term studies confirm that the adverse health effects are mainly due to atmospheric aerosols, especially small particles in aerodynamic diameter less than 10 μm (Klejnowski et al. 2012). Based on the Environmental Protection Agency (EPA) standards, the concentration of PM_{10} is regarded as an important criterion for determining the air quality index. PM_{10} is also one of the criterion pollutants in India and 24 h standard values prescribed by the NAAQS of India for PM_{10} is 100 μg/m^3 (CPCB 2009). Although, findings from various studies showed that the most of the Indian cities are highly polluted with airborne particulates and have concentrations that are well above the recommended limits of the NAAQS of India (Das et al. 2006; Deshmukh et al. 2010; Singh and Sharma 2011; Gupta et al. 2012). Several investigators have studied the mass and size distribution of atmospheric aerosols in Indian region (Mauli et al. 2006; Tiwari et al. 2009; Bhaskar et al. 2010; Deshmukh et al. 2012a; Pandey et al. 2012). However, there have been almost no studies to evaluate size distribution of size-segregated aerosols for Durg City, India. Therefore, the present study analyze the size distribution and seasonal variation of size-segregated aerosols in the ambient air of Durg City,

India, focusing mainly on the following objectives: (1) to evaluate the size distribution and seasonal variation of size-segregated aerosols in an urban area of Durg City, India; (2) establishing the baseline for PM_{10} mass concentration level, which could be used in the future to assess the effectiveness of any implemented emission control strategies; (3) comparing the observed PM_{10} concentration level to the corresponding NAAQS of India standard and other studies carried out in India and all over the world; (4) revealing the fraction of days that are unhealthy for the population based on air quality index values. It should be noted that such studies are lacking in the urban area of eastern central region of India and this is the first attempt that examines the size distribution and seasonal variation of size-segregated aerosols and air quality index over Durg City, India.

Durg City (Fig. 1) (20°23′–22°02′N, 80°46′–81°58′E, ~317 m above sea level), a rapidly growing industrial city with a population of ~0.6 million (Deshmukh et al. 2012b) is located in the eastern central region of India. There is a National Highway (NH–6) at a distance of 100 m from the sampling point having high volume of traffic; mostly consisting of diesel-powered buses and trucks, two-stroke motorcycles, and three-wheelers. Durg City and its surroundings are covered with different kinds of industries like steel plants, power plants, cement plants, and sponge iron industries, in a radius of only about 10–40 km (Deshmukh et al. 2011).

Materials and Methods

The collection of size-segregated aerosols was carried out between July 2009 and June 2010 on a roof of a double-storied building about 15 m above from the ground level in front of the Government College of Science by using the nine-stage cascade sampler (Model TE 20–800, USA; flow rate 28.3 liter per minute). The cascade sampler had aerodynamic size cuts of 9.0–10.0 μm (stage 0), 5.8–9.0 μm (stage 1), 4.4–5.8 μm (stage 2), 2.5–4.4 μm (stage 3), 2.1–2.5 μm (stage 4), 1.0–2.1 μm (stage 5); 0.7–1.0 μm (stage 6), 0.4–0.7 μm (stage 7) and 0.0–0.4 (stage 8). The limit of detection (LOD) for the filter substrate employing the nine-stage cascade impactor was calculated for all individual aerodynamic size range based on the estimation of 3 times the standard deviation for 12 measurements of mass value of field blanks. The LOD of impactor ranged between

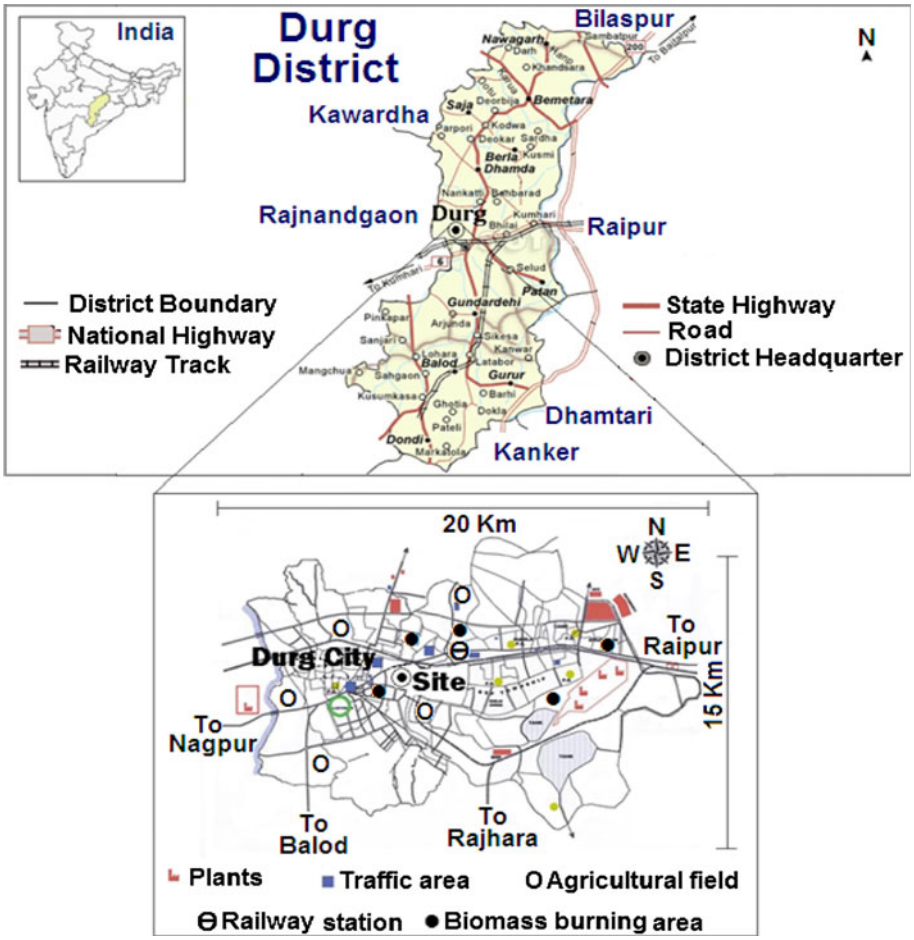

Fig. 1 Map of the study area showing the location of sampling site in Durg City, India

Table 1 The statistics of meteorological variables in Durg City, India between July 2009 and June 2010

Seasons	Temperature (°C) Mean ± SD[a] (Range)	Rainfall (mm) Mean ± SD[a] (Range)	Relative humidity (%) Mean ± SD[a] (Range)	Wind speed (m/s) Mean ± SD[a] (Range)	PWD[b]
Monsoon (n = 30)	25.8 ± 0.8 (21.6–30.8)	66.6 ± 95.2 (5.2–335.2)	83.0 ± 6.0 (58.0–96.0)	6.2 ± 3.2 (3.0–12.7)	SW, NE
Winter (n = 40)	19.0 ± 3.4 (5.8–30.5)	4.8 ± 12.5 (0.0–52.0)	67.0 ± 8.0 (22.0–95.0)	2.1 ± 1.3 (1.0–6.2)	NE
Spring (n = 20)	24.6 ± 3.8 (10.4–38.2)	1.1 ± 2.2 (0.0–6.8)	47.0 ± 10.0 (15.0–89.0)	3.4 ± 1.8 (1.4–6.6)	NE
Summer (n = 30)	31.5 ± 2.5 (19.7–42.4)	11.1 ± 19.1 (0.0–62.6)	42.0 ± 18.0 (11.0–86.0)	7.5 ± 1.8 (4.1–10.2)	SW, NW
Annual (n = 120)	26.4 ± 5.5 (5.8–42.4)	22.5 ± 54.7 (0.0–335.2)	64.0 ± 19.0 (11.0–96.0)	4.8 ± 3.1 (1.0–2.7)	SW, W

[a] Standard deviation, [b] Prevalent wind direction

Table 2 Descriptive statistics on concentrations (μg/m^3) of nine-size ranges of aerosols in Durg City, India from July 2009 to June 2010

Particle size[a]	Annual (n = 120) Mean ± SD[b] (Min., Max.)	Monsoon (n = 30) Mean ± SD[b] (Min., Max.)	Winter (n = 40) Mean ± SD[b] (Min., Max.)	Spring (n = 20) Mean ± SD[b] (Min., Max.)	Summer (n = 30) Mean ± SD[b] (Min., Max.)
9.0–10	24.7 ± 8.4 (10.2, 45.3)	18.6 ± 8.9 (10.2, 38.2)	29.8 ± 7.9 (18.6, 45.3)	24.8 ± 5.6 (19.9, 38.6)	23.8 ± 5.8 (11.0, 31.4)
5.8–9.0	30.8 ± 12.7 (10.4, 70.5)	21.2 ± 12.3 (10.4, 51.7)	35.6 ± 11.9 (22.1, 70.5)	33.4 ± 13.4 (18.2, 58.2)	32.0 ± 9.0 (18.1, 50.0)
4.4–5.8	24.8 ± 8.7 (10.2, 49.2)	20.2 ± 8.8 (10.2, 38.4)	29.0 ± 6.5 (21.0, 46.1)	30.1 ± 10.4 (20.7, 49.2)	20.3 ± 4.9 (11.8, 30.5)
2.5–4.4	38.4 ± 18.3 (11.0, 91.0)	24.1 ± 17.5 (11.0, 66.0)	46.7 ± 18.0 (30.7, 91.0)	41.7 ± 18.8 (29.2, 86.6)	38.9 ± 10.2 (26.4, 66.6)
2.1–2.5	35.4 ± 20.4 (8.8, 69.8)	19.9 ± 9.6 (11.2, 40.8)	56.6 ± 14.5 (25.0, 69.8)	32.0 ± 21.2 (11.2, 63.3)	25.0 ± 8.3 (8.8, 39.9)
1.0–2.1	34.9 ± 20.7 (9.2, 68.8)	18.7 ± 8.2 (10.6, 35.1)	57.1 ± 13.9 (24.8, 68.8)	35.9 ± 19.4 (11.8, 62.3	21.0 ± 5.9 (9.2, 27.5)
0.7–1.0	33.7 ± 19.5 (2.2, 68.1)	18.0 ± 9.4 (11.2, 43.6)	54.1 ± 12.0 (20.0, 68.1)	36.9 ± 17.2 (17.4, 58.2)	19.9 ± 7.7 (2.2, 26.6)
0.4–0.7	22.0 ± 17.9 (3.4, 66.6)	1.2 ± 7.4 (10.1, 38.3)	34.8 ± 12.3 (12.8, 66.6)	27.8 ± 19.1 (16.6, 62.1)	11.0 ± 6.5 (3.4, 27.6)
0.0–0.4	(9.2 ± 3.6) (2.9, 22.5)	6.2 ± 4.2 (3.3, 12.4)	12.4 ± 6.1 (6.6, 18.2)	11.4 ± 3.5 (4.3, 22.5)	6.6 ± 2.8 (2.9, 12.8)

[a] Unit in μm, [b] Standard deviation

0.5 and 2.0 μg/m^3 for the entire size range. Whatman 41 filters with diameters of 81 mm were used for collection of aerosols and the sampler was run continuous for 24 h. Aerosol samples were collected twice in a week during the study period. The mass concentrations for night-size ranges of aerosol particles were determined by gravimetric analysis. Before and after the sampling campaign, filters were kept for ~24 h in desiccators in an environmentally conditioned room with a relative humidity of 40 % and a temperature of 20°C and weighed by analytical balance (Sartorius, Model CP225D) with a reading precision of 10 μg. Field blanks (n = 24), i.e., filters brought to the field and installed in the sampler but through which no air was pumped, were also collected for later weight correction.

During the study period, meteorological parameters such as temperature (°C), rainfall (mm), relative humidity (%), wind speed (m/s) and wind direction (degree) were monitored (Table 1). The months of the year are combined into four major seasons, namely monsoon (July–September), winter (October–December), spring (February–March) and summer (April–June). The highest daily temperature was recorded as 42.4°C on May 24, 2010 and lowest was 5.8°C on January 3, 2010. April 11, 2010 was recognized as the driest week (RH 11 %) and August 24, 2009 was the most humid (RH 96 %). The highest daily wind speed was recorded as 12.7 m/s on July 19, 2009 and the lowest was 1.0 m/s on January 17, 2010. The highest daily rainfall was recorded as 335.2 mm on July 11, 2009. During the monsoon season, the winds are from the western regions surrounding India. During the winter and spring, the winds are from the northeast direction. During the summer period, the winds are from the southwest and northwest directions.

Results and Discussion

The statistical summary on mass concentrations of nine-size ranges of aerosols separated by cascade impactor sampler is given in Table 2. Out of the total aerosol mass, 54.6 % and 45.4 % of the aerosol mass were distributed in the fine size range (0.4–2.5 μm) and coarse size range (4.4–10.0 μm), respectively. During winter, large part of the aerosol mass was accounted for by the fine size fractions (60 %) than coarse size fraction (40 %), which may be due to the intense biomass burning activities and brick kiln emissions during this period. However, summer showed a different behavior, with large part of the aerosol mass having accounted for by the coarse size fraction (58.4 %) than the fine size fractions (41.6 %). Road dust resuspension may in fact have a significant influence on

aerosol levels in Durg City, India since there are more than 200,000 registered motor vehicles and traffic volume was about 2050–2120 vehicles per hour at a nearby highway. Therefore, the higher contribution of coarse mode particles during summer could be attributed to the presence of loose soil particles.

The seasonal size distribution of nine-size ranges of aerosol particles during the study period is shown in Fig. 2. The aerosol mass size distribution was bimodal with a peak at 2.5–4.4 μm size ranges in the coarse mode and 2.1–2.5 μm size ranges in the fine mode. Bimodal size distribution with a peak at 2.5–4.4 and 2.1–2.5 μm were mainly due to the prevalence of soil dust at Durg City, India. The four seasons had different distribution patterns of aerosol mass concentrations for the particle size ranges classified by the cascade sampler. Fig. 2 showed that the aerosol size distribution for monsoon period appears to unimodal trend corresponding to coarse mode (2.5–4.4 μm), while during winter, it showed a trimodal distribution, with all three peaks appearing in the fine mode (0.7–1.1, 1.1–2.1 and 2.1–2.5 μm). The size distribution of aerosol mass concentrations in spring showed a bimodal distribution. The major peak appeared in the coarse particle size mode (2.5–4.4 μm), with other peak showing in the fine mode (0.4–0.7 μm). Bimodal size distribution of aerosol particles was also observed in summer period with both peaks appearing in the coarse mode (2.5–4.4 μm and 5.8–9.0 μm). The difference in the meteorological conditions among the seasons could lead to the difference in size and mass distribution of aerosols. Dry atmospheric conditions may increase more aerosol concentrations over coarse particle size ranges during summer than those in spring and winter seasons. The peak existing in the fine mode, particularly from 0.4 to 0.7 μm, in spring season is possibly due to the combination effect of traffic engine emissions and industrial emissions such as combustion of fossil fuels.

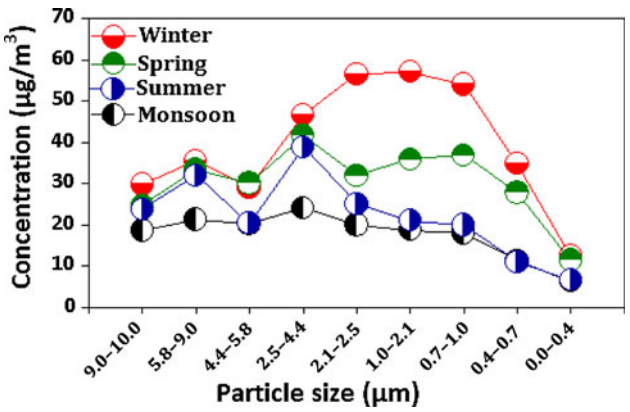

Fig. 2 Seasonal size distribution of nine-size ranges of aerosols separated by cascade impactor sampler in Durg City, India

The seasonal concentrations of nine-size ranges of aerosols are also given in Table 2. The highest aerosol mass levels for all the size ranges, except 4.4–5.8 μm, were observed during winter season. This could be due to the huge biomass burning activities especially during night time owing to the use of combustible goods like, fire wood, wooden blocks and cow dung cake as bonfire in the open space to keep warm in winter days. The high aerosol mass in winter is also due to the operation of a number of brick kilns, resulting in significant quantities of ashes in the atmosphere. Prevailing meteorology in Durg City during winter had also influenced the mass levels of aerosols. Lower inversion layer caused by the lower mixing height due to the high relative humidity, low temperature and low wind speed limits the dispersion of aerosol particles, which helped high aerosol mass loading during winter. One of the coarse sizes range, 4.4–5.8 μm, had the highest concentration during spring followed by winter and lowest during monsoon. The low concentrations of nine-size fractions of aerosols observed during monsoon was due to the higher precipitation in this season, which promoted the removal of aerosol particles from the atmosphere and reduced the concentrations of dust of the ground.

PM_{10} concentration was calculated by summing the concentration of all the nine-size ranges of aerosols classified by the nine-stage cascade sampler and the results are given in Table 3. The 24 h average PM_{10} concentration varied from 99.0 to 432.1 μg/m^3 with an average of 253.5 ± 99.4 μg/m^3. Annual mean PM_{10} concentration was significantly higher than the annual limit value of 60 μg/m^3 proposed by the CPCB, India (CPCB 2009). Concerning the 24 h limit value of 100 μg/m^3 for PM_{10} aerosols, 116 exceedances in 120 cases (96.7 %) were observed in Durg City, India. This high PM_{10} concentration in Durg City, India could be attributed to the local man-made sources like industrial and vehicular emissions adjacent to the sampling site. The higher PM_{10} concentrations in Durg City, India is also due to the use of biomass as domestic fuel that release a large amount of anthropogenic aerosols in the atmosphere.

The concentration of PM_{10} aerosols found in this study is compared with other studies carried out in the cities of India and all over the world. The data on comparison among the average concentrations of PM_{10} aerosols observed in this study with those at other sites in India and all over the world are presented in Table 4. The concentration of PM_{10} found in Durg City, India is higher as compared to that reported for Tirupati (Mauli et al. 2006), Delhi (Tiwari et al. 2009), Madurai (Bhaskar et al. 2010), Korba (Deshmukh et al. 2010), Bilaspur (Deshmukh et al. 2010), Agra (Singh and Sharma 2011), and Mumbai (Gupta et al. 2012) City, India but lower than those reported for Kolkata (Das et al. 2006) and Raipur City (Deshmukh et al.

Table 3 The statistics of concentration (μg/m^3) of PM_{10} aerosols in Durg City, India between July 2009 and June 2010

		Annual (n = 120)	Monsoon (n = 30)	Winter (n = 40)	Spring (n = 20)	Summer (n = 30)
PM_{10}	Mean ± SD[a]	253.5 ± 99.4	158.0 ± 79.2	356.1 ± 37.7	273.9 ± 79.6	198.5 ± 31.6
	Range	99.0–432.1	95.1–350.5	237.2–432.1	192.5–423.2	94.0–230.4

[a] Standard deviation

Table 4 Comparison of average mass concentration of PM_{10} aerosols in Durg City, India and different sites over the world

Area and place	Study period	PM_{10} concentration (μg/m^3)	References
Durg, India	Jul 2009–Jun 2010	253.5	This study
Kolkata, India	2001–2002	303.8	Das et al. (2006)
Tirupati, India	Oct 2001–Sep 2002	32.7	Mauli et al. (2006)
Delhi, India	Jan 2007–Dec 2007	219.0	Tiwari et al. (2009)
Madurai, India	Jul 2005–Jun 2006	152.2	Bhaskar et al. (2010)
Korba, India	Apr 2005–Mar 2006	231.0	Deshmukh et al. (2010)
Bilaspur, India	Apr 2005–Mar 2006	226.2	Deshmukh et al. (2010)
Raipur, India	Jul 2009–Jun 2010	270.5	Deshmukh et al. (2012a)
Agra, India	Mar 2007–Feb 2008	155.4	Singh and Sharma (2011)
Mumbai, India	Apr 2007–Mar 2008	230.9	Gupta et al. (2012)
Beijing, China	2002–2003	184.4	Sun et al. (2004)
Zongurdak, Turkey	2006–2007	44.1	Akyuz and Cabuk (2009)
Elche, Spain	Dec 2004–Nov 2005	34.3	Nicolas et al. (2009)
Athens, Greece	Jan 2005–Dec 2005	40.6	Pateraki et al. (2010)
Lahore, Pakistan	Jan 2007–Jan 2008	340.0	Stone et al. (2010)
Shenyang, China	Aug 2001–Aug 2005	188.1	Ni et al. (2012)
Anshan, China	Aug 2001–Aug 2005	159.4	Ni et al. (2012)
Huludao, China	Aug 2001–Aug 2005	275.4	Ni et al. (2012)

2012a), India. The concentration of PM_{10} observed in Durg City, India is higher as compared to that found in Beijing, China (Sun et al. 2004); Zongurdak, Turkey (Akyuz and Cabuk 2009); Elche, Spain (Nicolas et al. 2009); Athens, Greece (Pateraki et al. 2010); Shenyang, China (Ni et al. 2012), and Anshan, China (Ni et al. 2012); but lower than those reported for Lahore, Pakistan (Stone et al. 2010), and Huludao (Ni et al. 2012), China. The comparison of the concentration of PM_{10} aerosols found in Durg City, India with that of the above mentioned studies carried out in the cities of India and all over the world, it is concluded that, Durg City experiences much higher concentration of PM_{10} aerosols and this can be regarded as a real environmental problem that is continuously posing a serious risk to the quality of life.

To understand the seasonal variability of PM_{10} aerosols, seasonal concentrations have been calculated and the results are presented in Table 3. The PM_{10} concentration was highest during winter and spring followed by summer and lowest during monsoon. The highest level of PM_{10} in Durg City, India during winter was due to the huge agricultural practices and brick kiln emissions. During the winter season, heaps of solid waste comprising mostly of fallen leaves, garden cuttings, plastic bags and paper are set alight along road sides. A newly formed state "Chhattisgarh" with more than 600 rice mills is known as rice bowl of central India. Consequently, there is an intense agricultural work in and around Durg City with the main crop being rice and wheat. After crop harvesting the biomass residues are set on fire on the field to fertilize the land for the coming year. The reason for highest PM_{10} concentration in winter is also due to the massive biomass burning especially during night time in winter days. Peoples use combustible goods like, wooden blocks, fire wood, and cow dung cake as bonfire in the open space to keep themselves warm in winter season, resulting in significant quantities of ashes in the atmosphere. The high PM_{10} mass in winter is also due to the operation of a number of brick kilns approximately 10 km northeast to the sampling site, which utilize low quality coal, paddy husk and other combustible materials available at low cost. The

meteorological conditions prevailing at the study area also had the influence on the higher PM_{10} concentration during winter, and lower concentrations in summer and monsoon. The high relative humidity (95 %, October–January), low temperature (5.8°C, January) and relatively calm wind speed (~1.0 m/s, October) helped high aerosol mass in winter (October–January) and spring (February–March) months due to the lower inversion layer caused by low mixing height that limits dispersion of aerosol particles. High temperature (~42°C, April–June), low relative humidity (11 %, April), frequent changes in wind speed (4.1–10.2 m/s, April–June) and direction increased the atmospheric turbulence during summer months, thereby increasing the dispersion of atmospheric particles. Low concentration during monsoon months (July–September) could be due to the wash-out effect of precipitation (5.2–335.2 mm, July–September) which led to reduction in suspension of crustal particles. Previous studies also indicated higher PM_{10} concentration during winter and lower during monsoon (Tiwari et al. 2009; Bhaskar et al. 2010; Singh and Sharma 2011).

Air pollution indices are commonly used in order to define the level of impact of air pollution on human health (Deshmukh et al. 2012a). As a consequence, the air quality index (AQI) is a powerful precautionary tool to ensure public health protection. The AQI varies from 0 to 500 divided into six categories and its health indicators are mentioned in Table 5. The higher the AQI value, the greater the level of air pollution and the greater are the health concerns. Based on the technological rules related to AQI, the following formula was used to derive the AQI from PM_{10} concentration.

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \quad (1)$$

Where I is the (Air Quality) sub-index, C is the pollutant concentration, I_{low} and I_{high} are the index breakpoint corresponding to C_{low} and C_{high}, respectively, and C_{low} and C_{high} are the concentration breakpoint that are ≤C or ≥C.

Air pollution standards as defined by the USEPA specified that AQI values can be higher than 100 on only 1 day of the year. It was found that AQI values exceeded 100 on 94 days out of 120 (78.3 %) in Durg City, India. As shown in Table 5, 42 days (35 %) were regarded as unhealthy for sensitive group, 48 days (40 %) were unhealthy or very unhealthy, and 4 days (3.3 %) were hazardous. On the basis of the rating scale given in Table 5, it is found that the atmospheric environment of Durg City, India is polluted from moderate to hazardous levels. This indicates an urgent need for systematic control of atmospheric pollutants from anthropogenic sources especially the particulate pollutants to safeguard the human population, flora, and fauna as well as social assets such as cultural sites in Durg City, India.

Monthly and seasonal average AQI values over Durg City, India between July 2009 and June 2010 is given in Table 6. High AQI values were estimated mostly during winter and spring, and low in summer and monsoon. The highest AQI values observed in winter and spring can be attributed to the higher rate of anthropogenic activities and prevailing meteorological conditions. Precipitation and high wind velocity is a major reason for low AQI values in monsoon and summer seasons.

Acknowledgment The authors would like to thank Head, School of Studies in Chemistry, Pt. Ravishankar Shukla University, Raipur, India for providing laboratory support to carry out this work.

Table 5 Determination of health quality with air quality index value and level of health concerns in Durg City, India between July 2009 and June 2010

S. no.	PM_{10} (μg/m^3)	Air quality index	Days	Percent	Health quality
1	0–54	0–50	0	0.0	Good
2	55–154	51–100	26	21.7	Moderate
3	155–254	101–150	42	35.0	Unhealthy for sensitive people
4	255–354	151–200	30	25.0	Unhealthy
5	355–424	201–300	18	15.0	Very unhealthy
6	≥425	301–500	4	3.3	Hazardous

Table 6 The annual and seasonal statistics of AQI values in Durg City, India between July 2009 and June 2010

		Annual (n = 120)	Monsoon (n = 30)	Winter (n = 40)	Spring (n = 20)	Summer (n = 30)
AQI	Mean ± SD[a]	155 ± 59	102 ± 40	213 ± 35	167 ± 55	122 ± 16
	Range	71–199	142–310	120–299	70–138	70–310

AQI air quality index

[a] Standard deviation

References

Akyuz M, Cabuk H (2009) Meteorological variations of $PM_{2.5}$/PM_{10} concentrations and particle-associated polycyclic aromatic hydrocarbons in the atmospheric environment of Zonguldak Turkey. J Hazard Mater 170:13–21

Bhaskar BV, Rajasekhar RJV, Muthusubramanian P, Kesarkar AP (2010) Ionic and heavy metal composition of respirable particulate in Madurai, India. Environ Monit Assess 164:323–336

CPCB (2009) Central Pollution Control Board, India. National Ambient Air Quality Standards (NAAQS). Gazette notification, New Delhi, 18 November 2009

Das M, Maiti SK, Mukhopadhyay U (2006) Distribution of $PM_{2.5}$ and $PM_{10-2.5}$ in PM_{10} fractions in ambient air due to vehicular pollution in Kolkata megacity. Environ Monit Assess 122:111–123

Deshmukh DK, Deb MK, Verma SK (2010) Distribution patters of coarse, fine and ultrafine atmospheric aerosol particulate matters in major cities of Chhattisgarh. Indian J Environ Prot 30:184–197

Deshmukh DK, Deb MK, Tsai YI, Mkoma SL (2011) Water soluble ions in $PM_{2.5}$ and PM_1 aerosols in Durg city, Chhattisgarh, India. Aerosol Air Qual Res 11:696–708

Deshmukh DK, Deb MK, Mkoma SL (2012a) Size distribution and seasonal variation of size-segregated particulate matter in the ambient air of Raipur city, India. Air Qual Atmos Health. doi: 10.1007/s11869-011-0169-9

Deshmukh DK, Tsai YI, Deb MK, Zarmpas P (2012b) Characteristics and sources of water-soluble ionic species associated with PM_{10} particles in the ambient air of central India. Bull Environ Contam Toxicol. doi:10.1007/s00128-012-0806-5

Gupta I, Salunkhe A, Kumar R (2012) Source apportionment of PM_{10} by positive matrix factorization in urban area of Mumbai, India. Sci World J. doi:10.1100/2012/585791

Klejnowski K, Pastuszka JS, Kozłowska WR, Talik E, Krasa A (2012) Mass size distribution and chemical composition of the surface layer of summer and winter airborne particles in Zabrze, Poland. Bull Environ Contam Toxicol 88:255–259

Mauli PC, Mohan SV, Reddy J (2006) Chemical composition of atmospheric aerosols (PM_{10}) at a semi-arid urban site: influence of terrestrial sources. Environ Monit Assess 117:291–305

Mohanraj R, Solaraj G, Dhanakumar S (2011) $PM_{2.5}$ and PAH concentrations in urban atmosphere of Tiruchirappalli, India. Bull Environ Contam Toxicol 87:330–335

Ni T, Han B, Bai Z (2012) Source apportionment of PM_{10} in four cities of northeastern Chine. Aerosol Air Qual Res. doi: 10.4209/aaqr.2011.12.0243

Nicolas JF, Galindo N, Yubero E, Pastor C, Esclapez R, Crespo J (2009) Aerosol inorganic ions in a semiarid region on the southeastern Spanish Mediterranean coast. Water Air Soil Pollut 201:149–159

Pandey P, Khan AH, Verma AK, Singh KN, Mathur N, Barman SC (2012) Seasonal trends of $PM_{2.5}$ and PM_{10} in ambient air and their correlation in ambient air of Lucknow city, India. Bull Environ Contam Toxicol 88:265–270

Pateraki S, Asimakopoulos DN, Maggos Th, Vasilakos Ch (2010) Particulate matter levels in a suburban Mediterranean area: analysis of a 53-months long experimental campaign. J Hazard Mater 182:801–811

Pipalatkar PP, Gajghate DG, Khaparde VV (2012) Source identification of different size fraction of PM_{10} using factor analysis at residential cum commercial area of Nagpur city. Bull Environ Contam Toxicol 88:260–264

Singh R, Sharma B (2011) Composition, seasonal variation, and sources of PM_{10} from world heritage site Taj Mahal, Agra. Environ Monit Assess, doi:10.1007/s10661-011-2392-0

Stone E, Schauer J, Quraishi TA, Mahmood A (2010) Chemical characterization and source apportionment of fine and coarse particulate matter in Lahore, Pakistan. Atmos Environ 44:1062–1070

Sun Y, Zhuang G, Wang Y, Han L, Guo J, Dan M, Zhang W, Wang Z, Hao Z (2004) The air-borne particulate pollution in Beijing—concentration, composition, distribution and sources. Atmos Environ 38:5991–6004

Tiwari S, Srivastava AK, Bisht DS, Bano T, Singh S, Behura S, Srivastava MK, Chate DM, Padmanabhamurty B (2009) Black carbon and chemical characteristics of PM_{10} and $PM_{2.5}$ at an urban site of North India. J Atmos Chem 62:193–209