Bull Environ Contam Toxicol (2012) 88:717–721
DOI 10.1007/s00128-011-0518-2

Particle Size Distribution of Ambient Aerosols in an Industrial Area

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Received: 25 August 2011 / Accepted: 28 December 2011 / Published online: 4 February 2012

Abstract Aerosol samples of PM_{10} and $PM_{2.5}$ were collected from 38 sampling locations in and around the industrial area. The 24 h average mass concentration of PM_{10} and $PM_{2.5}$ was 137.5 and 61.5 µg/m^3 respectively during summer, 122 and 97.5 µg/m^3 respectively in winter and 70 and 54 µg/m^3 respectively during post monsoon season. The relative contribution of coarse, fine and ultrafine particle to ambient air was analyzed for its temporal and seasonal variability in an industrialized area. This paper aims to establish baseline between PM_{10} and $PM_{2.5}$ mass concentration levels.

Keywords Ambient aerosol · Industrial area · Size fractions · $PM_{2.5}/PM_{10}$ ratio

Various researchers have identified particulates among the air pollutants for adverse health effect, because of its strongest association with daily mortality rate. The relative strength of association of air pollutants with mortality were reported as follows: $PM_{2.5} \geq PM_{10} \geq SO_2 \geq H^+ \geq O_3 \geq$ NOx (Dockery et al. 1992). Dockery and Pope (1994) reported that for each 10 µg/m^3 increase in concentration of particulate matter (PM) less than 10 µm in diameter, there is an estimate of increase in mortality of 0.6%–1.6% with an average increase of 1% (Ostro1996). The health impacts of finest particulate $PM_{2.5}$ is greater because it can penetrate deep into unciliated and alveolar sections of the lung were well reported in (Spengler et al. 1990). Many scientists, policy analysts, and governmental agencies in the US and Europe believe that current concentrations of pollution-derived particulate matter (PM) in ambient (outdoor) air are deadly causing thousands of premature deaths annually, (Colburn and Johnson 2003; Dockery et al. 1993; Dominici et al. 2003; Kjellstrom et al. 2002; Pope et al. 2002; Samet et al. 2000; Schwartz 1991).

In India, there was AAQ standard for criteria pollutants including SPM and PM_{10} up till Dec-2009. Recently the new NAQM standard has incorporated $PM_{2.5}$ along with 11 more pollutants as criteria pollutants. In view of this, very limited data is available on fine/ultrafine toxicity of dust and other pollutants. This demands an urgent need for study on the ratio of $PM_{2.5}/PM_{10}$ in ambient air so that regional as well as global comprehensive inventory based air quality management may be delineated. The state of Orissa with its abundant resources has been an important player in the Indian economy. This has led to the development of many industries in various regions of it. The north-western part of it has shown incredible growth in industries since last decade (mostly air polluting type). The region has extensive mining and trading activities along with number of sponge iron, thermal power plants, aluminum smelters spread in an area of 30 sq. km. All these have led to huge air pollution impact in this area. In an effort to address this issue, monitoring and analysis of fine particles ($PM_{2.5}$ and PM_{10}) was conducted during the year 2010–2011 for different seasons. In this work, the relative contribution of very fine ($PM_{2.5}$) to inhalable ambient particulate matter PM_{10} was analyzed to examine their relationship.

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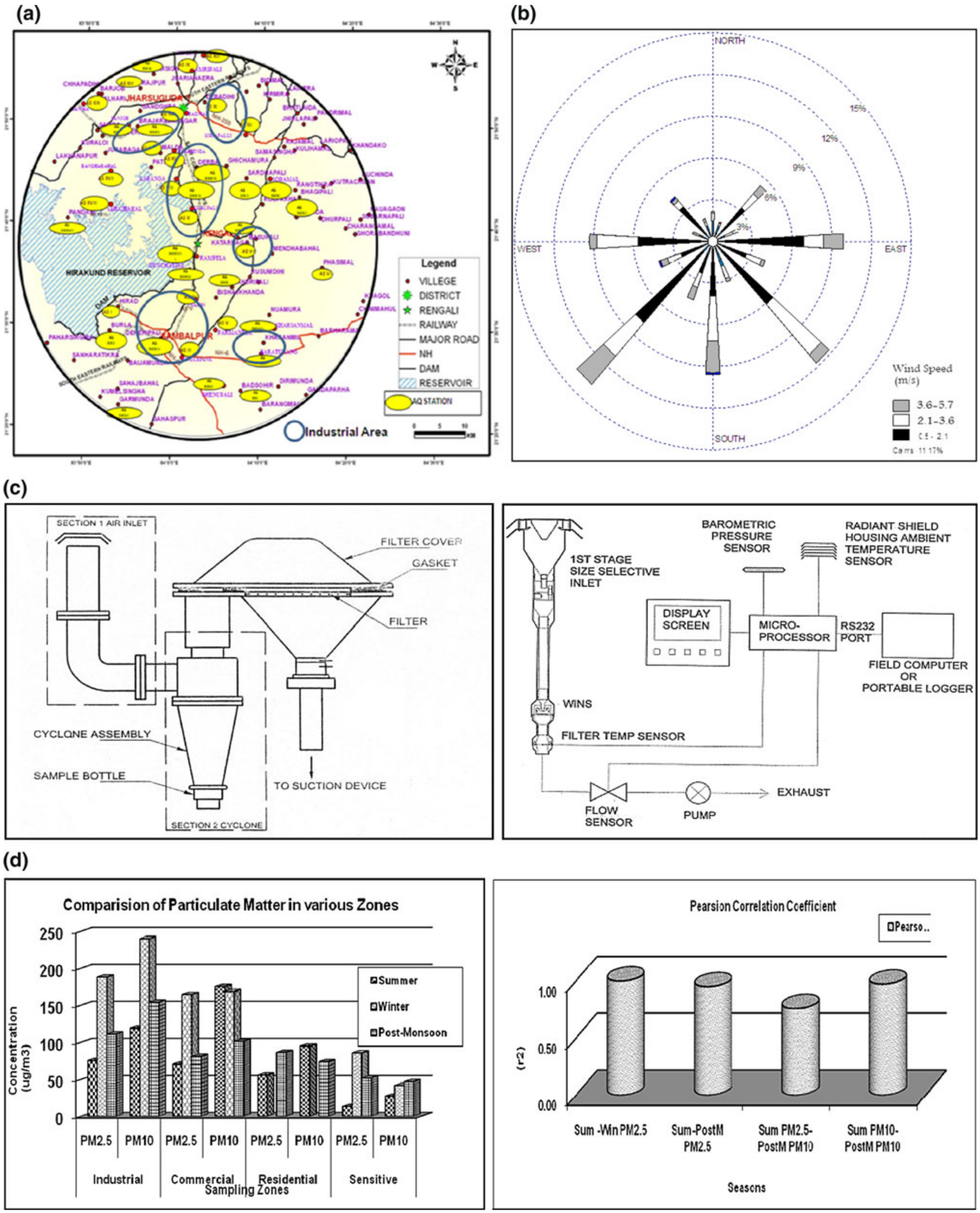

Fig. 1 Description of study area, meteorology, methods and results of particulate distribution in ambient air. **a** Location of sampling station. **b** Annual wind rose: study area. **c**. Schematic diagram of samplers for PM measurement. **d** Seasonal and temporal variation of particulate fractions

Table 1 Results of PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$ mass concentrations, $PM_{2.5}/PM_{10}$ ratio for summer, winter and post-monsoon

Sampling sites	Summer				Winter				Post monsoon			
	$PM_{2.5}$	PM_{10}	PM_{10}–$PM_{2.5}$	$PM_{2.5}$/PM_{10}	$PM_{2.5}$	PM_{10}	PM_{10}–$PM_{2.5}$	$PM_{2.5}$/PM_{10}	$PM_{2.5}$	PM_{10}	PM_{10}–$PM_{2.5}$	$PM_{2.5}$/PM_{10}
Hirakud (industrial)	28	180	152	0.1	97	16	70	0.5	43	92	49	0.47
Malda (industrial)	373	196	–	1.9	13	64	–	2.1	58	99	41	0.59
Sason (industrial)	ND	ND	ND	ND	11	11	–	1.0	ND	ND	ND	ND
Katarbaga (industrial)	ND	ND	ND	ND	63	10	46	0.5	ND	ND	ND	ND
Lapanga (industrial)	ND	ND	ND	ND	12	13	9	0.9	64	77	13	0.83
Amripalli (industrial)	ND	ND	ND	ND	87	17	92	0.4	63	87	24	0.72
Gurupali (industrial)	ND	ND	ND	ND	16	18	14	0.9	ND	ND	ND	ND
Debadihi (industrial)	33	63	30	0.5	95	14	45	0.6	48	79	31	0.61
Siriapalli (industrial)	ND	ND	ND	ND	96	96	0	1.0	ND	ND	ND	ND
Jharsuguda (industrial)	ND	ND	ND	ND	42	98	56	0.4	ND	ND	ND	ND
Rajpur (industrial)	ND	ND	ND	ND	12	11	–	1.0	ND	ND	ND	ND
Nuakhinda (industrial)	ND	ND	ND	ND	18	13	–	1.3	ND	ND	ND	ND
Badmal (industrial)	ND	ND	ND	ND	61	76	15	0.8	ND	ND	ND	ND
Bandhabahal (industrial)	ND	ND	ND	ND	11	17	57	0.6	84	126	42	0.67
Sahajbahal (industrial)	36	66	30	0.5	44	11	74	0.3	ND	ND	ND	ND
Kanika (industrial)	ND	ND	ND	ND	71	94	23	0.7	ND	ND	ND	ND
Sanjob (industrial)	ND	ND	ND	ND	77	16	92	0.4	ND	ND	ND	ND
Sardhapalli (industrial)	15	155	140	0.1	ND	ND	ND	ND	ND	ND	ND	ND
Rengali (industrial)	38	61	23	0.6	ND	ND	ND	ND	61	72	11	0.85
Rampela (industrial)	ND	ND	ND	ND	ND	ND	ND	ND	94	53	–	1.77
Brajrajnagar (industrial)	33	154	121	0.2	ND	ND	ND	ND	79	115	36	0.69
Derba (industrial)	82	98	16	0.8	ND	ND	ND	ND	20	48	28	0.42
Burla (commercial)	ND	ND	ND	ND	ND	ND	ND	ND	71	78	7	0.91
Sambalpur (commercial)	56	95	39	0.5	ND	ND	ND	ND	59	33	–	1.79
Gunchamal (residential)	ND	ND	ND	ND	ND	ND	ND	ND	58	46	–	1.26
Pandripalli (residential)	35	136	101	0.2	ND	ND	ND	ND	59	70	11	0.84
Kharsanmal (residential)	ND	ND	ND	ND	ND	ND	ND	ND	26	55	29	0.47
Badsohir (residential)	22	54	32	0.4	ND	ND	ND	ND	ND	ND	ND	ND
Barturang (residential)	80	219	139	0.3	ND	ND	ND	ND	ND	ND	ND	ND
Garmunda (residential)	ND	ND	ND	ND	ND	ND	ND	ND	53	78	25	0.68
Ghenupali (residential)	ND	ND	ND	ND	ND	ND	ND	ND	48	55	7	0.87
Loisign (residential)	17	422	405	0.0	ND	ND	ND	ND	ND	ND	ND	ND
Parmanpur (residential)	ND	ND	ND	ND	75	18	11	0.4	ND	ND	ND	ND
Sindurpank (residential)	ND	ND	ND	ND	90	68	–	1.3	ND	ND	ND	ND
Pandari (sensitive)	14	27	13	0.5	ND	ND	ND	ND	68	71	3	0.96
Sodamal (sensitive)	ND	ND	ND	ND	ND	ND	ND	ND	21	35	14	0.60
Bhagipali (sensitive)	ND	ND	ND	ND	ND	ND	ND	ND	15	35	20	0.43
Phasimal (sensitive)	ND	ND	ND	ND	86	42	–	2.0	ND	ND	ND	ND
Average	61.57	137	76.0	0.51	97	12	25	0.90	54	70	15.60	0.82

ND not detected

– Values of $PM_{2.5}$ were much higher than PM_{10} due to industries in the vicinity

Materials and Methods

The study region comprises an area of around 30 sq. km from Rengali, It consists of many industries, mines and sponge iron Fig. 1a units on North and South direction, while on eastern side, there is Hirakud Dam and other water bodies and on the western side, there are reserve forests and agricultural fields. About 38 sampling site

Table 2 Results of temporal and spatial variation of PM_{10}, $PM_{2.5}$, $PM_{10-2.5}$ mass concentrations and $PM_{2.5}/PM_{10}$ ratio

Sampling sites	Pollutants	N	Minimum	Maximum	Mean ± SD	Seasons		
						Summer	Winter	Post monsoon
Hirakud	PM_{10}	25	92	180	136 ± 62	180	167	92
	$PM_{2.5}$	25	28	97	62.5 ± 48	28	97	43
	$PM_{2.5}/PM_{10}$		0.15	0.58	0.37 ± 0.30	0.15	0.58	0.46
Debadihi	PM_{10}	25	63	140	101.5 ± 54	63	140	79
	$PM_{2.5}$	25	33	95	64 ± 43	33	95	48
	$PM_{2.5}/PM_{10}$		0.5	0.67	0.60 ± 0.10	0.52	0.67	0.60
Malda	PM_{10}	25	64	196	130±93.3	196	64	99
	$PM_{2.5}$	25	58	373	215.5 ± 222	373	137	58
	$PM_{2.5}/PM_{10}$		0.58	2.14	1.36 ± 1.0	1.90	2.14	0.58

spread in an area of around 30 sq. km were monitored on 24 hourly bases twice a week for 4 months comprising all the seasons of the year 2010–2011. These sites were selected on the basis of land use pattern and meteorology of the region. It represents mostly industrial areas which are highly affected due to particulates generated from various industrial activities. The micrometeorology was studied and wind rose diagram is shown in Fig. 1b.

PM_{10} were sampled on Whatman make glass fiber filter paper GR-A (200 × 250 mm^2) by using RDS (Model APM 46 0 NL of M/s Envirotech at flow rate 1.2 m^3/min) following the CPCB Guidelines for PM sampling, whereas $PM_{2.5}$ was sampled on PTFE filter paper by using Partisol Federal Reference Method Partisol-2000 R&P at flow rate of 16.7 L/min). Design of the size selective inlet for $PM_{2.5}$ follow the standard rules as laid down by USEPA (1997), cyclone inlet (Rupprecht & Patashnick Co.) was used. Glass fiber filters were equilibrated for 24 h in desiccators before and after collection of samples and then weighted on Electronic Microbalance. PM_{10} and $PM_{2.5}$ samples were collected for 24 h simultaneously at 38 different industrial sites at Orissa. Schematic diagram for both PM_{10} and $PM_{2.5}$ sampler has been shown in Fig. 1c.

Results and Discussion

In order to study, the seasonal and temporal variation of the ultrafine particulates, the statistics of ambient $PM_{2.5}$ and PM_{10} data were analyzed and has been given in Table 1 and Fig. 1d. Windrose plot shows predominant wind direction during summer, post monsoon and winter as SE, SW and WS respectively. It was observed that during sampling time, RH% was higher during winter and post monsoon (average RH are 85% and 87%). With lower RH (45%) coarse particle concentration was higher (SPM and PM_{10}). Measured concentrations were compared with National Ambient Air Quality Standard NAAQS, CPCB, 2009. The average concentration of PM_{10} was found maximum in summer i.e. 137.5 μg/m^3 than in winter 122.80. Both were above standard but in case of post-monsoon, it was below standard i.e. 70.2 μg/m^3 may be due to washout is given in Table 1.

While PM_{10}–$PM_{2.5}$ which represent intermediate mass fraction of PM_{10} and $PM_{2.5}$ were found as 25.30 and 15.60 μg/m^3 for winter and post monsoon respectively. Average ratio of $PM_{2.5}/PM_{10}$ in summer, winter and post monsoon was 0.51, 0.90 and 0.82 respectively Table 1.

The spatial/temporal variation of particulate fraction was undertaken. $PM_{2.5}/PM_{10}$ mean ratio at Malda, Debadihi and Hirakud were 2.1, 0.67 and 0.58 respectively. Considering whole range of measured values, $PM_{2.5}$ generally made up to 60%–70% of PM_{10}. The $PM_{2.5}/PM_{10}$ mean ratio was higher at Malda (1.36 ± 1.0) than at Debadihi (0.60 ± 0.1) and was minimum at Hirakud (0.37 ± 0.30) that have been shown in Table 2. PM_{10} and $PM_{2.5}$ were found maximum in industrial zone due to thermal power plant and sponge iron industries than in commercial area where vehicular and domestic emission plays an important role and were likewise found minimum in sensitive zone comprising of vegetation and forests. The summer correlation for the coarser particle fractions was about the same (except R^2 between $PM_{2.5}$ and PM_{10}) while in post monsoon and winter again local sources remained dominant for the fine particulate matter. Generally, the higher correlation values were observed during summer season because of the higher content of fine fractions of PM in the total particulate mass concentration. The Pearson Coefficient for Summer–Winter $PM_{2.5}$, Summer–Post Monsoon $PM_{2.5}$, Summer $PM_{2.5}$–Post Monsoon PM_{10} and Summer PM_{10}–Post Monsoon PM_{10} were 0.99, 0.94, 0.97 and 0.99 respectively which are nearly agreeable, indicating similar activities and micro-meteorology has been shown in Fig. 1d.

Acknowledgments The authors are grateful to Director, National Environmental Engineering Research Institute, Nehru Marg, Nagpur-440020, India, for providing encouragement and facilities to carry out this work and for permission to publish these finding. The authors also express their deep gratitude to Odissha State Pollution Control Board, Sambalpur, Odissha for providing information and technical assistance in carrying out the detailed air quality study in the region.

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