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Amit Awasthi, Ravinder Agarwal, Susheel K. Mittal, Nirankar Singh ...+2 more authors

Institutions: Thapar University, National Physical Laboratory

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PAPER

Study of size and mass distribution of particulate matter due to crop residue burning with seasonal variation in rural area of Punjab, India

Amit Awasthi,[a] Ravinder Agarwal,[a] Susheel K. Mittal,*[a] Nirankar Singh,[a] Khem Singh[b] and Prabhat K. Gupta[b]

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Emission from field burning of agricultural crop residue is a common environmental hazard observed in northern India. It has a significant potential health risk for the rural population due to respirable suspended particulate matter (RSPM). A study on eight stage size segregated mass distribution of RSPM was done for 2 wheat and 3 rice crop seasons. The study was undertaken at rural and agricultural sites of Patiala (India) where the RSPM levels remained close to the National Ambient Air quality standards (NAAQS). Fine particulate matter ($PM_{2.5}$) contributed almost 55% to 64% of the RSPM, showing that, in general, the smaller particles dominated during the whole study period with more contribution during the rice crop as compared to that of wheat crop residue burning. Fine particulate matter content in the total RSPM increased with decrease in temperature. Concentration levels of PM_{10} and $PM_{2.5}$ were higher during the winter months as compared to that in the summer months. Background concentration levels of PM_{10}, $PM_{2.5}$ and $PM_{10-2.5}$ were found to be around 97±21, 57±15 and 40±6 μg m^{-3}, respectively. The levels increased up to 66, 78 and 71% during rice season and 51, 43 and 61% during wheat crop residue burning, respectively. Extensive statistical analysis of the data was done by using pair t-test. Overall results show that the concentration levels of different size particulate matter are greatly affected by agricultural crop residue burning but the total distribution of the particulate matter remains almost constant.

Introduction

Agriculture crop residue burning (ACRB) is a widespread practice, especially in the developing countries like India. Burning of crop residue has been an agricultural practice for many years due to many reasons such as: it is the cheapest mode of disposal, less time consuming and less laborious to prepare the land for further farming. It reduces the ambient air quality by producing huge amounts of aerosols in the form of particulate matter and gases into the atmosphere.[1–6] Particulate matter is an air pollutant consisting of a mixture of particles that can be solid, liquid or both, suspended in the air for long time. Along with chemical and metal characterisation of particulate matter,[7–11] particle size is regarded as one of the important physical characteristics.[12–15] The emitted particles have a certain falling velocity (depending on size of particles) due to the downward acting force of gravity, which is opposed by aerodynamic drag of the atmosphere. The balance between these forces is readily attained and particles remain suspended in the air for long time.[16] Hence, the smaller the size of the particles, the greater the residence/residing time. Suspended particulate matter (SPM) is the particulate having its particle's aerodynamic size varying from 0 to 100 μm. PM_{10} represents the particles with an aerodynamic diameter of 10 μm or less, or, more strictly, particles which pass through a size selective inlet with a 50% efficiency cut-off at 10 μm aerodynamic diameter.[17] PM_{10} is also called the respirable

[a]*Thapar University, Patiala, 147004, Punjab, India. E-mail: smittal@thapar.edu; Fax: +91-175-2364498; Tel: +91-175-2393128*

[b]*National Physical Laboratory, New Delhi, 110 012, India*

Environmental impact

An in depth study on the distribution of respirable particulate matter generated during crop residue burning is discussed. Due to the differences in the composition and magnitude of the fine particulate matter generated from two different crops of wheat and rice, the distribution of particulates is different. During crop residue burning practices, often rice harvesting releases more $PM_{2.5}$ as compared to PM_{10}. This is the first report of its kind where particle size distribution after crop residue burning is compared for two major food crops in northern India. Moreover, size distribution is in favour of $PM_{2.5}$ than PM_{10} during months of crop residue burning practices as compared to non-crop residue burning periods.

suspended particulate matter (RSPM) as they are able to reach inside the respiratory tract. In an analysis reported in 1979, EPA scientists endorsed the need to measure fine and coarse particles, separately.[18] Based on the availability of a dichotomous sampler with a separation size of 2.5 μm, they recommended 2.5 μm as the cutoff point between fine and coarse particles. Because of the wide use of this cutoff point, the $PM_{2.5}$ fraction is frequently referred to as "fine" particles.[19] $PM_{10-2.5}$ represents the particles with an aerodynamic diameter between 10 and 2.5 μm, called the coarse fraction of PM_{10}. The health impacts of the finest particulate $PM_{2.5}$ is greater because it can penetrate deep into alveolar sections of lung.[20,21] Particulate matter from the open field burning of agricultural waste has an adverse impact on visibility, human health, and regional air quality.[22] The most conclusive evidence has been provided by cohort and time series studies that have linked elevated concentrations of PM to increased morbidity and mortality.[23–26]

Assessment of PM_{10} and $PM_{2.5}$ concentrations, as well as their share of total PM concentration, assumes significance from environmental and health perspectives. Although industrialization and the use of motor vehicles are overwhelmingly the most significant contributors to air pollution, biomass or crop residue burning also plays an important role in air pollution.[1,12,21,27,28] The exhaustive burning period of rice and wheat crop residues usually starts in the first or second week of October and April, respectively, and lasts over four weeks. A recently published paper by Mittal *et al.*[2] studied the contribution of ACRB on the concentration of SPM, sulfur oxide and nitrogen dioxide. The studies showed that RSPM has more adverse effects,[1] as RSPM alone or along with deposition, as gases enter deep inside the lungs in the alveoli region which creates hazardous effects on the lungs, heart and blood circulation. Hence, the study of RSPM is of great importance. In northern parts of India like Punjab and Uttar Pradesh, emission from field burning of agriculture crop residues is a common environmental hazard.[1,3] In the present study, the effects of rice and wheat crop residue burning on the concentration level of RSPM and their size segregation has been carried out.

Material and methods

Study design

Sidhuwal village in Patiala district of Punjab, India was considered for the measurement of particulate matter. It is a rural/agricultural area located between 30°21′ N and 76°27′ E (Fig. 1).

Measurements of mass-size distribution of aerosols have been carried out by using Anderson-1-CFM Ambient Sampler. The Anderson sampler was placed 3 meters above ground level on the roof of a school building in Sidhuwal village, located 6 km North-West (NW) of Patiala city. In order to obtain a representative sample, the sampler was positioned in such a way where there were no obstructions, like high buildings or walls, that might prevent free air flow. The site was surrounded by areas almost exclusively devoted to agriculture and has minimal traffic density. There was no heavy or small industries within a 10 km radius and the national highway was beyond the 10 km circumference from the selected position of the Anderson Sampler. The instrument was placed after considering the general trend of wind direction (NW).

Fig. 1 Location of study site in Punjab (India).

Mechanism of collection

The Anderson sampler is an eight staged (0, 1, 2 …7 and F, filter holder), multi-jet, multi-stage instrument, that are held together by three spring clamps and gascated with "O" ring seals, which separates particulates of diameter ranging from 10 μm and above down to 0.4 μm into nine ranges. When air is drawn in through the sampler, particles are driven towards a collecting surface. By varying the velocity (orifice size of the jet), the size of particles collected in each stage is controlled. The range of particle size collected on each stage of the instrument depends on the jet velocity of the current stage and the cut off range of the previous stage. The size of the jet is constant for each stage but for each succeeding stage, the jet gets smaller. Impaction occurs when the particle's inertia overcome the aerodynamic drag. Otherwise, the particle remains in the air stream and is passed on to the next stage through the edge and so on. The number of orifice in each stage, diameter of each orifice, effective cut diameter (ECD) of each stage and range of particles size collected in each stage are shown in Table 1.

Study period and measurements

Aerosol sampling was done for 2.5 years from August 2007 to January 2010. The study included a total of 65 samples, of which 25 were collected during 10 burning months of wheat and rice crop residues and the remaining 40 samples were collected during the 20 non-burning months during the study period of 2.5 years. Each sampling was done continually for 72 h, twice a month in non-burning months and once a week during burning months, using the Anderson sampler at a flow rate of 28 l min^{-1}. Aerosol samples were taken on pre-fired (≥ 2 h at 500 °C), pre-desiccated and pre-weighed Whatman-quartz fibers filters (QM-A). Exposed filters were removed and dried in desiccators for 24 h and then re-weighed. From the weight differences and airflow rate, the mass as well as concentration of aerosols in ambient air were measured by prescribed standard methods.[29] For each

Table 1 Characteristics of different stages of Anderson Sampler

Stages in Impactor	Orifice diameter (inches)	Number of orifices	Particle range collected (μm)	Effective cut diameter (μm)
0	0.1004	96	> 9.0	9.0
1	0.0743	96	5.8–9.0	5.8
2	0.0360	400	4.7–5.8	4.7
3	0.0280	400	3.3–4.7	3.3
4	0.0210	400	2.1–3.3	2.1
5	0.0135	400	1.1–2.1	1.1
6	0.0100	400	0.7–1.1	0.7
7	0.0100	201	0.4–0.7	0.4
F	0.1100	Filter holder	0.0–0.4	0

sample, PM_{10} was quantified into nine-different size ranges based on effective cut diameter (ECD, in μm). Each stage of the Anderson sampler gives the concentration of the specific range of particle size (Table 1). To find the exact segregation of fine and coarse fractions in total respirable particulate matter, $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} were measured. PM_{10} for one sample was calculated by adding the concentration of particulate matter in all nine ranges. Since, there was no stage in the Anderson sampler with an ECD of 2.5μm (Table 1), $PM_{2.5}$ was not calculated directly, but by the addition of different stage particulate matter concentrations. $PM_{2.5}$ fractions for each sample were calculated by plotting the log (ECD) versus cumulative mass concentration less than the stated size.[30,31] Cumulative mass concentration corresponding to the log 2.5 gave the concentration of $PM_{2.5}$ for that particular sample. $PM_{10-2.5}$ was calculated by subtracting the value of $PM_{2.5}$ from PM_{10}. Along with particulate measurements, wind direction (WD) and speed, relative humidity (RH) and temperature were also recorded. The average minimum and maximum temperatures were 11.9 °C and 29.9 °C, average minimum and maximum wind speeds were 0.75 km h^{-1} and 4.31 km h^{-1}, the prominent wind direction was NW and the average minimum and maximum RH was 46.1% and 83.3%, respectively.

Statistical Analysis

For statistical analysis, Statistical Package for Social Sciences (SPSS) (for windows, version 16) was used and standard methods were applied. To analyze the difference for PM at different time intervals, Paired t-test was used. Graph Pad Prism version 4 was used for plotting different types of graphs. All statistical significance tests were 2-tailed and the confidence index set at 95%. A level of p-value ≤ 0.05 was considered to be statistically significant. Descriptive statistics were shown as mean and standard deviation.

Results and discussion

ACRB emits substantial amounts of aerosols in the form of particulate matter and other pollutants into the atmosphere.[3,32] After harvesting of crops, farmers burn the residue in open fields which varies from region to region. Open ACRB is not spread throughout the year; rather, it is typically localized/regionalized and episodic for time or season. Badrinath *et al.*,[33] through IRS-P6 AWiFS satellite, found that exhaustive burning of rice crop residue in Indo-Gangetic Plains occurred in the month of October–November, whereas wheat crop residue burning occurred in the months of April–May. In Patiala, exhaustive burning of rice crop residues starts during the first week of October and continues up to middle of November and the wheat crop residue burning starts in the first week of April and continues up to the middle of May, as already documented by Mittal *et al.*,(2009).[2] To study the contribution of ACRB, site selection and instrument installation was done in such a way that impact due to other means was minimized and in accordance with wind direction *i.e.*, NW.

The average mass-size distribution of aerosols for different months for different ranges of particle size is given in Table 2. It is clear from the table that concentrations of particulate matter with size in the range 0.4–1.1 μm were more comparable to all other ranges throughout the study period and particle concentrations with the size in the range 1.1–2.1 μm were found to be maximum. Monthly average values (Table 2) clearly indicate that the concentration of the coarse fraction remained low in all the months in contrast to particles of fine range. During the total study period, the highest mass fractions of PM was observed in the size range of 1.1–2.1 μm and 0.7–1.1 μm, followed by 0.4–0.7 μm. Contribution of different size particulates (0 to 10 μm) vary from 8 to 17% of total PM_{10} with maximum distribution of size range 1.1–2.1 μm and minimum in the size range > 9 μm. Another imperative observation was that the mass concentrations of all size range particulate matters increase abruptly in the months of October–November and April–May, which was due to exhaustive burning of rice and wheat crop residues. Fig. 2 represents the monthly average variation of PM of size between 0.0–3.3 μm on the basis of the ECD. Contribution of wheat and rice crop residue burning on the fine fraction of particulate matter is clearly observed by the highest peak value during the months of April–May and October–November (Fig. 2).

For comparison of distribution and concentration levels of different size particulate matter during total, non-burning and burning periods, box plots (Fig. 3) were drawn for total (July 2007 to January 2010), non-burning (except April–May and October–November of studied years) and burning months (April–May and October–November of 2007, 2008 and 2009). Fig. 3 indicates that concentrations of all different size particulate matter have higher values during the burning periods, which indicates that due to the burning, concentrations of different size PM increased, irrespective of their sizes. Contribution of different size particulates (0 to 10 μm) in total PM_{10} varies from 8 to 16% in non-burning months and 8 to 17% in burning months and particles in the range between 2.1–3.3 μm, 3.3–4.4 μm, 4.7–5.8 μm, 5.8–9.0 μm and > 9.0 μm have contributions of 8, 9, 9 and 10%, respectively, during burning months. The results were the same for burning and non-burning, *i.e.*, burning does not have much effect on the contribution and distribution of different size particulate matter. Thus, it can be concluded that concentration of the PM is greatly affected by the burning practices but the total distribution of the particulate matter remains almost constant during burning and non-burning periods.

PM_{10} (RSPM) concentrations

From Fig. 4, it can be found that, there is a significant increase in the mean concentration level of RSPM in the months of October

Table 2 Monthly average concentration of particulate matter of different size ranges[a]

	Concentration levels of PM								
Mon, Yr	>9.0 μm	5.8–9.0 μm	4.7–5.8 μm	3.3–4.7 μm	2.1–3.3 μm	1.1–2.1 μm	0.7–1.1 μm	0.4–0.7 μm	0.0–0.4 μm
Aug′07	6.19	9.02	9.79	7.90	6.44	13.49	12.80	8.85	5.24
Sep′07	7.71	7.71	7.14	11.94	8.28	12.55	12.12	12.59	7.06
Oct′07	10.44	12.73	11.30	15.84	14.11	29.64	26.81	15.24	8.19
Nov′07	10.52	12.70	11.36	12.20	11.19	25.07	24.06	20.44	9.00
Dec′07	7.48	8.17	7.13	7.25	8.90	15.30	15.03	15.00	6.67
Jan′08	6.47	9.42	7.95	7.95	6.47	16.58	17.03	13.06	5.11
Feb′08	6.12	9.22	7.80	7.18	8.33	19.50	15.60	13.74	4.70
Mar′08	6.29	9.32	7.87	7.56	7.40	18.04	16.32	13.40	4.90
Apr′08	10.75	13.58	15.05	15.40	14.43	21.24	21.39	17.79	9.38
May′08	9.61	14.85	11.51	12.21	18.64	24.40	21.16	16.75	7.11
Jun′08	6.96	8.13	9.94	8.77	9.04	13.28	13.37	10.84	5.60
Jul′08	7.44	9.05	8.77	7.49	9.59	13.52	13.97	12.56	5.57
Aug′08	6.35	9.04	9.93	7.66	7.77	13.08	13.20	9.87	5.94
Sep′08	5.13	8.58	9.86	8.12	9.85	14.12	14.13	9.44	5.14
Oct′08	11.57	12.73	12.79	12.55	13.48	26.77	29.28	24.95	15.09
Nov′08	11.74	11.75	13.15	14.09	16.90	27.69	25.35	21.14	19.26
Dec′08	8.24	6.93	6.95	7.81	10.83	16.91	15.60	15.60	10.84
Jan′09	10.69	7.84	6.49	7.41	9.56	22.10	17.96	22.44	7.05
Feb′09	6.66	9.02	9.97	6.16	10.44	18.07	16.17	15.21	9.49
Mar′09	8.77	7.82	9.83	9.93	7.43	11.66	10.27	12.75	9.53
Apr′09	12.20	18.56	16.97	20.67	16.93	21.20	20.16	21.21	11.67
May′09	14.60	14.10	19.32	15.14	12.02	18.80	17.76	18.80	17.76
Jun′09	7.51	10.14	9.07	8.54	7.47	11.21	10.14	10.67	8.54
Jul′09	8.34	8.29	7.78	11.38	6.22	10.36	9.32	9.33	10.38
Aug′09	7.24	7.24	7.21	15.60	12.72	11.45	11.48	10.86	8.45
Sep′09	5.81	7.94	5.86	15.36	16.05	16.16	12.23	12.23	8.40
Oct′09	11.77	12.09	12.73	11.76	16.24	26.41	25.47	24.83	19.10
Nov′09	16.95	21.61	15.48	14.70	15.27	52.65	31.65	20.33	13.76
Dec′09	10.39	7.18	7.66	12.59	25.26	20.51	24.41	25.03	16.01
Jan′10	10.55	10.99	8.44	13.12	21.21	23.67	26.16	23.71	17.78

[a] The number of samples for each month is two except for May and November where it is three.

2007 which continued until November 2007. The concentration showed a remarkable decrease in December, which remained almost constant until March 2008. The concentration again showed a significant increase in April 2008 until May. In June, levels of RSPM again declined which continued until July (Fig. 4). During the study period, the overall average concentrations of PM_{10} were found as 116 ± 34 μg m^{-3} and background (average except burning period months) concentrations were

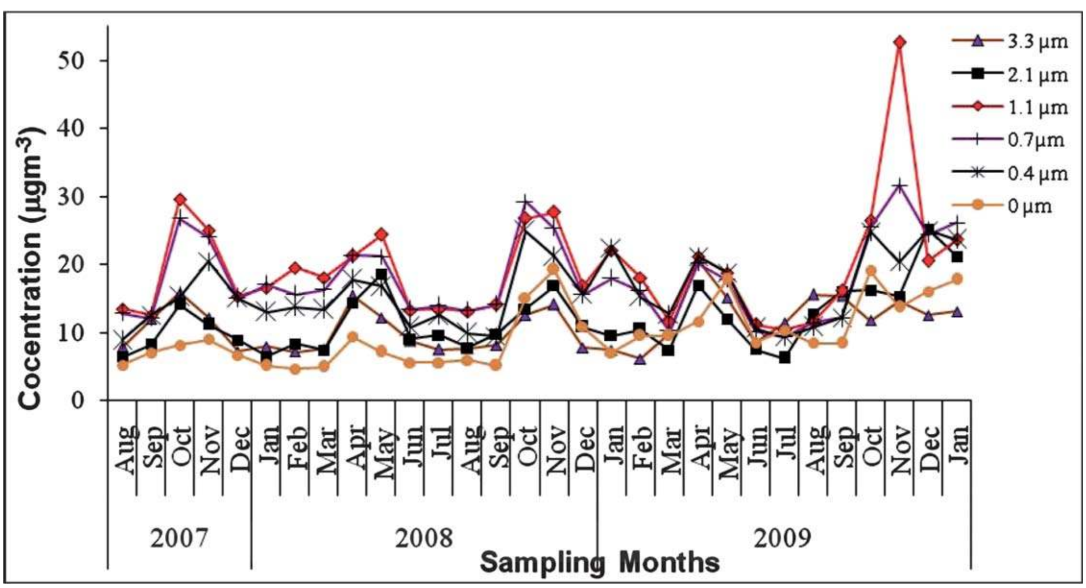

Fig. 2 Monthly variation in concentration of particulate matter of different sizes (0–3.3 μm) on the basis of their effective cut diameters (ECD).

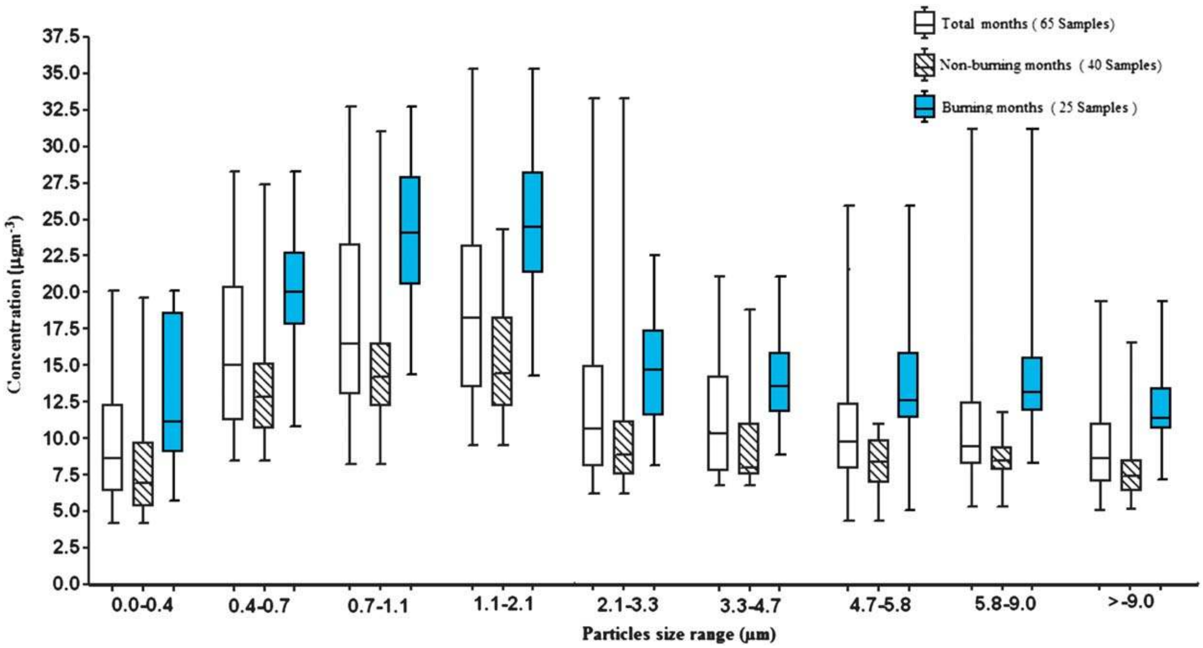

Fig. 3 Size distribution of PM for total, non-burning and burning months.

around 97 ± 21 μg m^{-3}. The maximum concentration of PM_{10} was found in the month of November 2009 (202 μg m^{-3}) compared to October 2009 (159 μg m^{-3}), during which exhaustive burning of rice and wheat crop residue was being carried out. There was an increase of 66% and 51% in the concentration levels of respirable particulate matter in comparison to the background values, during rice crop residue burning and wheat crop residue burning, respectively, indicating a clear contribution from the crop residue burning to the PM_{10} levels. The difference of PM_{10} calculated between background and burning periods by using the paired t-test is found to be statistically significant ($p < 0.001$) which clearly signifies the effect of ACRB on PM_{10}. It was found that the concentration levels of PM_{10} generally remain below the national ambient air quality standard (NAAQS) but crossed the NAAQS level during the months of burning period.

$PM_{2.5}$ (Fine Particulate matter) concentrations

Almost the same trend was seen in the monthly mean concentration of fine fraction as that of RSPM (Fig. 4). A high concentration was observed during October–November with the maximum in the year 2009 (100 and 147 μg m^{-3}) and then in

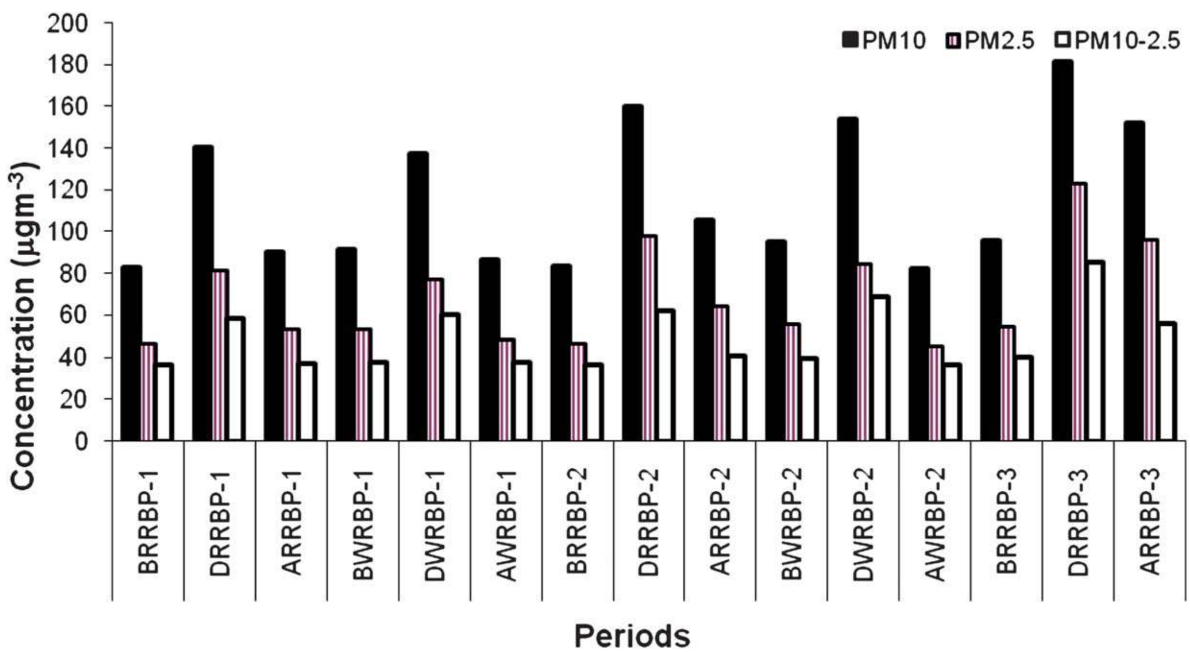

Fig. 4 Periodical variation in concentration of fine, coarse and respirable particulate matter.

April–May 2008 (82 and 87 μg m^{-3}). $PM_{2.5}$ varied from 44 to 147 μg m^{-3} with mean value of 69 ± 24 μg m^{-3}. The background mean concentration of the fine fraction was 57 ± 15 μg m^{-3}. There was a 78% increase in the concentration of fine particulate matter during rice crop residue burning and a 43% increase during wheat crop residue burning, in comparison to background values and the difference between burning and background concentrations is found to be statistically significant ($p < 0.001$).

$PM_{10-2.5}$ (Coarse Particulate matter) concentrations

The trend of coarse fraction was found to be almost the same as that of PM_{10} and $PM_{2.5}$ (Fig. 4) *i.e.*, a peak value was seen in the month October–November 2007 and April–May 2008. The concentration of $PM_{10-2.5}$ varied from 36 to 111 μg m^{-3} with a mean value of 49 ± 17 μg m^{-3} and the background concentration was 40 ± 6 μg m^{-3}. In this case, there was a 71% increase in the concentration of coarse particulates during rice crop residue burning and a 61% increase during wheat crop residue burning compared to the background values.

PM levels (Fig. 4) in the rural cum residential cum agricultural area of Sidhuwal village shows a significant increase during the months of ACRB. It was observed that concentration levels of different size particulate matter cross different national and international standard limits at least one third period of the year. An increase in levels of particulate matter during ACRB months was due to the production of smoke as a result of incomplete and improper combustion of residues in open fields. In ideal combustion conditions, sufficient mixing of the fuel and combustion air takes place, along with sufficient gas-phase residence times at high temperatures. This assures a high degree of completeness of the combustion reaction which limits pollutant emissions due to incomplete combustion. Open burning due to less than ideal combustion conditions, typically produces soot and particulate matter that are visible as dense smoke. The average concentration of PM_{10} was 116 μg m^{-3}, which is higher than the Indian NAAQS of 100 μg m^{-3} in 24 h for residential and sensitive areas.

Relationship between $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10}

The average mass concentration ratios $PM_{2.5}/PM_{10}$ varied between 0.54 to 0.64 with an average of 0.58 ± 0.03 during the whole study period (Table 2). The ratio of $PM_{2.5}/PM_{10}$ indicates that the major part *i.e.*, up to 63.8% of the PM_{10} contained $PM_{2.5}$. $PM_{10-2.5}/PM_{10}$ ratio was found to be 0.42 ± 0.08, which is lower than $PM_{2.5}/PM_{10}$ of 0.57 ± 0.03 (Table 3), indicating a higher contribution of $PM_{2.5}$ in PM_{10}. There was no significant change observed in the ratios of particulate matter during the burning periods. Different ratios of particulate matter indicate that RSPM contains more fractions of lower size particulate matter ($PM_{2.5}$) as compared to the coarse fraction ($PM_{10-2.5}$) of aerosols. This may be due to large surface area and lower settling velocity of small size particles, well supported by a number of other studies conducted in different countries.[34–37]

To find the association between the different sizes of particulate matter, linear regression among $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} was carried out and is shown in Fig. 5. $PM_{2.5}$ and $PM_{10-2.5}$ were significantly correlated (Pearson) with PM_{10} while $PM_{2.5}$ is more closely associated with PM_{10} ($r = 0.976$; $p < 0.001$) as compared to the association between $PM_{10-2.5}$ and PM_{10} ($r = 0.929$; $p < 0.001$). This was expected, because $PM_{2.5}$ (fine fraction) contributes more in PM_{10} during all monitoring months irrespective of burning or non-burning episodes. Wilson and Suh (1997) also reported that PM_{10} and $PM_{2.5}$ exhibit a high degree of correlation whereas the correlation between $PM_{10-2.5}$ and $PM_{2.5}$ is found to be low.[37]

Table 3 Monthly ratio of fine to respirable particulate matter[a]

	Monthly ratios of $PM_{2.5}/PM_{10}$		
Months	2007–08	2008–09	2009–10
Aug	0.55	0.56	0.57
Sep	0.57	0.56	0.59
Oct	0.58	0.61	0.62
Nov	0.59	0.61	0.58
Dec	0.59	0.61	0.64
Jan	0.58	0.61	0.63
Feb	0.59	0.60	n.a.
Mar	0.59	0.56	n.a.
Apr	0.56	0.54	n.a.
May	0.56	0.59	n.a.
Jun	0.56	0.55	n.a.
Jul	0.56	0.55	n.a.
Mean	0.57	0.58	0.60
Stdev	0.01	0.03	0.03
Min	0.55	0.54	0.57
Max	0.59	0.61	0.64

[a] The number of samples for each month is two except for May and November where it is three; n.a. = Data not available.

Comparison between rice and wheat crop residue burning

As observed from the study, particulate levels increase during the burning of agriculture crop residues. To find which crop residue burning contributes more to the particulate matter, average values of different size particulate matter during rice and wheat residue burning periods were calculated and are shown in Table 4.

It was observed that PM_{10} and $PM_{2.5}$ concentration levels were high (140.42 and 81.52 μg m^{-3}) (Table 4) during rice crop residue burning periods as compared to wheat crop residue burning periods in all three years. In both burning periods, contribution of $PM_{2.5}$ in PM_{10} was high (58% and 56%) as compared to $PM_{10-2.5}$, but the fraction of $PM_{2.5}$ was 2% higher in the rice residue burning period compared to the wheat crop residue burning period. This indicates that during rice crop residue burning, PM_{10} contains a higher percentage of $PM_{2.5}$ as compared to wheat crop residue burning. Moreover, the respective percentage increase compared to background levels during the rice crop residue burning is more comparable to wheat crop residue burning. Differences between rice and wheat crop residue burning periods were calculated by using the paired t-test. The total difference between the rice and wheat crop residue burning for the value of PM_{10} and $PM_{2.5}$ are 4.47 and 8.84 μg m^{-3}, respectively, which is statistically significant ($p < 0.05$). Hence, among two crop residue burning seasons, the impact of rice crop residue burning was found to be greater on

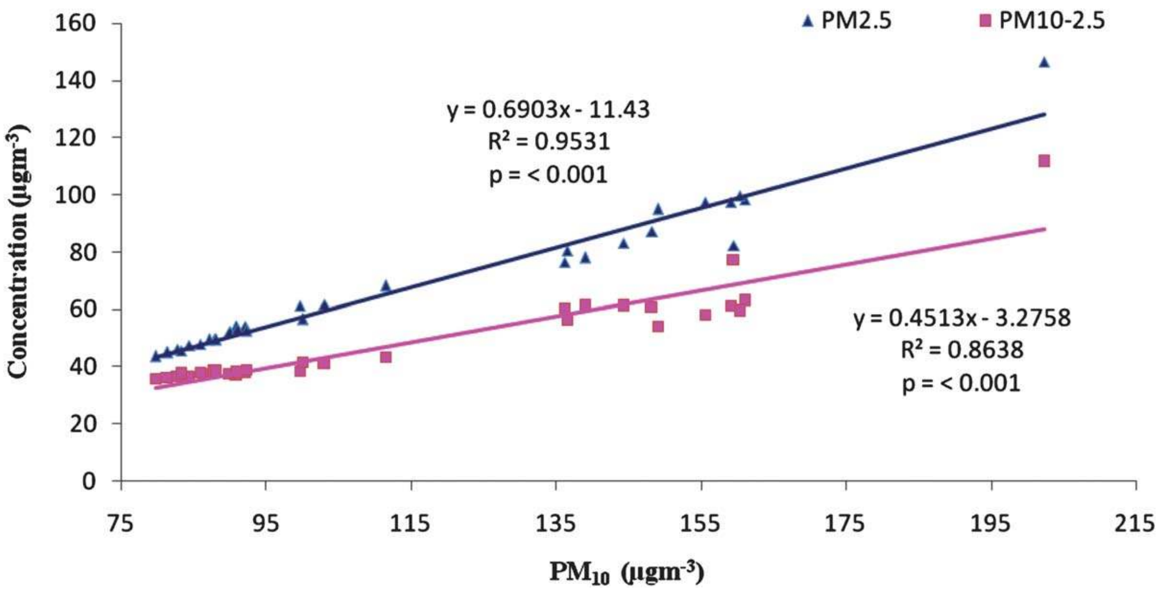

Fig. 5 Relationship between $PM_{2.5}$, $PM_{10-2.5}$ with PM_{10}.

the mass concentration of aerosol as compared to wheat crop residue burning.

Higher concentrations of particulate matter during rice crop residue burning as compared to wheat crop residue burning may be due to the larger quantities of rice crop residue being disposed off by open field burning, since a part of wheat crop residue is also used as fodder. This is also supported by the results given by Badrinath *et al.*,[33] that emissions from wheat crop residues in Punjab are relatively low as compared to those from paddy fields. Moreover, burning of rice crop residue takes place in the October and November months of the winter season, when the ambient temperature is quite low (≈ 18 °C) than that in April–May (≈ 31 °C). This is due to the movement of the boundary layer towards a lower height, resulting in a higher concentration of PM in winter than during the burning of wheat residue in the summer months of April and May.

Seasonal variation of particulate matter

On the basis of the meteorological parameters of Patiala city, during the study period, the monthly average temperature was 23.6 ± 7 °C with an average minimum temperature of 11.9 °C in January 2008 and maximum temperature of 32.7 °C in June 2009. From Fig. 6 it is observed that December to February were three consecutive cold months and June to August were three consecutive hot months having the maximum temperature. So as to study the seasonal variation of particulate matter and excluding the effect of burning period months (October–November and April–May), the average value of three consecutive months, December–February for winter and June–August for summer were calculated and are shown in Table 5.

The concentration of PM_{10} and $PM_{2.5}$ were higher during winter in comparison to that in the summer (Table 5). The ratio of $PM_{2.5}/PM_{10}$ was also found to be high in the winter months as compared to in summer months. PM_{10} contains a maximum of 64% $PM_{2.5}$ in winter and a maximum of 57% in summer, which indicates that the fine fraction contributes more during the winter season than in the summer season. Negative significant correlation ($r = -0.660$; $p < 0.05$) between $PM_{2.5}/PM_{10}$ with temperature indicates that with a decrease in temperature, the percentage of $PM_{2.5}$ in PM_{10} increases. Significant ($p < 0.05$) differences of 12.31 μg m^{-3}, 10.80 μg m^{-3} and 0.04 were observed in PM_{10}, $PM_{2.5}$ and $PM_{2.5}/PM_{10}$ between winter and summer which supports the observation that during winter months, concentration levels were higher than in summer months.

In summer, higher solar heating of the land increases the boundary layer height, which increases the ventilation coefficient and further leads to faster dispersion of aerosols. Thus, the increase in ventilation coefficient results in a decrease in the concentration of particulate matter. Thus, the dilution effect due

Table 4 Average concentration of particulate matter during burning periods of wheat and rice crop residue[a]

	PM_{10} (μg m^{-3})			$PM_{2.5}$ (μg m^{-3})			$PM_{2.5}/PM_{10}$		
	2007–08	2008–09	2009–10	2007–08	2008–09	2009–10	2007–08	2008–09	2009–10
DWBP	138 ± 3.5	154 ± 4.3	n.a.	77 ± 1.7	85 ± 2.9	n.a.	0.57 ± 0.01	0.55 ± 0.01	n.a.
DRBP	140 ± 3.6	160 ± 2.8	181 ± 9.5	82 ± 1.5	98 ± 2.4	12 ± 5.4	0.58 ± 0.01	0.61 ± 0.01	0.60 ± 0.01

[a] The numbers of samples for each period is five; data are represented as Mean ± S.D; DRBP: during rice crop residue burning period (October–November 2007′08′09); DWBP: during wheat crop residue burning period (April–May 2008′09); n.a = data not available.

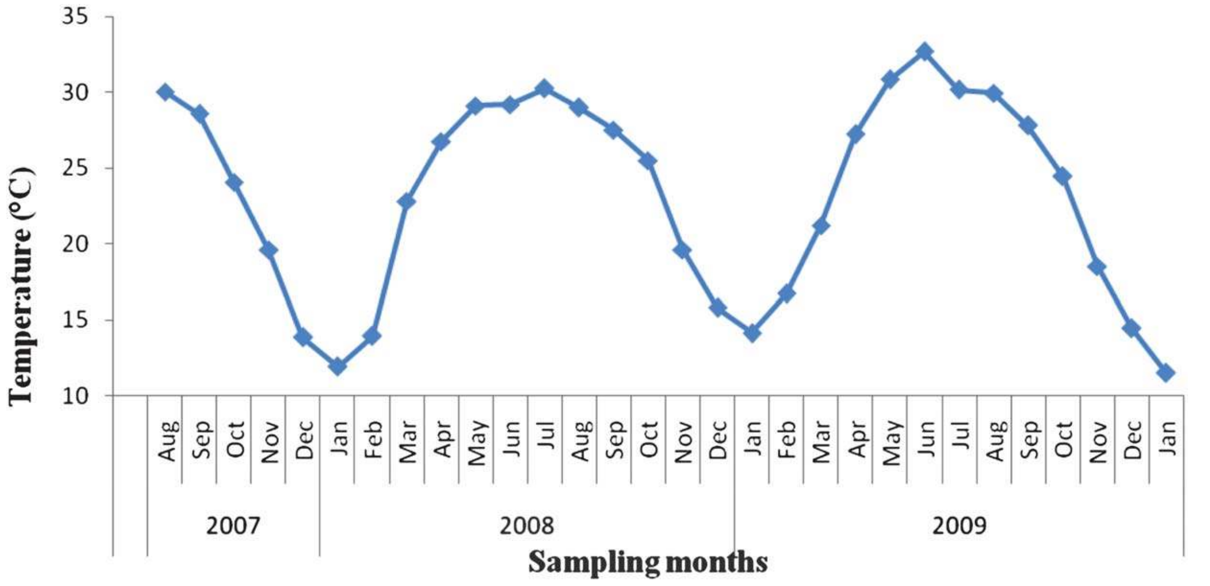

Fig. 6 Monthly average temperature values in Patiala (India) from August 2007 to January 2010.

to the increase in mixing depth and precipitation in summer reduced the concentrations of particulate matters.[38] During the winter season, low relative humidity and low solar heating of land results in slower dispersion of aerosols and a decrease in boundary height results in an increase in the concentration of particulate matter. During the winter season, there is a greater exposure risk as pollutants often get trapped in the lower layers of the atmosphere thereby resulting in high concentrations of PM. Similar results were observed by different authors in earlier studies.[39–43]

Particles in the respirable range are responsible for most of the airborne particle threats to human health because of their small size range. The inhalation and deep penetration capability of these particles in the respiratory system leads to their morbidity threats.[21] Particles with a size above 2.5 μm are deposited in the nose or in the upper respiratory tract but fine particulates are small enough to bypass the screening of the nose and can penetrate in the alveoli and get deposited in the lower respiratory tract and hence are of serious concern. Health studies also suggest that fine particles ($PM_{2.5}$) are more harmful than coarse particles.[21,44–48] According to World Health Report (2002),[49] analysis based on particulate matter, estimates that the ambient air pollution causes about 5% of trachea, bronchus and lung cancer, 2% of cardio-respiratory mortality and about 1% of respiratory infections mortality globally. Hence, it is now a serious concern to control the particulate matter concentration.

Although the contribution to ambient aerosol from agriculture burning smoke was episodic but there is a lot of evidence which shows that health effects also occur after short-term increases in particulate air pollution, such as increased respiratory symptoms, a decrease in level of lung functions in both asthmatic and non-asthmatic children and adults and in healthy subjects without asthma.[21,50–53]

Conclusions

ACRBs emit substantial amounts of aerosols that produce a momentous increase in the concentration of particulate matter that sometimes even cross the standard limits. Effects of rice crop residue burning is found to be higher in comparison to wheat crop residue burning as the fraction of fine particles in total RSPM is higher during rice crop residue burning. Seasonal variation of aerosols suggests that the percentage of $PM_{2.5}$ in PM_{10} is greater in winter than in summer months. In winter months, pollutants get trapped in lower layers of the atmosphere, thereby resulting in high concentrations of particulate matter, especially fine fraction particles. Another important inference can be drawn from the non uniform segregation of different size particulate matter, that concentration of smaller size particulate matter was greater than coarse particulate matter during the course of this study. The $PM_{2.5}/PM_{10}$ ratio showed that $PM_{2.5}$ contributes up to 59% of the total mass concentration of PM_{10}.

Table 5 Average concentration of particulate matter in summer and winter season[a]

Season	PM_{10} (μg m^{-3})		$PM_{2.5}$ (μg m^{-3})		$PM_{2.5}/PM_{10}$	
Summer (June–Aug)	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
	85 ± 2.6	86 ± 2.1	48 ± 1.8	48 ± 1.1	0.56 ± 0.01	0.56 ± 0.01
Winter (Dec–Feb)	**2008**	**2009**	**2008**	**2009**	**2008**	**2009**
	91 ± 3.9	105 ± 4.5	53 ± 1.6	64 ± 3.5	0.58 ± 0.01	0.61 ± 0.01

[a] The number of samples for each season is six; data are represented as Mean ± S.D.

Although ACRB is an episodic process which does not have much of an effect on the total distribution of particulate matter of different sizes, it also increases their concentration levels for more than one third of the year. Hence, necessary steps must be taken to control it as it creates a hazardous effect on the environment and health.

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References

1 K. V. S. Badarinath, S. K. Kharol, A. R. Sharma and V. K. Prasad, *J. Atmos. Sol.–Terr. Phys.*, 2009, **71**, 1267–1276.
2 S. K. Mittal, N. Singh, R. Agarwal, A. Awasthi and P. K. Gupta, *Atmos. Environ.*, 2009, **43**, 238–244.
3 S. Sahai, C. Sharma, D. P. Singh, C. K. Dixit, N. Singh, P. Sharma, K. Singh, S. Bhatta, S. Ghude, V. Gupta, R. K. Gupta, M. K. Tiwari, S. C. Garg, A. P. Mitra and P. K. Gupta, *Atmos. Environ.*, 2007, **41**, 9173–9186.
4 R. Sharma, S. K. Khrol, K. V. S. Badrinath and D. Singh, *Annales Geophysicae*, 2010, **28**, 367–379.
5 S. Viboland and S. Towprayoon, *Environ. Monit. Assess.*, 2010, **161**, 301–313.
6 K. V. S. Badarinath, K. M. Latha, T. R. K. Chand and P. K. Gupta, *Atmos. Res.*, 2009, **91**, 87–93.
7 D. Contini, A. Genga, D. Cesari, M. Siciliano, A. Donateo, M. C. Boveand and M. R. Guascito, *Atmos. Res.*, 2010, **95**, 40–54.
8 S. B. Hong, D. S. Kim, S. Y. Ryu, Y. J. Kim and J. H. Lee, *Atmos. Res.*, 2008, **89**, 62–75.
9 J. M. Lim, J. H. Lee, J. H. Moon, Y. S. Chung and K. H. Kim, *Atmos. Res.*, 2010, **95**, 88–100.
10 S. K. Verma, M. K. Deb, Y. Suzuki and Y. I. Tesai, *Atmos. Res.*, 2010, **95**, 65–76.
11 A. K. Sharma, K. A. Jensenb, J. Ranka, P. A. White, S. Lundstedt, R. Gagnec, N. R. Jacobsen, J. Kristiansen, U. Vogel and H. Wallin, *Mutat. Res., Genet. Toxicol. Environ. Mutagen.*, 2007, **633**, 95–111.
12 S. Janhall, M. O. Andreae and U. P. Oschl, *Atmos. Chem. Phys.*, 2010, **10**, 1427–1439.
13 R. M. Harrison and J. Yin, *Sci. Total Environ.*, 2000, **249**, 85–101.
14 U. Makkonen, H. Hellen, P. Anttila and M. Ferm, *Sci. Total Environ.*, 2010, **408**, 644–651.
15 J. Y. Park, P. C. Raynor, A. D. Maynard, L. E. Eberly and G. Ramachandran, *Atmos. Environ.*, 2009, **43**, 502–509.
16 K. W. Nicholson, *Atmos. Environ.*, 1988, **22**, 2639–2651.
17 US Federal Register (1987). *Ambient monitoring reference and equivalent methods. United States Environmental Protection Agency*. Federal Register 40 CFR Part 53. 1 July 1987.
18 F. J. Miller, D. E. Gardner, J. A. Graham, R. E. Lee Jr., W. E. Wilson and J. D. Bachmann, *Journal of Air Pollution Control Association*, 1979, **29**, 610–614.
19 W. E. Wilson, J. C. Chow, C. Claiborn, F. S. Wei, J. Engelbrecht and J. G. Watson, *Chemosphere*, 2002, **49**, 1009–1043.
20 R. Agarwal, A. Awasthi, S. Mittal, N. Singh and P. K. Gupta, *J. Med. Eng. Technol.*, 2010, **34**, 23–28.
21 D. W. Dockery, C. A. Pope, X. P. Xu, J. D. Spengler, J. H. Ware, M. E. Fay, B. G. Ferris and F. E. Speizer, *N. Engl. J. Med.*, 1993, **329**, 1753–1759.
22 S. Y. Ryu, B. G. Kwon, Y. J. Kim, H. H. Kim and K. J. Chun, *Atmos. Res.*, 2007, **84**, 362–373.
23 C. A. Pope, M. J. Thun, M. M. Namboodiri, D. W. Dockery, J. S. Evans, F. E. Speizer and C. W. Heath, *American Journal of Respiratory Critical Care Medicine*, 1995, 151, pp. 669–674.
24 J. H. Seinfeld and S. N. Pandis, 1998, *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. John Wiley & Sons.Inc. New York.
25 J. M. Samet, F. Dominici, F. C. Curriero, I. Coursac and S. L. Zeger, *N. Engl. J. Med.*, 2000, **343**, 1742–1749.
26 C. L. S. Wilson and F. Zereini, *Sci. Total Environ.*, 2009, **407**, 2493–2500.
27 V. Ulevicius, S. Bycenkiene, V. Remeikis, A. Garbaras, S. Kecorius, J. Andriejauskiene, D. Jasineviciene and G. Mocnik, *Atmos. Res.*, 2010, **98**, 190–200.
28 O. Zarate, A. J. P. Ezcurra, P. Lacaux and J. D. V. D. Argandona, *Atmos. Res.*, 2005, **73**, 161–170.
29 IS: 5182 (Part XV), Mass concentration of particulate matter in the atmosphere, *Indian standard methods for measurement of air pollution*, 1974.
30 AOM (Anderson Operational Manual). (1993). *IACFM Non- viable Sampler (Series 20-800)*. Thermo Anderson. Smyrna. GA. pp. 16.
31 M. Das, S. K. Maiti and U. Mukhopadhyay, *Environ. Monit. Assess.*, 2006, **122**, 111–123.
32 P. M. Lemieux, C. C. Lutes and D. A. Santoianni, *Prog. Energy Combust. Sci.*, 2004, **30**, 1–32.
33 K. V. S. Badarinath, T. R. Kiran Chand and V. K. Prasad, *Current Science*, 2006, **91**, 1085–1089.
34 Y. Chan and W. S. Kwok, *Atmos. Environ.*, 2001, **35**, 3177–3182.
35 R. M. Harrison, A. R. Deacon, M. R. Jone and R. S. Appleby, *Atmos. Environ.*, 1997, **31**, 4103–4117.
36 H. Hauck, A. Berner, T. Frischer, B. Gomiseck, M. Kundi, M. Neuberger, H. Puxbaum and O. Preining, *Atmos. Environ.*, 2004, **38**, 3905–3915.
37 W. E. Wilson and H. H. Suh, *Journal of Air and waste Management Association*, 1997, **47**, 1238–1249.
38 K. F. Ho, S. C. Lee, J. J. Cao, J. C. Chow, J. G. Watson and C. K. Chan, *Sci. Total Environ.*, 2006, **355**, 276–287.
39 K. Furuya, Y. Kudo, K. Okinaga, M. Yamuki, S. Takahashi, Y. Araki and Y. Hisamatsu, *Journal of Trace and Microprobe Techniques*, 2001, **19**, 469–485.
40 A. S. Zakey, M. M. Abdel-Wahab, J. B. C. Petterson, M. J. Gatari and M. Hallquist, *Atmosphera*, 2008, **21**, 171–186.
41 D. V. Hebel and D. M. Karl, *Deep-Sea Res., Part II*, 2001, **48**, 1669–1695.
42 A. P. Hyvarinen, H. Lihavainen, M. Komppula1, T. S. Panwar, V. P. Sharma, R. K. Hooda and Y. Viisanen, *Atmos. Chem. Phys.*, 2010, **10**, 7241–7252.
43 A. Srivastava, S. Gupta and V. K. Jain, *Atmos. Res.*, 2009, **92**, 88–99.
44 G. Hoek, B. Brunekreef, S. Goldbohm, P. Fischer and P. A. Vanden Brandt, *Lancet*, 2002, **360**, 1203–1209.
45 F. Laden, L. M. Neas, D. W. Dockery and J. Schwartz, *Environ. Health Perspect.*, 2000, **108**, 941–947.
46 R. Lal, M. Kendall, K. Ito and G. D. Thurston, *Atmos. Environ.*, 2004, **38**, 5217–5226.
47 T. F. Mar, G. A. Norris, J. Q. Koenig and T. V. Larson, *Environment Health Perspectives*, 2000, **108**, 47–353.
48 C. A. Pope, R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito and G. D. Thurston, *JAMA, J. Am. Med. Assoc.*, 2002, **287**, 1132–1141.
49 *World Health Report*: 2002, WHO publication.
50 C. S. Tang, L. T. Chang, H. C. Lee and C. C. Chan, *Sci. Total Environ.*, 2007, **382**, 43–51.
51 J. H. Kim, D. H. Lim, J. K. Kim, S. J. Jeong and B. K. Son, *J. Korean Med. Sci.*, 2005, **20**, 42–45.
52 C. A. Trenga, J. H. Sullivan, J. S. Schildcrout, K. P. Shepherd, G. G. Shapiro, L. J. Liu, J. D. Kaufman and J. Q. Koenig, *Chest*, 2006, **129**, 1614–1622.
53 C. W. Wu, I. C. Kuo, T. C. Su, Y. R. Li, L. Y. Lin, C. C. Chan and S. C. Hsu, *Am. J. Epidemiol.*, 2010, **171**, 1299–1309.