J. Indian Chem. Soc.,
Vol. 97, January 2020, pp. 85-100

Seasonal variation and health implications of long-range transported and provincial size distributed aerosols at eastern central India

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Manuscript received online 06 December 2019, accepted 26 December 2019

Size distributed aerosols are collected from October 2016 to July 2017 at eastern central India. This work for the first time investigates the possibilities of long-range transport and inhalation dose of particulate matters in different size at study site. During winter the aerosols were enriched in fine mode particles size however, they are more enriched in coarse mode during summer and post-monsoon season. Significant loading of particulate matters was observed during summer season. Crop residues are burnt in large scale which increases fine particles in the atmosphere. Strong correlation between the fine size fraction were observed in summer and winter season which must be due to the strong biomass burning. The percentage loading of upper respiratory tract, respiratory tract and lungs were obtained to be 30, 69 and 52%, respectively during winter. High value of inhalation dose over entire study period which may responsible for severe health implications.

Keywords: Size-distribution, inhalation dose, seasonal variation, biomass burning, eastern central India.

Introduction

Aerosols are suspended small liquid droplets and solid particles in air (except cloud particles) with size ranges from 10^{-2} to 10^{2} μm[1,2]. Atmospheric aerosols have adverse effect on human health and plays important role in atmospheric chemistry. They have some optical properties due to which they interact with incoming solar radiation and significantly affect Earth's climate and participates as cloud condensation nuclei (CCN), amending cloud formation and albedo. Particle size, shape, life time and chemical components are the properties that can be useful to predict the quality of air and the extent of pollution[3]. In recent years India has experienced a significant raise in frequency of severe air pollution. In contrast eastern central India has experienced an increase in Particulate Matters. Earlier studies reported that burning events like wildfire, Bourne fire, firecrackers burning and vehicular emission can inject fine and ultrafine particulates in atmosphere, and then these particles can be easily transported by air masses along the Earth because of their long-life time in atmosphere[4–6]. Aerosols have variety of chemical species they might be water-soluble inorganic ions, metals and organic compounds their compositions depend upon the sources from which they originated and atmospheric conditions[7–9]. Regardless of making significant efforts to control air pollution, these problems are growing as emerging issue regionally as well as globally. Recent study reported that approximately 800,000 people per year die due to air pollution hence air pollution control is one of the most relevant matter[10,11].

Size of the particles are the most important properties that decides the approach of the particles to different part of human respiratory system. Particles with size <10 μm are the respirable suspended particulate matters (RSPM), which are more important because of associated health problems in human being. Particles with size 2.5–10 μm ($PM_{2.5–10}$) and 2.5 ($PM_{2.5}$) μm are the coarse and fine particles whereas particles with size < 1 μm are ultrafine particles, smaller the particles have more harmful health effect because their approach to the deeper respiratory regions[12,13]. Wang *et al.* (2019) stated that $PM_{4.4–10}$ can affect nasal and pharynx region whereas $PM_{1.0–4.4}$ and $PM_{<1}$ can enters bronchi and alveoli regions of the lungs, hence more harmful to human health, also these are responsible for mortality, morbidity, asthma attack, exacerbation and cancer[14].

Most of the studies done represents aerosols effects in particular event or particular season, hence reflect aerosols transformation in short duration. Also, many studies have been done that only presents either PM_{10} or $PM_{2.5}$ at a time.

The present work is focused on the aerosol size distribution in nine different size fractions over a year at eastern central India hence provide more information of aerosols formation process and their sources of emission over a year. Present work also explains meteorological variables influence on atmospheric aerosols. Aerosols may be either local originates, long range transported or both, present work also determines the long-range possibilities via backword air mass trajectories to the study site over a year.

Material and method:

Study area:

Geographical location of Raipur is 22°33′ to 21°14′ N latitude and 82°6′ to 81°38′ E longitude. The aerosol collection was performed at rooftop of double storied building of chemistry department at Pt. Ravishankar Shukla University Raipur, Chhattisgarh (Fig. 1). The study area is bordered by heavy traffic discharge, housing, frequent industrial and agricultural activities, and extreme biomass burning.

Collection of samples:

Anderson eight-stage cascade impactor sampler (TE 20-800, USA) was used for sampling. The sampling campaign was performed during September 2016 to June 2017 by using nine stage cascade size-segregated sampler with constant flow rate of 28.3±0.3 L min^{-1}. h cut off diameter of sampler are 10.0 μm, 9.0 μm, 5.8 μm, 4.4 μm, 2.5 μm, 2.1 μm, 1.0 μm, 0.7 μm and < 0.4 μm. The PM_{10} refers to the sum of stage 0 to stage 8, similarly $PM_{2.5–10}$ refers to the sum of stage 0 to stage 3, $PM_{2.5}$ refers to the sum of stage 4 to stage 8 including back up filter and lastly PM_1 refers to the sum of stage 7 and stage 8 including back up filter of eight stage cascade impactor. Total 18 sets of size-distributed aerosols were collected on daily mean basis each for 24 h. All samples were collected using pre-treated quartz microfiber filters (Whatman 41; diameter 81 mm). Field blanks was collected before and after the sampling by putting the filters onto the sampler for a few minutes without any air suction. After sampling, the sample and field blank filters was transported to laboratory for gravimetric analysis.

Gravimetric analysis:

The mass concentration of size-segregated aerosols was determined by the gravimetric analysis. The filters were placed in desiccators for ~24 h before and after the sampling to remove the absorbed water and weighed in a controlled environment chamber, after taking the filters out of the desiccators, using an analytical balance (Sartorius, Model CP225D) with a reading precision of 10 μg.

The gravimetric mass (μg) were calculated by subtracting the weight of the filter after sampling from that of the prior

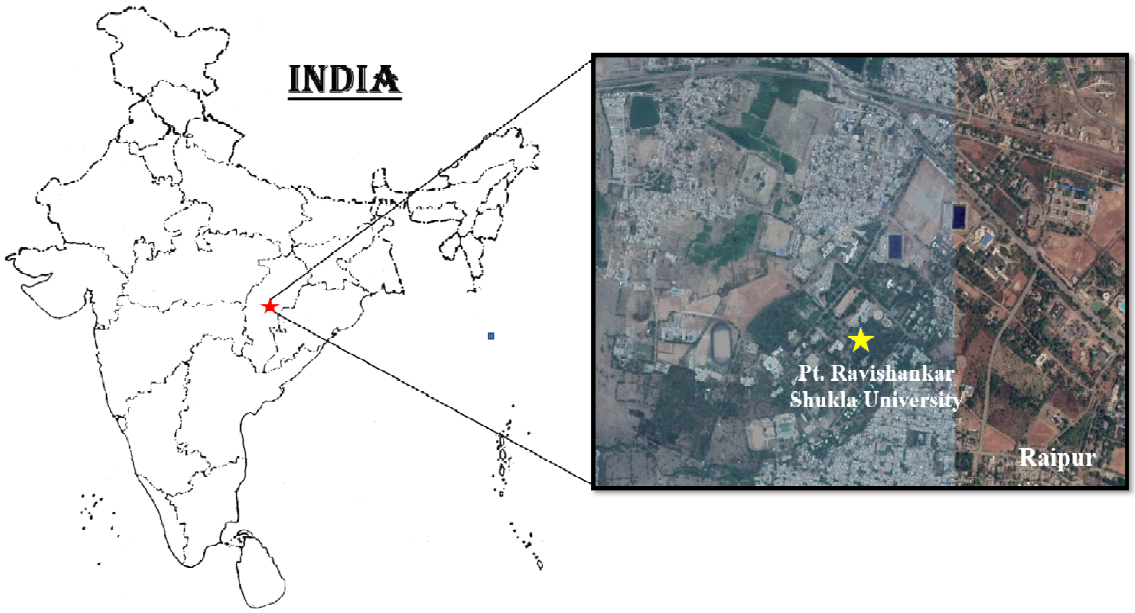

Fig. 1. Geographical location of study site eastern central India.

sampling and the concentration (μg/m^3) were determined by dividing the aerosol mass by total volume of air sampled (m^3). After the gravimetric analysis, the loaded filters and field blanks were placed in clean polyethylene (PE) bottles and stored in a refrigerator at about ~4°C to prevent the loss of volatile or semi-volatile species from the sample filters. The mass of the sampled filters obtained will be corrected for field blank values.

Air mass trajectories and meteorological variables:

Backword air mass trajectories at 500 m height analysed using NOAA's HYSPLIT model. Meteorological variables i.e. temperature, relative humidity, vapour pressure, rainfall, wind speed and wind directions were downloaded from weather undergrounds website.

Estimation of inhalation dose:

Firstly, human exposure is calculated by Duan and Ott[15–17]. Many of the researchers have estimated the average exposure to find the extent of air pollutants in a certain period of time[16–18]. Another term 'integrated exposure' is used by many researchers to estimate the inhalation of particles by humans. Average exposure is calculated by average concentration of air pollutants in certain time intervals. Risk exposure is then calculated by evaluating the dose of pollutant can deposit on human body with certain duration of time spent. The relationship between dose and exposure can be estimated by following equation:

$$D = \int C_p \times (IR).\Delta t.dt \quad (1)$$

Here, D indicates the inhalation dose (μg), C_p indicates the concentration of pollutant in specific time (μg m^{-3}), $IR\Delta t$ represents the breathing rate i.e. 0.027 m^3 min^{-1} (1.62 m^3 h^{-1}) average exposure value of female and male (age range 21–51 years) as recommended by United States Environmental Protection Agency[19]. t is the time duration that people spent for outdoor activities (8 h).

Results and discussion

Size distribution of atmospheric aerosol:

Fig. 2 displayed the size distribution of aerosols in monsoon, summer, winter and post-monsoon season at eastern central India. Fig. 3 displayed the enrichment of aerosols in nine different size fractions during winter, summer, monsoon and post-monsoon season. Bimodal size distribution of aerosols was obtained during monsoon season at eastern central India. The intense peak found in fine mode (0.4–0.7 μm

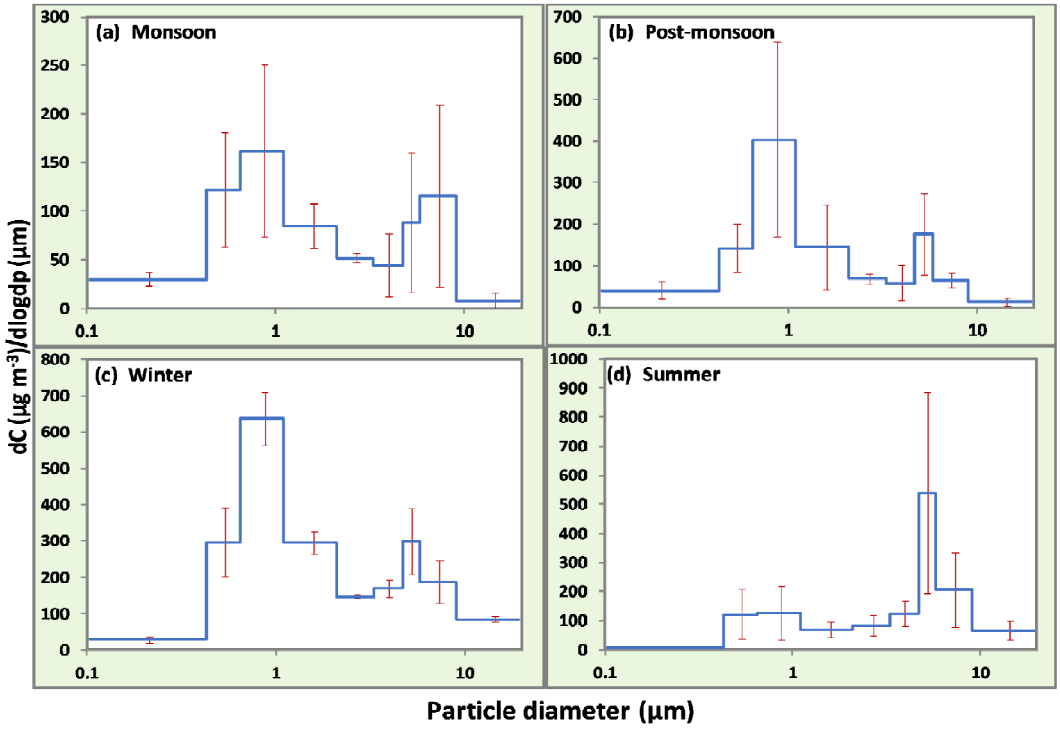

Fig. 2. Size distribution of aerosols in nine different size fractions during monsoon, winter, summer and post-monsoon season.

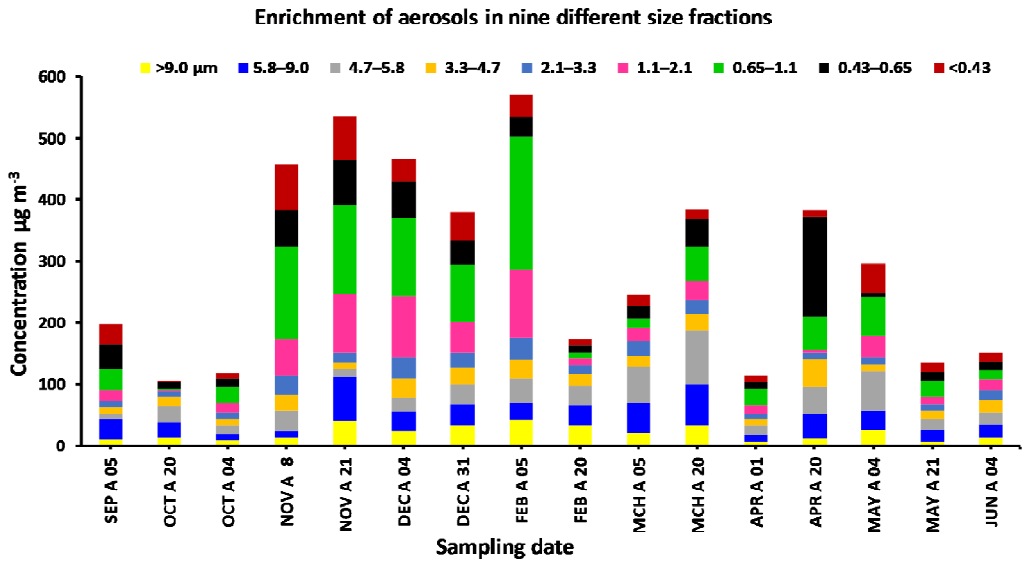

Fig. 3. Enrichment of particulate matters in nine different size fractions at eastern central India.

with MMAD at 0.85 µm). However, the distribution is less intense in coarse size with 4.4–5.8 µm (MMAD: 5.55 µm). Overall aerosols distribution is found to be dominated in fine size fraction. The low intense peak in coarse size during monsoon may attributed due to the quick wet removal phenomenon by precipitation. Lower MMAD values of aerosols observed in monsoon season that might be due to biomass and coal combustion from domestic cooking and industrial emission in urban region eastern central India. Contrastingly, in winter bimodal peak obtained with fine (0.4–0.7 µm, MMAD: 0.87 µm) and coarse particle size (4.4–5.8 µm, MMAD: 5.81 µm). MMAD value 2.81 µm is obtained for all nine size fractions. In winter season aerosols mass concentration was highly enriched in fine particles size i.e. 0.4–0.7 µm. High energy demand for domestic heating and cooking are require, such biomass burning emissions are significantly contributes in fine size of aerosols. Primary gaseous pollutants are released during biomass burning that gases can absorb or condensed over the pre-existing particles (mostly fine particles which have large surface area than coarse one)[24,25]. Wang *et al.* (2019) also reported that the biomass burning emissions were mostly occurs in 0.1–0.5 µm size (condensation mode)[26]. Xiao *et al.* (2019) found that such particles can humidify and can grow via coagulation of smaller particles[27]. Many other researchers[28,29] reported that meteorological favoured conditions like high relative humidity and lower temperature in winter triggers the growth of particles via condensation of atmospheric gases. Kim *et al*. (2019) reported that observed lower MMAD value in fine mode is due to biomass burning[21]. It is reported that particle emitted with size 0.1–0.5 mm are as a result of biomass burning and the particle can further grow in their size via absorbing humidity as winter days have high humidity, hence biomass burning has strong deposition in fine size fraction[22]. Kumar *et al.* (2018) also found similar peak and the reason reported is soil dusts from nearby areas and also prevailed meteorology[20].

The emission source of aerosols and their process of formation elect the distribution of aerosols in different size hence, different sources generate aerosols with different size fractions. Alves *et al*. (2019) and Han *et al*. (2019) reported that particles from wood burning and particles from crop residue burning are different in their size, crop burning emits particles with size greater than particles from wood burning hence, MMAD reported here was quite higher from crop residues then wood burnings[22,23]. Because of above reason we have found high value of MMAD in fine mode peak in summer compared with winter season.

On the other hand, bimodal size distribution with coarse mode dominated peak (4.4–5.8 µm) over fine mode peak (0.4–0.7 µm) size ranges. The MMAD values was found to be 4.11 µm, 7.21 µm and 1.23 µm found for total aerosols (PM_{10}), coarse and fine mode respectively. In post-monsoon

season bioaerosols like fungal spores, pollen grains are increased along with soil dusts in the atmosphere[30–32]. However, in summer season, the bimodal size distribution was found with coarse dominated peak (4.4–5.8 μm) over fine mode peak (0.4–0.7 μm). Average MMAD value obtained to be 6.01 μm and 1.12 μm, respectively for coarse and fine mode of aerosols. High loading in coarse size fractions may occurred due to the high soil dust resuspension process at eastern central India. MMAD obtained in fine size fractions may occurred because of crop residue burning activity in agricultural areas during the month of April-June period. Nirmalkar and Deb (2015) have reported that large scale burning of rice crop residue occurs in summer season at Rajim, India for the preparation of upcoming growing period of rice crop[33]. Aerosols formation process and type of emission sources along with atmospheric variables are the general factors which control the size distribution of aerosols in atmosphere. Crop residue burning and hard wood burning both can be differentiated using size distribution studies because both contributes to different size ranges[34]. Crop residues burning have comparatively larger size fractions contribution over hard wood burning emission, which contributes towards small size fractions[35,36]. Hence MMAD values obtained were also in larges for fine size fraction in summer season than winter season[37]. The overall season have bimodal size distribution with fine mode and coarse mode of aerosols at eastern central India. MMAD value of annual period was found 3.11, 5.89 and 1.11 in total aerosols, coarse and fine mode of aerosols, respectively. Seasonal variation was found along with significant variation in MMAD of aerosols in this study. Size distribution was shifted in fine size during post-monsoon and summer season at eastern central India. This also suggest that the variation in the natural and anthropogenic contribution in different seasons over the study site.

PM_{10}, $PM_{2.5–10}$, $PM_{2.5}$ and PM_1 mass concentration:

The average mass loading of PM_1, $PM_{2.5}$, $PM_{2.5–10}$ and PM_{10} during monsoon, post-monsoon and winter season are listed in the Table 2. However, particulate matters loading in nine different size fractions are listed in Table 1. The average abundance if PM_{10} was observed to be 138.9±50.73 μg m^{-3} (103.6–197.05 μg m^{-3}), 241.06±118.83 μg m^{-3} (135.50–382.90 μg m^{-3}), 481.02±74.66 μg m^{-3} (378.64–570.83 μg m^{-3}) and 228.4±117.27 μg m^{-3} (113.06–384.91

Table 1. Statistical summary of aerosols in nine different size fractions in summer, winter, monsoon and post-monsoon season at eastern central India

	Monsoon				Winter				Summer				Post-monsoon			
	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max
> 9.0 μm	10.32	2.420	7.779	12.60	29.27	11.74	12.68	40.65	22.74	11.79	7.525	32.06	14.23	7.222	7.53	24.29
5.8–9.0	23.18	11.18	10.86	32.68	35.93	22.74	10.47	72.59	39.22	24.59	8.998	66.25	26.99	10.97	17.18	39.98
4.7–5.8	14.82	8.101	8.29	23.88	27.28	10.24	12.11	38.77	49.15	31.73	15.47	88.65	36.82	21.36	18.65	63.31
3.3–4.7	12.95	3.495	10.10	16.85	25.99	8.725	11.09	32.64	18.85	6.705	10.96	27.32	22.28	15.63	11.36	44.82
2.1–3.3	10.16	0.800	9.232	10.62	28.53	7.580	16.70	35.34	16.25	6.904	7.660	21.84	13.32	2.263	11.11	16.03
1.1–2.1	12.35	9.043	2.045	18.96	83.06	27.69	48.01	113.4	19.06	7.831	12.92	29.28	15.97	11.98	3.926	32.15
0.65–1.1	20.16	16.44	1.472	32.37	145.6	44.40	93.43	214.5	28.56	21.47	9.243	58.32	40.13	22.38	15.54	63.31
0.43–0.65	20.83	16.81	10.74	40.24	53.14	16.12	32.33	71.41	21.59	15.48	11.37	44.09	49.09	74.99	7.362	161.46
< 0.43	14.15	16.96	0.737	33.21	52.20	19.69	33.21	74.11	13.01	4.722	8.916	17.10	22.25	16.64	11.36	46.95

Table 2. Statistical summary of aerosols in coarse, fine and ultrafine size fractions in summer, winter, monsoon and post-monsoon season at eastern central India

Size	Monsoon				Winter				Summer				Post-monsoon			
	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max
$PM_{2.5}$	67.50	55.05	14.99	124.78	334.02	67.46	226.68	396.86	82.22	46.38	42.45	148.79	127.42	79.95	60.77	230.98
$PM_{2.5-10}$	71.43	7.02	10.86	23.18	147.00	21.99	112.99	173.97	146.2	77.51	50.61	236.13	113.64	41.56	67.33	151.92
PM_{10}	138.9	50.73	103.6	197.05	481.02	74.66	378.64	570.83	228.4	117.27	113.06	384.91	241.06	118.83	135.50	382.90
PM_1	55.15	47.02	12.95	105.82	250.96	49.03	178.66	287.76	63.16	39.05	29.53	119.50	111.46	83.46	44.09	227.06

μg m^{-3}) during monsoon, post-monsoon, winter and summer season, respectively. Likewise, $PM_{2.5}$ abundance was obtained to be 334.02±67.46 (225.68–396.86 μg m^{-3}), 67.50±55.05 (14.99–124.78), 127.42±79.95 (60.77–230.98) and 82.22±46.38 (42.45–148.79 μg m^{-3}) during winter, monsoon, post-monsoon and summer season, respectively. However, during winter season PM_1 abundance was found significant during entire study period. The meteorological variables like less wind speed, less relative humidity and lower solar radiation leads to suppress the diffusion of aerosols and also cause lower planetary boundary layer height are responsible factors for accumulation of aerosols particles in troposphere[37,38]. Additionally, increase in biomass burning activity during winter season could be the major factor for high loading of aerosols particles. On the other hand, intense solar radiation with high planetary boundary layer height in summer season, cause wide diffusion of particles over cause low concentration in surface level[39–41]. The percentage contribution of ultrafine, fine and coarse mode particles was obtained to be 39, 48 and 51% during monsoon, 52, 69 and 30% during winter, 27, 35 and 64% during summer, 64, 52 and 47% during post-monsoon season, respectively. High fine mode contribution during winter could be due to the high biomass burning activities at eastern central India. On the other hand, high contribution of coarse particles was found during summer and post-monsoon season this must be due to soil dust and road dusts[42,43]. 24-h average loading of PM_{10} was more abundant in winter season over, post-monsoon, winter and summer season, respectively. aerosols loading obtained in our study was significantly higher in entire study period than the Central Pollution Control Board standards (60 μg m^{-3} for $PM_{2.5}$) India[44].

Possible human health implications:

Size of the aerosols particles is also an important factor that alters the approach of particles in the different part of lungs. The aerosols particles were segregated according to their approach towards the respiratory organs. They are upper respiratory tract, respiratory tract and lungs. The particle size 4.4 to 10, 1.0 to 4.4 and < 1.0 μm can interact with upper respiratory tract, respiratory tract and lungs[45]. The percentage loading of upper respiratory tract, respiratory tract and lungs were obtained to be 30, 69 and 52%, respectively during winter season. However, the percent contribution of lungs, respiratory tract and upper respiratory tract were found to be 64%, 52% and 47% during post-monsoon season.

In recent years air quality and public health has become one of the most emerging issue due to wide variety of chemical constituents and different size of particulate matters released from variety of sources into the atmosphere[46]. UNICEF (2016) has published a report in which they mentioned that in poor countries approximately 600,000 children every year dying due to bad air quality[47]. When we are dealing with PMs and their inverse effect on human health the major factor that controls the path of particles into respiratory system is the aerodynamic diameter, that depends upon the sources and formation mechanism of aerosols[48,49]. Particles with size < 2.5 μm and < 1 μm are given more attention because their extreme bad health impact due to their deeper approach into human respiratory system[50,51]. Several studies reported major diseases due to bad air quality i.e. cardiovascular disfunction, acute asthma, decreased in lung function, lower resistance to foreign substances etc.[52,53]. Some studies reported that some carcinogenic effects can be associated with indoor and outdoor burning sources of aerosols[54,55].

The criteria of health effect strongly associated with the particle size of the pollutants. Upper respiratory tract and nose are exposed with the particles of size greater than 2.1 μm whereas, different regions of lower respiratory tract are exposed with particle size less than the 2.1 μm. Submicron particles (size < 1) are shown to be most harmful because their approach to the lower respiratory region of lungs and they have also capacity to penetrate tissues[56]. Analysis regarding air pollutants at global level shows that atmospheric particulates are responsible for the 5% cases of cancer (lung, trachea, bronchi), 2% cases of mortality due to cardio-respiratory problems and 1% mortality due to the respiratory infections[57].

The results of calculated inhalation dose of EC in eastern central India during winter, summer, monsoon and post-monsoon are listed in Table 3. The calculated dose in this work is found significantly high during winter over post-monsoon, monsoon and summer period that can cause severe respiratory diseases in humans and there is a strong need of attention to protect human health. Earlier work reported that increase in detrimental pollutants present in air can cause increase in daily hospital visit due to respiratory disease from 2007 to 2013[58,59]. High value of inhalation dose of fine particles was obtained during winter for ultrafine mode, fine mode and coarse mode with average 3729.4, 4966.7 and 1962.6

Table 3. Statistical summary of aerosols inhalation dose in coarse, fine and ultrafine size fractions in summer, winter, monsoon and post-monsoon season at eastern central India

	Monsoon				Winter				Summer				Post-monsoon			
Size	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max	Avg	Sd	Min	Max
$PM_{2.5}$	1800.5	657.4	1342.2	2553.7	6234.0	967.6	4907.2	7397.9	2960.3	1519.9	1465.3	4988.5	3124.2	1540.0	1756.1	4962.4
$PM_{2.5-10}$	874.8	713.4	194.3	1617.1	4328.9	874.3	2937.8	5143.3	1065.5	601.1	550.2	1928.3	1651.4	1036.2	787.6	2993.6
PM_{10}	925.8	227.8	692.8	1147.9	1905.1	285.0	1464.4	2254.7	1894.8	1004.6	655.9	3060.2	1472.7	538.7	872.6	1968.9
PM_1	714.7	609.3	167.8	1371.5	3252.5	635.4	2315.5	3729.4	818.5	506.1	382.7	1548.8	1444.5	1081.7	571.4	2942.7

μm. This indicates the high health risk of particulate matters in during winter and post-monsoon season days. Also, inhalation dose of particulate matters found highest in fine mode over ultrafine mode and coarse mode. Lowest concentration was observed during monsoon period in coarse, fine and ultrafine mode.

Correlation analysis:

The Pearson correlation calculated between the nine different size fractions during winter, summer, post-monsoon and monsoon season and results are listed in Table 4. The Pearson correlation are marked to indicates the significance level $p < 0.05$ and $p < 0.01$. strong correlation between the

Table 4. Correlation of PM in nine different size fractions in winter, monsoon, summer and post-monsoon season at eastern central India

Size	> 9.0	5.8–9.0	4.7–5.8	3.3–4.7	2.1–3.3	1.1–2.1	0.65–1.1	0.43–0.65
Monsoon								
5.8–9.0	0.53[b]							
4.7–5.8	0.42[a]	0.92						
3.3–4.7	–0.75	–0.24	–0.48					
2.1–3.3	–0.06	–0.48	–0.25	–0.22				
1.1–2.1	–0.26	–0.02	–0.01	0.03	0.43[a]			
0.65–1.1	0.01	–0.03	–0.02	0.09	0.58[b]	0.59[b]		
0.43–0.65	0.15	0.04	0.07	–0.19	0.35	0.28	0.59[a]	
< 0.43	0.27	0.31	0.45[a]	–0.29	–0.18	–0.46	0.09	0.04
Summer								
5.8–9.0	0.91[b]							
4.7–5.8	0.89[b]	0.87[b]						
3.3–4.7	0.83[b]	0.89[b]	0.91[b]					
2.1–3.3	0.51[b]	0.46[b]	0.65[b]	0.61[b]				
1.1–2.1	0.41[b]	0.40[b]	0.55[b]	0.46[b]	0.30			
0.65–1.1	0.21	0.17	0.41[a]	0.42[a]	0.84[a]	0.81[a]		
0.43–0.65	0.08	0.15	0.31	0.21	0.67[b]	0.68[b]	0.77[b]	
< 0.43	0.18	0.28	0.41[a]	0.28	0.56[a]	0.45[a]	0.54[b]	0.52[b]
Winter								
5.8–9.0	0.48[b]							
4.7–5.8	0.48[b]	0.43[b]						
3.3–4.7	0.41[b]	0.70[b]	0.81[a]					
2.1–3.3	–0.23	–0.19	–0.04	–0.50[a]				
1.1–2.1	0.02	0.41[a]	–0.40[a]	–0.43[b]	0.54[b]			
0.65–1.1	0.08	–0.42[a]	–0.44[a]	–0.68	0.43	0.55[b]		
0.43–0.65	0.03	–0.23	–0.17	–0.57[b]	0.41[b]	0.45[a]	0.47[b]	
< 0.43	–0.44	–0.32	–0.23	–0.80	0.59	0.63	0.56	–0.46
Post-monsoon								
5.8–9.0	0.85[b]							
4.7–5.8	0.56[a]	0.69[b]						
3.3–4.7	0.65[b]	0.41[b]	0.58[b]					
2.1–3.3	0.22	0.28	0.25	0.26				
1.1–2.1	0.01	0.02	0.34	0.12	0.08			
0.65–1.1	0.04	0.06	0.39	0.08	0.14	0.91		
0.43–0.65	–0.09	–0.11	0.03	0.11	0.19	0.44	0.39	
< 0.43	0.09	0.29	0.30	0.57[a]	–0.06	0.46	0.31	0.15

[a]Correlation is significant at 0.01 level. [b]Correlation is significant at 0.05 level.

particles indicates the similar sources of emission. Whereas, weak correlation indicates the different source of origin[60,62]. During monsoon season, there is significant correlation between 0.4–0.7 and 0.7–1.0 μm and 2.1–2.5 μm particle size. However, the correlation between 9.0–10.0, 5.8–9.0 and 4.4–5.8 size ranges were found to be weak (Table 4). On the other hand, in winter season the 0.4 μm, 0.5–0.74, 0.7–1.0 and 2.1–2.5 μm size range were found significant at eastern central India. However, the weak correlation between the coarse and fine mode particles were found significantly negative. Such correlation may due to the increase in coal and wood burning for domestic cooking and heating purpose along with favourable meteorological conditions. Furthermore, strong correlation between 4.4–5.8, 5.8–9.0 and 2.5–9.0 μm size fractions in winter was obtained at eastern central India. Dusts particles from soil dusts-resuspension might be the responsible sources of coarse mode significant loading of aerosols. These was supported by the strong correlation between coarse mode particles. In winter season negative correlation in between coarse and fine particles obtained that indicates the contribution of different sources at eastern central India. However, during post monsoon season good correlation between particle size ranges 2.5–4.4 ad 5.8–9.0 μm was found. This correlation indicates that coarse particles are under the influence of soil dusts in post-monsoon season. The weak correlation between fine size fraction was found except for 1.0–2.1 and 0.7–1.0 μm indicated that there is less influence from cooking emission and biomass burning in post-monsoon season at eastern central India. In summer season the correlation between 5.8–9.0, 4.4–5.8 and 2.5–4.4 μm were tightly correlated ($r^2 = 0.91$), high wind speed and dry atmosphere during summer season could enhances the dust particles emission in the atmosphere. The strong correlation between size ranges 1.0–2.1, 0.7–1.0, 0.4–0.7 and < 0.4 μm (fine mode), such correlation may be due to significant emission from crop residue burning for land preparation for further farming. Sharma *et al.* (2005) also reported significant fine mode loading during crop residue burning[59].

Comparison with other studies:

Table 5 listed the particulate matter concentration from different literatures and compared with eastern central India. The obtained PM_{10} concentration during winter at eastern central India was found higher than those reported by Shandilya *et al.*, 2007; Akyuz and Cabuk, 2009; Calesso *et al.*, 2009; Awasthi *et al*., 2011; Stone *et al*., 2011; Godec *et al.*, 2012[61–69], however, summer time concentration was lower than those reported in India[59, 63] and Spain[27]. The fine particles contribution over PM_{10} at eastern central India was found higher than those reported at Satna, India[61], Canary Islands, Spain[70], but comparable with that found in Nagpur, India[67]; Patiala, India[66]; Delhi, India[63]; Kanpur, India[59]; Candiota, Brazil[69]; Gosan, Korea[68].

Long-range transport:

To find the possible importance of diverse source region on aerosol mass loading at the sampling sites the air mass

Table 5. Comparison of particulate matters abundance to earlier reported literatures

Sr. No.	Study site	Region	Period	PM_{10}	$PM_{2.5}$	PM_1	Refs.
1.	Eastern Central India	Urban	Winter	418.02	334.02	250.96	This Study
2.	Eastern Central India	Urban	Summer	228.4	82.22	63.16	This Study
3.	Eastern Central India	Urban	Monsoon	138.9	67.50	55.15	This Study
4.	Eastern Central India	Urban	Post-monsoon	241.06	127.42	111.46	This Study
5.	Nagpur, India	Urban	Annual	300	137	–	67
6.	Patiala, India	Rural	Annual	138	77.0	–	66
7.	Delhi, India	Urban	Winter	219	97.0	–	63
8.	Kanpur, India	Urban	Winter	272	146	–	59
9.	Satna, India	Urban	Winter	102	20.1	–	61
10.	Zonguldak, Turkey	Urban	Annual	44.1	–	–	64
11.	Candiota, Brazil	Rural	Annual	10.7	5.8	–	69
12.	Gosan, Korea	Rural	Winter	68	31	–	31
13.	Zagreb	Urban	Winter	42.7	37.4	–	68
14.	Canary	Urban	July 2002	312	98	26	70

trajectories were calculated using HYSPLIT model of the air resources laboratory of NOAA[71]. Trajectories ending at 500 m AGL were also calculated for detailed episode studies. Figs. 4, 5, 6 and 7 shows the five days backward air mass trajectories at 500 m reaching at eastern central India during monsoon, post-monsoon, winter and summer. Summer and winter season have significantly high particulate matters loading and their bimodal size distribution with minor peak in

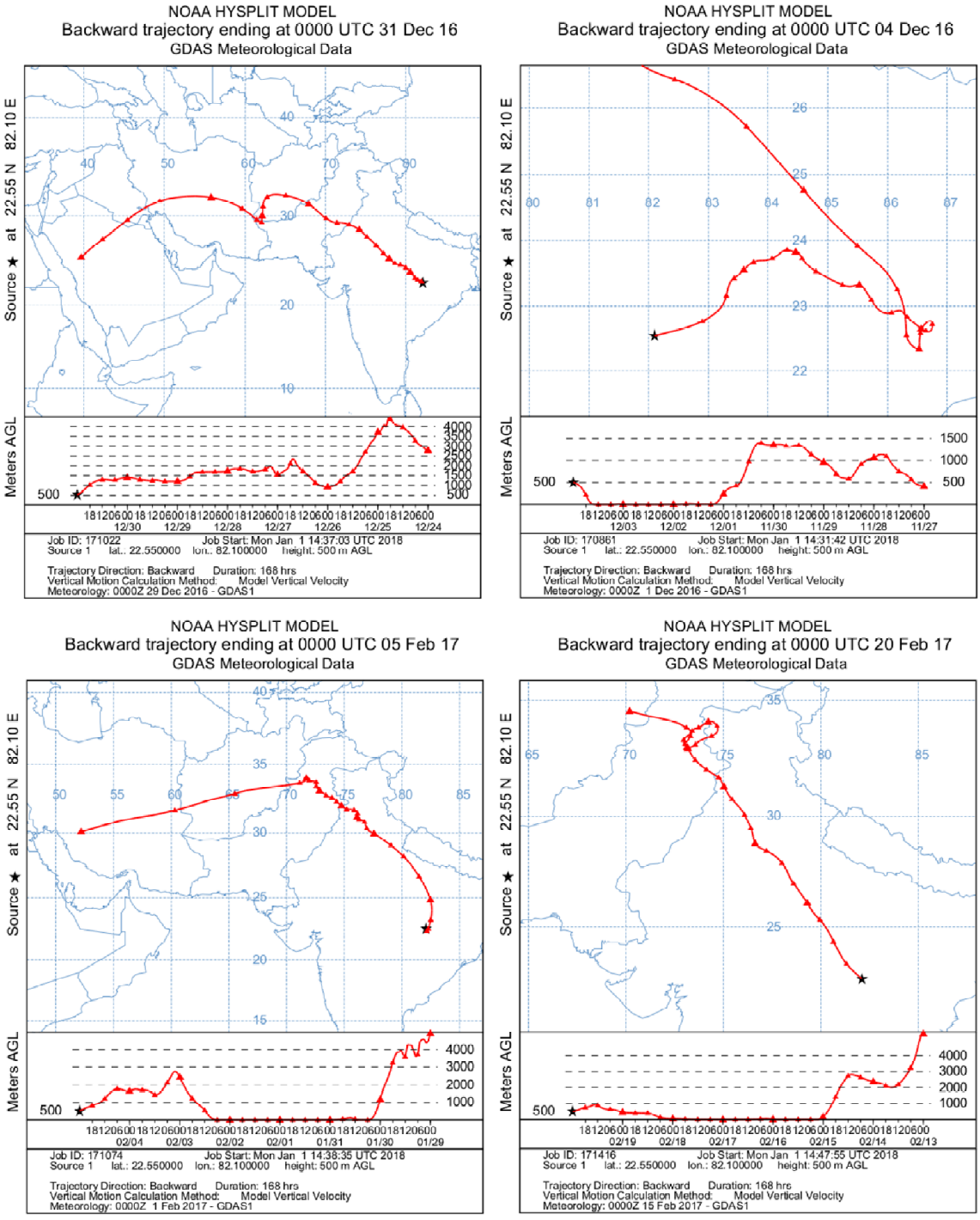

Fig. 4. Backward air mass trajectories arriving at eastern central India during winter season.

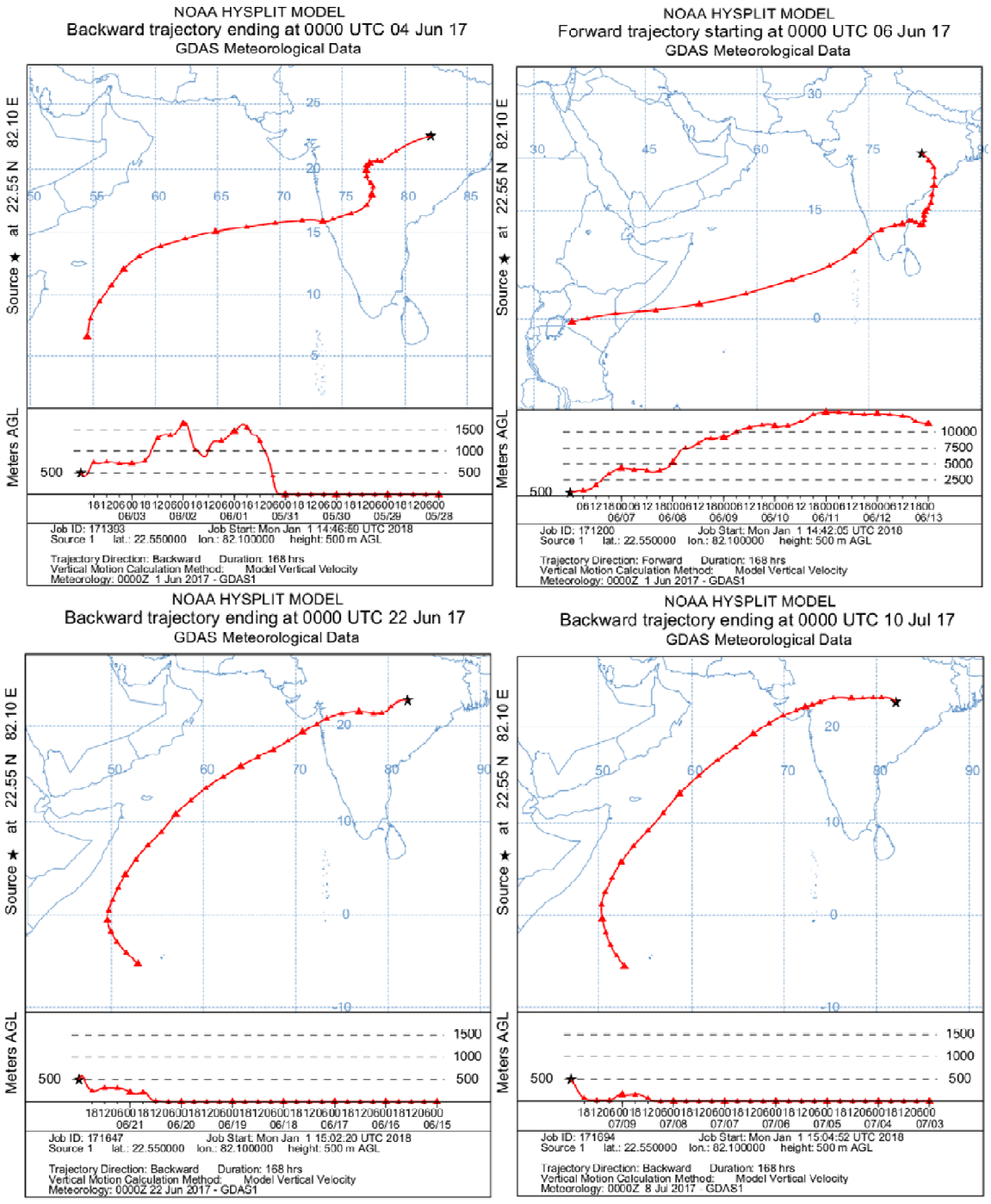

Fig. 5. Backward air mass trajectories arriving at eastern central India during summer season.

coarse mode and major peak in fine mode clearly indicates the strong possibilities of biomass burning. Air mass trajectories are segregated in three different ways, (i) air masses coming towards the south and south west and mostly from sea (monsoon), (ii) air masses originated from north direction (summer), (iii) mixed air masses (some trajectories are similar to monsoon whereas others are mixed trajectories). Monsoon season has lower aerosols loading, it's because the air masses are coming from sea which brings clean marine air to Raipur. Besides these trajectories are also cover-

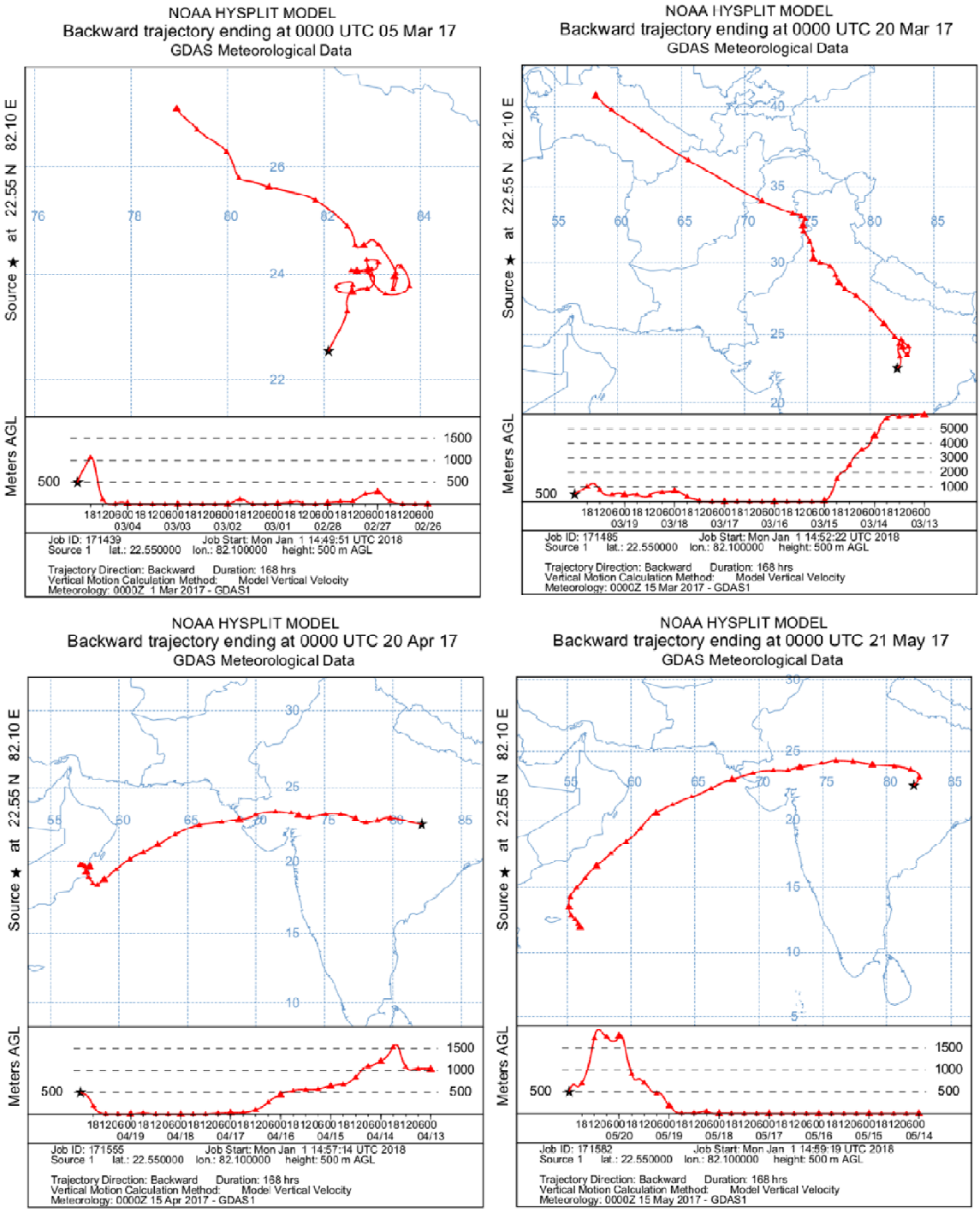

Fig. 6. Backward air mass trajectories arriving at eastern central India during post-monsoon season.

ing the coastal inland areas of north Indian region which must be the responsible for significant contribution of transported aerosols along with local contributions in coarse and fine mode both during monsoon. Post-monsoon season has air masses from sea with significant trajectories from Indo Gangetic Plain (IGP) region with prevailed meteorology would be the reason for the significantly high concentration of aerosols at eastern central India. IGP region is the most polluted

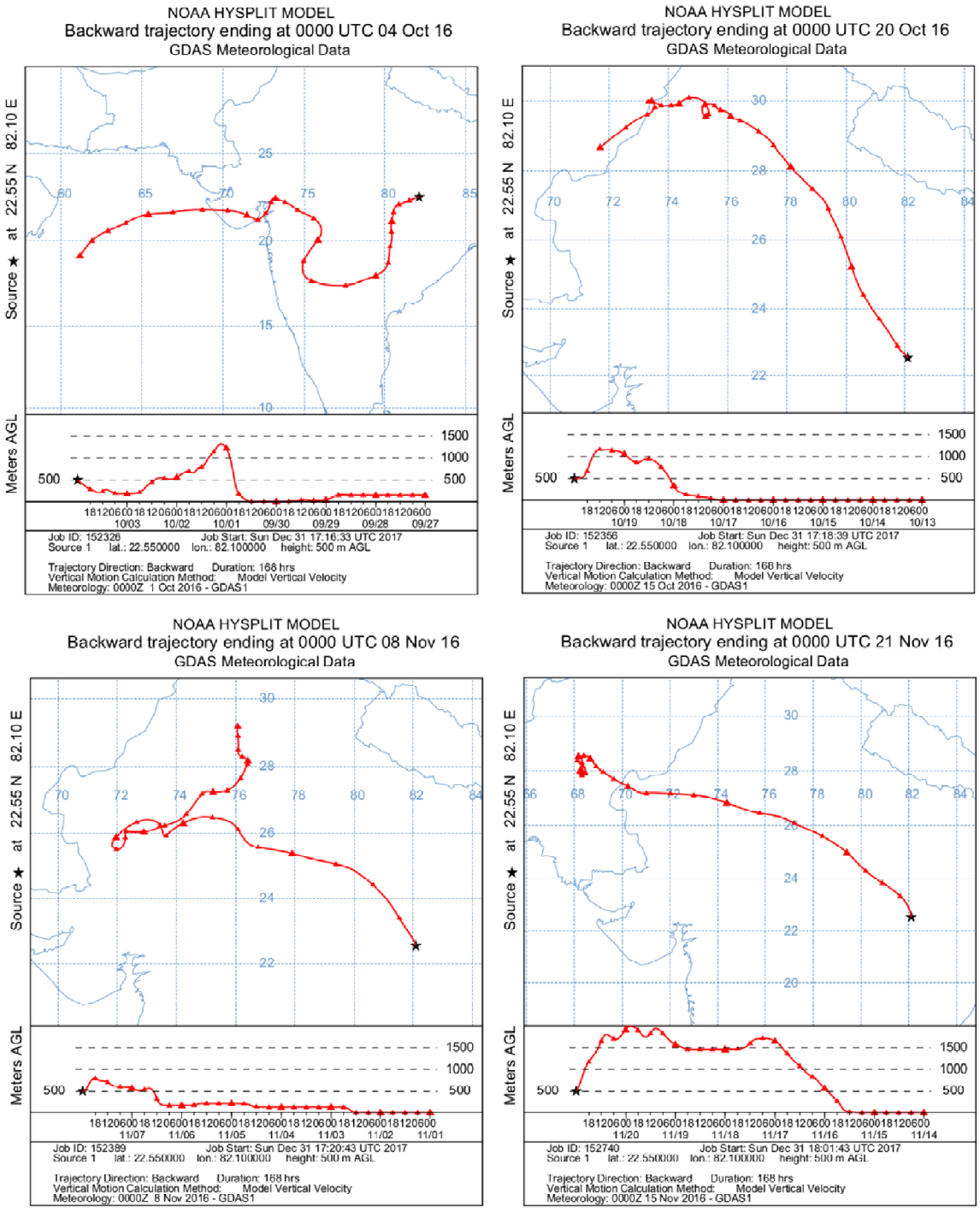

Fig. 7. Backward air mass trajectories arriving at eastern central India during monsoon season.

region in India. Ram *et al.* (2010) also reported that trajectories from IGP region can carry particulates and causes considerable loading of transported aerosols to targeted study site[72]. In the present work it has been found that high loading of coarse and fine mode aerosols obtained during post-monsoon which is due to transportation of aerosols form IGP region, in addition of prevailed meteorology and local emission. Summer and winter have the air masses originating

from north. Winter season has some trajectories from Thar desert which may be the responsible factor for high coarse mode aerosols loading in winter. Summer season has also the trajectories form IGP regions, which may cause high loading in winter due to the transportation from heavily polluted region and also with prevailed meteorology.

Conclusions

Size distributed air sampling was completed over an urban area of eastern central India during winter, monsoon, summer and post-monsoon season during 2016-2017. The percentage loading of upper respiratory tract, respiratory tract and lungs were obtained to be 30, 69 and 52%, respectively during winter season. However, the percent contribution of lungs, respiratory tract and upper respiratory tract were found to be 64%, 52%, and 47% during post-monsoon season. Significant loading in summer must due to the crop residue burning over nearby agriculture sites. Particle displayed bimodal size distribution in winter and monsoon season. The upper respiratory tract and lungs approaching particles were found more abundant in winter season however respiratory tract were observed to be high in summer season. During winter season good correlation between fine size fractions were obtained which might be due to domestic wood burning for cooking and heating purpose. However, in summer season strong correlation between fine size fractions were found which must be due to the crop residue burning in nearby agricultural fields. The strong correlation between coarse size fraction during post-monsoon and summer season obtained because of soil dusts resuspension and abrasion at eastern central India.

Acknowledgements

Authors are thankful to the head of the department School of Studies in Chemistry, Pt. Ravishankar Shukla University, Raipur, India for providing laboratory supports. The authors also thank DST-FIST (LEVEL-I) and UGC-SAP (DRS-II), New Delhi for financial provision.

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