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Analysis of Exceedance in the Daily Pm_{10} Mass Concentrations Over Five Mega South Indian Cities

[1]C. Manjunatha, T. Chakradhar Rao, [2]G. Balakrishnaiah, K. Rama Gopal, [3]T. Lokeswara Reddy, B. Elijabetthamma, [4]R. Ramakrishna Reddy
Aerosol & Atmospheric Research Laboratory, Department of Physics, Sri Krishnadevaraya University, Anantapur – 515003, A.P., India.
*Email: krgverma@yahoo.com**

Abstract- Particulate matter concentration in the atmosphere has a significant effect on human health and climate change. In addition to health impacts particulate matter bring about changes in rainfall pattern, temperature levels etc. Keeping in view the growing interest in the air pollution attributed morbidity and mortality, this study investigates the levels of ambient fine particulate matter over the rapidly developing and agglomerating Indian cities. The data used in this study for the period of 2010-2015 was collected in three different regions of the selected five cities such as industrial area; residential, rural and other areas; and sensitive areas of Thiruvananthapuram, Bangalore, Hyderabad, Vishakhapatnam and Pune. The highest PM_{10} values are observed over industrial areas of Bangalore and lowest values over sensitive areas of Thiruvananthapuram. All the cities are experienced critical and high levels of PM_{10} values during all the seasons with respect to WHO standards.

Index Terms- PM_{10}, WHO, NAAQS, Exceedance Factor

1. INTRODUCTION

Atmospheric aerosols, particularly those near the surface, have strong direct and indirect influence on the environment, air quality, visibility and human health with immediate repercussions. Also they alter the radiation budget of the Earth-atmosphere system through radiative forcing thereby affecting the climate on a long-term scale [1,2,3]. Even though the significance of aerosols in these processes are globally recognized and several efforts have been made to model their characteristics from the above perspective, there still exists large uncertainties not only globally [4] but also regionally [5,6,7]. This arises mainly because of the large heterogeneity (spatial and temporal) in their properties (physical and chemical composition) and lack of experimental data with adequate spatiotemporal resolution.

Near the surface, where the boundary layer process are active, the variability's in aerosol characteristics are considerably higher, primarily because of the large diversity in the sources and sinks of aerosols, their short atmospheric residence time and also transport processes [8,7,9]. The most important physical parameter of an aerosol is the particle size. Many important properties of particles are size dependent one. For instance, the deposition rate of inhaled particles in the respiratory track, which is needed for assessing health risk of ambient aerosols, depends on particle size. Particles generated by combustion are mostly in nuclei and accumulation mode, but may have some in the coarse particle mode. Particles produced by mechanical processes are generally in the coarse particle mode. The chemical composition of a particle is determined by its source. As particles generated by different processes have distinct size distributions and have different chemical compositions. Fine particles consist mostly of sulfates and nitrates, where coarse particles are mainly composed of crustal materials such as calcium carbonate and oxides of crustal elements (silicon, aluminum, titanium, and iron).

Over the last decade, the alarming air quality situation and health concerns over India, caused by airborne PM, lead to a variety studies. They include (i) fixed station monitoring [10]; (ii) emission inventory [11]; (iii) in-traffic exposures [12,13]; (iv) source apportionment [14,1516,17]; (v) satellite remote sensing of surface PM [18,19]; (vi) exposure to fine particles and health response relationship [20]; (vii) air pollution trends [21]; (viii) statistical modelling [22] etc. Most of these studies are city and urban centric studies due to various reasons such as lack of infrastructural support and trained man power in rural areas.

It is evident that especially PM_{10} encompasses a wide range of particle types regarding size, chemical composition (dust, combustion particles, marine primary particles, secondary organic aerosol, secondary inorganic aerosol), and sources (natural, traffic, industry, domestic households, secondary processes). This complex composition hampers the understanding of PM_{10} as a function of local sources, long-range transport and meteorology for a given site. Due to the scientific evidence of health effects as a result of airborne particulate matter exposure, health effects scientists have called for a more serious consideration of efficient abatement measures [23].

This study mainly focused on the variation of PM_{10} concentration over south Indian cities such as Thiruvananthapuram, Bangalore, Hyderabad, Vishakhapatnam and Pune within a time period of 2010-2015. The data was available in three distinct places of the each city like Industrial areas, residential; rural and other areas; and sensitive areas. This study emphasizes the exceedance of the daily and annual limit value of PM_{10} in the above said cities.

2. DATA AND STUDY LOCATIONS

The author retrieved PM_{10} data for the period between 2010 and 2015 from Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Govt. of India through https://data.gov.in/catalog/historical-daily-ambient-air-quality-data. In this chapter, the author focused on the concentrations of PM_{10} over major southern Indian cites and the exceedance factors with respect to National ambient air quality standards (NAAQS) and World Health Organisation (WHO) standards.

Concentration ranges for the different pollutants, based on the Notification Standards and area classes described by the Central Pollution Control Board (CPCB), can be calculated through an Exceedance Factor (EF) as follows:

$$EF = \frac{\text{Observed annual mean concentration of a criterion pollutant}}{\text{Annual standard for the respective pollutant and area class}}$$

Such air quality can be expressed in terms of low, moderate, high or critical according to the following criteria, based on the EF of the various sites monitored is shown in Table 1:

Table 1 Criteria for pollution levels classifications

Levels	EF (NAAQS)	EF (WHO)
Critical (Red)	> 1.5	> 3.5
High (Orange)	1.0 - 1.5	2.0 – 3.5
Moderate (Blue)	0.5 – 1.0	1.5 – 2.0
Low (Green)	< 0.5	< 1.5

The selected five major cities in the study area are located in southern part of India; Thiruvananthapuram (TVD; 8.50N, 77.52E), Bangalore (BLR; 13.03N, 77.54E), Hyderabad (HYD; 17.28N, 78.26E), Visakhapatnam (VSKP; 17.70N, 82.80E) and Pune (PUNE; 18.31N, 73.52E) are shown in Fig.1. Visakhapatnam is a major sea port on the south east coast of India and is the largest city in the Indian state of Andhra Pradesh. The city was identified as one of the fastest growing in the world, economically and demographically. It got the tag of a hotspot for pollution way back in 1990 when Nagpur-based NEERI, in a study, expressed serious concern over the level of pollution.

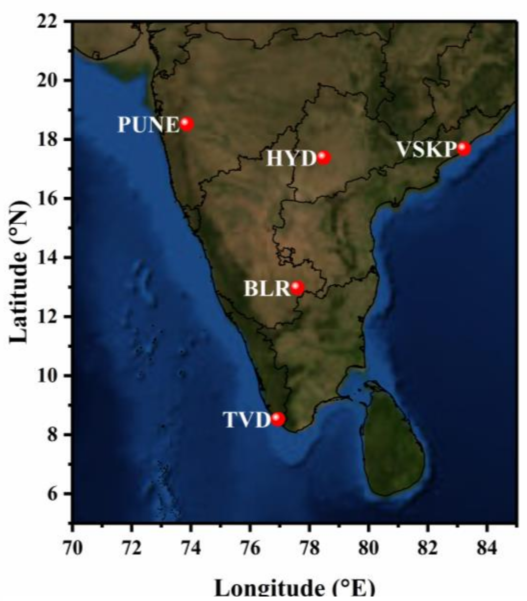


Fig. 1 Geographical locations of the five India cities (study locations)

Hyderabad has a tropical wet and dry climate bordering on a hot semiarid climate. It produces around 4500 tonnes of solid waste daily, which is transported from surrounding areas.

Bangalore is the fifth most populous city in India and the 18th most populous city in the world, with a growth rate of 65% during the last decade. Its elevation is the highest (900 m) among the major large cities of India.

Pune has a tropical wet and dry and hot arid climate. It is the ninth most populous city in India and the second largest in the state of Maharashtra after the state capital city of Mumbai. Also it is one of the fastest growing cities in the Asia Pacific region. The "Mercer 2015 Quality of Living rankings" evaluated local living conditions in more than 440 cities around the world where Pune ranked at 145, second in India after Hyderabad (138). Thiruvananthapuram is the capital city of the Indian state of Kerala. It is the largest and the most populous city in Kerala and the fifth largest urban agglomeration in Kerala. The city has a climate that borders between a tropical savannas' climate and a tropical monsoon climate. The humidity is high and rises to about 90% during the monsoon season. The city gets heavy rainfall of around 1700 mm per year.

3. RESULTS AND DISCUSSIONS

3.1. Annual distributions

Fig. 2 presents the annual distributions of the daily mean PM_{10} over five major southern Indian cities. Solid dot and the whiskers indicate the mean and the standard deviation, while the horizontal lines of the box from the bottom represent the 25, 50 and 75th percentile values respectively.

Industrial areas:

It depicts that the highest mean PM_{10} over industrial areas was recorded at BLR: (146.03 ± 23.77 µg m^{-3}) followed by PUNE (102.08 ± 39.05 µg m^{-3}), HYD (94.35 ± 33.14 µg m^{-3}), TVD (59.95 ± 7.04 µg m^{-3}) and VSKP (52.28 ± 11.73 µg m^{-3}). The PM_{10} range was found to be 199.13 to 106.36 µg m^{-3} over BLR, 216.45 to 42.38 µg m^{-3} over PUNE, 144.80 to 20.67 µg m^{-3} over HYD, 79.43 to 48.30 µg m^{-3} over TVD and 88 to 30 µg m^{-3} over VSKP.

Residential areas:

Over residential areas the highest mean PM_{10} was observed over BLR: (130.87 ± 40.01 µg m^{-3}) followed by PUNE (90.75 ± 29.05 µg m^{-3}), HYD (87.58 ± 19.09 µg m^{-3}), VSKP (79.23 ± 17.64 µg m^{-3}) and TVD (52.56 ± 3.61 µg m^{-3}). The PM_{10} range was found to be 217.5 to 61.67 µg m^{-3} over BLR, 171.41 to 43.77 µg m^{-3} over PUNE, 121.82 to 33.70 µg m^{-3} over HYD, 68.65 to 44.29 µg m^{-3} over TVD and 125.18 to 48.75 µg m^{-3} over VSKP.

The highest PM_{10} over IA and RR in Bangalore might be due to the advance of economic development in the city that leads to a rise in population and number of vehicles. Moreover, it is accommodating largest of number of IT, electronic and bio-tech industries in and around the city.

This has exerted a tremendous pressure on the infrastructure of the city which is now witnessing a significant increase in air pollutants and a deterioration of environmental quality and health. They include population and its density, types of emission sources, emission strengths, transport pathways, meteorological conditions, orography, agriculture residue burning, cultural contrast etc. [24, 25].

Sensitive areas:

The highest mean PM_{10} was observed over HYD: (80.8 ± 22.79 µg m^{-3}) followed by BLR (76.67 ± 32.23 µg m^{-3}), VSKP (53.31 ± 13.41 µg m^{-3}) and TVD (52.85 ± 3.76 µg m^{-3}). The PM_{10} range was found to be 186.11 to 33.69 µg m^{-3} over BLR, 138.25 to 25.20 µg m^{-3} over HYD, 64.43 to 43.96 µg m^{-3} over TVD and 82.89

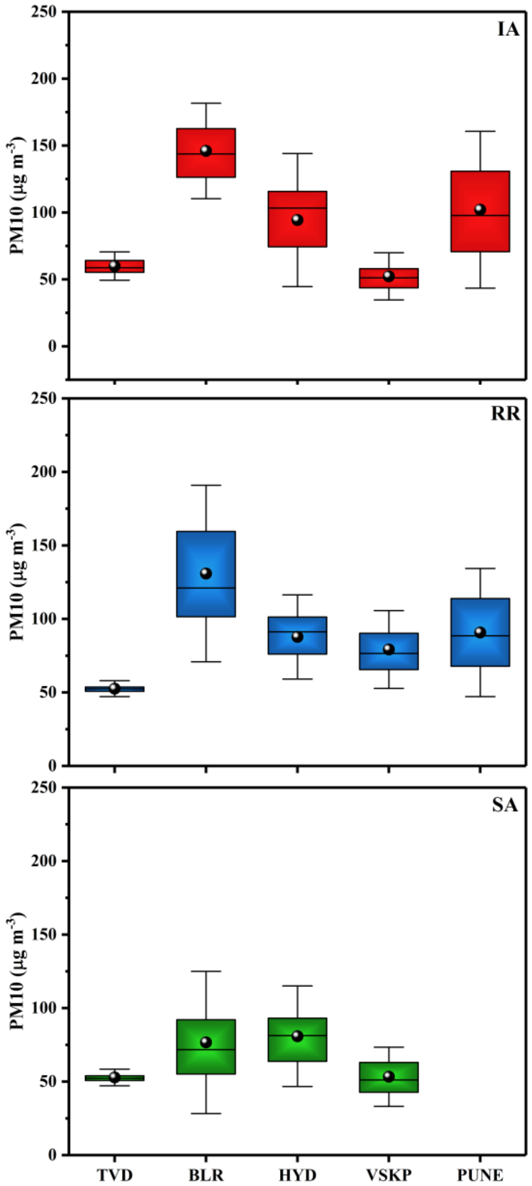


Fig. 2 Annual distributions of PM_{10} over the different areas of the study cities.

o 28.22 µg m^{-3} over VSKP. Rapid urbanization and growing industries around the HYD might be the region for the highest PM_{10} values over sensitive areas.

Higher AOD value in VSKP were reported by [26] that are due to intense anthropogenic activities associated with small and large scale industrial emissions, transportation and an elevated rate of combustion of fuels for domestic and commercial purposes in the city.

3.2. Seasonal distributions

The seasonal pattern of the daily mean PM_{10} over the study cities is shown in Fig. 3. The months of the year are divided into four major seasons: winter (WIN; December-February), summer (SUM; March-May), monsoon (MON; June-August), and post monsoon (POM; September-November), primarily on the basis of different meteorological conditions prevailing over the sites. Most of the rainfall occurs in the monsoon months across Indian (except southeast of India, where it receives rainfall during October and November).

The meteorological conditions will be intermediate in post-monsoon months. For all the study cities and areas within, WIN season recorded the highest PM_{10} values followed by SUM. But in VSKP Residential areas SUM being the highest followed by WIN, POM and MON. The combined effect of the increased emissions, the stable metrological conditions and shallow PBLH are responsible for the highest PM_{10} values during WIN. Lowest PM_{10} concentrations are observed in MON season. TVD being located in south west of India receives most of the rainfall during retreating monsoon. Wet scavenging of aerosol particles plays a major role during MON months resulting in the lower concentrations.

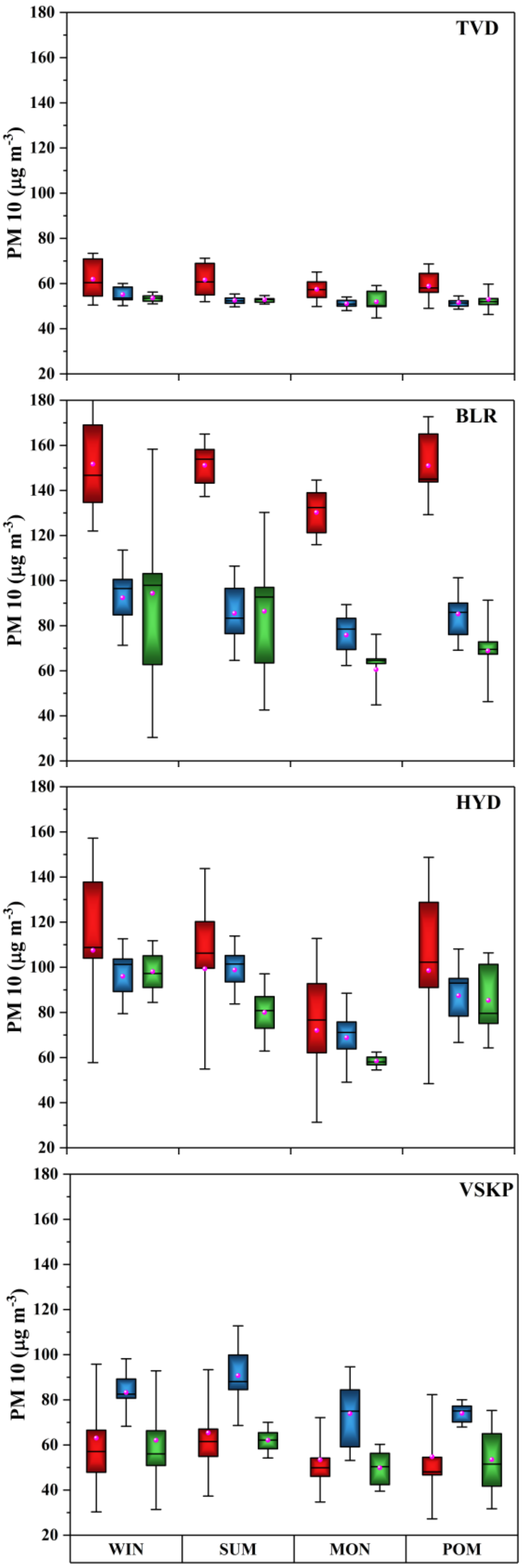
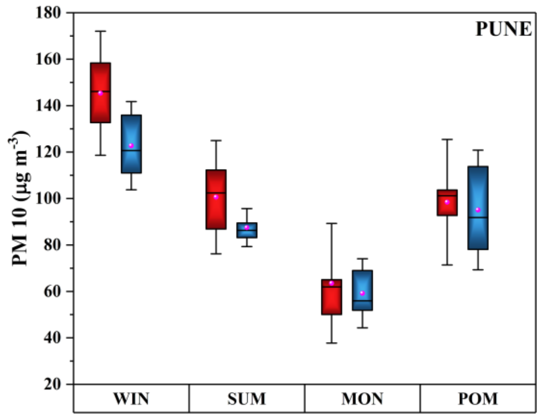


Fig. 3 Seasonal distributions of daily mean PM_{10} over the Industrial Areas (Red), Residential, rural and other areas (Blue) and Sensitive areas (Green) of Thiruvananthapuram, Bangalore, Hyderabad, Vishakhapatnam cities.

Table 2



Same as Fig. 4 but for Pune city

SUM concentrations are intermediate between that of POM and MON. Deeper PBLH and higher wind speeds during SUM compared to that of other seasons lessens the PM_{10}.

From Fig. 3, we can observe that the northward increasing trend in PM_{10} is conserved in all seasons. BLR records the highest concentrations compared to all other cities throughout all the seasons.

The statistical data of seasonal annual mean and median PM_{10} are given in Table 2, 3 and 4 for Industrial areas (IA), Residential, rural and other sites (RR) and sensitive areas (SA) respectively. Despite of the fact that the study locations are not located on the same longitude, there exists a clear latitudinal gradient in the PM_{10} as we move from TVD (south) to PUNE (north). TVD being the lowest and BLR is the highest; a sharp decrease of PM_{10} from BLR to VSKP was observed over and there after gradually increased to PUNE irrespective of study areas.

Over all the study cities a total of 17139 samples during 2010 – 2015 were analysed, among which 8974 fall in the RR, 5738 in IA and 2427 in SA. Less number of sampling were available over TVD (2546) whereas highest being HYD with 4298 number of samplings. In IA, RR and SA IQR values are high over BLR, it represents that BLR experiencing wide range of PM_{10} concentrations in compared with other cities.

Seasonal annual statistics on daily mean PM_{10} over the Industrial Area of study cities.

Industrial Area						
Station	**Season**	**N***	**Mean ($\mu g\ m^{-3}$)**	**Standard Deviation SD ($\mu g\ m^{-3}$)**	**Median ($\mu g\ m^{-3}$)**	**Inter quartile range IQR ($\mu g\ m^{-3}$)**
TVD	Win	154	61	10	59	9
	Sum	161	62	10	60	12
	Mon	163	58	8	57	11
	PoM	157	58	8	58	8
BLR	Win	320	151	79	134	90
	Sum	342	151	76	139	81
	Mon	373	129	61	121	67
	PoM	360	151	89	133	86
HYD	Win	395	115	54	114	74
	Sum	444	106	46	105	60
	Mon	434	82	44	76	58
	PoM	454	104	54	96	67
VSKP	Win	345	56	27	51	32
	Sum	345	58	31	52	38
	Mon	347	48	26	41	30
	PoM	339	47	24	42	28
PUNE	Win	155	147	65	146	67
	Sum	152	100	53	89	62
	Mon	155	65	46	49	41
	PoM	143	100	51	91	72

* N = Total number of datasets recorded during the study period.

In IA regions, highest mean and SD values of PM_{10} were observed over BLR with no significant seasonal distribution during Win (151 ± 79 $\mu g\ m^{-3}$), Sum (151 ± 76 $\mu g\ m^{-3}$) and PoM (151 ± 89 $\mu g\ m^{-3}$). Moreover median values during these seasons are similar with slight variation. Among which the highest median values observed over BRL during Sum (139 $\mu g\ m^{-3}$). The lowest mean and SD values were observed over VSKP with peak during Sum (58 ± 31 $\mu g\ m^{-3}$) and drops away PoM (47 ± 24 $\mu g\ m^{-3}$).

Table 3
Seasonal annual statistics on daily mean PM_{10} over the Residential, Rural and other Areas of study cities.

Residential, Rural and other Areas						
Station	**Season**	**N***	**Mean ($\mu g\ m^{-3}$)**	**Standard Deviation SD ($\mu g\ m^{-3}$)**	**Median ($\mu g\ m^{-3}$)**	**Inter quartile range IQR ($\mu g\ m^{-3}$)**
TVD	Win	321	55	21	53	4
	Sum	312	53	5	53	5
	Mon	320	51	5	51	5
	PoM	318	52	4	52	5
BLR	Win	234	157	81	146	113
	Sum	264	135	75	124	94
	Mon	265	117	65	108	75
	PoM	252	127	96	104	79
HYD	Win	518	98	44	96	54
	Sum	550	100	39	97	48
	Mon	536	75	34	71	44

	PoM	587	90	44	84	48
VSKP	Win	502	84	43	77	45
	Sum	514	88	48	80	51
	Mon	507	71	41	61	42
	PoM	511	74	39	68	42
PUNE	Win	618	124	52	124	63
	Sum	613	89	43	81	53
	Mon	607	58	40	43	40
	PoM	625	95	52	84	69

In RR regions, highest mean and SD values of PM_{10} were observed over BLR during Win (157 ± 81 μg m^{-3}) followed by Sum (135 ± 75 μg m^{-3}), PoM (127 ± 96 μg m^{-3}) and Mon (117 ± 65 μg m^{-3}). The lowest mean and SD values were observed over TVD with peak during Win (55 ± 21 μg m^{-3}) and drops away Mon (51 ± 5 μg m^{-3}). Moreover median and IQR values also follow the similar pattern with BLR being the highest and TVD the lowest. It also can be observed that seasonal mean PM_{10} values show highest during Win for all cities except for HYD and VSKP which shows during Sum.

Table 4
Seasonal annual statistics on daily mean PM_{10} over the Sensitive Area of study cities.

Sensitive Area						
Station	**Season**	**N***	**Mean (μg m^{-3})**	**Standard Deviation SD (μg m^{-3})**	**Median (μg m^{-3})**	**Inter quartile range IQR (μg m^{-3})**
TVD	Win	153	54	5	53	4
	Sum	166	53	4	53	4
	Mon	160	52	6	51	8
	PoM	161	53	6	52	5
BLR	Win	196	97	83	58	86
	Sum	235	80	54	56	69
	Mon	220	64	45	45	27
	PoM	221	69	57	46	40
HYD	Win	81	95	38	87	43
	Sum	109	81	29	79	31
	Mon	94	63	32	58	41
	PoM	96	81	34	78	40
VSKP	Win	134	55	25	51	31
	Sum	135	58	26	54	31
	Mon	134	47	20	43	28
	PoM	132	53	28	48	27
PUNE	Win	NA	NA	NA	NA	NA
	Sum	NA	NA	NA	NA	NA
	Mon	NA	NA	NA	NA	NA
	PoM	NA	NA	NA	NA	NA

In SA regions, the seasonal mean PM_{10} values show highest during Win for all cities except for VSKP which shows during Sum. The highest mean and SD values of PM_{10} were observed over BLR during Win (97 ± 83 μg m^{-3}) followed by HYD (95 ± 38 μg m^{-3}). The lowest mean and SD values were observed over TVD with peak during Win (54 ± 5 μg m^{-3}) and drops away Mon (52 ± 6 μg m^{-3}). Moreover median and IQR values also follow the similar pattern with BLR being the highest and TVD the lowest.

3.3. Frequency distribution of PM_{10} concentration

Figure 4 represents the statistical frequency distributions of daily PM_{10} concentration over IA, RR and SA for the five study cities. The entire datasets are divided into 16 bins starting from 0 to >300 μg m^{-3} with 20 μg m^{-3} interval each. The red and magenta short dashed lines represent the daily

PM_{10} limits proposed by WHO (50 µg m^{-3}) and NAAQR (100 µg m^{-3}). Over IR regions unimodal positively skewed distributions are observed over all the cities except BLR and HYD where multi model distributions are noticed.

The peak frequency of PM_{10} over TVD is at 40-60 µg m^{-3} bin with 56%, VSKP at 20-40 µg m^{-3} bin with 34% and PUNE at 40-60 µg m^{-3} bin with 21%. It clearly shows that, IA regions of TVD, VSKP and PUNE are within the permissible limits of both

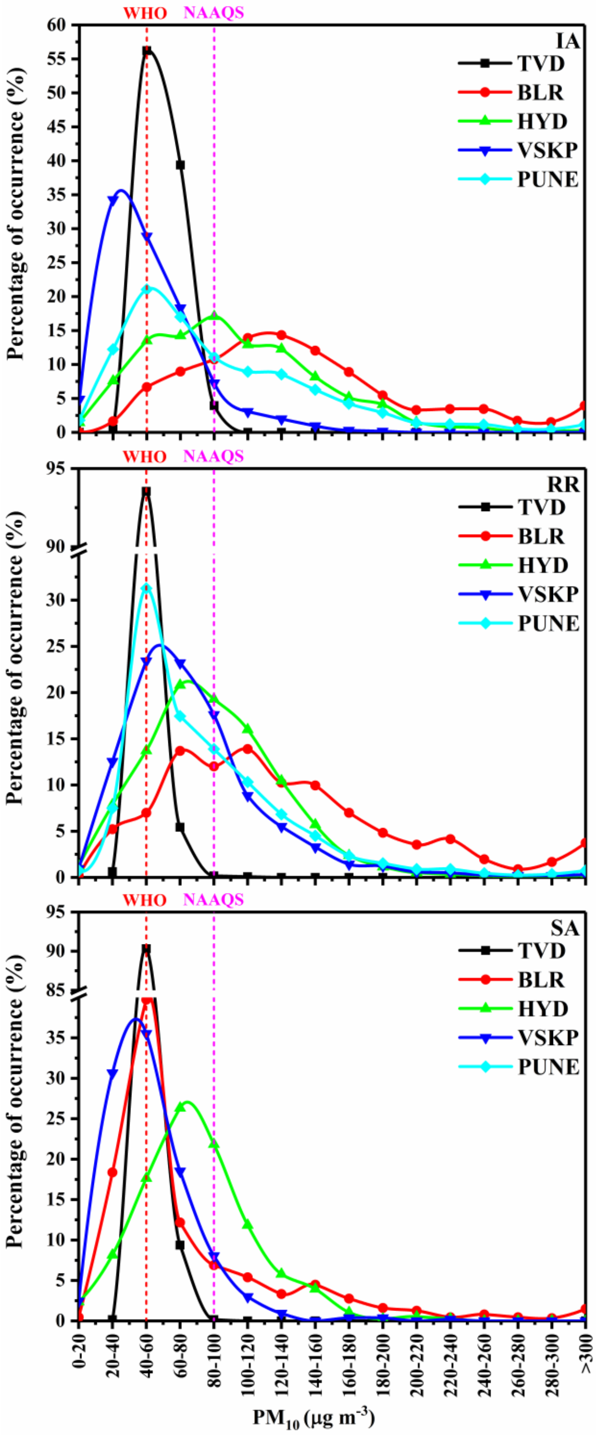


Fig.4 Frequency distribution (in %) of PM10 concentrations over IR, RR and SA regions of all the study cities

WHO and NAAQS standards. The PM_{10} concentrations over HYD and BLR are distributed to the higher concentrations those exceeds the permissible limits. HYD showed peak at 80-100 µg m^{-3} bin with 17% and BLR at 120-140 µg m^{-3} bin with 14%. Thus a remarkable atmospheric pollution induced by PM_{10} over IR regions of BLR and HYD can be sets them the most polluted areas as compared to the remaining study cities.

Except BLR, all RR regions of over the study cities showed a unimodal positively skewed distributions those are within the permissible limits of WHO and NAAQS. HYD, VSKP and PUNE cities showed less decreasing distributions those exceeds the NAAQS standards. But BLR showed two prominent peaks with 14% each, one within NAAQS standards at 60-80 µg m^{-3} and another that excceds NAAQS standards at 60-80 µg m^{-3} bins. This emphasize that, RR regions of HYD, VSKP and PUNE are at the edge of the permissible limits with high pollution whereas BLR is at critical pollution.

All the SA regions of the study cities are within the WHO and NAAQS standards. It is remarkable to note that BLR which showed pollution at critical levels over IA and RR regions showed ~ 40% of PM_{10} values are concentrated at 40-60 µg m^{-3} bin over BLR and very less prominent peak at 140-160 µg m^{-3} bin over SA regions. This signifies the importance of study on spatial distribution.

3.4. Weekday and weekend variations

The daily values of PM_{10} concentration during Monday through Friday taken as weekday whereas Saturday and Sunday as weekend BC concentration for the present analysis. Figure 5 shows the weekdays and weekends for four seasons and the statistics for the same are given in Table 5, 6 and 7 for IA, RR and SA respectively. Comparably strong weekday and weekend variations are observed over BLR and PUNE IR regions. Both weekday and weekend days over BLR and weekdays over PUNE exceeds the NAAQS daily standard. Similar variations are observed over RR regions but only BLR exceeds the standards. Similar latitudinal gradients are observed for the distributions of weekday and weekend concentrations among the study cities. A plunge in traffic emissions contribution to the ambient concentrations is expected during weekends. In traffic PM_{10} values are in general, found to be 1.5 times higher than that of ambient concentrations [13]. In contrast, similar weekday, weekend concentrations are observed over TVD, VSKP and HYD.

Table 5
Weekday and weekend statistics on daily mean PM_{10} over the Industrial Area of study cities.

Industrial Area						
Station	**Week**	**N**	**Mean ($\mu g\ m^{-3}$)**	**Standard Deviation SD ($\mu g\ m^{-3}$)**	**Median ($\mu g\ m^{-3}$)**	**Inter quartile range IQR ($\mu g\ m^{-3}$)**
TVD	WE	126	60	8	59	8
	WD	509	60	9	59	10
BLR	WE	217	150	83	133	84
	WD	1178	144	76	130	79
HYD	WE	454	104	50	98	68
	WD	1273	100	51	94	69
VSKP	WE	444	53	27	48	32
	WD	991	52	27	46	34
PUNE	WE	194	101	65	88	82
	WD	411	104	60	91	89

Table 6
Weekday and weekend statistics on daily mean PM_{10} over the Residential, Rural and other Areas of study cities.

Residential, Rural and other Areas						
Station	**Week**	**N**	**Mean ($\mu g\ m^{-3}$)**	**Standard Deviation SD ($\mu g\ m^{-3}$)**	**Median ($\mu g\ m^{-3}$)**	**Inter quartile range IQR ($\mu g\ m^{-3}$)**
TVD	WE	258	54	24	51	5
	WD	1013	52	5	52	6
BLR	WE	137	146	101	131	93
	WD	878	132	78	115	85
HYD	WE	539	94	41	89	51
	WD	1652	89	41	86	53
VSKP	WE	626	79	39	72	43
	WD	1467	79	44	70	46
PUNE	WE	456	89	53	78	80
	WD	2007	92	53	84	76

Table 7
Weekday and weekend statistics on daily mean PM_{10} over the Sensitive Area of study cities.

Sensitive Area						
Station	**Week**	**N**	**Mean ($\mu g\ m^{-3}$)**	**Standard Deviation SD ($\mu g\ m^{-3}$)**	**Median ($\mu g\ m^{-3}$)**	**Inter quartile range IQR ($\mu g\ m^{-3}$)**
TVD	WE	152	52	6	52	6
	WD	488	53	5	53	5
BLR	WE	128	69	55	44	37
	WD	744	78	62	52	51
HYD	WE	101	80	37	75	44
	WD	279	79	34	78	40
VSKP	WE	210	52	21	49	25
	WD	384	54	26	50	29
PUNE	WE	NA	NA	NA	NA	NA
	WD	NA	NA	NA	NA	NA

For BLR and PUNE, a significant amount of reduction in daily mean weekend concentrations compared to that of weekdays is observed over all types of areas except for Sensitive areas of BLR. The statistical data of the weekdays and weekends are as shown in tables 5-7. In 17139 samples during 2010 – 2015 over all the study cities 13274 (77%) fall under weekdays and 4042 (23%) fall under weekends. Unlike seasonal variations of IQR values, weekday and weekend IQR values showed large variability over both BLR and PUNE especially during weekends.

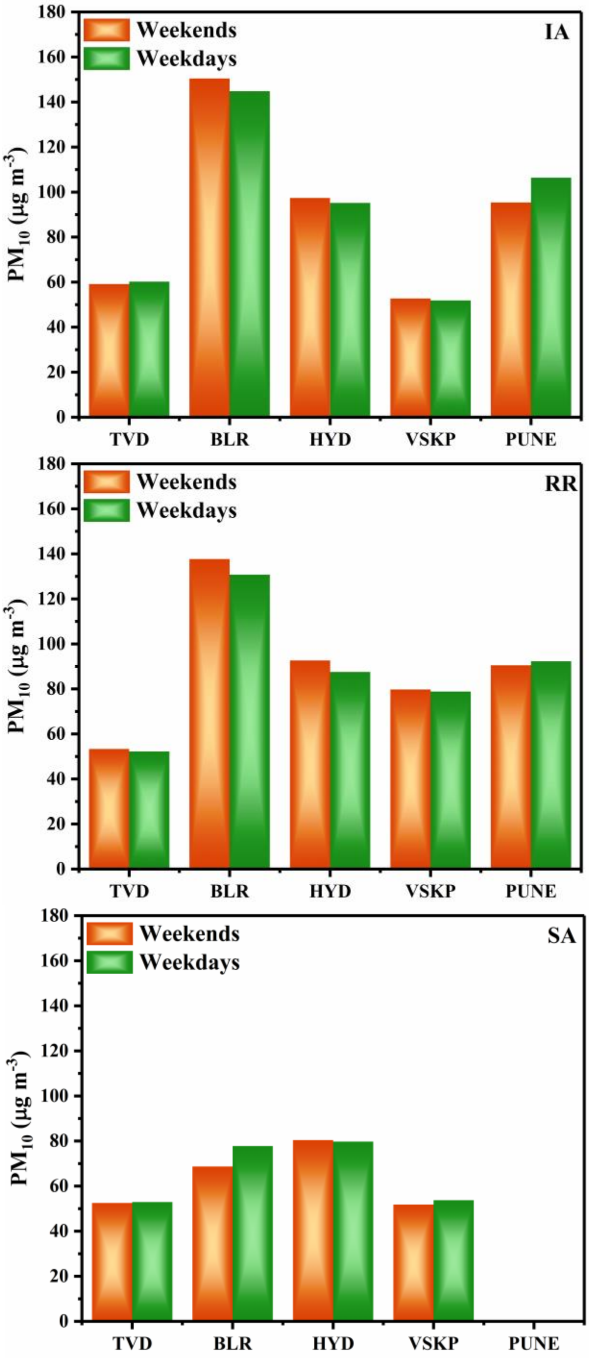


Fig. 5 Weekday (WD) and weekend (WE) distributions of daily mean PM10 over the study cities.

3.5. WHO and Indian NAAQS

In view of the public interest and their health, various world countries imposed National Ambient Air Quality Standards (NAAQS). In addition, World Health Organization (WHO) also offers global guidance on thresholds for the vital air pollutants that pose health risks. The PM_{10} NAAQS in India were set to 60 and 100 µg m^{-3} for annual and daily means respectively. The WHO standards are far less compared to Indian standards, 20 and 50 µg m^{-3} being the thresholds for the annual and daily mean PM_{10} respectively.

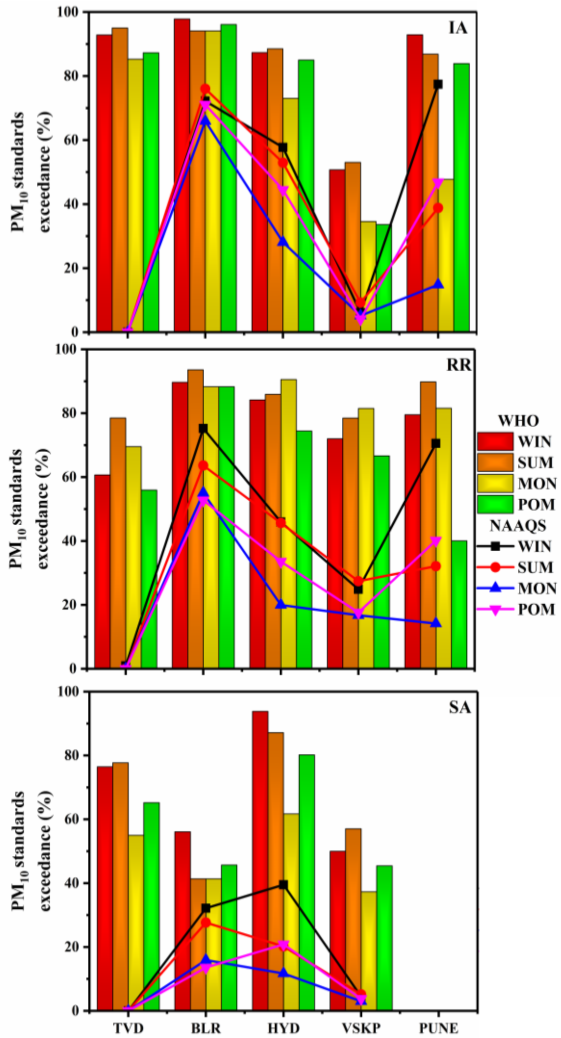


Fig.6 Season-wise exceedance days percentage with respect to WHO daily mean air quality standard for daily mean PM_{10} (Left y-axis); Indian NAAQS for daily mean PM_{10} (Right y-axis).

From Fig. 6, it can be observed that, large number of daily mean PM_{10} concentrations is exceeding the NAAQS, especially in winter. Exceedance of PM_{10} concentrations above the set standard can pose potential health hazard, especially to the sensitive groups such as children, elderly people and who are already suffering from respiratory and pulmonary ailments.

Seasonal wise PM_{10} exceedance (with respect to WHO and Indian NAAQS standard) days percentage of the daily mean PM_{10} are shown in Fig. 6. More than 90% of the WIN and SUM days over both TVD (IA, RR) and BLR (IA, RR) are observed to exceed the WHO standard. The lowest WHO exceedance day's percentages were observed over VSKP during all seasons. During all the seasons WHO exceedance day's percentages are comparable to that of IA areas over all study cities and SA areas being the lower of other two areas. MON recorded the lowest exceedance day's percentage during over all the study sites of IA and SA areas but in RR areas MON days being polluted than other seasons. With respect to daily mean Indian PM_{10} NAAQS, almost all of the WIN days are polluted and all MON days are less polluted. As observed in the annual and seasonal PM_{10} distributions, the exceedance days' percentage also shows similar latitudinal trends from TVD to PUNE in all seasons. Least number of polluted days is observed over TVD Followed by VSKP. In summary, WIN days pose higher health risk compared to other seasons and the risk (in all seasons).

3.6. Exceedance Factor

The main sources of PM_{10} are identified to be automobile exhausts (especially diesel) and road dust. Fig. 7 (based on NAAQ standards) and 8 (based on WHO standards) show the levels of PM_{10} during 2010 - 2015 at the five sites under consideration. Fig. 7 illustrates the year wise PM Exceedance Factor Classification based on NAAQS over the different areas of the study sites.

Green indicates Low, Blue: Moderate, Orange: High and Red: Critical levels of PM_{10}. Fig. 8 is same as Fig. 7 but the EF was estimated based on WHO standards. White shaded lines indicate the missing of data during the respective years and sites. From Fig. 7, it is clear that the Industrial area of BLR has seen alarmingly increasing levels of PM_{10} over all the study years, with an air quality classification of critical. The levels of PM_{10} were never below the recommended standard for the area over all the six years. Similarly HYD and PUNE have also shown critical levels during all the years except in the year 2010. The sensitive area varies from moderate to high levels of PM_{10} over all the study period and sites. All the areas of TVD were classified as the moderate polluted city for all the years except for the few years in industrial areas.

On the hand, from the Fig. 8 it is clear that all the study cities irrespective of the areas and study periods the air quality are at critical levels based on WHO standards.

A study conducted by The Energy Research Institute (TERI) concluded that 50% of Bangalore's PM_{10} is caused by dust.

A multitransit rail system (MTRS) proposed for Bangalore to improve the public transport system began its first construction phase of the project from 2007. The city witnessed more widening of roads and increased construction activities, inevitably increasing the dust level in the city. This may have

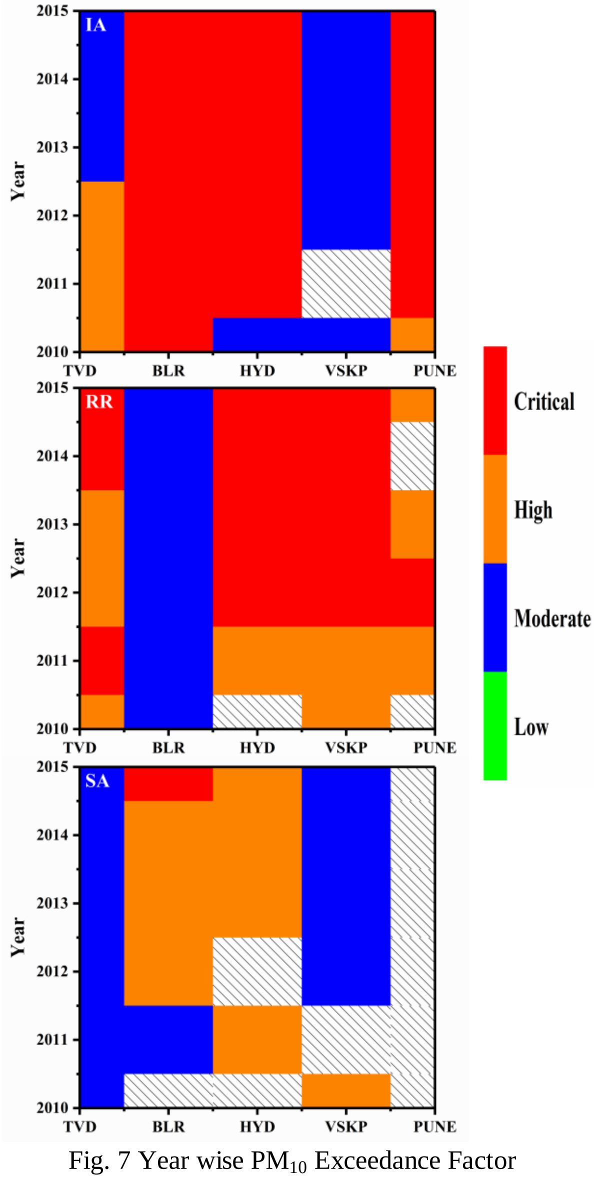


Fig. 7 Year wise PM_{10} Exceedance Factor Classification based on NAAQS over the different areas of the study sites

largely contributed to the elevated levels of PM_{10} at various locations of BLR.

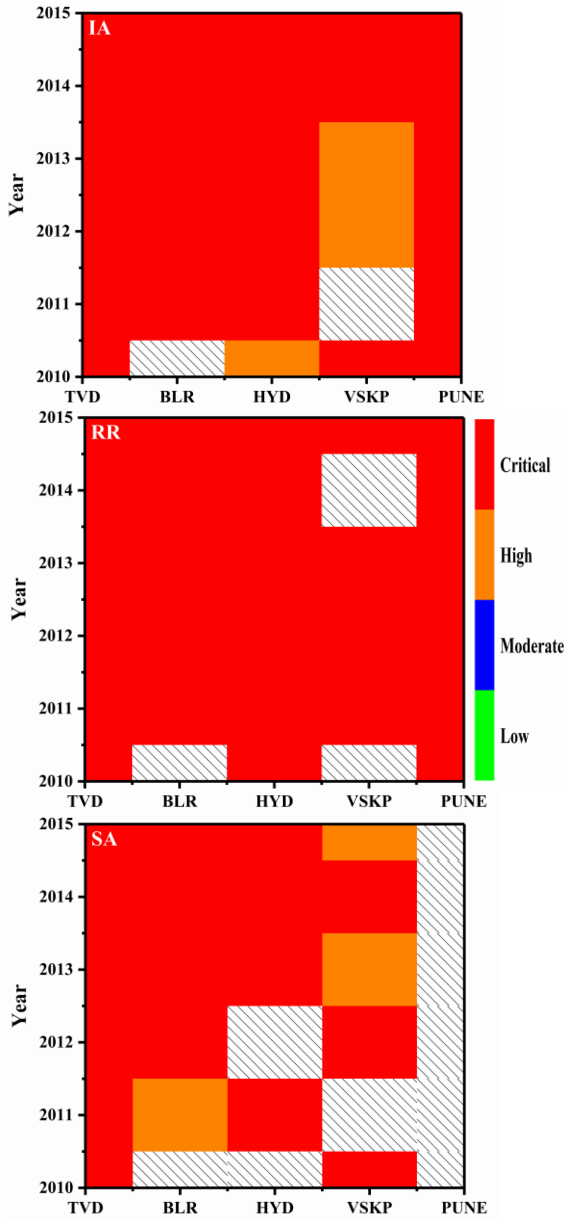


Fig. 8 Year wise PM_{10} Exceedance Factor Classification based on WHO standards over the different areas of the study sites

CONCLUSIONS:

- The highest PM_{10} values are observed over IA of BLR and lowest values over SA of TVD.
- The highest PM_{10} values are found during winter followed by summer, post monsoon and monsoon over all the cities except over RR of VSKP with interchange of winter with summer.
- Seasonal wise PM_{10} exceedance day's percentage indicates IA regions of TVD and BLR shows more than 90% during winter and summer with respective to WHO standards.
- The IA regions of BLR, HYD and PUNE are experiencing critical levels of PM_{10} with respect to NAAQS standards.
- All the cities are experiencing critical and high levels of PM_{10} values during all the seasons with respect to WHO standards.

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REFERENCES:

[1] Charlson, R. J., J. E. Lovelock, M. O. Andreae, and S. G. Warren, Oceanic phytoplankton, atmospheric sulphur, cloud albedo and cli- mate, Nature, 326, 655-661, 1987.

[2] Charlson, R. J., Schwartz, S. E., Hales, J.M., Cess, R. D., Coakley, J. A., Hansen, J. E., Hoffmann, D. J.: Climate forcing by anthropogenic aerosols. Science, 255, 423-440, 1992.

[3] Boucher, O., Anderson, T. L., 1995. General circulation model assess- ment of sensitivity of direct radiative forcing by anthropogenic sulfate aerosols to aerosol size and chemistry. J. Geophys. Res. 100, 26117– 26134.

[4] Penner, J. E., et al. (2001), Aerosols, their direct and indirect effects, in Climate Change 2001: The Scientific Basis, edited by J. T. Houghton et al., pp. 289–348, Cambridge Univ. Press, Cambridge, U. K.

[5] Ramanathan, V., Crutzen,P. J., Kiehl, J. T., Rosenfeld, D., 2001. Aerosol, climate and hydrological cycle. Science294,2119–2124.

[6] [6]Moorthy, K. K., A. Saha, B. S. N. Prasad, K. Niranjan, D. Jhurry, and P. S. Pillai, Aerosol optical depths over peninsular India and adjoining oceans during the INDOEX campaigns: Spatial, temporal, and spectral characteristics, Journal of Geophysical Research,106, 28,539 – 28,554, 2001

[7] Moorthy, K. K., Babu, S. S., and Satheesh, S. K. (2003), Aerosol spectral optical depths over the Bay of Bengal: Role of transport, Geophysical Research Letter, 30(5), 1249, doi:10.1029/2002GL016520

[8] Pillai, P.S., Suresh Babu, S., Krishna Moorthy, K., 2002. A study of PM, PM_{10} and $PM_{2.5}$ concentration at a tropical coastal station. Atmos. Res. 61, 149–167. https://doi.org/10.1016/S0169-8095(01)00136-3

[9] Vakeva M, Hameri K, Puhakka T, Nilsson E D, Holli H, and Makela J M, 2000, Effects of meteorological processes on aerosol particle size distribution in an urban background area, J Geophys Res 105, 9805.

[10] Tiwari, S., Chate, D.M., Pragya, P., Ali, K., Bisht, D.S., 2012. Variations in mass of the PM 10, PM 2.5 and PM 1 during the monsoon and the winter at New Delhi. Aerosol Air Qual. Res. 12 (1), 20–29.

[11] Guttikunda, S.K., Calori, G., 2013. A GIS based emissions inventory at 1 km×1 km spatial resolution for air pollution analysis in Delhi, India. Atmos. Environ. 67, 101–111.

[12] Srimuruganandam, B., Nagendra, S.S., 2011. Chemical characterization of PM 10 and PM 2.5 mass concentrations emitted by heterogeneous traffic. Sci. Total Environ. 409 (17), 3144–3157.

[13] Apte, J.S., Kirchstetter, T.W., Reich, A.H., Deshpande, S.J., Kaushik, G., Chel, A., Marshall, J.D., Nazaroff, W.W., 2011. Concentrations of fine, ultrafine, and black carbon particles in auto-rickshaws in New Delhi, India. Atmos. Environ. 45 (26), 4470–4480.

[14] Kumar, A.V., Patil, R.S., Nambi, K.S.V., 2001. Source apportionment of suspended particulate matter at two traffic junctions in Mumbai, India. Atmos. Environ. 35 (25), 4245–4251.

[15] Kar, S., Maity, J.P., Samal, A.C., Santra, S.C., 2010. Metallic components of traffic-induced urban aerosol, their spatial variation, and source apportionment. Environ. Monit. Assess. 168 (1), 561–574.

[16] Pant, P., Stephen, J., Baker, R. G., Guttikunda, S., Goel, A., Shukla, A., Roy, Harrison, M., 2015. Analysis of size-segregated winter season aerosol data from New Delhi, India. Atmos. Pollution Res. 1 – 10.

[17] Guo, H., Kota, S.H., Sahu, S.K., Hu, J., Ying, Q., Gao, A., Zhang, H., 2017. Source apportionment of PM2. 5 in North India using source-oriented air quality models. Environ. Pollut. 231, 426–436.

[18] Dey, S., Di Girolamo, L., van Donkelaar, A., Tripathi, S.N., Gupta, T., Mohan, M., 2012. Variability of outdoor fine particulate (PM 2.5) concentration in the Indian subcontinent: a remote sensing approach. Remote Sens. Environ. 127, 153–161.

[19] Sreekanth, V., Mahesh, B., Niranjan, K., 2017. Satellite remote sensing of fine particulate air pollutants over Indian mega cities. Adv. Space Res. 60 (10), 2268–2276.

[20] Tonne, C., Salmon, M., Sanchez, M., Sreekanth, V., Bhogadi, S., Sambandam, S., Balakrishnan, K., Kinra, S., Marshall, J.D., 2017. Integrated assessment of exposure to PM 2.5 in South India and its relation with cardiovascular risk: design of the CHAI observational cohort study. Int. J. Hyg. Environ. Health 220 (6), 1081–1088.

[21] Gurjar, B.R., Ravindra, K., Nagpure, A.S., 2016. Air pollution trends over Indian megacities and their local-to-global implications. Atmos. Environ. 142, 475–495

[22] Guttikunda, S.K., Kopakka, R.V., Dasari, P., Gertler, A.W., 2013. Receptor model-based source apportionment of particulate pollution in Hyderabad, India. Environ. Monit. Assess. 185 (7), 5585–5593.

[23] Annesi-Maesano, I., Forastiere, F., Kunzli, N., and Brunekref, B.: Particulate matter, science and EU policy, Eur. Respir. J., 29, 428–431, 2007.

[24] Guttikunda, S.K., Goel, R., Pant, P., 2014. Nature of air pollution, emission sources, and management in the Indian cities. Atmos. Environ. 95, 501–510.

[25] Pant P, Hegde P, Dumka U C, Sagar R, Satheesh S K, Moorthy K K, Saha A and Srivastava M K 2006 Aerosol Characteristics at a High Altitude Location in Central Himalayas: Optical Properties and Radia- tive Forcing; J. Geophys. Res. 111(D17) D17206, 10.1029/2005JD006768.

[26] Gopal, R.K., K. Raja Obul Reddy, G. Balakrishnaiah, S. MD. Arafath, N. Siva Kumar Reddy, T. Chakradhar Rao, T. Lokeswara Reddy, R. Ramakrishna Reddy. Regional trends of aerosol optical depth and their impact on cloud properties over southern India using MODIS data. Journal of Atmospheric and Solar-Terrestrial Physics, Vol.146, 38-48, (2016).