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Variability of Fine and Inhalable Particles in Controlled and Unbridled Anthropogenic Activities: From a Perspective of Lockdown Containment Measures in Visakhapatnam City

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ABSTRACT

Rapid industrialization and urbanization contributed to deteriorating air quality via the pollutants generated through industrial and concomitant activities. Air quality has an impact on human health, especially respiratory and heart related diseases. The present study attempts to analyze the average concentrations of fine particulate matter of the sizes $PM_{2.5}$ and PM_{10} in Visakhapatnam city of Andhra Pradesh state of India. The study infers that the $PM_{2.5}$ and the PM_{10} are predominantly dominated by the increasing vehicular traffic and the pollutants released by industrial activities including port. The seasonal variations of $PM_{2.5}$ and PM_{10} ratios showed the dominance of anthropogenic aerosols because of industrialization and heavy traffic in the city. The impact of lockdown as a preventive measure to contain COVID-19 during the period 25th March 3rd May 2020 improved air quality significantly which can be clearly seen in day and night time concentrations of $PM_{2.5}$ and PM_{10} during summer season.The study finds that day and night time average concentrations of $PM_{2.5}$ and PM_{10} are low in summer in comparison to the other seasons. The impact of lockdown as a preventive measure in COVID-19 pandemic period covering the period 25th March 3rd May 2020 is conspious and the lockdown containment measures improved the air quality significantly which can be inferred from the day and the night time concentrations of $PM_{2.5}$ and PM_{10} during summer season.

Keywords $PM_{2.5}$, PM_{10}, Lockdown, COVID-19,Visakhapatnam.

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INTRODUCTION

Rapid Industrialization and urbanization together contributed to increasing air pollution, which effects human health adversely (UN 2004, CEPI 2013, NEERI 2005, Yang 2002, Shendell *et al.* 2002, Wang *et al.* 2003). The sources include combustion processes in traffic, power plants, industry, agriculture and house-hold activities and biomass-burning (Cacciola *et al.* 2002, DOT 2002, Economopoulou and Economopoulos 2002). Fossil fuels-coal, oil and gas- the primary source of energy, are also responsible for production of particulate matter. In coastal areas, shipping activities have great impact on air pollution. Vehicular emissions from trans-boundary transport, road dust, firework activity and secondary inorganic aerosols also contribute to air pollution (Guttikunda *et al.* 2014, Singh *et al*. 2014, Das *et al*. 2015, Jingyan *et al.* 2017, Chandu and Dasari 2020). Among the pollutants the main focus is on particulate matter. The particulate matter with aerodynamic diameter of 2.5 and 10 μm are the most dangerous air pollutants. According to NAAQs'(expand), the permissible limits of $PM_{2.5}$ and PM_{10} are 60 and 100 $\mu g/m^3$ respectively. Particulate matter is a mixture of solid and liquid particle suspended in air (Wrobel *et al.* 2000). It varies in size and chemical composition. It originates from a wide range of natural and anthropogenic sources. Particulate matter is capable of remaining air-borne for a long period and especially with smaller dimensions. They can penetrate deep into respiratory tract. Elevated levels of PM possibly exacerbate rates of cardiovascular diseases, diabetes, cancer, pneumonia and lower respiratory infections (Samet *et al.* 2000, Sarnat *et al.* 2001, Katsouyanni *et al.* 2001, Ito *et al*. 2007). Meteorology also plays a significant role in formation, deposition and dispersion of the air pollutants. Significant meteorological parameters include temperature, humidity, rainfall, wind speed and wind direction. Low wind speed and temperature are favorable conditions for non-dispersion/stagnation of pollutants while high relative humidity and temperature can accelerate secondary PM formation by speeding up the chemical reactions (Beer 2001, Elminir 2005).

Visakhapatnam (17°422N; 83°202E) is a major industrial city in the north-eastern coastal Andhra Pradesh, India. The major industries along with the Port are located within a distance of 13 km from the coast. With major industries such as Hindustan Zinc Limited (HZL), Coromandel Fertilizers Limited (CFL), Visakhapatnam Port Trust (VPT), Hindustan Petroleum Corporation Limited (HPCL), Bharat Heavy Plates and Vessels (BHPV), Hindustan Polymers Limited (HPL), Visakhapatnam Steel Plant (SP), Coastal Chemicals (CC), Andhra Cement Company (ACC) and Simhadri Thermal Power Corporation (STPC) and about 200 ancillary industries, the city is experiencing rapid industrialization and urbanization. The emissions from these industries and port activities along with vehicular exhaust contribute significantly to air pollution in this city. This situation is further aggravated by atmospheric aerosol content which is the highest during the "dry" periods, resulting in a high ionic content due to precipitation scavenging. Marine aerosols also add to the industrial "contribution". The emissions and aerosols are shielded from the wind by mountains on three sides, only allowing coastal spray (marine aerosols) from the east. Visakhapatnam, thus, is subject to heavy air Pollution (Srinivas and Purushotham 2013, Chandu and Dasari 2020).

The present study analyses the variations in concentration of particulate matter in three seasons during November 2019 – May 2020.

MATERIALS AND METHODS

The real-time hourly mass concentrations of $PM_{2.5}$ and PM_{10}, were recorded by the National air quality index of the Central Pollution Control Board (CPCB) compiled for each city under the Ministry of Environment, Forests and Climate Change, Government of India. The instruments measuring the mass concentrations are located in the central point of the city. The data are publicly accessible and the data used in this paper were obtained from the website (https://app.cpcbccr.com/AQI_India/). The data related to meteorological parameters such as temperature, relative humidity, rainfall and wind speed are obtained from the India Meteorological Department (IMD).

Sampling protocol

$PM_{2.5}$ and PM_{10} concentrations for three seasons post monsoon (November- December), winter (January-February) and summer (March to May) during November 2019 – May 2020, and 1-hr average concentrations during day (7AM- 9PM) and night (9PM-7AM) time for the same study period are con-

Table 1. Season wise minimum and maximum values of PM concentrations.

Description		Post monsoon		Winter		Summer	
		$PM_{2.5}$ (μg/m³)	PM_{10}(μg/m³)	$PM_{2.5}$ (μg/m³)	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)	PM_{10}(μg/m³)
Entire season	Avg	121.91±13.32	109.30±13.51	120.31±16.47	108.25±16.21	123.59±5.74	113.58±6.68
	Max	153.17	140.93	149.59	159.76	53.17	85.33
	Min	101.45	90.38	73.01	75.75	23.45	44.18
	Avg	96.80±23.24	103.35±8.10	97.92±28.25	101.13±28.47	96.46±13.15	108.65±17.10
Day	Max	152.6	142.35	147.04	156.78	53.17	85.33
	Min	101.6	92.07	73.01	75.94	23.45	44.15
	Avg	35.96±8.10	63.18±11.83	36.11±10.10	63.07±14.91	36.42±4.34	65.10±6.00
Night	Max	138.04	127.49	129.10	145.13	46.47	79.32
	Min	116.84	104.23	83.31	89.73	31.11	58.25

sidered for the study.

RESULTS AND DISCUSSION

Table 1 summarizes the average PM concentrations during post monsoon, winter and summer seasons. During the post monsoon season, the average concentrations of $PM_{2.5}$ and PM_{10} were found to be in the range of 101.45-153.17 μg/m³ and 90.38 and 140.93 μg/m³ respectively whereas in winter and summer they ranged between 73.01-149.59 μg/m³, 75.75-159.76 μg/m³ and 23.45-53.17 μg/m³, 44.18-85.38 μg/m³ respectively. The average $PM_{2.5}$ concentrations for post monsoon, winter and summer were found to be 121.91±13.32, 120.31±16.47, 123.59±5.74 μg/m³ respectively. On the other hand, the average PM_{10} concentrations are 109.30±13.51, 108.25±16.21, 113.58±6.68 μg/m³ for post monsoon, winter and summer respectively. The standard deviation of PM concentrations was lower in summer and higher in winter compared to the other seasons. The higher deviation in winter can be attributed to low wind speed and suspension of particulates in a stable atmosphere for longer hours due to favorable inversion conditions and hence hovering of suspended particles to stagnate over an area arresting any ventilation or dispersion of the pollutants.

Table 2 provides the ratios of $PM_{2.5}/PM_{10}$. The ratio and upper and lower limit are high during post monsoon when compared to the other seasons. The ratio of $PM_{2.5}/PM_{10}$ ranged between 1.03–1.24, 0.8-1.07 and 0.49-0.63 for post monsoon, winter and summer respectively. In all seasons, the day time ratios are high compared to night time. The seasonal variations of $PM_{2.5}$ /PM_{10} ratios range between 0.48 and 1.24 which shows the dominance of anthropogenic aerosols because of industrialization and heavy traffic in Visakhapatnam city.

The correlation between $PM_{2.5}$ and PM_{10} during day and night time and for entire seasons of pre-monsoon, winter and summer is shown in Table 3. Higher R^2–value is observed during day time in all three seasons and low R^2–value is observed at night time in post monsoon season (R^2= 0.25). Except at night

Table 2. Hourly average PM concentrations, PM ratios and standard deviations for post-monsoon, winter and summer seasons.

Description		$PM_{2.5}$ (μg/m³)	PM_{10}(μg/m³)	$PM_{2.5}$/ PM_{10}
	Entire season	121.91±13.32	109.30±13.51	1.11±0.05
Post monsoon	Day	120.31±16.47	108.25±16.21	1.11±0.048
	Night	123.59±5.74	113.58±6.68	1.09±0.06
	Entire season	96.80±23.24	103.35±8.10	0.93±0.05
	Day	97.92±28.25	101.13±28.47	0.96±0.05
Winter	Night	96.46±13.15	108.65±17.10	0.89±0.035
	Entire season	35.96±8.10	63.18±11.83	0.56±0.03
	Day	36.11±10.10	63.07±14.91	0.56±0.04
Summer	Night	36.42±4.34	65.10±6.00	0.55±0.03

Table 3. Correlation between $PM_{2.5}$ and PM_{10} concentrations.

	Post-monsoon		Winter		Summer	
	Best-fit equation	R^2	Best-fit equation	R^2	Best-fit equation	R^2
Entire season	0.8987x+23.686	0.83	0.9165x+2.076	0.91	0.6587x-5.6566	0.92
Day	0.9721x+15.086	0.91	0.97033x-0.1998	0.95	0.6563x-5.2738	0.93
Night	0.433x+74.331	0.25	0.7503x+14.9542	0.95	0.6392x-5.1917	0.77

time in post monsoon season, the correlation during day time, night time and for entire season was very high. During peak traffic hours, day time $PM_{2.5}$ and PM_{10} exhibited high correlation in all seasons. The day time correlations for post monsoon, winter and summer are 0.91, 0.95 and 0.93 respectively.

Compared to other seasons, high correlation between $PM_{2.5}$ and PM_{10} is found in winter during day (R^2=0.95), night (R^2=0.95) and for entire season (R^2=0.91). The R-squared of linear regression model between $PM_{2.5}$ and PM_{10} is 0.95 in winter representing remarkable coherence between the two of them. The remarkable coherence indicates the proportion of $PM_{2.5}$ contained in PM_{10} is high and stable. This indicates that fine particulate matter with diameter less than 2.5 µm may be the main component of PM_{10} at this location.

Table 4 and Fig. 1, represent frequency distribution of $PM_{2.5}$ and PM_{10} during the study period. The

Table 4. Percentage of frequency distribution 24-h average of PM concentrations.

	Post-monsoon		Winter		Summer	
AQI	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
0 - 50	9	5	10	3	83	31
51 - 100	29	31	58	45	17	68
101 - 200	50	60	29	49	0	1
201 - 300	10	4	3	3	0	0
>300	2	0	0	0	0	0

PM concentrations are divided into five categories for all the seasons. It is observed that 50 % of time the PM concentrations during post monsoon are under moderate category (100 – 200 µg/m^3) while 10 % and 4 % of time $PM_{2.5}$ and PM_{10} fall under poor category. During winter season 29 % and 49 % of time the $PM_{2.5}$ and PM_{10} concentrations are under moderate level. 3% of both the concentrations fall under poor category in this season. The lockdown effect imposed during March 25th – May 3rd of 2021 i.e., during summer season could be due to controlled/ suspended industrial activities topped with lesser quantum of vehicular traffic and due to better dispersion conditions, there

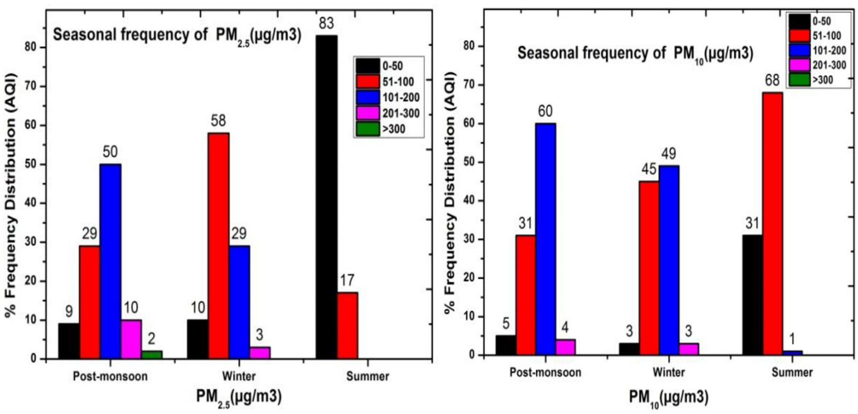

Fig. 1. Frequency distribution of (a) $PM_{2.5}$ and (b) PM_{10} concentrations during the study period.

Table 5. Minimum, Maximum and Average values of meteorological data season wise.

	Post-monsoon			Winter			Summer		
	Min	Mix	Avg	Min	Mix	Avg	Min	Max	Avg
Temperature (°C)	23.47	30.26	26.27	22.69	29.10	25.44	27.16	32.73	29.61
Humidity (%)	62.13	77.54	71.20	67.73	80.63	75.45	65.53	83.41	75.38
Rainfall (mm)	0	0.003279	0.000273	0	5.08	0.66	0	15.31	1.56
Wind speed (m/sec)	2.12	3.89	2.91	2.00	4.14	2.66	2.66	5.06	3.61

is improvement in the air quality which is clearly observed from the values of $PM_{2.5}$ and PM_{10}. 83 % of time $PM_{2.5}$, 68 % of time PM_{10} in summer season are under good category.

The minimum, maximum and average values of meteorological data recorded during post monsoon, winter and summer seasons are shown in Table 5. The average temperature, humidity and rainfall recorded during post monsoon, winter and summer are 26.27 °C, 71.20%, 0.0002 mm, 25.44 °C, 65.53%, 0mm, 29.61 °C, 75.38% and 1.56 mm respectively. The wind speed is low in winter and post monsoon and high in summer season. The average wind speed recorded during post monsoon, winter and summer are 2.91, 2.66 and 3.61 m/sec respectively. It is evident from Figs. 2 – 5 that $PM_{2.5}$ and PM_{10} are positively correlated with humidity and windspeed. A negative correlation is observed with temperature. In post monsoon season, a low positive correlation with rainfall

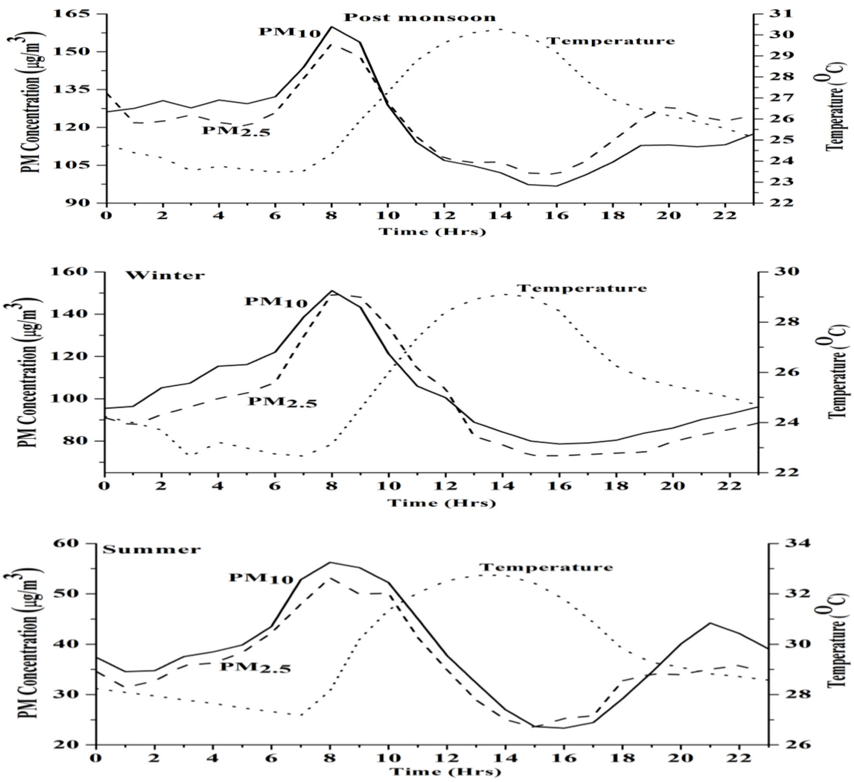

Fig. 2. $PM_{2.5}$ and PM_{10} versus temperature during study period.

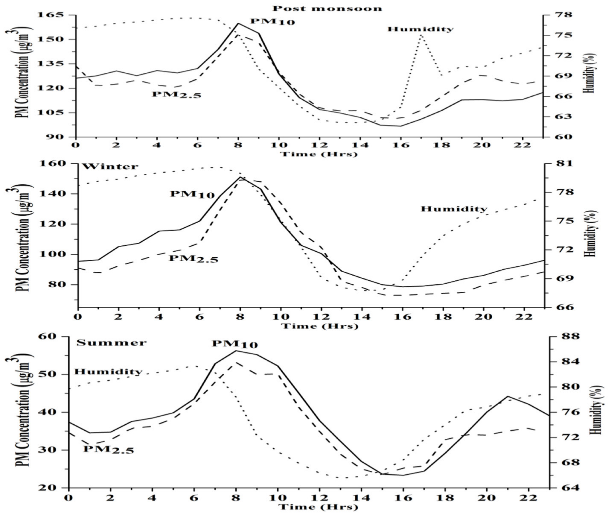

Fig. 3. $PM_{2.5}$ and PM_{10} versus humidity during study period.

is observed. In winter and summer, the particulate matter is negatively correlated with rainfall.

CONCLUSION

The seasonal variations of $PM_{2.5}$ and PM_{10} during three seasons during November 2019 – May 2020 are investigated. It is observed that day and night time average concentrations of $PM_{2.5}$ and PM_{10} are low in summer compared to the other seasons. The impact of lockdown as a preventive measure in COVID-19 covering the period 25th March – 3rd May 2020 improved air quality significantly which can be clearly seen in day and night time concentrations of $PM_{2.5}$ and PM_{10}

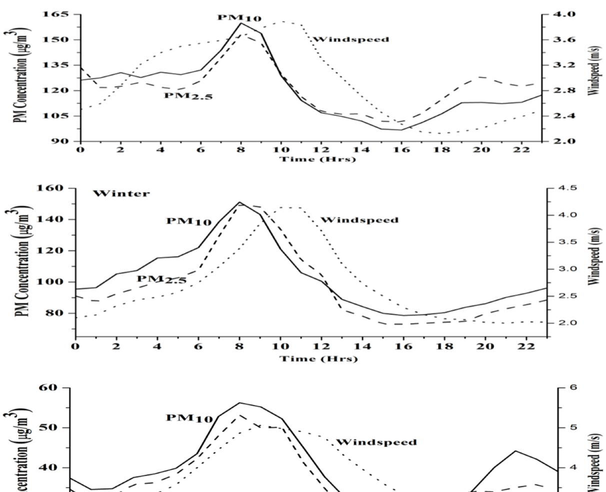

Fig. 4. $PM_{2.5}$ and PM_{10} versus windspeed during study period.

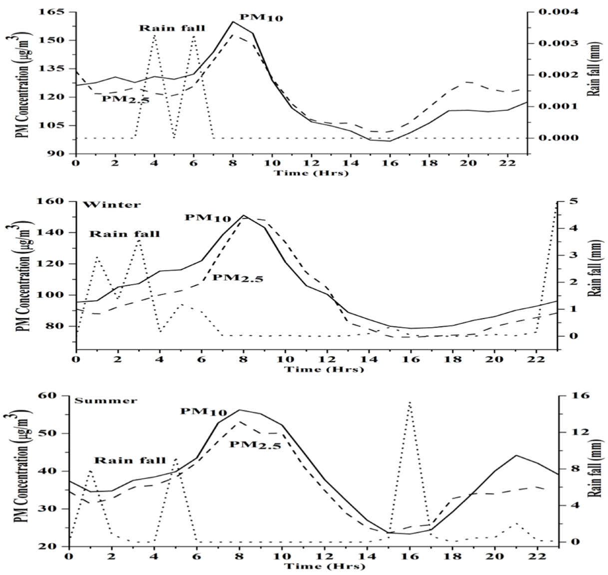

Fig. 5. $PM_{2.5}$ and PM_{10} versus rainfall during study period.

during summer season. A higher standard deviation observed in PM concentrations during winter season could be attributed to low wind speed and suspension of paricles for long hours due to unfavorable meteorological conditions. The seasonal variations of $PM_{2.5}$/PM_{10} ratios showed the dominance of anthropogenic aerosols because of industrialization and heavy traffic in the city. During peak traffic hours, day time $PM_{2.5}$ and PM_{10} exhibited high R^2 values in all seasons. The R square in linear regression model between $PM_{2.5}$ and PM_{10} during winter (day, night time and for entire season) showed remarkable coherence indicating the proportion of $PM_{2.5}$ contained in PM_{10} is high and stable at this location. Most of the time the frequency distribution of $PM_{2.5}$ and PM_{10} during winter and post-monsoon seasons fall under moderate category while in summer 83% of time $PM_{2.5}$, 68% of time PM_{10} fall under good category due to lockdown imposed and due to better dispersion conditions. The influence of lockdown is also observed in day and night time average values of $PM_{2.5}$ and PM_{10}. Very low average values are observed. A significant positive correlation of $PM_{2.5}$ and PM_{10} with humidity and wind speed is observed. Hence, meteorological factors also played a vital role in formation and dispersion of particulates.

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