Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 19 No. 3 pp. 1187-1193 2020
Original Research Paper
https://doi.org/10.46488/NEPT.2020.v19i03.032
Open Access Journal

Variation in Concentrations of $PM_{2.5}$ and PM_{10} During the Four Seasons at the Port City of Visakhapatnam, Andhra Pradesh, India

Kavitha Chandu and Madhavaprasad Dasari†
Department of Electronics and Physics, GITAM Institute of Science, GITAM (Deemed to be) University, Visakhapatnam, 530045, Andhra Pradesh, India
†Corresponding author: Madhavaprasad Dasari; madhavaprasaddasari@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 15-10-2019
Revised: 02-11-2019
Accepted: 11-12-2019

Key Words:
Air quality
Particulate matter
Air pollution
Gaseous pollutants

ABSTRACT

This paper presents a summary of $PM_{2.5}$, PM_{10} and gaseous pollutant concentrations measured during each season of the year from March 1, 2018 to February 28, 2019 in Visakhapatnam city (17.6868°N, 83.2185°E) located on the east coast of India. The city is studded with 14 major industries and surrounded on three sides by mountains and the Bay of Bengal on the fourth side. The monthly variations of mass concentrations of $PM_{2.5}$, PM_{10} and gaseous pollutants SO_2, NO_2 and CO recorded revealed the impact of atmospheric pollutants originating from industry, urbanization and increased automobile traffic. The seasonal variability of PM concentrations, highest in winter and lowest in summer, is observed. The annual averages for 2018 in Visakhapatnam are 103.5 ± 55.1 μg/m^3 and 111.5 ± 29.1 μg/m^3 for $PM_{2.5}$ and PM_{10} respectively. To establish the causal relationship between $PM_{2.5}$, PM_{10} and the gaseous pollutants we used Pearson correlation and regression statistical methods. The Pearson correlation coefficients between PMs and gaseous pollutants were either high or moderate. Regression results further confirmed that NO_2 and SO_2 significantly impacted $PM_{2.5}$ and PM_{10} in Visakhapatnam city.

INTRODUCTION

Exposure to particulate matter $PM_{2.5}$ and PM_{10} with an aerodynamic diameter less than 2.5 and 10 μm respectively is a global concern due to their adverse health effects. Prolonged exposure to these particles affects healthy people and seriously impacts those with existing diseases. It causes breathing discomfort for people with asthma and heart diseases. According to WHO, an increase in total PM by 10 μg/m^3 per year increases mortality by 6 per cent. Most cities in India have been experiencing severe air pollution due to fast-paced urbanization and rapid economic growth. SPM primarily originating from gaseous pollutants is posing a grave threat to human health. Gaseous pollutants CO, SO_2 and NO_2 are reported in several studies to be leading to high PM levels. Several studies considered the pollutant conditions in cities across the world and analysed the impact of these pollutants on human health (Samet 2000, Sarnat 2001, Katsouyanni 2001, Ito et al. 2007). However, studies on Visakhapatnam city are scanty and even those done refer to an earlier period.

The research presented here is an analysis of $PM_{2.5}$ and PM_{10} concentrations from the industrial zone of Visakhapatnam. The industrial development, initiated around 1950, triggered a population explosion in Visakhapatnam. The population of Visakhapatnam in the year 2018 as per estimated data was 4.056 Million (Population of India 2018). The city is studded with major industries mainly 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). About 200 ancillary industries were also established to supplement the main industries, which turned the central basin of Visakhapatnam into an “air-polluting chimney”. The city was declared as one of the critical (NEERI 2005) and severely polluted areas (CEPI 2013) in the country.

The city with an area of about 680 km^2 is surrounded on three sides by mountains and the Bay of Bengal on the fourth. It is effectively shielded from winds, with only marine air moving into the basin. The major industries along with the Port are located within a distance of 13 km from the coast.

Combustion emits large quantities of chemicals from industries such as zinc, fertilizer, polymers, cement, steel production and petroleum. This situation is further aggravated by atmospheric aerosol content which is 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, when compared to inland areas. Also, urbanization increased automobile traffic, and industrialization produces large emissions of SO_x and NO_x. The concentrations of air pollution vary from location to location as they depend on atmospheric conditions (Murthy 2004) like wind direction, speed, temperature and humidity.

In India, 99.9% of the country's population resides in areas that exceed the WHO Air Quality Guideline of 10 µg/m^3 (annual average), and half of the population resides in areas where the Indian National Ambient Air Quality Standard (NAAQS) for PM2.5 (40 µg/m^3) is exceeded (Greenstone et al. 2015, Srinivas 2013, Venkataraman et al. 2018). In another report, the annual averages for 2012 in Vishakhapatnam were 70.4±29.7, 18.9±14.4 and 15.6±6.3 for PM_{10}, SO_2, and NO_2 respectively (Guttikunda et al. 2015). Rao & Satish (2014) reported that the cause of air pollution in Visakhapatnam is not only due to the industries but also due to traffic.

Against this background, the present study focuses on analysing the mass concentrations of PM and gaseous pollutants. The objectives of the study are to examine the present levels of PM concentrations and their causative factors.

MATERIALS AND METHODS

The real time hourly mass concentrations of $PM_{2.5}$, PM_{10}, CO, NO_2 and SO_2 are recorded by National Air Quality Index of Central Pollution Control Board compiled for each city under the Ministry of Environment, Forests and Climate Change, India. The instruments measuring the mass concentrations are located in the central point of the city. The mass concentrations of $PM_{2.5}$ and PM_{10} are measured using beta attenuation method. The gas pollutants NO_2, SO_2 and CO are measured using the gas phase chemiluminescence method, ultraviolet fluorescence method and NDIR spectroscopy respectively. The data are publicly accessible and data used in this paper were obtained from the website (https://app.cpcbccr.com/).

The hourly mean variations of $PM_{2.5}$, PM_{10}, NO_2, SO_2 and CO in each season (Summer: March, April and May, Rainy: June, July, August and September, Autumn: October and November, Winter: December, January and February) during March 2018 - February 2019 at the present location were measured.

RESULTS AND DISCUSSION

The annual mean $PM_{2.5,}$ PM_{10} and the gaseous pollutants NO_2, SO_2 and CO concentrations in Visakhapatnam are 103.514.4±3.0 ,49.3±8.6 ,29.1±111.5 ,55.1± and 35.57.8± µg/m^3, respectively for the year 2018-2019. Both $PM_{2.5}$ and PM_{10} levels have exceeded the annual mean limit, posing a high health risk (Balakrishnan et al. 2013, CPCB 2009). Based on the annual average values, the worse air quality may be attributable to some specific feature of local/regional emission sources mixed with meteorological influences. The mean values of concentrations of PMs and air pollutants for different seasons are listed in Table 1.

Seasonal Variations

The hourly data were used to examine diurnal variability of $PM_{2.5}$ and PM_{10} concentrations and major air pollutants in each season. The seasonal variability of $PM_{2.5}$ (Fig. 1) and PM_{10} (Fig. 2) is lowest in summer and highest in winter. The higher concentrations of $PM_{2.5}$ and PM_{10} were observed during winter (178.5, 150.7 µg/m^3 respectively) and autumn (111.05, 115.6 µg/m^3 respectively) than summer and rainy seasons (Latha & Badarinath 2005). The PM concentrations are high during daytime than night time. The peak value was observed at 11:00 a.m. and falls to lowest in afternoon hours at 1:00 p.m. It is evident from NO_2 (Fig. 3) observations, that the increase in PM after 4:00 p.m. and before 11:00 a.m. is because of vehicle emissions as a result of transportation in rush hours. The heavy-duty vehicle traffic is more during the morning and night hours. As traffic-related emissions are less from 12:00 p.m. to 3:00 p.m., there is a significant decrease in NO_2 and PM concentrations in all seasons. The emissions from heavy-duty vehicles are more than those of light weight vehicles. The decreasing boundary layer heights also contribute to an increase in PM concentrations after 4:00 p.m. In all the seasons during night time, the high $PM_{2.5}$ levels

Table 1: Mean values of PMs and gaseous pollutants for different seasons in Visakhapatnam.

	Summer	Rainy	Winter	Autumn	Annual Mean
$PM_{2.5}$	58.24±10	66.46±6.2	178.57±41.8	111.05±22.5	103.58±55.1
PM_{10}	84.74±10.8	95.10±5.8	150.77±37.8	115.68±20.9	111.57±29.1
NO_2	42.37±10.7	49.49±9.29	61.48±25.8	43.97±15.3	49.33±8.6
SO_2	16.74±8.19	12.96±2.07	17.23±6.2	10.78±2.5	14.43±3
CO	28.79±9.5	32.84±8.8	46.98±11.2	33.75±5.16	35.59±7.9

are due to accumulation of emissions from automobiles and secondary PM formation.

The variation pattern of SO_2 (Fig. 4) is similar in different seasons and exhibited unique high SO_2 levels in summer. During summer, the major contributing factors for SO_2 may be coal stocked in Port and used in thermal power plant and other industries and vehicle exhaust. It is well known that wind flows from south-west direction during summer and rainy seasons where all the industries are located while the airflow is from northeast direction during the remaining part of the year. The wind direction could be obstructing the pollutants to go into the atmosphere during winter.

The variations in CO concentrations (Fig. 5) peaks during morning and evening traffic hours and valley in afternoon shows a clear link to the boundary layer height evolution.

Pearson Correlation Coefficients

Correlation method is used to gauge the extent and nature of the relationship between each of the impacting (independent) variables considered in the present study and PM levels. The results are presented in Table 2. The Pearson correlation coefficients between PMs and NO_2 and SO_2, as observed (Table 2) were either high or moderate in different seasons ($PM_{2.5}$ with NO_2: r =0.89-0.59; PM_{10} with NO_2: r = 0.89-0.79; $PM_{2.5}$ with SO_2: r = 0.85-0.47; PM_{10} with SO_2: r = 0.39-0.79, $PM_{2.5}$ with CO: r =0.71-0.43; PM_{10} with CO: r =0.70-0.33). The correlation between $PM_{2.5}$ and CO is higher than the correlation between PM_{10} and CO.

It may be observed that all the three independent variables exhibited the theoretically expected positive relationship with PM levels indicating that NO_2, SO_2 and CO contribute

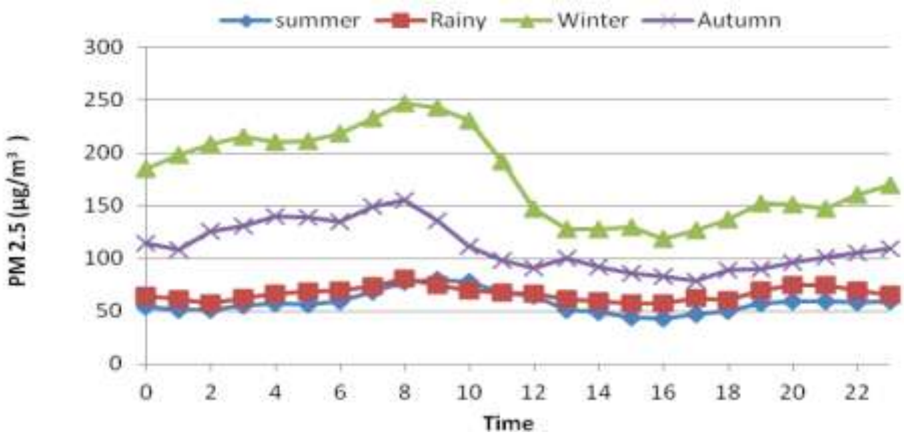

Fig. 1: Diurnal variations of hourly $PM_{2.5}$ concentrations.

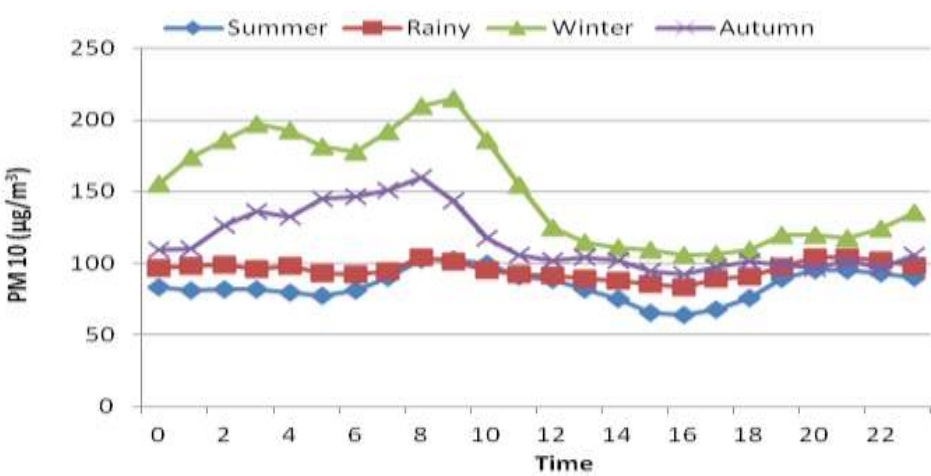

Fig. 2: Diurnal variations of hourly PM_{10} concentrations.

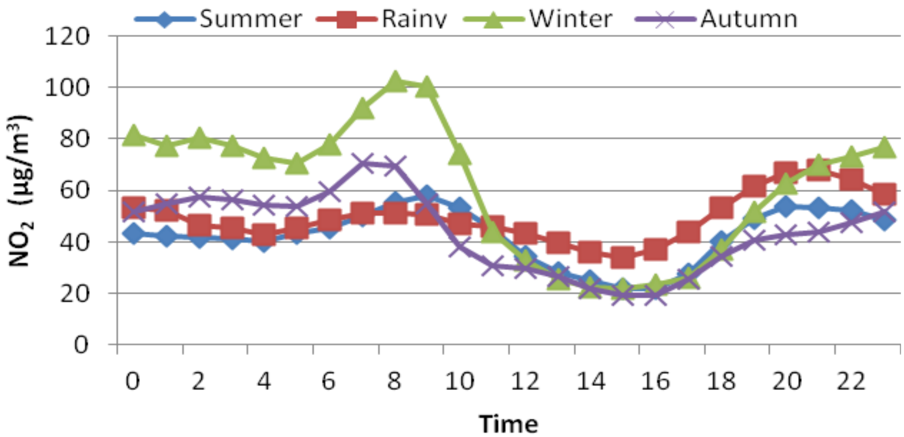

Fig. 3: Diurnal variations of hourly NO_2 concentrations.

to the pollution levels recorded in Visakhapatnam city. The positive impact is visible through all the four seasons of the year. It could be further observed that the magnitude of the correlation coefficients varies across variables and seasons. In the summer season, all the three variables recorded high correlation with $PM_{2.5}$ and PM_{10} levels excepting CO on $PM_{2.5}$ with moderate correlation. During rainy season NO_2 recorded high correlation while SO_2 and CO exhibited weak to moderate correlation. All the variables evinced a high correlation with $PM_{2.5}$ and PM_{10} levels in the winter season. In autumn NO_2 and SO_2 registered high correlation while CO recorded weak correlation with PM levels. All the coefficients are statistically significant across all the variables and seasons. It may be concluded that the three variables considered in the study are significantly correlated with PM levels with varied magnitude across seasons and even variables.

The exact magnitude of the impact of each of the independent variable on pollution levels could be further discerned through the following equation.

$$Y = a + bX_1 + cX_2 + dX_3 + U \quad \ldots(1)$$

Where Y = $PM_{2.5}$ and PM_{10} levels taken independently, X_1 = NO_2 mean levels, X_2 = SO_2 mean levels, X_3 = CO mean levels, U = error term and a, b and c are the estimated coefficients of the three independent variables.

The variables are theoretically expected to possess a linear relationship with PM levels and hence multiple linear regression method is adopted to estimate the coefficient values of the variables.

The regression results are presented in Tables 3-6 by season. It could be discerned (Table 3) that the considered variables explained 79 per cent of the variation in $PM_{2.5}$ level in summer season in Visakhapatnam city as observed from adjusted . Both NO_2 and SO_2 registered expected signs. The coefficients of both NO_2 and SO_2 are significant at 5 and 1 per cent respectively. Further, one unit change in NO_2 is likely to cause 0.43 unit change in $PM_{2.5}$. Similarly, a unit change in SO_2 may impact $PM_{2.5}$ by 0.74 units. It may, therefore, be inferred that NO_2 and SO_2 significantly impact $PM_{2.5}$ during the summer season in Visakhapatnam city.

It is evident from Table 3 that the influence of the considered variables on PM_{10} for the same season. The results show

Table 2: Pearson correlation coefficients between PMs and gaseous pollutants.

Pollutants	Seasons							
	Summer		Rainy		Winter		Autumn	
	r ($PM_{2.5}$)	r (PM_{10})	r ($PM_{2.5}$)	r (PM_{10})	r ($PM_{2.5}$)	r (PM_{10})	r ($PM_{2.5}$)	r (PM_{10})
NO_2	0.767	0.889	0.591	0.793	0.870	0.825	0.891	0.804
SO_2	0.855	0.750	0.475	0.396	0.771	0.719	0.752	0.789
CO	0.429	0.701	0.472	0.347	0.714	0.638	0.453	0.337

Table 3: Regression analysis results for the summer season.

Dependent variable	Intercept	Independent variable			$\bar{R}^2$
		NO_2	SO_2	CO	
$PM_{2.5}$	31.61	0.43** (2.94)	0.74* (4.78)	-0.15 (-1.10)	0.79
PM_{10}	48.10	0.55* (3.97)	0.40** (2.74)	0.21 (1.63)	0.83

Note: Figures in brackets are 't' values; *significant at 1% level, ** significant at 5% level

Table 4: Regression analysis results for the rainy season.

Dependent variable	Intercept	Independent variable			$\bar{R}^2$
		NO_2	SO_2	CO	
$PM_{2.5}$	42.27	0.31 (1.96)	0.64 (0.85)	0.01 (0.06)	0.29
PM_{10}	68.10	0.62 (5.92)	0.41 (0.83)	-0.27 (-2.09)	0.65

Note: Figures in brackets are 't' values

that adjusted is 0.83 explaining 83 per cent of the variation in PM_{10} by the considered variables. All the coefficients bear expected signs, however, NO_2 and SO_2 turned out to be significantly determining PM_{10} levels in the city. A unit change in NO_2 causes 0. 55 unit change in PM_{10}. In the case of SO_2, one unit change in SO_2 leads to 0.40 unit change in PM_{10} level. Hence even in the case of PM_{10} only NO_2 and SO_2 are significant factors contributing to PM_{10} levels in summer in Visakhapatnam city.

Turning to the rainy season, as observed (Table 4), is low explaining 29 per cent of the variation in $PM_{2.5}$ level. Of the variables, none is significant as impacting $PM_{2.5}$. However, all the variables have only a tendency to determine $PM_{2.5}$ positively. When it comes to PM_{10} the is high (0.65) and NO_2 and CO are significant causative factors. Unexpectedly, CO impacts PM_{10} negatively albeit the magnitude of the variable is low (0.27). SO_2 is not a significant determinant of PM_{10}. Hence, NO_2 is the only factor contributing to PM_{10} levels in rainy season in Visakhapatnam city.

For winter (Table 5), high for both $PM_{2.5}$ and PM_{10} indicate that the considered variables could explain 94 per cent and 91 per cent of variation respectively in pollution levels. All the variables registered expected signs and significant at the 1 per cent level.

The magnitudes of coefficients of both NO_2 and SO_2 are high indicating that one unit change in them impact $PM_{2.5}$ and PM_{10} by more than twice. However, CO is significantly contributing negatively to both $PM_{2.5}$ and PM_{10}. The negative sign could be due to a high correlation between NO_2 and CO resulting in the biased estimate of CO.

In autumn (Table 6), $PM_{2.5}$ is significantly impacted by all three variables. So is the case with $PM_{10.}$ values are high. NO_2 and SO_2 are significant, so is CO but the sign is negative. It may be inferred that NO_2 and SO_2 are significant factors impacting both $PM_{2.5}$ and PM_{10} levels.

CONCLUSIONS

It is observed that the annual averaged PMs exceeded the WHO standards (10μg/m^3) in all seasons. The PM concen-

Table 5: Regression analysis results for the winter season.

Dependent variable	Intercept	Independent variable			$\bar{R}^2$
		NO_2	SO_2	CO	
$PM_{2.5}$	139.21	2.40* (8.24)	2.20* (5.18)	-3.11 (-4.97)	0.94
PM_{10}	154.39	2.74* (8.88)	1.46** (3.23)	-4.20 (-6.33)	0.91

Note: Figures in brackets are 't' values; *significant at 1% level, ** significant at 5% level

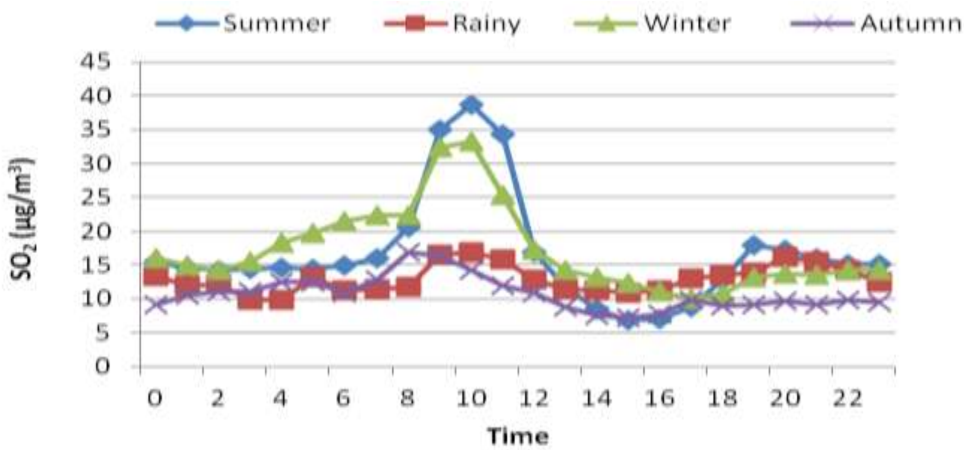

Fig. 4: Diurnal variations of hourly SO_2 concentrations.

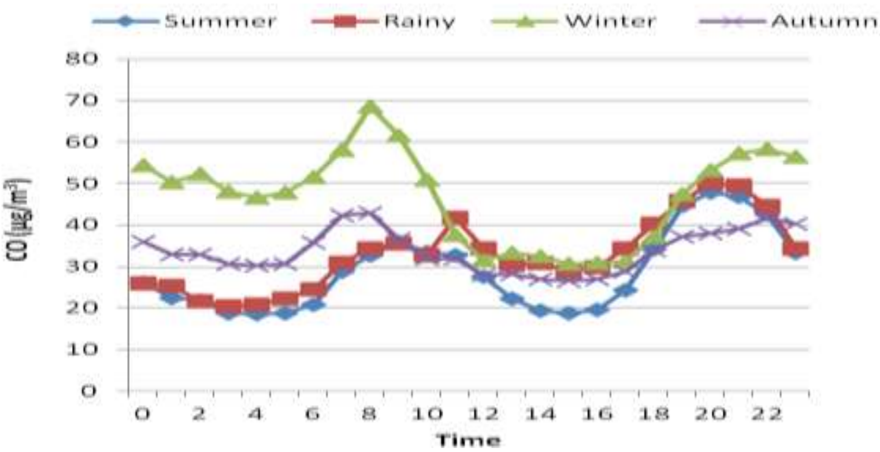

Fig. 5: Diurnal variations of hourly CO concentrations.

trations showed a remarkable seasonal variability, highest during winter and lowest during the summer. The winter maximum is due to temperature inversion and stagnant weather. The diurnal variations of PM concentrations and gaseous pollutants were analysed. The concentration of PM and air pollutants showed significant correlation. The major contributing factors are NO_2, a tracer for vehicle emissions and SO_2, a tracer for combustion. It is clear from the study that high health risk is evident associated with fine particulate matter pollutions to the people living in Visakhapatnam city.

Table 6: Regression analysis results for the autumn season.

Dependent variable	Intercept	Independent variable			$\bar{R}^2$
		NO_2	SO_2	CO	
$PM_{2.5}$	62.21	1.36* (7.66)	2.48** (2.95)	-1.33 (-3.02)	0.88
PM_{10}	82.77	1.11* (5.59)	3.53** (3.76)	-1.60 (-3.26)	0.83

Note: Figures in brackets are 't' values; *significant at 1% level, ** significant at 5% level

ACKNOWLEDGEMENTS

The authors are thankful to the National Air Quality Index of Central Pollution Control Board compiled for each city under the Ministry of Environment, Forests and Climate Change, Government of India for open data.

REFERENCES

Balakrishnan, K., Ganguli B. and Ghosh, S. 2013. A spatially disaggregated time-series analysis of the short-term effects of particulate matter exposure on mortality in Chennai, India. Air Qual. Atmos. Health, 6: 111-121.

CEPI 2013. Criteria for Comprehensive Environmental Assessment of Industrial Clusters, Central Pollution Control Board, New Delhi.

CPCB 2009. National Ambient Air Quality Standards. Notification B-21906/20/90/PCI-L. Central Pollution Control Board, New Delhi, India.

Greenstone, M., Nilekani, J., Pande, R., Ryan, N., Sudarshan, A. and Sugathan, A. 2015. Lower pollution, longer lives: Life expectancy gains if India reduced particulate matter pollution. Econ. Polit. Wkly., L 40-46.

Guttikunda, S.K., Goel, R., Mohan, D., Tiwari, G. and Gadepalli, R. 2015. Particulate and gaseous emissions in two coastal cities-Chennai and Vishakhapatnam, India. Air Quality, Atmosphere & Health, 8(6): 559-572.

Katsouyanni, K., Touloumi, G., Samoli, E., Gryparis, A., Le Tertre, A., Monopolis, Y., Rossi, G., Zmirou, D., Ballester, F., Boumghar, A., Anderson, H.R., Wojtyniak, B., Paldy, A., Braunstein, R., Pekkanen, J., Schindler, C. and Schwartz, J. 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: Results from 29 European cities within the APHEA2 project. Epidemiology, 12: 521-531.

Ito, K., Thurston, G.D. and Silverman, R.A. 2007. Characterization of PM2.5, gaseous pollutants, and meteorological interactions in the context of time-series health effects models. Journal of Exposure Science and Environmental Epidemiology, 17: S45–S60.

Latha, K.M. and Badarinath, K.V. 2005. Seasonal variations of PM10 and PM2.5 particles loading over tropical urban environment. Int. J. Environ. Health Res., 15(1): 63-68.

Murty, B.P. 2004. Environmental Meteorology. IK International Pvt. Limited.

NEERI 2005. Ambient air quality survey and air quality management plan for Visakhapatnam Bowl Area. National Environmental Engineering Research Institute Nagpur.

Population of India 2018. Retrieved from https://indiapopulation2018.in/population-of-visakhapatnam-2018.html

Rao, V.L. and Satish, P. 2014. The study of an increment of air pollution over a coastal city. Int. J. Curr. Microbiol. App. Sci., 3(8): 910-924.

Samet, J.M., Dominici, F., Zeger, S., Schwartz, J. and Dockery, D.W. 2000. The National Morbidity, Mortality, and Air Pollution Study (NMAPS). Part I. Methods and methodological issues, Cambridge, MA: Health Effects Institute, 2000 (Report No. 94).

Sarnat, J.A., Schwartz, J., Catalano, P.J. and Suh, H.H. 2001. Gaseous pollutants in particulate matter epidemiology: Confounders or surrogates? Environ Health Perspect, 109: 1053-1061.

Srinivas J. and Purushotham A.V. 2013. Determination of air quality index status in industrial areas of Visakhapatnam, India. Res. J. of Engineering Sci., 2(6): 13-24.

Venkataraman, C., Brauer, M., Tibrewal, K., Sadavarte, P., Ma, Q., Cohen, A., Chaliyakunnel, S., Frostad, J., Klimont, Z., Martin, R.V., Millet, D.B., Phillip, S., Walker, K. and Wang, S. 2018. Source influence on emission pathways and ambient PM2.5 pollution over India (2015-2050). Atmos. Chem. Phys., 18: 8017-8039.