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MODELLING OF PARTICULATE MATTER OVER A COASTAL INDUSTRIAL STATION VISAKHAPATNAM (INDIA) FOR THE PERIOD 2016 - 2019

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ABSTRACT. Study of particulate matter concentration has gained significance in view of increased air pollution and its adverse effects on human and other living beings[4,7]. Precautionary measures may be taken based on the trends obtained by analysing $\mathcal{PM}_{2.5}$, $\mathcal{PM}_{10}$ (particulate matter) and concentrations of $\mathcal{NO}_2$, $\mathcal{SO}_2$, $\mathcal{NO}_2$, $\mathcal{NO}_x$, $\mathcal{CO}$, $\mathcal{NH}_3$ (pollutant) and RH(Relative Humidity) as well as temperature. Continuous monitoring of air pollution by has gained more emphasis in urban locations because of its huge impact on the sustainable development and ecological balance. In this context an attempt was made to analyse the trends in particulate matter concentration at Visakhapatnam (India) a costal urban and industrial station. Two regression models were developed with $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ as dependent variable and $\mathcal{SO}_2$, $\mathcal{NO}_x$, $\mathcal{NO}_2$, $\mathcal{CO}$, $\mathcal{NH}_3$, temperature(Temp) and relative humidity(RH) as independent variables. The efficiency of the models was tested with known independent variables and $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ was estimated. It is found that observed and estimated values of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ are highly correlated.

1. INTRODUCTION

India being one of the fast developing countries has been experiencing huge population growth as well as rapid urbanization and industrialization leading

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to increase in vehicular and industrial emissions apart from other emissions due to various sources. These changes significantly affect atmospheric environment which affects health of mankind [5]. The affect of particulate matter on global climate, health of mankind as well as visibility was reported [3]. Analysis of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ concentrations at 8 regions in China were reported [8]. The results indicated that $\mathcal{PM}_{2.5}$ / $\mathcal{PM}_{10}$ ratios increase from northwest to southeast based on various economic developments and types of industries. All regions show high values during winter while weekends show higher ratios than during weekdays in majority of the regions. [4] measured $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ concentrations for 16 sites of Kolkata(India) and reported 83–783 $\mu g/m^3$ for 2013 and 167–928 $\mu g/m^3$ for 2014 winter months through sampling. It is also reported that ambient levels of $\mathcal{PM}_{2.5}$ has started declining from the year 2000 in US due to various measures taken [5]. At the same time the report of [6] was of significance which stated that PM10 (particulate matter having diameter $<10\mu m$) is responsible for injecting chemicals of harmful nature into the respiratory system of human beings. This increases diseases related to heart, blood vessels as well as human respiratory system. As per the report of [7] death count of people due to air pollution in 2010 was 3.2 millions. In view of the severity, Central Pollution Control Board (CPCB) has fixed a 24 hour limit of 100 $\mu g/m^3$ and yearly limit of 60 $\mu g/m^3$ for $\mathcal{PM}_{10}$ all over India [1]. Even then, increase in unavoidable industrial and vehicular emissions increase the levels of $\mathcal{PM}_{10}$ concentrations beyond the limits specified by CPCB in majority of the cities [11]. Delhi is one of the examples which recently experienced huge air pollution during November 2019. This alarming situation has raised concern to study the concentration of particulate matter in polluted cities of India. Since particulate matter and its concentration is primarily concerned with health issues an attempt was made to study the particulate matter concentration of Visakhapatnam which is a fast developing city of Andhra Pradesh (India).

Visakhapatnam is one of the fast growing cities in the state of Andhra Pradesh (India). It is a coastal, urban and industrial station with continuously increasing population and traffic on day to day basis. At present it has an approximate population of 24 lakhs in 2019 which is increased by 20Review of CPCB and Comprehensive Environmental Pollution Index (CEPI) by Ministry of Environment and Forests identified Visakhapatnam as one of the critically polluted stations. Regular measurements of the atmospheric parameters like solar UV-B radiation were started in Visakhapatnam in 1985 as part of Indian Middle Atmosphere Programme (IMAP). However emphasis on measurement of air quality index and its related parameters gained significance only after initiation of NAMP (National Air Quality Monitoring Program) in 1984.

As per the standards of National Ambient Air Quality set by CPCB (Central Pollution Control Board) the standard for concentration of RSPM in ambient air (24 hours) for an industrial site is 150 $\mu g/m^3$ while for residential, rural and other site is 100 $\mu g/m^3$ while in sensitive areas it is 75 $\mu g/m^3$ [1]. The annual mean values for industrial, residential and sensitive areas of Visakhapatnam are reported to be 120 $\mu g/m^3$, 60 $\mu g/m^3$, and 50 $\mu g/m^3$ respectively (D.S.Satish Kumar,2013). It is reported that the SPM level in the residential areas of Visakhapatnam is high while the PM_{10} level in the residential areas is moderate [1]. As per the CPCB the RSPM levels are reported to exceed by a factor of 1.0 - 1.5 at almost all urban locations of Visakhapatnam while it is moderate with exceedence factor of 0.5 to 1 in industrial locations of Visakhapatnam. This situation needs to be addressed immediately. [2] reported that very few research papers have been published about the monitoring and analysis of PM for Visakhapatnam station till date. Hence the present study may help us to know the status of existing air quality at this industrial station and to instigate some strategic plans for ensuring better and healthy environment to the people of Visakhapatnam. In this context an attempt was made to develop a regression model with $\mathcal{PM}_{10}$ as dependent variable and $\mathcal{PM}_{10}$, $\mathcal{NO}_2$, $\mathcal{SO}_2$,$\mathcal{NO}$, $\mathcal{NO}_x$, $\mathcal{CO}$, $\mathcal{NH}_3$ (pollutant) and RH as well as temperature as independent variables. The idea is to check the dependence of $\mathcal{PM}_{2.5}$concentration on other variables as well as to use the developed model for statistics of forecasting the concentration of PM2.5 for this urban station Visakhapatnam. [9] reported the dependence of PM concentration on Relative Humidity in a detailed manner. The same exercise will be continued with either of $\mathcal{NO}_2$,$\mathcal{SO}_2$,$\mathcal{NO}$,$\mathcal{NO}_x$,$\mathcal{CO}$,$\mathcal{NH}_3$ concentrations as dependent variables while other as independent variables. This will be done by comparing the cost of trace gas monitoring instruments.

1.1. **Data and Modelling.** Hourly values of $\mathcal{PM}_{10}$, $\mathcal{PM}_{2.5}$, $\mathcal{NO}_2$, $\mathcal{SO}_2$,$\mathcal{NO}$, $\mathcal{NO}_x$, $\mathcal{CO}$, $\mathcal{NH}_3$ (pollutant) and RH as well as temperature for the period October 2016 – November 2019 were obtained from the official website of Central

Pollution Control Board [12]. From these values monthly means and standard deviations were calculated. Since the data was obtained from Government Website it is assumed that no compromise in quality exists. To assess the dependence of $\mathcal{PM}_{2.5}$ on other parameters relevant analysis was done.

2. Relevant Feature Analysis between $\mathcal{PM}_{10}$, $\mathcal{PM}_{2.5}$ concentrations and other variables

Relevant feature analysis was done in order to develop a regression model to know about the concentration of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ and their correlation with other variables. It is reported [10] that significanct correlation exists between $\mathcal{PM}_{2.5}$ and concentrations of other variables for Xi'an station in China with the help of multi regression analysis. Similarly correlation analysis between $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ concentration and other variables for Visakhapatnam (India) was done with double variable correlation indexes calculate formula given by

$$\mathrm{r} = \frac{n\sum(xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}},$$

where x and y are two variables, n is the sample size. The bivariate correlation analysis between $\mathcal{PM}_{2.5}$ and relevant parameters is obtained as follows.

TABLE 1. Significance level between $\mathcal{PM}_{2.5}$ and other variables

Variables	Correlation coefficients	Significance level	Sample size
$\mathcal{PM}_{2.5}$ & $\mathcal{SO}_2$	0.228894392	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{NO}$	0.279472053	0.00	16582
$\mathcal{PM}_{2.5}$ &$\mathcal{NO}_2$	0.475810546	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{NO}_x$	0.42346651	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{NO}_3$	0.24655445	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{CO}$	0.309112155	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{RH}$	-0.055293291	0.00	16582
$\mathcal{PM}_{2.5}$ & $\mathcal{TEMP}$	-0.025037937	0.001262257	16582

Table 1 indicates that the significance levels between $\mathcal{PM}_{2.5}$, $\mathcal{SO}_2$,$\mathcal{NO}$, $\mathcal{NO}_x$, $\mathcal{NH}_3$, $\mathcal{CO}$, and $\mathcal{RH}$ Temperature while Table 1(b) indicates the significance levels between PM10.and other parameters If the significance level is less than 0.05, it shows that the respective parameter has passed the significance test and can be used for building calculation model. From the two tables it is clear that there is a significant +ve correlation existing between $\mathcal{PM}_{2.5}$ & $\mathcal{PM}_{10}$ with $\mathcal{SO}_2$,$\mathcal{NO}$, $\mathcal{NO}_x$, $\mathcal{NH}_3$ and $\mathcal{CO}$ while a significant negative correlation exists between $\mathcal{PM}_{2.5}$ and $\mathcal{RH}$, $\mathcal{PM}_{2.5}$ and Temperature also $\mathcal{PM}_{10}$ and RH, $\mathcal{PM}_{10}$ and Temperature. Since the significance levels are less than 0.05 and respective parameters have passed the significance test they can be used for building $\mathcal{PM}_{2.5}$ & $\mathcal{PM}_{10}$ concentration calculation models. The bivariate correlation analysis between $\mathcal{PM}_{10}$ and relevant parameters is obtained shown in Table 2.

TABLE 2. Significance level between $\mathcal{PM}_{10}$ and other variables

Variables	Correlation coefficients	Significance level	Sample size
$\mathcal{PM}_{10}$ & $\mathcal{SO}_2$	0.257817363	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{NO}$	0.378875615	0.00	16582
$\mathcal{PM}_{10}$ &$\mathcal{NO}_2$	0.54100386	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{NO}_x$	0.531659716	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{NO}_3$	0.208841851	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{CO}$	0.296092294	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{RH}$	-0.044833457	0.00	16582
$\mathcal{PM}_{10}$ & $\mathcal{TEMP}$	-0.037823706	0.00	16582

3. REGRESSION MODEL

Multivariate Linear Regression is a statistical technique that estimates a single regression model with more than one variable as the outcome. In order to predict the dependent variable (Y) the independent variables are fitted in a linear equation given by

$$\text{Y} = C_1 + C_1X_1 + C_2X_2 + ... + C_nX_n + \varepsilon, \tag{3.1}$$

where $X_1, X_2....., X_n$ represent independent variables,$C_1, C_2....C_n$ represent regression coefficients, C_0 a constant while ε stands for estimated error term obtained from random sampling of normal distribution with mean zero and constant variance. We constructed a Multivariate Linear Regression with $\mathcal{PM}_{2.5}$ as dependent variable(Y) and $\mathcal{RH}(\mathcal{X}_1)$, Temp ($\mathcal{X}_2$), $\mathcal{SO}_2(\mathcal{X}_3)$, $\mathcal{NO}(\mathcal{X}_4)$, $\mathcal{NO}_2(\mathcal{X}_5)$, $\mathcal{NO}_x(\mathcal{X}_6)$, $\mathcal{NH}_3$ ($\mathcal{X}_7$), $\mathcal{CO}$ ($\mathcal{X}_8$) as independent variables. In this model m = 8 and n= 16582, the output of the model is given by Table-3. Table 3 indicates

TABLE 3. Regression Statistics for $\mathcal{PM}_{2.5}$ and other independent variables

Regression Statistics				
	Multiple R value		0.538152843	
	R2 value		0.289608482	
	Adjusted R2 value		0.289265567	
	Standard Error		30.40415121	
	No. of observations		16582	
Parameter	Coefficients	Standard Error	t Stat	P-value
$\mathcal{INTERCEPT}$	60.96476183	3.865006144	15.77352262	0.00
$\mathcal{RH}$	-0.247865106	0.027552438	-8.996122405	0.00
$\mathcal{TEMP}$	-0.957709135	0.111711478	-8.573059364	0.00
$\mathcal{SO}_2$	0.141869737	0.020276719	6.996681183	0.00
$\mathcal{NO}$	-0.622411133	0.045012082	-13.82764583	0.00
$\mathcal{NO}_2$	0.094717108	0.029302231	3.232419669	0.001229866
$\mathcal{NO}_x$	0.813137627	0.054139391	15.01933457	0.00
$\mathcal{NH}_3$	0.74326583	0.029428695	25.25649949	0.00
$\mathcal{CO}$	5.708565768	0.344523778	16.56943911	0.00

the probability value of regression coefficient in the significance test. Here it is observed that all the significance levels are less than 0.05, hence the model is feasible. The final regression equation can be expressed as

$$\begin{aligned} \text{Y} = 60.96476183 - 0.247865106X_1 - 0.957709135X_2 + \\ 0.141869737X_3 - 0.622411133X_4 + 0.094717108X_5 \\ +0.813137627X_6 + 0.74326583X_7 + 5.708565768X_8 \end{aligned} \tag{3.2}$$

Similarly we constructed a Multivariate Linear Regression with PM10 as dependent variable(Y) and RH ($\mathcal{X}_1$), Temp ($\mathcal{X}_2$), SO2 ($\mathcal{X}_3$), NO ($\mathcal{X}_4$), $\mathcal{NO}_2$ ($\mathcal{X}_5$), $\mathcal{NO}_X$ ($\mathcal{X}_6$), $\mathcal{NH}_3$ ($\mathcal{X}_7$), CO ($\mathcal{X}_8$) as independent variables. In this model m=8 and n=16582, the output of the model is given by Table 4.

Table 4 indicates the probability value of regression coefficient in the significance test. Here it is observed that all the significance levels are less than 0.05, hence the model is feasible. The final regression equation can be expressed as

TABLE 4. Regression Statistics for $\mathcal{PM}_{10}$ and other independent variables

Regression Statistics				
	Multiple R value		0.607519689	
	R2 value		0.369080173	
	Adjusted R2 value		0.36877562	
	Standard Error		55.02069053	
	No. of observations		16582	
Parameter	Coefficients	Standard Error	t Stat	P-value
$\mathcal{INTERCEPT}$	144.9128468	6.994285268	20.71874985	0.00
$\mathcal{RH}$	-0.616244048	0.049860105	-12.35946148	0.00
$\mathcal{TEMP}$	-1.9820946	0.202158009	-9.804680061	0.00
$\mathcal{SO}_2$	0.296521504	0.036693643	8.081004751	0.00
$\mathcal{NO}$	-1.95503489	0.081455846	-24.00116123	0.00
$\mathcal{NO}_2$	-0.412460728	0.053026607	-7.778372993	0.00
$\mathcal{NO}_x$	2.929915388	0.097973025	29.90532727	0.00
$\mathcal{NH}_3$	1.077024527	0.053255463	20.22373804	0.00
$\mathcal{CO}$	6.075098494	0.623465397	9.744082875	0.00

$$\begin{aligned} \text{Y} = 144.9128468 - 0.616244048X_1 - 1.9820946X_2 + \\ 0.296521504X_3 - 1.95503489X_4 + 0.412460728X_5 \\ +2.929915388X_6 + 1.077024527X_7 + 6.075098494X_8 \end{aligned} \tag{3.3}$$

4. RESULTS AND DISCUSSION

4.1. **Estimated $\mathcal{PM}_{2.5}$ versus observed $\mathcal{PM}_{2.5}$ concentrations.** A graph (Fig-1) was plotted with number of day on x-axis and the corresponding observed and estimated concentrations of $\mathcal{PM}_{2.5}$ on y-axis.

The regression equation (4.1) defined above is used to estimate the $\mathcal{PM}_{2.5}$ concentration for the month of December 2019 whose values are not used in developing the model by substituting the known values of independent variables. This exercise was done to check the efficiency of the developed regression

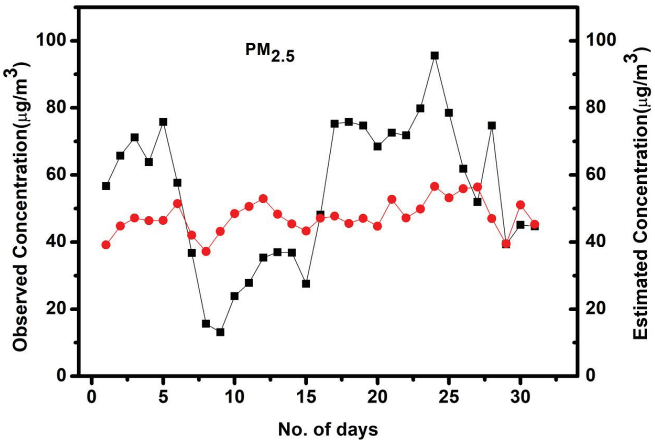

FIGURE 1. Plot showing observed $\mathcal{PM}_{2.5}$ versus estimated $\mathcal{PM}_{2.5}$ concentrations

equation. From the plot it is very clear that both observed and estimated $\mathcal{PM}_{2.5}$ concentrations are correlated. This allows us to forecast the concentration of $\mathcal{PM}_{2.5}$ for known values of other independent variables for Visakhapatnam station in future.

4.2. **Estimated $\mathcal{PM}_{10}$ versus observed $\mathcal{PM}_{10}$ concentrations.** A graph (Fig-2) was plotted with number of day on x-axis and the corresponding observed and estimated concentrations of $\mathcal{PM}_{10}$ on y-axis.

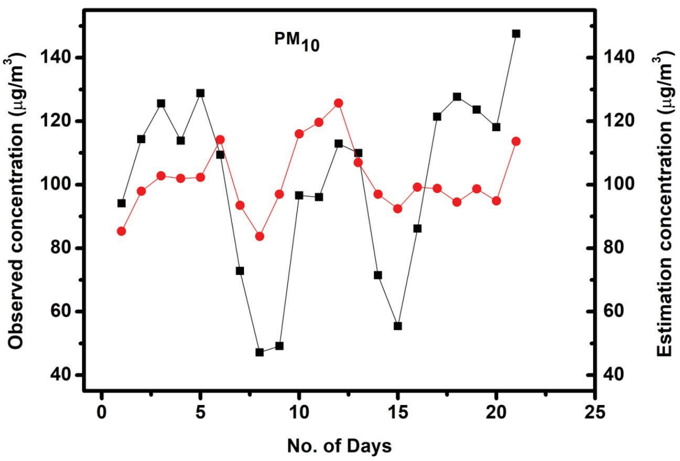

FIGURE 2. Plot showing observed $\mathcal{PM}_{10}$ versus estimated $\mathcal{PM}_{10}$ concentrations

The regression equation (4.2) defined above is used to estimate the $\mathcal{PM}_{10}$ concentration for the month of December 2019 whose values are not used in developing the model by substituting the known values of independent variables. This exercise was done to check the efficiency of the developed regression equation. From the plot it is very clear that both observed and estimated $\mathcal{PM}_{10}$ concentrations are correlated. This allows us to forecast the concentration of $\mathcal{PM}_{10}$ for known values of other independent variables for Visakhapatnam station in future.

4.3. **Dependance of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ concentrations on other variables at Visakhapatnam.** The above regression analysis indicate the dependence of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$concentrations on other variables like $\mathcal{SO}_2$, $\mathcal{NO}_{2.5}$, $\mathcal{NO}_2$, $\mathcal{NO}_x$, $\mathcal{NH}_3$, $\mathcal{CO}$ and $\mathcal{RH}$ and Temperature. Since all the parameters pass the significant test the dependence of $\mathcal{PM}_{2.5}$ concentration on other parameters to be analysed and hence the equation (4.2) is developed. In a similar way equation (4.3) was developed to test the dependence of $\mathcal{PM}_{10}$ concentration on other parameters. From Table 2(a) it is clear that correlation coefficients of RH, Temperature and NO were indicating negative correlation with $\mathcal{PM}_{2.5}$ while Table 2(b) indicate a negative correlation between$\mathcal{PM}_{10}$ and $\mathcal{RH}_{2.5}$, Temperature ,$\mathcal{NO}$, $\mathcal{NO}_2$ Since Visakhapatnam is a location with high relative humidity as well as moderate temperature round the clock its effect on $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ need to be analysed in more detailed manner.

5. Conclusions

In this paper, we used the latest three years monitoring data from 2016-2019 of a coastal, urban, industrial station Visakhapatnam as experimental data. A multi variant correlation analyses between $\mathcal{PM}_{2.5}$ concentration and other variables was made. Similar correlation analysis between $\mathcal{PM}_{10}$ concentration and other variables was made The results shows that the concentrations of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$, $\mathcal{SO}_2$, $\mathcal{NO}$, $\mathcal{NO}_2$, $\mathcal{NO}_x$, $\mathcal{NH}_3$, $\mathcal{CO}$ and $\mathcal{RH}$ and temperature have linear relationship during this period. However correlation exists between different pollutants due to production, formation and involvement of changing processes. Hence we developed a multivariate linear regression model between the concentrations of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$, $\mathcal{SO}_2$, $\mathcal{NO}$, $\mathcal{NO}_2$, $\mathcal{NO}_x$, $\mathcal{NH}_3$, $\mathcal{CO}$ and

$\mathcal{RH}$ Temperature. The developed models were tested with reserved monitoring data of December 2019 which was not used in developing the model. This exercise was done to verify the efficiency of the developed model. The main conclusions drawn are:

1. Significant relevance exist between the concentration of $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$, $\mathcal{SO}_2$, $\mathcal{NO}$, $\mathcal{NO}_2$, $\mathcal{NO}_x$, $\mathcal{NH}_3$, $\mathcal{CO}$ and $\mathcal{RH}$ Temperature. Hence all these variables can be used for building $\mathcal{PM}_{2.5}$ and $\mathcal{PM}_{10}$ regression models.
2. The values of correlation coefficients indicate the correlation with $\mathcal{PM}_{2.5}$ from higher to lower value in the order of $\mathcal{NO}_2(0.47)$, $\mathcal{NO}_x(0.2)$, $\mathcal{CO}(0.30)$, $\mathcal{NO}(0.27)$, $\mathcal{NH}_3(0.24)$, $\mathcal{SO}_2(0.22)$, $\mathcal{RH}(-0.05)$ and Temperature (-0.02).
3. The values of correlation coefficients indicate the correlation with $\mathcal{PM}_{10}$ from higher to lower value in the order of $\mathcal{NO}_2(0.54)$, $\mathcal{NO}_x(0.53)$, $\mathcal{NO}(0.37)$, $\mathcal{CO}(0.29)$, $\mathcal{SO}_2(0.25)$, $\mathcal{NH}_3(0.20)$, $\mathcal{RH}(-0.04)$ and Temperature (-0.03).
4. Efficiency of the developed model was tested for 25 days data of December 2019 which was not used for developing the model. This indicated excellent correlation as shown in Figures. 1 and 2 and hence the models can be used to forecast $\mathcal{PM}_{2.5}$ as well as $\mathcal{PM}_{10}$ for this station.

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