ORAL PRESENTATION – 7. Engineering Sciences

Regression modeling of gaseous air pollutants and meteorological parameters in a steel city, Rourkela

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Abstract

Traditional algorithms such as diffusion model employed for estimating the distribution of pollutants in ambient air are complicated involving the solution of complex differential equations. Employing multivariate statistical models which attempt to find the underlying relationships between a set of inputs and outputs may give an easy way to predict these gaseous pollutants. A multiple linear regression model has been developed for predicting sulphur dioxide, oxides of nitrogen, ammonia and carbon monoxide in a steel city using the meteorological parameters like temperature, relative humidity, wind speed and wind direction. Results have shown a good correlation between predictors and predicted values (R^2≈0.7). A uniform effect of the meteorological parameters in distributing these gaseous pollutants has been observed.

Keywords: regression modelling, steel city, correlation analysis.

1. Introduction:

Air pollution is one of the basic problems being faced in urban areas. Exposure to ambient air pollution has been associated with a number of different health outcomes such as, skin irritation, respiratory and cardiovascular diseases.Besides deleterious effects on human health, it also causes evident negative effects on ecosystems, materials, and the visibility [1,2]. These effects are giving urban air quality an increasing attention these days. The main constituents of air pollution path of the urban atmosphere are emission and transmission of air pollutants resulting in the ambient air pollution [3]. Although, urban air pollution was considered as a problem mainly associated with domestic heating and industrial emissions initially, contribution of traffic emissions are also considered at present [4].All emitted pollutants are dispersed and diluted in the atmosphere and these processes are strongly affected by meteorological conditions, such as rainfall, air temperature, wind speed (WS), and wind direction (WD) [5]. Therefore, air quality in the urban areas has been generally interpreted with the combination of various meteorological factors [6].

For estimation of flow of energy and performance of systems analytical computer codes are often used. The algorithms employed are usually complicated involving the solution of complex differential equations. These programs usually require a large computer power and need a considerable amount of time for accurate predictions. One approach to predict atmospheric air quality is to use a detailed atmospheric diffusion model. Such models aim to resolve the underlying physical and chemical equations controlling pollutant concentrations and therefore require detailed emissions data and meteorological fields. Collet and Oduyemi [7] provided a detailed review of this particular type of model. The second approach is to devise statistical models which attempt to determine the underlying relationship between a set of input data and targets. Regression modelling is such a statistical approach that has been applied to air quality modelling and prediction in a number of studies [8, 9].

Rourkela, well known steel city, where one of the major industrial complexes of SAIL (Steel Authority of India Limited) for steel production has been considered location for the present study. Four gaseous pollutants namely sulphur dioxide (SO_2), oxides of nitrogen (NO_x), ammonia (NH_3) and carbon monoxide (CO) were considered for the regression modelling using meteorological parameters such as wind direction (WD), wind speed (WS), temperature (T) and relative humidity (RH). Multiple linear regression (MLR) was used for studying the linear correlation between individual gaseous pollutants and meteorological parameters.

2. Study area:

A steel city, Rourkela (22°12' N, 84°54' E) situated at 219 m above msl is selected as a study area in the present research work. It is one of the most important industrial cities in the Sundargarh district of the state of Odisha, India. It is located at the heart of a rich mineral belt and surrounded by a range of hills and encircled by rivers. As per 2011 census report of India, population of Rourkela is 6,89,298. The city is spread over an area of 121.7km^2 in close proximity of iron ore, dolomite, lime stone and coal belts. The perennial Koel River flows through this valley and meets another perennial river Sankh at Vedavyas on the outskirts of Rourkela. It has a tropical climate having average annual rainfall between 160–200 cm.

Three monitoring sites have been selected for the present ambient air quality study. Indira Gandhi Park,Udit Nagar and Jalda which are in the proximity of the steel plant emissions as shown in Figure 1.

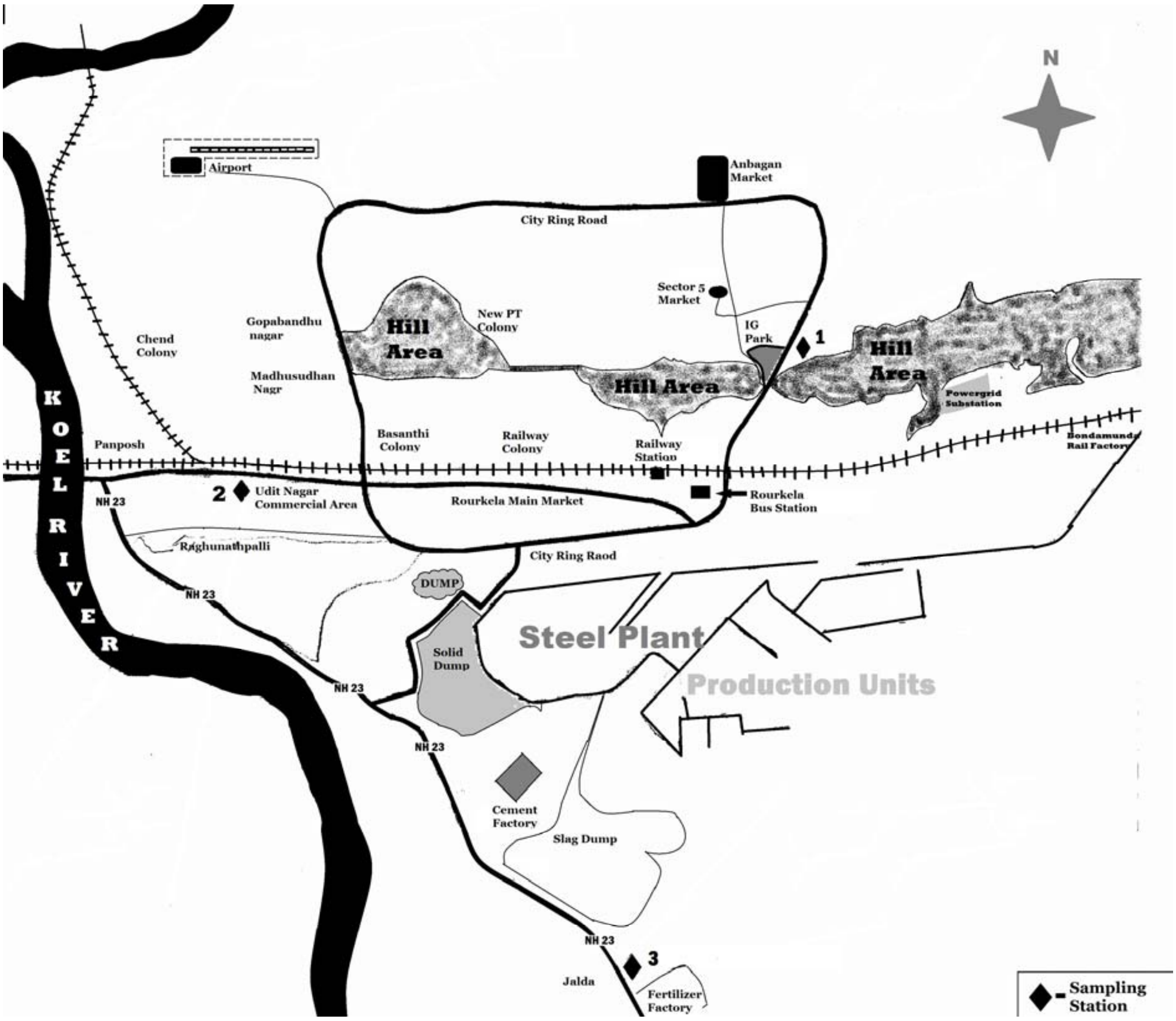

Figure 1: Study area. Three sampling stations were chosen, 1) IG Park 2) Udit Nagar 3) Jalda.

3. Sampling Protocol:

The concentration of gaseous pollutants (NO_x, SO_2, and NH_3) havebeen measured by using absorbing solution in their respective impinger attached to the respirable dust sampler. Sampled air is allowed to pass through each impingerat a flow rate of 0.6 lpm for a duration of 8 h. The preparation of absorbing solutions and their analysis for NO_x and SO_2 have been performed according to the ASTM standards, D1607-91 and D2914–01 respectively. Analysis of NH_3 was done following the Nesselerization method prescribed by American Public Health Association (APHA, 1985) [10]. The concentration of CO is measured by using the help of an instrument called HT-1000 Carbon monoxide metre (HT-1000).

Sampling has been performed twice in a week, preferably one weekday and another weekend. All the samples were collected during January to December 2011. A total of 77 samples have been collected during the study period.

4. Multiple Linear Regression:

Multiple linear regression attempts have been made to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data. Every value of the independent variable x is associated with a value of the dependent variable y. The population regression line for p explanatory variables x_1, x_2, ... ,x_p is defined to be

$$\mu_y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + ...\beta_p x_p$$

This line describes how the mean response μ_y changes with the explanatory variables. The observed values for y vary about their means μ_y and are assumed to have the same standard deviation σ. The fitted values b_0, b_1, ...,b_p estimate the parameters β_0, β_1,... β_p of the population regression line.

Since the observed values for y vary about their means μ_y, the multiple regression model includes a term for this variation. In words, the model is expressed as

DATA = FIT + RESIDUAL

where the "FIT" term represents the expression $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + ...\beta_p x_p$. The "RESIDUAL" term represents the deviations of the observed values y from their means μ_y, which are normally distributed with mean 0 and variance σ^2. The notation for the model deviations is ε.

Formally, the model for multiple linear regression, given n observations, is

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + ...\beta_p x_{ip} + \varepsilon_i \text{ for } i = 1,2,3,....,n$$

All the regression analysis was done by using IBM-SPSS software.

5. Results and Discussion:

During the study period the average concentration of SO_2, NO_x, NH_3 and CO are found to be 26.9µg/m^3, 38.21 µg/m^3, 366.77 µg/m^3 and 572.11 µg/m^3respectively. The descriptive statistics of both gaseous pollutants and meteorological parameters are presented in Table 1.

Table 1: Descriptive statistics of gaseous pollutants and meteorological parameter during the study period.

	WS (m/s)	Temperature (°C)	RH	WD(degrees)	SO_2(µg/m^3)	NO_x(µg/m^3)	NH_3(µg/m^3)	CO(µg/m^3)
N	92	92	92	92	92	92	92	92
Mean	.70	26.0132	65.5868	216.12	26.9043	38.2163	366.7761	572.1108
Std. Deviation	.849	3.49877	12.16226	61.928	6.98646	10.63080	165.60986	268.44990
Range	4	15.80	50.40	225	26.77	45.54	765.58	1033.43
Minimum	0	17.00	35.20	45	14.86	20.53	117.92	104.45
Maximum	4	32.80	85.60	270	41.63	66.07	883.50	1137.89

Monthly averages of gaseous pollutant concentrations were presented in figures 2 and 3. Very low concentrations of gaseous pollutants can be observed during the monsoon season of the year and higher concentrations during spring. This can be attributed to the atmospheric stability and the inversion effects that take place during spring season and increase in the wind turbulences during the monsoon season.

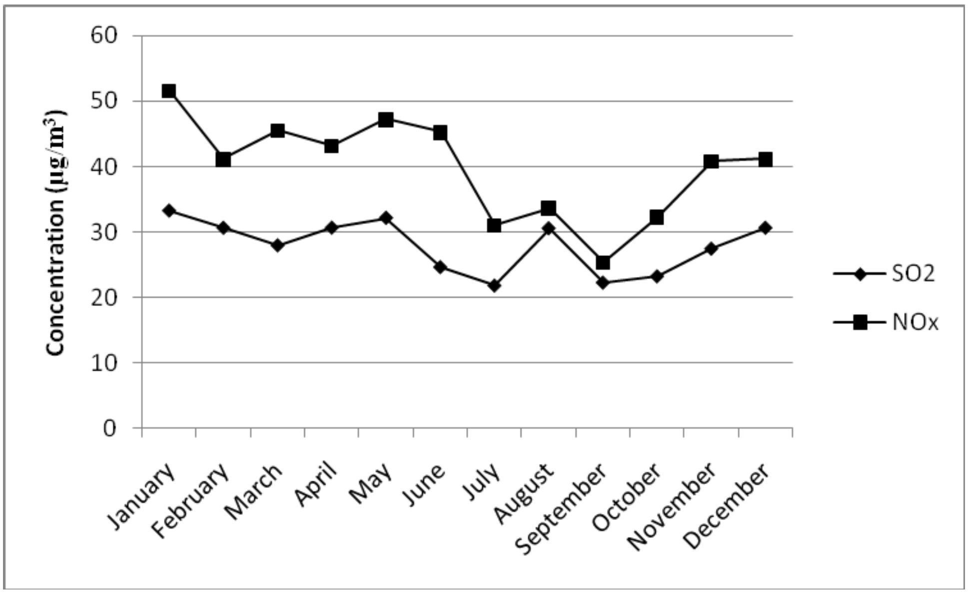

Figure 2: Monthly average concentrations of SO_2 and NO_x during the study period.

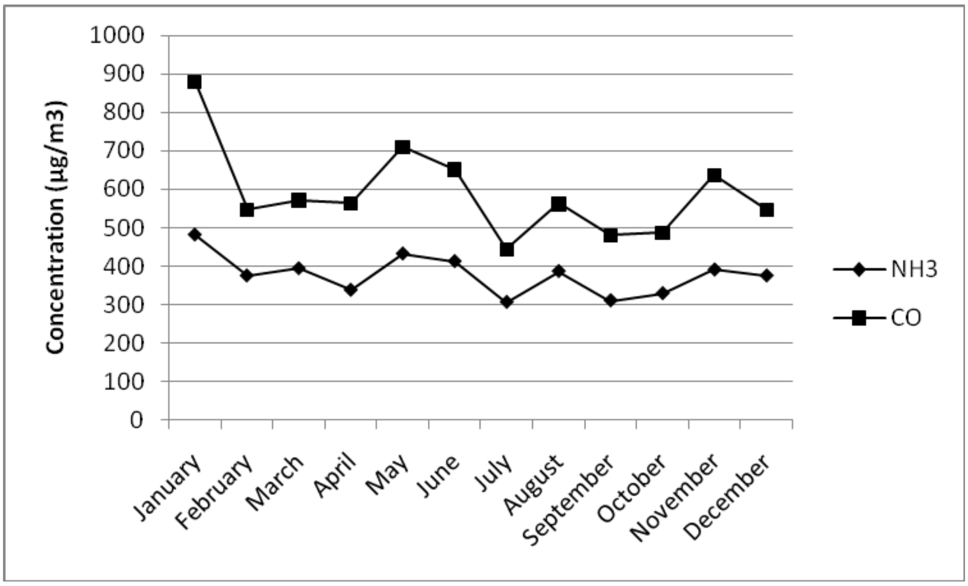

Figure 3: Monthly average concentrations of NH_3 and CO during the study period.

The regression analysis of gaseous pollutants with the meteorological parameters has shown a good correlation between them (Table 2 & 3). Almost all of the gaseous pollutants have resulted in similar regression coefficient values indicating that the effect of meteorological parameters on these four gaseous pollutants is almost uniform. SO_2has shown a relatively low linear correlation with the meteorological parameters. Thiscan be due to the presence of various excluded atmospheric reactionsinvolving SO_2. For, e.g., well-known photooxidation reactionsresulting with ozone formation influence SO_2 concentrations considerablyaccording to the following equations [11]:

$$SO_2^* + O_2 \rightarrow SO_4$$

$$SO_4 + O_2 \rightarrow SO_3 + O_3$$

Such disregarded atmospheric reactions of SO_2 may causea decrease in the efficiency of regression model run with themeteorological factors.

Table 2: Regression Model summery for different gaseous pollutants with the meteorological parameters.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Residuals
NOx	.849[a]	.720	.704	5.78058	.982
SO2	.834[a]	.696	.679	3.96064	1.322
NH3	.857[a]	.734	.720	87.70595	.910
CO	.853[a]	.727	.712	144.10201	.962

Table 3: Regression model coefficients of meteorological parameters for different gaseous pollutants.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
NOx	**(Constant)**	94.159	12.352		7.623	.000
	WS	-.474	.798	-.038	-.594	.554
	RH	-.468	.474	-.535	-.988	.327
	WD	-.003	.012	-.016	-.228	.820
	Temperature	-.936	1.661	-.308	-.563	.575
SO2	**(Constant)**	64.469	8.463		7.618	.000
	WS	-.549	.547	-.067	-1.005	.318
	RH	-.246	.325	-.428	-.757	.452
	WD	-.002	.008	-.015	-.217	.829
	Temperature	-.795	1.138	-.398	-.699	.487
NH3	**(Constant)**	1188.449	187.406		6.342	.000
	WS	-2.714	12.106	-.014	-.224	.823
	RH	-9.642	7.188	-.708	-1.341	.184
	WD	-.041	.178	-.015	-.231	.818
	Temperature	-6.863	25.197	-.145	-.272	.786
CO	**(Constant)**	1930.312	307.910		6.269	.000
	WS	-14.436	19.890	-.046	-.726	.470
	RH	-14.241	11.809	-.645	-1.206	.232
	WD	-.038	.292	-.009	-.129	.898
	Temperature	-15.606	41.399	-.203	-.377	.707

6. Conclusion:

The monthly average concentrations of four gaseous pollutants taken twice a week (one weekday and one weekend) for one year have shown higher concentrations during spring and lower concentrations during monsoon which may be due to the inversion effect in spring and the wash out during monsoon. The regression analysis of gaseous pollutants with meteorological parameters has shown a good correlation between them. One of the interesting observations that can be made is similar values of the regression coefficients which may be indicating the uniform effect of the meteorological parameters in distributing these gaseous pollutants.SO_2has shown a relatively low linear correlation with the meteorological parameters which can be attributed to the photooxidation reactionsresulting with ozone.

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