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Evaluation of Interpolation Technique for Air Quality Parameters in Port Blair, India

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Abstract:

Evaluation of interpolation technique was investigated for air quality parameters such as suspended particulate matter (SPM), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in ambient air of Port Blair, India. The interpolation methods such as inverse distance weighted (IDW) and kriging were tested to develop air quality model. The interpolated and corresponding measured values were compared by three statistical test such as mean absolute error (MAE), root mean square error (RMSE) and index of agreement (d). The ANOVA showed significant site wise variation for SPM, SO_2 and NO_2 concentrations. The concentration of SPM, NO_2 and SO_2 ranged between 35-174, 5-24 and 4-11 µg/m³ respectively. The observed concentrations of air quality parameters were found below the permissible limit of Central Pollution Control Board of India. The IDW showed better similarity between measured and interpolated values of SPM, SO_2 and NO_2 than kriging method. MAE and RMSE were low for air quality parameters in IDW method. The'd' was observed higher in IDW method, which attributes better similarity between measured and interpolated values. Interpolation methods and statistical result have been discussed in detail for assessment and monitoring of air quality parameters.

Keywords: Inverse distance weighted, Kriging, Interpolation, Mean absolute error, Root mean square error, index of agreement.

1.0 Introduction:

Pure air is most essential for the survival of all living organisms on the earth. The air pollution problem came into existence as soon as man started exploiting natural resources to make his life comfortable through industrialization. Even natural process such as volcanic eruptions, forest fires, dust, micro-organisms, pollen grains, natural organic and inorganic decays etc. are also responsible for air pollution. When air pollution exceeds a certain level, it can significantly influence human life. Therefore clean air is very essential for the survival and well being of living organisms including human life. The air is a mixture of gases, small solid and liquid particles. These substances come from natural and anthropogenic sources such as motor vehicles, domestic activities, industry, shipping etc. and it can be either particles, liquids or gaseous in nature (Alias *et al.,* 2007). Particulate matter and gaseous emissions from industries and auto exhausts are responsible for rising discomfort, increasing respiratory diseases and deterioration of artistic and cultural patrimony in urban centres. The air pollution monitoring is important to know the baseline status of various parameters such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), suspended particulate matters (SPM) and tiny solid particles-including lead from gasoline additives, called particulates (Goyal *et al.,* 2003).

Tourist influx and rehabilitation work after 'Tsunami' event in 2004, enhanced the infrastructure development activity in Port Blair. The construction activity contributes pollutants significantly to air, water and land environments. Ambient air quality is a major concern in urbanized sector but in Port Blair it was found better (safe) than any other Indian metropolitan cities like Delhi, Mumbai, Kolkata and Chennai. This study provides a baseline data of air quality parameters over Port Blair area which can be used to assess the environmental quality and its impact on future developmental work in A&N Islands.

Air quality sampling at all the desired location is practically difficult hence it is necessary to have suitable interpolation method to predict data for whole area of interest. Interpolation aims to predict values of un-sampled location based on the sampled data over whole area, which typically results in images or maps. Interpolation is one of the most successful tool in modeling spatial changes of environmental system (Goodchild, 1993). The ecological (Gignac *et al.,* 1991; Lindenmayer *et al.,* 1991; Box *et al.,* 1993), land evaluation (Kurtzman and Kadmon, 1999), agriculture (Hill *et al.,* 1996), water quality (Jha *et al.,* 2010) and climatic modeling (Klein and Dai, 1998) are some important modeling work carried out in the recent past. Apart from that, air pollution interpolation models have also been discussed (Ross *et al.,* 2007; Arain *et al.,* 2007; Denby *et al.,* 2005) to demonstrate the capability of GIS in air quality monitoring and management. In this preliminary investigation, objectives of the study were to assess and compare interpolation methods such as inverse distance weighted (IDW) and kriging. An evaluation was made to find out the suitability of interpolation method for air quality parameters using different statistical methods.

2.0 Materials and Methods:

2.1 Study Area:

The spatial distribution of existing air quality status was studied in Port Blair (area about 24 km^2) using GIS tool. The sampling locations (Figure a) were selected in such a way to include harbor, traffic junction, market, fish landing centre, stone quarry and tourist spot around Port Blair. Samplings were carried out at six sites and its geo-coordinates (±3 m) were recorded using a GPS (Garmin eTrex Vista H) and presented in Table 1.

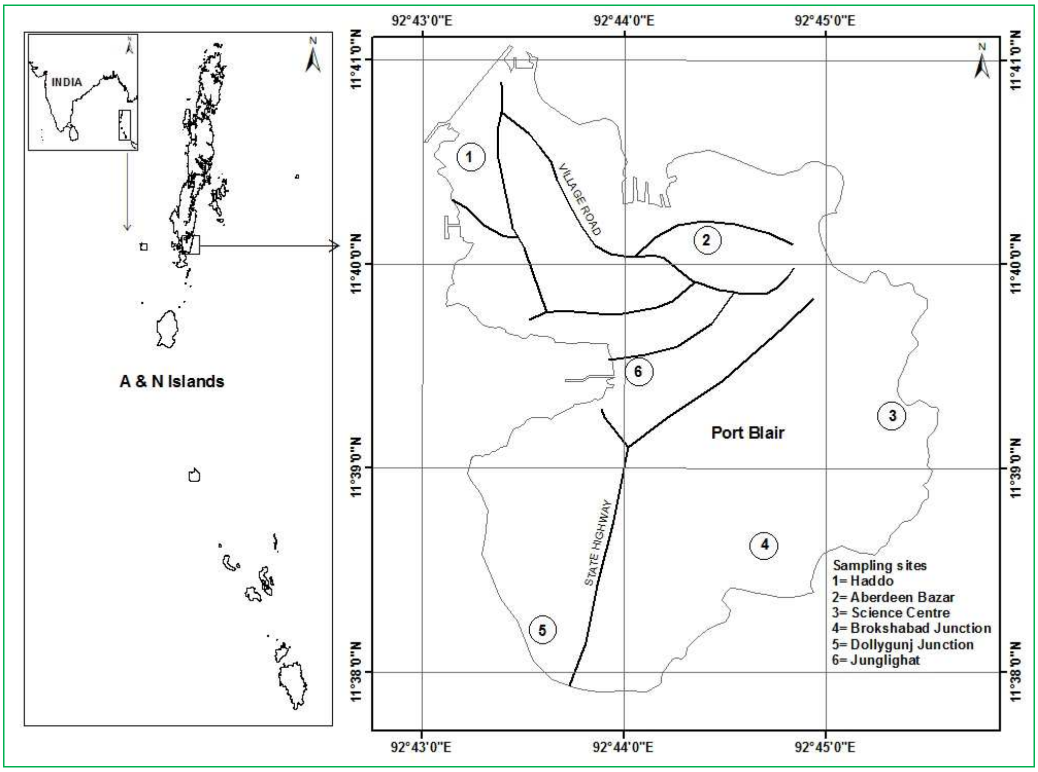


Figure a: Location map of the study area

2.2 Sample Collection and Analysis:

The air quality such as SPM, SO_2 and NO_2 were measured using High Volume Sampler (Envirotech APM-415/411) from November 2007 to January 2008 at selected sites in Port Blair. Each site monitored for twenty four hours and the duplicates samples were collected. Simultaneous measurements of temperature, humidity, wind speed and direction were also carried out.

Table 1: Study Area with Geo-Coordinates

Category of sites	Sites name	Latitude	Longitude
Harbour	Haddo harbour (HH)	11°40’33.10” N	92°43’20.83” E
Fish landing site	Junglighat (JG)	11°39’31.39” N	92°44’03.36” E
Traffic junction	Dollygunj (DG)	11°38’10.98” N	92°43’39.70” E
Market	Aberdeen Bazar (AB)	11°40’11.11” N	92°44’18.64” E
Stone quarry	Brokshabad Junction (BJ)	11°39’19.65” N	92°45’14.85” E
Tourist site	Science centre (SC)	11°39’13.74” N	92°45’18.93” E

SO_2 was measured by improved method of West and Gaeke (1956). Air was absorbed in absorbing solution of sodium tetrachloromercurate at a flow rate of 1.1 to 1.7 m^3 per minute. The sulphur dioxide was estimated by the colour produced when p-rosaniline hydrochloride was added to the solution. The absorbance was read at 560 nm using (Shimadzu UV-1201V) spectrophotometer. Whereas, NO_2 was measured by Jacob and Hochheiser method (1958) in which air was absorbed in absorbing solution of sodium hydroxide. The nitrogen dioxide was estimated by colour produced when hydrogen peroxide, sulphanilamide and NEDA solution added to the solution. The absorbance was read at 540 nm using the same spectrophotometer.

The SPM sampling was carried out using a High Volume Sampler (HVS-415, Envirotech). SPM was collected on pre-weighed filters papers (GF/A 8”X10”) using high volume sampler. The filter papers were dried for 3 hours in an oven at 105°C before and after sampling to remove the moisture to get constant weight. The flow rate of HVS was kept about 1.0±0.3 m^3/min. The difference in weight of filter paper was used for determining the concentration of SPM.

2.3 Air Quality Modeling and Statistical Analysis:

The database generated with geo-coordinates were brought to microsoft access and imported to Arc GIS software (ver. 9.3.1). Two different interpolation methods such as IDW and kriging were tested. The IDW method prefers the points closer to the processing points than the one away. The power parameter in IDW interpolation controls the significance of surrounding points. Hence higher power point two was set for creating air quality models as well as to study the errors. This method is widely used to interpolate the climatic data to create spatial models (Willmott and Matsuura, 1995).

Kriging method weights the surrounding values to predict values for unknown locality based on its spatial arrangement. Ordinary Kriging method with spherical semivariogram type was used to develop air quality model as well as to study error. In addition, one-way analysis of variance (ANOVA), correlation and regression were also performed to analyze the site-wise variation and validate the interpolation model of SPM, SO_2 and NO_2. Correlation is a simplified statistical tool to establish the relationship between two variables and also show the degree of dependency of one variable to the other (Belkhiri *et al.*, 2010).

The error analysis was carried out between actual and interpolated values by means of three statistical tests *viz.,* mean absolute error (MAE), root mean square error (RMSE) and index of agreement (d) to validate the model. MAE is a quantity used to measure how close forecasts or predictions are to the eventual outcomes.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|X_i - S_i\right| \qquad (1)$$

RMSE is another significant statistical parameter for error analysis.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(X_i - S_i)^2} \qquad (2)$$

Similarly,‘d’ estimates the close relation between actual and interpolated data.

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(X_i - S_i)^2}{\sum_{i=1}^{N}\left(\left|X_i - \mu_s\right| + \left|S_i - \mu_s\right|\right)^2}\right]; \qquad (3)$$

Where, $\mu_s = \frac{1}{N}\sum_{i=1}^{N} S_i$

Here, X_i, S_i and μ_s are measured, estimated and mean of the estimated values respectively. The‘d’ varies from 0 to 1 and is a dimensionless parameter.

Lower MAE and RMSE values and higher value of 'd', are used for better comparison.

3.0 Results and Discussion:

During the study period, for each parameter (SPM, SO_2 and NO_2), 24 samples (duplicates) were collected in winter season (October to January). The annual wind data clearly indicated the predominance of wind from NE to SW direction. The wind rose diagram of Port Blair is shown in Figure b. The wind velocity was recorded between 5-10 knots/hr. The humidity varied from 59 to 95% whereas temperature recorded between 19.7-32.3°C in Port Blair.

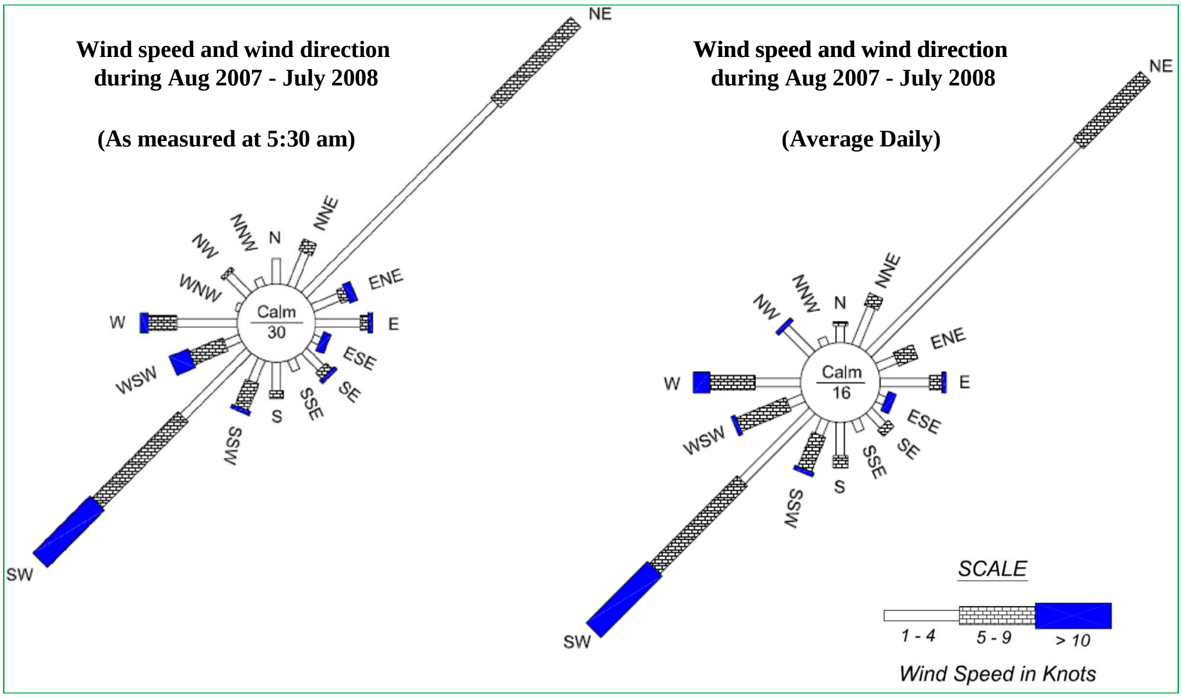


Figure b: Wind rose diagram of Port Blair city (Source: IMD, Port Blair).

3.1 Interpolation Analysis:

The statistical summary of errors (MAE, RMSE and'd') corresponding to each interpolation method is presented in Table 2. The MAE corresponding to 'SO_2' was low and varied from 0.069 to 0.867 whereas it was high for 'SPM' and ranged from 0.897 to 18.397 among the studied parameters. Similarly, RMSE was also low for 'SO_2' and varied from 0.115 to 1.041 whereas it was high for 'SPM' and varied from 1.169 to 22.639. This can be attributed to higher range of SPM (35-174 µg/m^3) and lower range of SO_2 (4-11µg/m^3) concentrations.

The MAE and RMSE for 'NO_2' varied from 0.115 to 2.268 and 0.143 to 2.945 respectively. The higher values of 'd' observed in IDW interpolation method for NO_2 (0.999), SO_2 (0.996) and SPM (0.998). The higher value of 'd' indicates better interpolation of observed data and similarity between actual and interpolated values. Kriging and IDW interpolation methods used to interpolate the SO_2, NO_2 and SPM values in the present study whereas Avellaneda (2007) used it for interpolating ozone values in Mexico City.

Table 2: Lowest MAE, RMSE and higher 'd' value in each method is given in bold numerals.

Parameter	MAE		RMSE		Index of agreement 'd'	
	IDW	Kriging	IDW	Kriging	IDW	Kriging
SPM	**0.897**	18.397	**1.619**	22.639	**0.998**	0.578
SO_2	**0.069**	0.867	**0.115**	1.041	**0.996**	0.523
NO_2	**0.115**	2.268	**0.143**	2.945	**0.999**	0.327

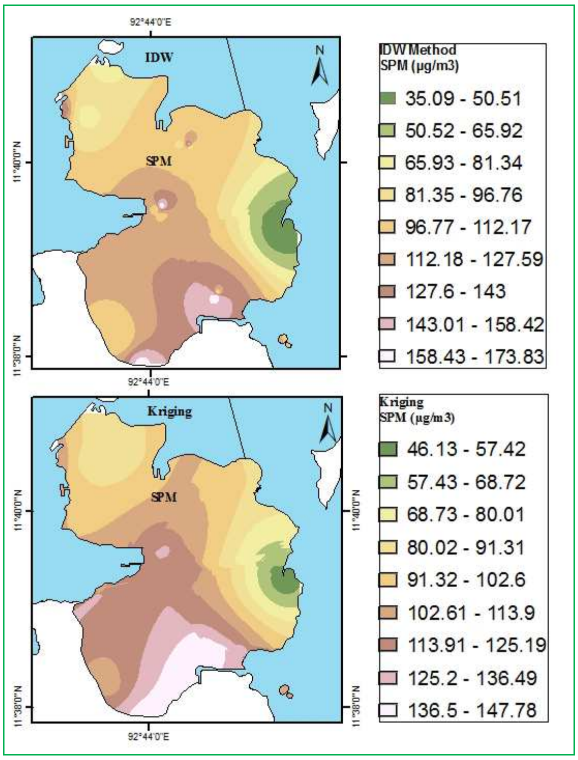


Figure c: Interpolated map of SPM

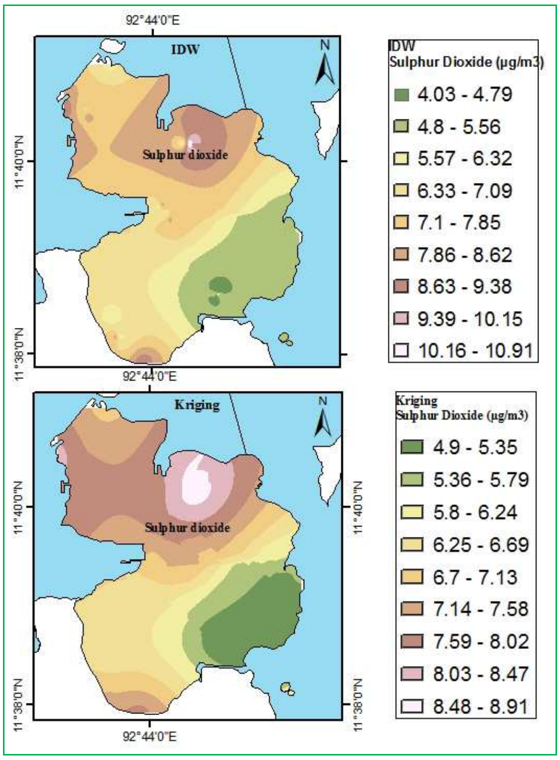


Figure d: Interpolated map of SO_2

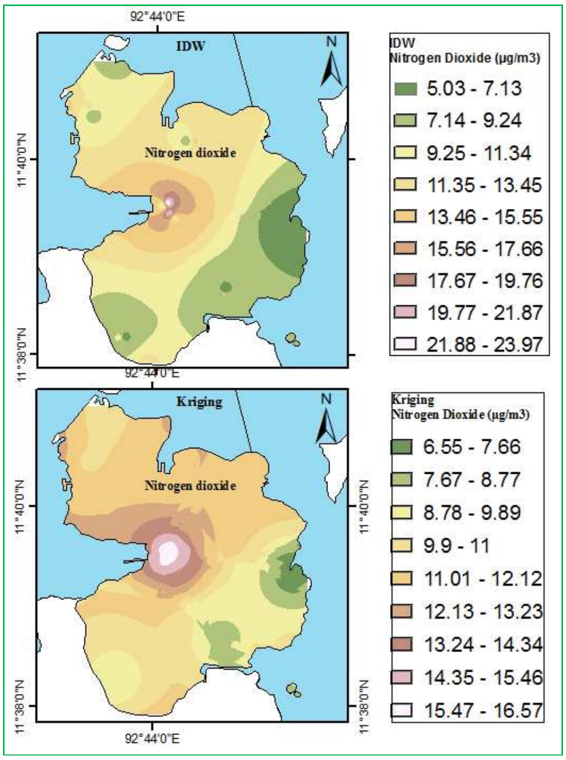
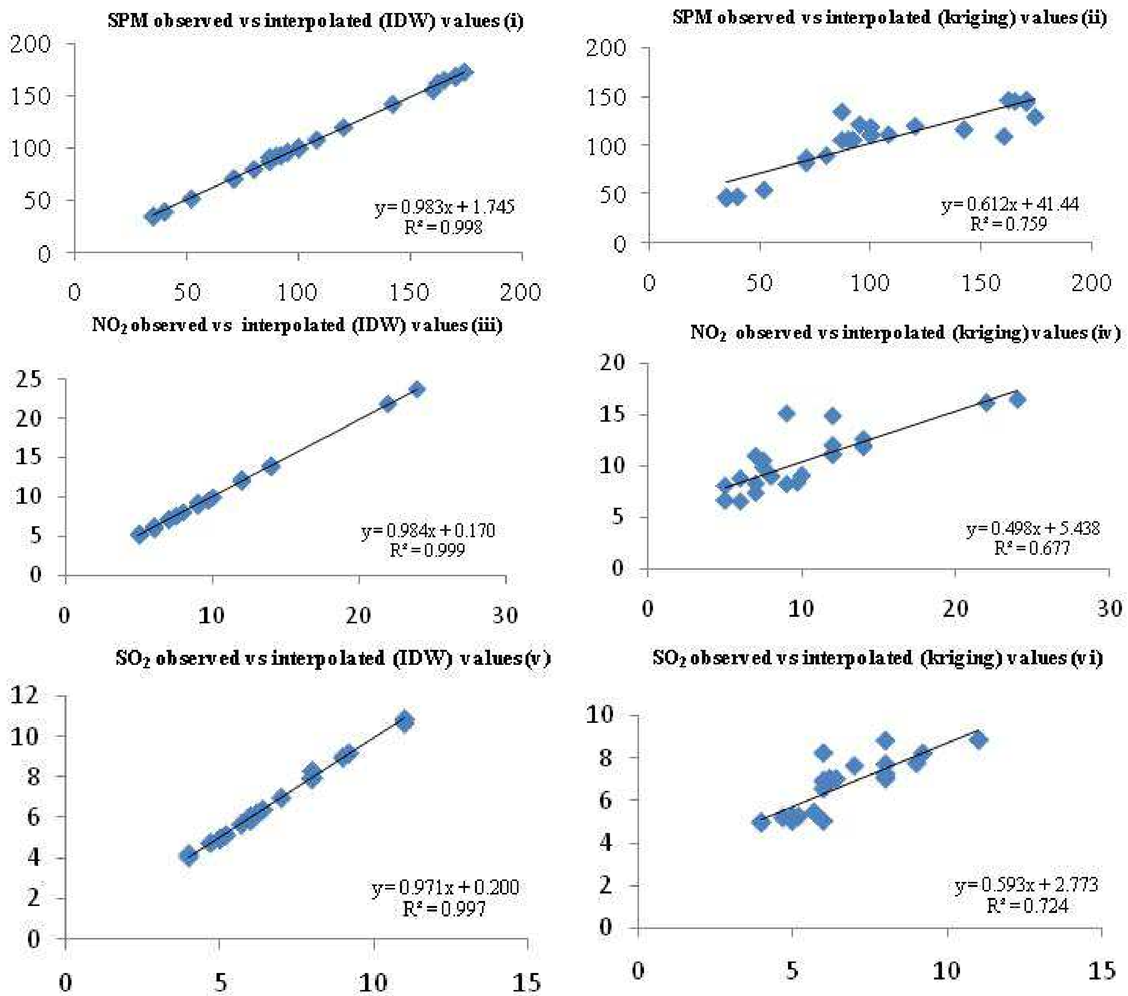


Figure e: Interpolated map of NO_2

Both interpolation methods given good results but IDW interpolation was relatively better than kriging method for the dataset used. This is visually apparent from the interpolated maps as well (Figures c-e). The IDW method created better interpolated surface for the whole area of interest based on the observed data. This analysis is useful when the area of interest is not covered due to accessibility and other practical intricacy to complete the study for better monitoring and management practices.

3.2 Descriptive Statistical Analysis:

Based on coefficient of determination for SPM concentration (r^2 =0.998 (IDW), r^2 =0.759 (kriging), all of the variance in the dependent variable (i.e., interpolated values) are explained by the derived regression equation in Figure f (i-ii). The significant positive correlation between observed and interpolated values recorded for SPM in IDW method. The kriging interpolation showed poor positive correlation for the same. Similarly, kriging interpolation method had poor positive correlation than IDW for remaining parameters (SO_2 and NO_2) and shown in Figures f (iii-vi).



Figures F (i-vi): Regression equation of observed and interpolated values

The descriptive statistics of SPM, SO_2 and NO_2 concentration is presented in Table 3. The national ambient air quality (NAAQ) standards prescribed are given in Table 4. One-way ANOVA was tested for site wise variation of pollutants concentrations and the results are given in Table 5.

Table 3: Descriptive Statistics for SPM, SO_2 and NO_2 Concentration

Sites	Minimum (μg/m^3)			Maximum (μg/m^3)			Mean (±SD)		
	SPM	SO_2	NO_2	SPM	SO_2	NO_2	SPM	SO_2	NO_2
HH	71	6.20	7.50	142	9.20	14.00	91.00±34.26	7.60±1.30	10.25±3.28
JG	95	6.20	9.00	174	8.00	24.00	122.25±36.15	7.15±0.98	16.75±7.37
DG	100	6.00	6.00	165	9.00	12.00	118.25±31.39	7.25±1.50	9.00±2.58
AB	87	6.00	7.00	160	11.00	14.00	107.25±35.23	9.00±2.45	11.75±3.30
BJ	87	4.00	5.00	170	6.00	9.70	147.25±40.34	4.75±0.96	7.68±2.12
SC	35	4.70	5.00	52	5.70	7.00	40.50±8.02	5.15±0.42	5.75±0.96

Table 4: National Ambient Air Quality Standards (NAAQS) of CPCB of India

Pollutants μg/m^3	Time weighed Average	Concentrations in Ambient air		
		Industrial Areas	Residential, rural and other areas	Sensitive Areas
SO_2	Annual	80	60	15
	24-h	120	80	30
NO_x	Annual	80	60	15
	24-h	120	80	30
SPM	Annual	360	140	70
	24-h	500	200	100

Table 5: Analysis of variance results for site wise variability of pollutant concentrations

Pollutant	F value	P value
SPM	4.96	< 0.05
SO_2	5.09	< 0.05
NO_2	3.97	< 0.05

The minimum and maximum SPM concentration 35 and 174 μg/m^3 recorded at Science Centre and Junglighat respectively. The low and high mean SPM concentration 40.5 and 147.25 μg/m^3 found at Science Centre and Brokshabad respectively. The higher and lower SD 40.34 and 8.02 observed at Brokshabad Junction and Science Centre respectively, which attributes wide and narrow range of variation. The SPM concentration showed significant site wise variation and F value was 4.96 ($P<0.05$). The suspended particulate matters are directly emitted into atmosphere through natural and anthropogenic activities (Adachi and Tainosho, 2004; Viana *et al.,* 2006). The mean concentration of SPM was high at Brokshabad Junction because of stone quarries in the adjacent area. Those stone quarries activities generate lot of fugitive dust particles in and around the Brokshabad Junction. There are no major industries in the region and hence stone quarry activities might have contributed to SPM concentrations.

The minimum and maximum SO_2 concentration 4 and 11μg/m^3 recorded at Brokshabad Junction and Aberdeen Bazaar respectively. The low and high mean SO_2 concentration 4.75 and 9.0 μg/m^3 found at Brokshabad Junction and Aberdeen Bazaar respectively. The higher and lower SD 2.45 and 0.42 observed at Aberdeen Bazaar and Science Centre respectively, which attributes wide and narrow range of variation. The SO_2 concentration showed significant site wise variation and F value was 5.09 ($P<0.05$). Aberdeen Bazaar is the main market and having town's largest bus depot. Hence, higher concentration of SO_2 was recorded due to vehicular movement in the region.

The minimum NO_2 concentration 5 μg/m^3 recorded at Brokshabad Junction & Science Centre. Its maximum concentration was 24 μg/m^3 at Junglighat. The low and high mean NO_2 concentration 5.75 and 16.75 μg/m^3 found at Science Centre and Junglighat respectively. The higher and lower SD 7.37 and 0.96 observed at Junglighat and Science Centre respectively. The NO_2 concentration showed significant site wise variation and F value was 3.97 ($P<0.05$). Junglighat is the major fish landing centre from where many trawlers are operated daily. Apart from this few small scale ice plant units are functioning in order to process the fish products.

Those things combined together contributing to NO_2 concentration in the region.

Based on the coefficient of determination (r^2 =0.31), it was evident that all the variance in the dependent variable (i.e. SO_2 concentration) explained by derived regression equation. A significant positive correlation between SO_2 and NO_2 was observed. The regression equation for SO_2 and NO_2 are given in Figure g whereas result's summary of correlation matrix presented in Table 6. The statistical test such as analysis of variance and correlation have been done for SPM, SO_2 and NO_2 concentrations in the present study whereas Sivaramasundaram and Muthusubramanian, (2010) used similar test for other air quality parameters (respirable particulate matter and total suspended particulate matter) in Tuticorin.

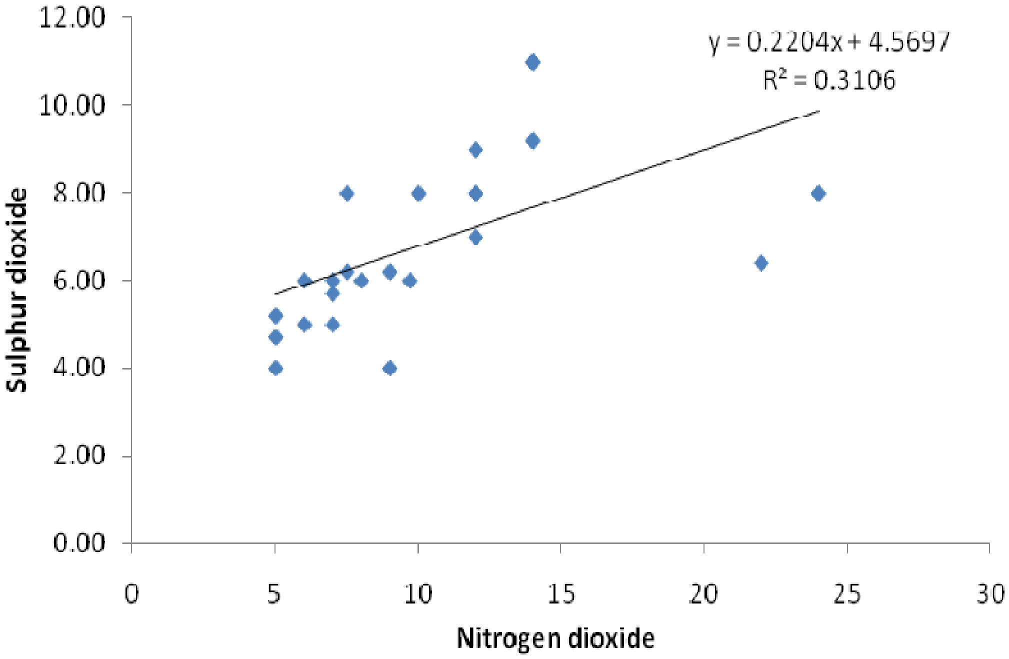


Figure G: Correlation between Sulphur dioxide and Nitrogen dioxide concentrations

Port Blair is the capital city of Andaman & Nicobar Islands and surrounded by few small scale industries such as timber mills, ice plant etc. which contribute air pollutants in the atmosphere. Apart from this vehicular traffic, shipping vessel, fishing boats and diesel generators for the production of electricity are identified as main sources of air pollution. Moreover, it is fast developing city and everyday an average of 30 vehicles (Transport Department, 2008) are being added to its total vehicular strength.

However due to vast coverage of evergreen/semi evergreen forest (80%), fugitive dust particles get washed off during rain. The forest cover works as an absorber of pollutants in Port Blair. It was reported by Mahajan *et al.*, (1996) that the air quality of this region found within the permissible limit of CPCB and similar results also obtained in the present study. Further, interpolation technique helps to get data for un-sampled site with accuracy and hence makes the decision process efficient. The IDW interpolation is comparatively better than kriging method for creating air quality model for dataset used in the present study.

Table 6: Summary of the Correlation Matrix

	SPM	SO_2	NO_2
SPM	1		
SO_2	0.309197	1	
NO_2	0.493747	**0.557312**	1

4.0 Conclusions:

The SPM, SO_2 and NO_2 concentrations showed statistically significant site wise variation in Port Blair. The correlation between SO_2 and NO_2 was positive. Moreover, in the present study interpolation technique applied to analyze modeling error of air quality parameters. Such technique was useful to derive data from the un-sampled locations. It was observed that IDW is suitable method for spatial modeling of air quality parameters when the point observations are less whereas kriging was comparatively less suitable for similar dataset.

Though all the recorded values were well below the permissible limits of Central Pollution Control Board, India, regular monitoring is vital to know the pollutants status for sustainable management. It is concluded that pristine nature of Island city can be maintained if developmental work go with proper environmental management plan.

5.0 Acknowledgements:

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