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Sensitivity of GIS-based interpolation techniques in assessing water quality parameters of Port Blair bay, Andaman

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Abstract

The surface water parameters such as temperature, salinity, conductivity, dissolved oxygen, pH and turbidity of Port Blair bay, Andaman & Nicobar Islands were measured *in situ* over 104 sampling points using a digital multi-parameter water quality instrument and a Global Positioning System (GPS) during high tide. These parameters were subsequently interpolated over the entire bay using three methods, viz., Inverse Distance Weighted (IDW), Spline and Kriging. The interpolated values over the sampling points were compared with the corresponding measured values by means of three statistical indices: Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Index of Agreement (d). It was found that among the three interpolation methods, IDW method showed better matching between the measured and interpolated values for four out of six parameters whereas Kriging method showed better results for the remaining two parameters with lower MAE and RMSE values, and higher values of 'd'. This paper describes the details of interpolation methods and its suitability to assess water quality parameters in the bay. In addition, it also highlights the capability of GIS as a tool to model spatial changes in environmental systems.

Keywords: Kriging, Inverse Distance Weighted, Spline, interpolation, water quality, Port Blair bay

Introduction

The pollution in Port Blair bay in South Andaman Islands, which caters to the need of over one lakh population of Port Blair city is increasing in recent years. The bay is navigated by commercial, passenger and tourist vessels in the A&N islands and is surrounded by different types of industries. The bay receives substantial amount of discharge from its surroundings and the sloppy terrain of the adjoining lands promotes mixing of rainwater and sewage water into the bay very rapidly. Although the large area of the bay (nearly 30 km^2) with high tidal amplitude (2.4 m) diminishes the effect of the pollutants in the bay very rapidly, water quality of the Port Blair bay is found degraded in recent years. In view of this, water quality parameters of Port Blair bay need to be monitored regularly in different locations.

Assessment of water quality requires a highly organized data collection programme that includes statistical evaluation of the results (Nelson and Ward, 1981). Many kinds of geographic data are often collected at irregular intervals as it is not possible to make such measurements at all the desired places and hence there is often a need to estimate values for locations where there are no measurements. These estimates are based on the data available and preferably understanding of the spatial variation of the phenomena. GIS is one such tool, which statistically estimates such survey to maximize the amount of information. This information is based on the fact that objects that are near are more important than those that are far away. With the limited number of sampled data, the values for places where there are no measurements can be interpolated using suitable techniques depending on the physical features or topography of the area.

Interpolation is one of most successful application areas of GIS in modeling spatial changes in environmental systems (Goodchild, 1993). The interpolation techniques used are Inverse Distance Weighted (Willmott and Matsuura, 1995; Dodson and Marks, 1997), Splines (Hulme *et al*., 1995) and Kriging (Hudson and Wackernagel, 1994; Hammond and Yarie, 1996; Holdaway, 1996).

In the present study we have measured *in situ* water quality parameters such as salinity, temperature, dissolved oxygen, pH, turbidity and conductivity at 104 locations distributed over Port Blair bay in April 2004 to find out the suitability of each interpolation method to create an accurate model for assessment of water quality parameters.

Material and Methods

Data Source and Water Quality Modeling: Several modelling techniques have been developed to deal with different aspects of water quality, ranging from nutrient conditions to the physicochemical parameters of seawater. There are five different types of models such as diffusion-based, economic optimization, spatio-temporal, neural networks and acid rain models (Rahmatizadeh *et al*., 2005). Among these five modelling techniques, spatio-temporal models are very accurate and practical. Hence, we used spatio-temporal model, which is basically a regression model. The sampling locations were fixed using a GPS (Garmin eTrex) *in situ* over 104 sampling points and water quality parameters were recorded using a digital multi-parameter water quality instrument (Hydrolab - Quanta) during high tide. A database of salinity, temperature, dissolved oxygen, pH, turbidity and conductivity with their geo-coordinates were developed in Microsoft Access and imported to Arc GIS software (ver. 9.0). These data were further processed to create the data model of water quality parameters using three interpolation methods to find the suitable one among IDW, Spline and Kriging. The accuracy of all the three methods was also examined using the Spatial analyst extension tool of Arc GIS.

Inverse Distance Weighted (IDW) interpolation: IDW weights the points closer to the processing points, greater than those farther away. The power parameter in the IDW interpolator controls the significance of the surrounding points upon the interpolated values. Hence higher power point 2 was set for creating the water parameters model as well to study the error.

Spline interpolation: The Spline interpolation method estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points. In the present study, 'tension' Spline type has been used to develop the model for comparative study.

Kriging interpolation: The Kriging interpolation method weights the surroundings measured values to derive a prediction for an unmeasured location and also on the overall spatial arrangement among the measured points and their values. In the present study, spherical semivariogram type was used to develop the model as well as to find error.

Accuracy Evaluation: Various errors could get incorporated into the data during measurement and analysis and are categorized as: measurement error, positioning error, modeling error, etc. In view of this, error analysis has been made between the actual and interpolated values for all the measured water quality parameters by means of three statistical quantities *viz*., MAE, RMSE and 'd' for all the three interpolated methods. In the present study, we have assumed that there are no error in measurements and positioning of stations and concentrated on modeling error only to find suitable interpolation method to assess water quality parameters.

MAE is a quantity used to measure how close forecast or a prediction is to the eventual outcomes and is given as:

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

RMSE is another very significant statistical parameter for error analysis and is given as:

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

Similarly the 'd', which is a measure of how closely the actual and interpolated data matches with each other, is calculated as:

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

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

Here, X_i, S_i and μ_s are the measured and estimated values and mean of the estimated values respectively. 'd' can vary from 0 to 1 and is a dimensionless parameter. Lower MAE and RMSE values and higher value of 'd' correspond to better matching.

Results and Discussion

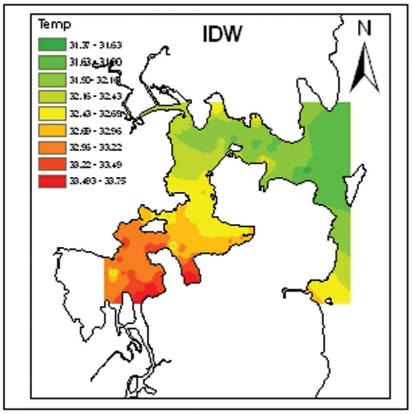
A statistical summary of the errors corresponding to each interpolation method is presented in Table 1. It is observed that the interpolation errors (MAE and RMSE) corresponding to the parameter pH is lowest in all the three interpolation methods with a range from 0.001 to 0.029 and that corresponding to the parameter turbidity is highest in all the three interpolation methods with a range from 0.85 to 2.46. This can be attributed to the higher range of turbidity data and lower range of pH data. Figures 1-3 show the GIS maps for spatial distribution of water quality parameters as interpolated using IWD, Spline and Kriging methods. It was also observed that the values of MAE and RMSE were lowest for the parameters pH, conductivity, dissolved oxygen and turbidity in IDW interpolation method whereas the same values were lowest for temperature and salinity in Kriging interpolation method. The Spline interpolation method however showed poor results in statistical error analysis, compared to the other two methods.

The 'd', which indicates how closely the actual and interpolated data match with each other, also showed similar trend as MAE and RMSE. The highest values of 'd' were observed in IDW interpolation method for the parameters pH (0.999), conductivity (0.999), dissolved oxygen (0.986) and turbidity (0.950). However, in Kriging interpolation method, the highest value of 'd' was observed for the parameters such as temperature (0.997) and salinity (0.957). The Spline interpolation method showed poor results for all parameters in all the three statistical indices. This can be visually perceived from the interpolated figures as well (Fig. 1-3). It may be concluded that both the IDW and Kriging interpolation methods are suitable for spatial analysis of water quality parameters with the point observations. Spline interpolation method is relatively unsuitable for this type of study.

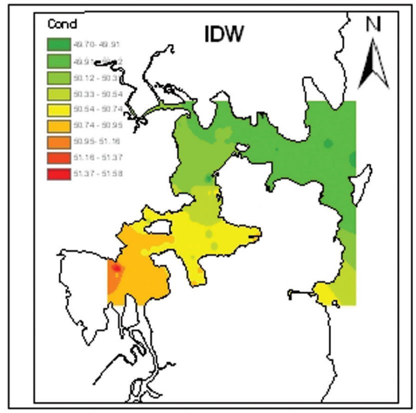
The water quality in a bay can be controlled by devising suitable mechanism to check terrestrial input to the bay and imposing regulations on domestic and industrial waste discharge into the bay. This can be achieved through suitable Water Quality Management (WQM) system using GIS. GIS is a powerful tool for WQM because the water quality parameters are related to geographical locations and time. The interpolation techniques available in GIS can be suitably utilized to derive data from the un-sampled locations from sampled data. The IDW and Kriging interpolation methods were found to be most suitable for spatial modeling of water quality parameters in the Port Blair bay.

Table 1. Error calculated in the different interpolation methods. The interpolation model that gave the lowest MAE, RMSE and higher'd' value in each method is given in bold

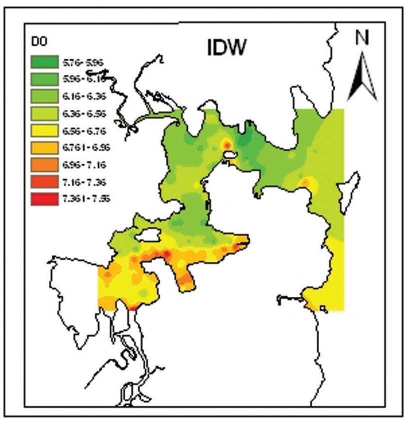
Parameters	MAE			RMSE			Index of agreement 'd'		
	IDW	Kriging	Spline	IDW	Kriging	Spline	IDW	Kriging	Spline
DO	0.017	0.192	0.201	0.091	0.261	0.360	0.986	0.815	0.775
Temperature	0.024	0.018	0.311	0.197	0.060	2.941	0.968	0.997	0.140
pH	**0.001**	0.018	**0.001**	**0.001**	**0.029**	**0.002**	**0.999**	**0.680**	**0.998**
Conductivity	0.002	**0.010**	0.014	0.007	0.033	0.089	**0.999**	**0.998**	0.984
Salinity	0.056	0.040	0.050	0.157	0.112	0.149	0.913	0.957	0.923
Turbidity	0.850	1.947	0.909	1.466	2.464	1.489	0.950	0.750	0.949



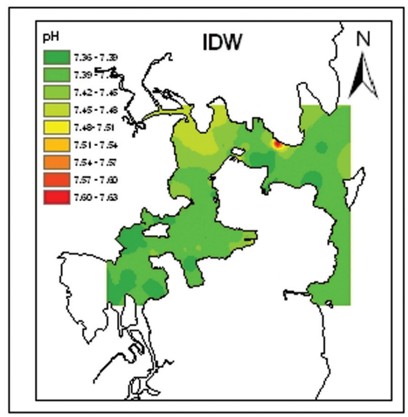
1a: Temperature



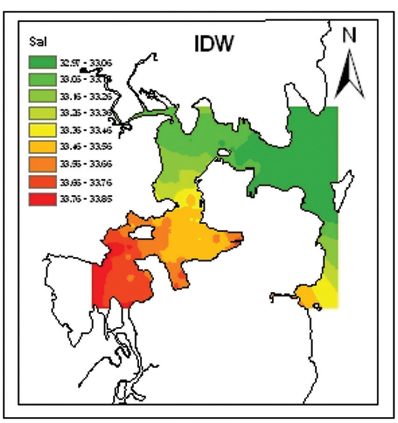
1b: Conductivity



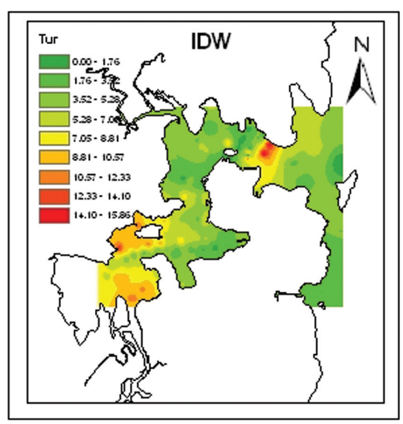
1c: Dissolved Oxygen



1d: pH

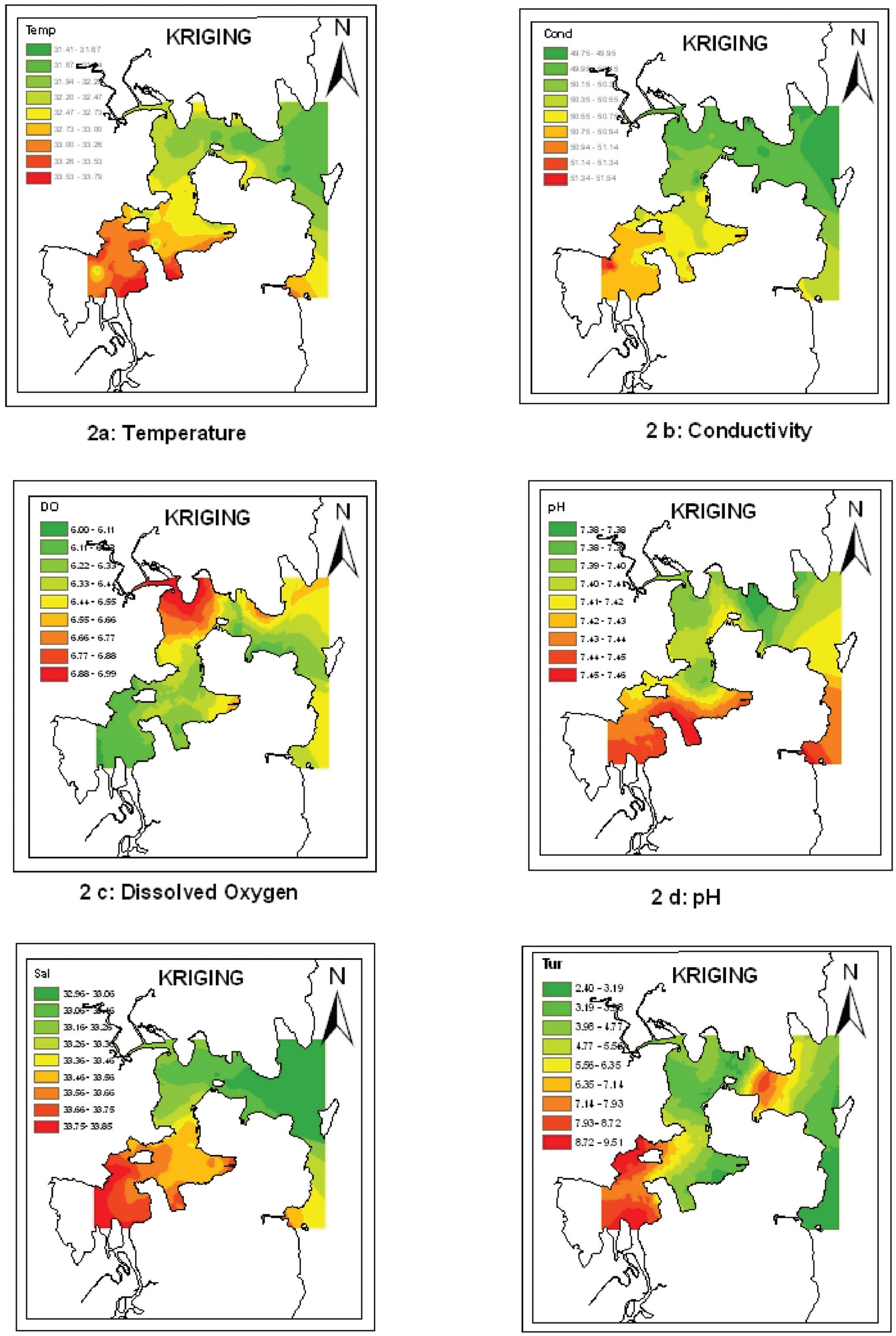


1e: Salinity



1f: Turbidity

Fig. 1. Spatial distribution of water quality parameters in Port Blair bay developed using IDW interpolation method



2a: Temperature

2 b: Conductivity

2 c: Dissolved Oxygen

2 d: pH

2 e: Salinity

2 f: Turbidity

Fig. 2. Spatial distribution of water quality parameters in Port Blair bay developed using Kriging interpolation method

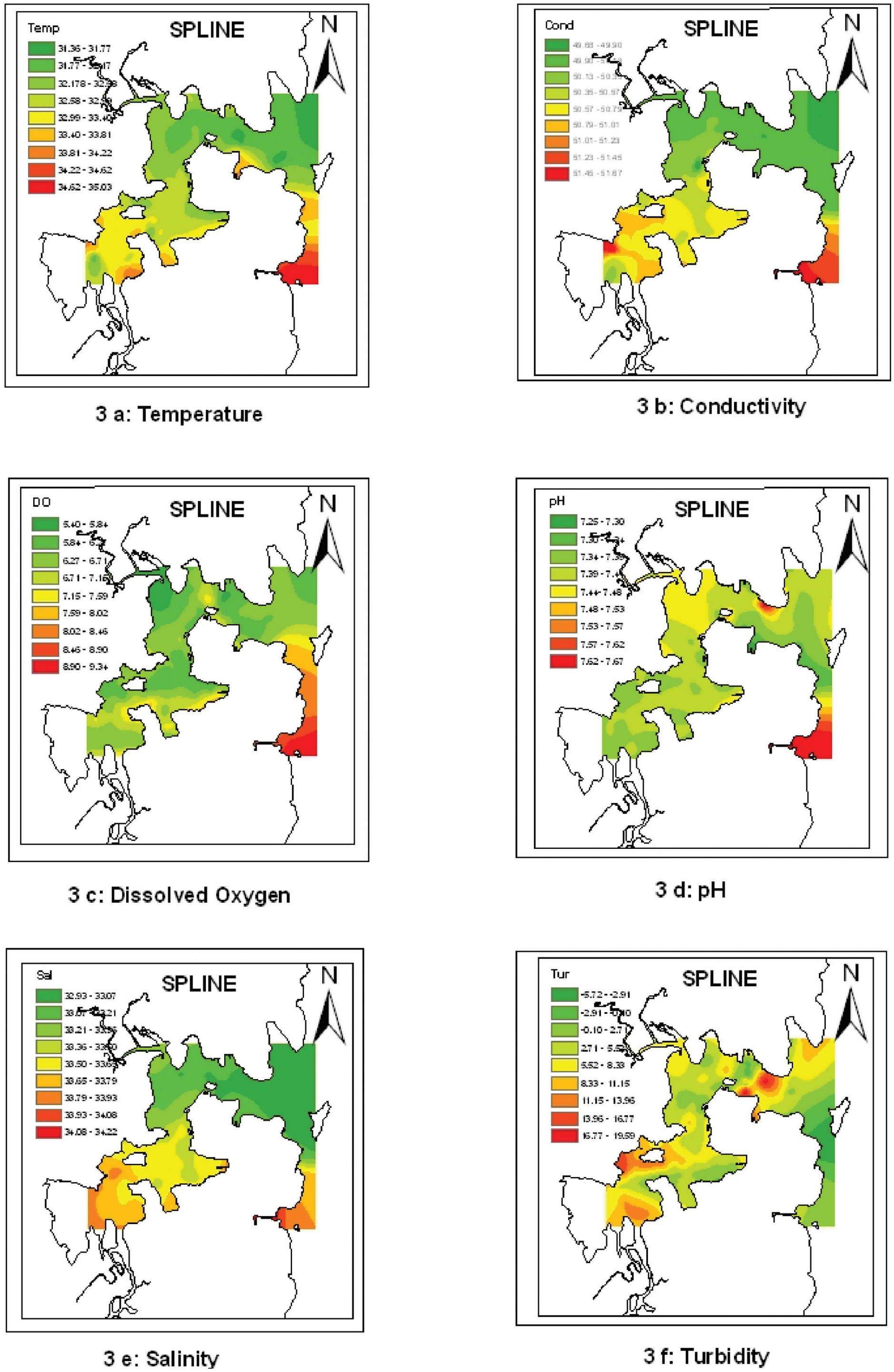


Fig. 3. Spatial distribution of water quality parameters in Port Blair bay developed using Spline interpolation method

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