Research Paper

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Comparative analysis of different techniques for spatial interpolation of phosphate concentration of Upper lake Bhopal

Engineering

KEYWORDS : Spatial interpolation, Inverse Distance Weighting, Kriging, phosphate.

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ABSTRACT

For an efficient watershed planning & management quick and reliable water quality data is essential. However, in practice water quality data at every point in the watershed area may not be available. In such a situation, the water quality parameters are predicted at unknown waterquality parameter point by using mathematical models. Many methods to estimate water quality data at unmeasured point have been proposed in literature and most of these are based on spatial interpolation algorithms.

In this research work different spatial interpolation methods have been used to produce a good continuous data set related to phosphate concentration in the Bhopal upper lake of Bhopal city. These methods investigated areInverse Distance Weighting, Local Polynomial Interpolation, Radial Basis Function, Ordinary Kriging, Simple Kriging, and Disjunctive Kriging. Optimization of different parameters of the interpolation methods has been carried out with a subset of the available dataset while the remaining subset was used to validate the results obtained by the different methods.

Validation results indicate that Simple Kriging is the most suitable method with mean error 0.076 and Root Mean Square 0.084.

Introduction

Spatially continuous data play an important role in planning and decision making in watershed planning. They are not readily available and expensive and difficult to acquire. Data on water quality are collected by point sampling. However, environmental managers require spatially continuous data over a water body of interest to make decisions for watershed management. Spatially continuous data of environmental parameters are required for watershed management using geographic information system and modeling techniques. For most of the water body, such data are not available and only sparsely and unevenly distributed point samples have been collected. Therefore, spatial interpolation techniques are required for the prediction of spatially continuous data of water quality parameters for the unsampled locations using data from the sampling point. A number of spatial interpolation methods are available. But these are data specific and their results depend on many factors *(Li and Heap, 2011).* It is very difficult to select an appropriate method for a given data set and study area *(Li and Heap, 2011).* In various research papers comparison between stochastic and deterministic approaches of spatial interpolation have been published to estimate missing data. Six methods of spatial interpolation were used by *Eischeid J., Pasteris P., Diaz H. Plantico M. and Lott N.,(2000)* to create a serially complete daily precipitation and temperature data set for the united states. Each of these methods was compared for each station by month. Daily climate variables were interpolated using thin plate smoothing spline and monthly and daily and rainfall data were interpolated using ordinary kriging (*Jeffrey, S.J., Carter, J.O., Moodie, K.B., Beswick, A.R., 2001*). Model averaging have been successfully applied to many disciplines such as biomedicine, ecology and hydrology. However, this does not apply in spatial interpolation of water quality parameters. Phosphorus played an important role in the ecological cycle in the water; however, nutrients were closely related to water pollution and may result in eutrophication (*Smith, 2003*; *Chai, C., Yu, Z.M. Song, X.X. 2006*).

The objective of this study is to find the most accurate spatial interpolation method to predict water quality parameters of the study area. In our paper different spatial interpolation techniques have been compared with each other through a validation procedure to choose the most appropriate method for interpolation of quantity of phosphate in lake water.

Method

Study area

The study area Upper Lake is located in the western part of Bhopal, the capital of Madhya Pradesh, India. Upper lake is the major source of potable water for the city located at 23°12' - 23°16' N, 77°18' - 77°23' E. It is surrounded by urban area in east, urban and agricultural land in the north, urban; rural; agriculture in the South and agriculture land in the west.

Water quality data for 18 sampling stations: Kolans, Bhori, Betha, Bairagarh, Bairagarh east, Khanugaon, Karbala, Medical college, Kamla park, yacht club, Van Vihar, Spill channel, Bhadbhada, Stud farm, Bisenkhedi and three deeper zones were provided by Environmental Planning & Coordination Organization (*EPCO*) Bhopal.

Spatial interpolation

Accuracy and comparison of spatial interpolation methods have been investigated in a number of studies. More reliable interpolation gives a better assessment of the spatial distribution of the data *(Robinson, T.P., Metternicht, G., 2006; Shi. W., Liu. J., Du. Z., Song. Y., Chen. C., Yue. T., 2009).* Methods used in this work are Inverse Distance Weighting, Local Polynomial Interpolation, Radial Basis Function, Ordinary Kriging, Simple Kriging, and Disjunctive Kriging.

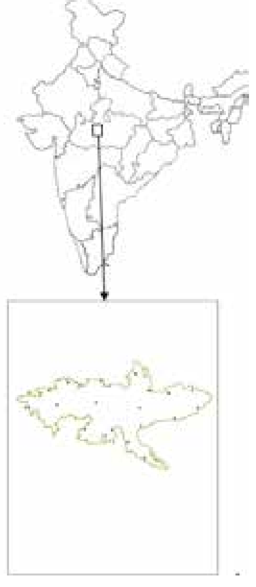

Fig. 1. Location of study area and sampling stations providing observed data.

Inverse Distance Weighted technique is an exact local deterministic interpolation method. This method assumes that the value at any point is a distance-weighted average of the values at sampling stations within a well defined neighborhood surrounding the estimated point. IDW considers that the predicted value will be more influenced by the points closer to the prediction location than points located farther away *(Tobler, 1970)*. Specifying a lower power increases the weight of points that are further away while a higher power increases the weight on the nearer points. Lower power will generate a smoother interpolated surface. Although the performance of inverse distance weighting method is poor in most cases, this method is one of the most commonly compared method *(Li and Heap, 2011)*. Radial Basis Functions are a group of exact deterministic interpolation methods that include different basis functions. As the RBFs are an exact interpolator, they permit the prediction of points below the minimum measured value and above the maximum measured value. Polynomial Interpolation method fits a mathematical function of the measured point. These functions range from first order to higher order polynomials. Polynomial interpolation is of two types – local and global. Local polynomial interpolation fits a number of polynomials using subsets of the measured points while Global polynomial fits a model based on all measured points to the entire surface (ESRI, 2008). Kriging method *(Isaaks and Srivastava, 1990, Kitadinis, 1997)* of spatial interpolation assumes that the spatial variation of data is neither stochastic nor deterministic. Kriging derives predicted values for unmeasured locations by calculating weights for measuring points. These weights are based on the distance between points. Kriging methods are classified as linear and nonlinear *(Moyeed R.A., Papritz A., 2002)*. Simple kriging assumes statistical variation, no underlying trend and a known constant mean. While ordinary kriging assumes an unknown constant mean. Mean must be estimated using data. Disjunctive kriging is a general nonlinear method.

Performance of spatial interpolation methods was tested by applying these methods to the phosphate concentration of water at sampling stations. The results obtained using different interpolation techniques were compared and analyzed. This comparison was carried out using phosphate concentration data of upper lake Bhopal at 18 sampling stations for the month of October 2010. Cross-validation method was used for accuracy assessment (*Isaaks and Srivastava, 1990, Robinson, T.P., Metternicht, G., 2006*). This method compares measured values with predicted values. The errors between measured and predicted values were used to evaluate the performance of different methods. Mean error and root mean square error were calculated using these data. Mean error (ME) was calculated using following formula:

$$ME = \frac{1}{N}\sum_{i=1}^{N}\{Z(Xi) - \check{Z}(Xi)\}$$

Root Mean Square error (RMSE) was calculated using following formula:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Z(Xi) - \check{Z}(Xi)\right)^2}$$

Where is the measured value and is the predicted value. N is the number of samples. Smaller RMSE and ME values indicate less error (Xie et al, 2011).

Results and discussion

The results of six different interpolation methods had different Phosphate concentration distribution tendency.

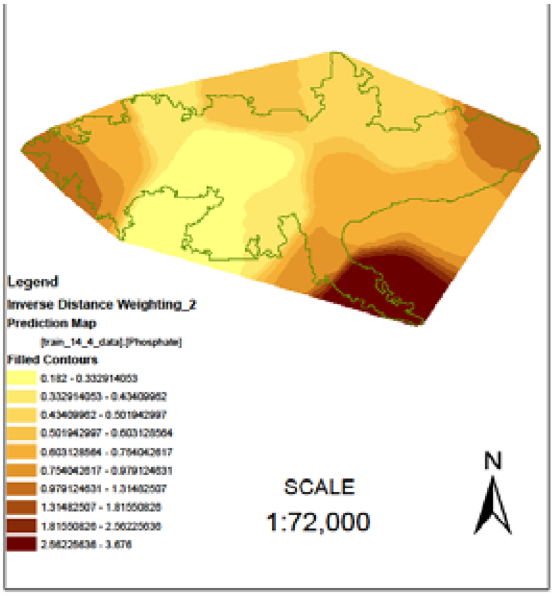

Fig1: Inverse Distance Weighing method

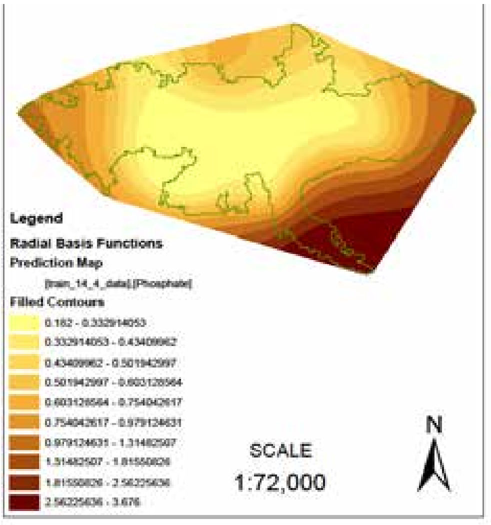

Fig2: Radial Basis Function

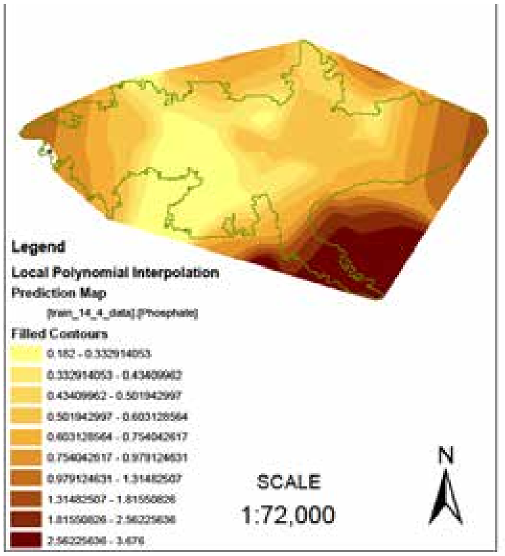

Fig3:Local Polynomial Interpolation method

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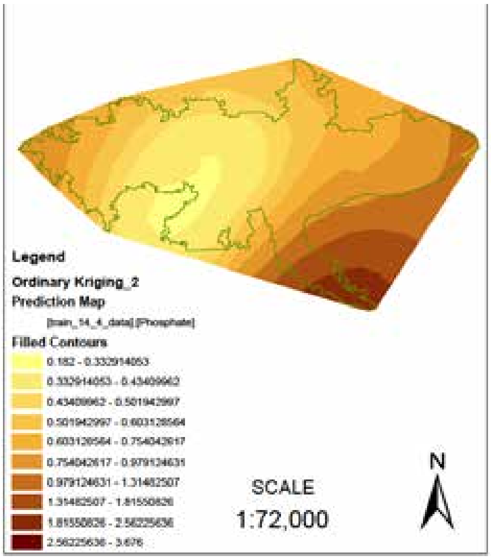

Fig4: Ordinary Kriging method

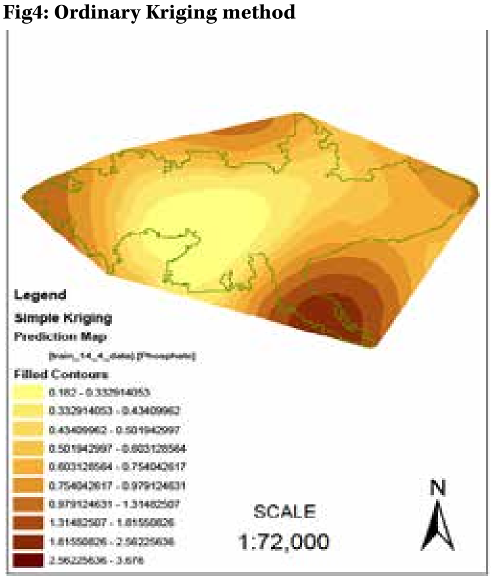

Fig 5 : Simple Kriging

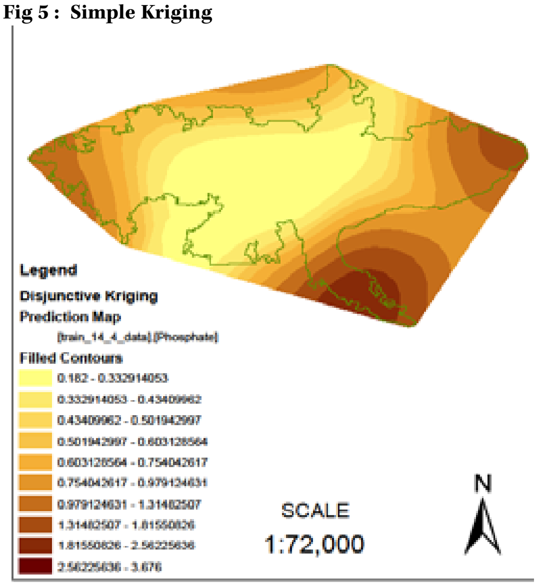

Fig 6 : Disjunctive Kriging

The Phosphorus concentration was highest on south east side and lowest in center and south west side. However Different interpolation methods are accompanied by uncertainty. Distance between sampling points, the number of sampling stations and interpolation method are the most important factors affecting the interpolation accuracy (*Xie, Y.F. Chen,T.B., Lei, M., et al. 2011*). The method of Local Polynomial Interpolation is the least effective with the value ME and RMSE 0.265 mg/l and 0.341 mg/l respectively. The contrary, the method of the Simple Kriging is the most suitable method with mean error 0.076 mg/l and Root Mean Square error 0.084 mg/l. Model parameters are the most important factor to obtain accurate simulation. In general IDW, LPI and RBF need less parameter. In contrast OK, SK and DK have more complex calculation with more input parameters. More input parameters and more complex calculations might be the reason of accurate prediction for SK, OK and DK. On the basis of best estimation method phosphate concentration can be found at any unmeasured location.

	IDW	LPI	RBF	OK	SK	DK
RMSE (mg/l)	0.284	0.341	0.361	0.236	0.084	0.327
ME (mg/l)	0.245	0.265	0.156	0.214	0.076	0.139

Table 1. Root mean square error Mean of errors and for each interpolation method

Conclusion

The spatial interpolation of phosphate concentration of upper lake Bhopal in the month of October 2010 was studied using different interpolation methods; Inverse Distance Weighting, Local Polynomial Interpolation, Radial Basis Function, Ordinary Kriging, Simple Kriging and Disjunct Kriging. RMSE and ME was used to analyse the result of different interpolation methods. Six interpolation methods show diverse results. It has been observed that the best performance has been obtained with the Simple Kriging method and LPI and RBF are the least accurate methods. The best results for the estimation of water quality can be achieved by using geostatistical interpolation methods. Finally the study has shown that through the best method of spatial interpolation, it is possible to estimate the phosphate concentration at any point in the lake.

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