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Comparative Study on the Spatial Interpolation Techniques in GIS

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Abstract— Rainfall process is known to exhibit a high degree of variability both in space and time. Due to the effect of Greenhouse and pollution, the climatic pattern all over the world is changing. But the rate and extent of these changes are varying from place to place. Using point measurements at selected locations it has always been a challenge to the scientific community to get the spatial distribution. This is overcome to some extent using interpolation techniques. There is variety of techniques available in the literature. An evaluation of these techniques by earlier studies has given in an understanding that suitability of a method is region specific. The objective of this study is to study the spatial and temporal pattern of the rainfall and the most suitable technique for interpolation of rainfall in the Coastal district of Dakshina Kannada. The dataset used for the study is rainfall data obtained from 31 rain gauge stations in Dakshina Kannada district of Karnataka state for a period of 30 years. The interpolation algorithms IDW, Spline, Trend surface and Geo-statistical Krigging were analysed in the present study. The Geostatistical tools and Spatial Analyst tools in ArcGIS® were used for the interpolation. The performance of each of these algorithms was evaluated based on the Root Mean Square error (RMSE) and the interpolated surface produced. From the results it can be seen that the Third order Trend Surface produced the largest RMSE error of 443.5 mm and the least was produced by First order Trend Surface, 364.3 mm. The Geo-statistical Krigging methods also produced comparatively less RMSE of 372.4 mm, and gave smooth and more realistic interpolated surface. So it was concluded that Krigging method is the best suitable method for the study..

Index Terms— Algorithms, GIS, Interpolations, Rainfall.

1. INTRODUCTION

The effects of climate change on various environmental variables have been widely observed in many regions around the world. Among these variables, rainfall is the most concerned climate-change Understanding the effects of spatial and temporal rainfall characteristics is therefore necessary for planning responsive measures and forecasting *(Ke-Sheng Cheng et al.,(2005).* Many sophisticated equipments or methods are used for the acquisition of these climatical data. But the climatic data are available at few selected climatic stations only. To capture their spatial variation interpolation methods are used.

Spatial interpolation is tool in GIS used to find the values of unknown points. It can be defined as a procedure of estimating the values of properties at un-sampled locations based on the set of observed values at known locations (*Burrough., 1986*). A large number of interpolation methods have been developed for use with point, line, and area data (*Tatalovich., 2006*). No matter which interpolation technique is used, the derived values are only estimates of what the real values should be at a particular location. The quality of any analysis that relies on interpolation of observed data is, therefore, subject to a degree of uncertainty (*Chiles and Delfiner., 1999*). Different interpolation methods can therefore generate different predictions at same locations.Many researchers have evaluated various methods for interpolation of different hydro climatic data. But accuracy of estimated values is varying from each methods based on the topography of the area, concentration and distribution of the measurement stations (RG stations). So in this study some of these interpolation methods used in GIS were analysed and checked their accuracy based on the results produced.

2. METHODOLOGY

There are two main groupings of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent of similarity (*Inverse Distance Weighted*) or the degree of smoothing (*Spline*). Geostatistical interpolation techniques (*kriging*) utilize the statistical properties of the measured points.

Interpolation algorithms such as *IDW, Spline, Trend surface* techniques and Geo-statistical methods such as *Krigging* were studied in the present study. Before the analysis of rainfall data, the base map of the study area and the map showing the spatial distribution of the raingauge stations were prepared using the software ArcGIS9.3

i) Inverse Distance Weighting

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This method estimates the value of an un-sampled point, area or pixel (in raster models), as a weighted average of a defined number of neighbourhood points, and the weight assigned to each point diminishes as the distance between points increases. The working of IDW interpolator can be graphically represented as shown in the figure 1.

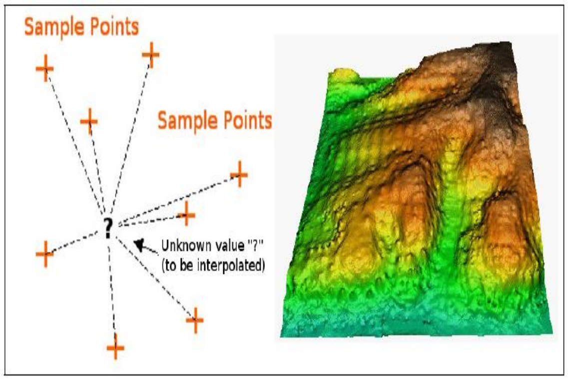

Fig. 1 Graphical representation of IDW interpolation

The estimator of the IDW model is given as in equation (1):

$$z(u_0) = \frac{\sum_{\alpha=1}^{n} z(u_\alpha) d_{\alpha 0}^{-r}}{\sum_{\alpha=1}^{n} d_{\alpha 0}^{-r}} \quad (1)$$

Where:

$z(u_0)$ = the estimate at the location u_0

n = the number of neighbouring observations $z(u_0)$

d = the distance between observations

r = an exponent that describes the similarity between observations

ii) Trend Surface Analysis

Trend surface analysis is the most widely used global surface-fitting procedure. The mapped data are approximated by a polynomial expansion of the geographic coordinates of the control points, and the coefficients of the polynomial function are found by the method of least squares, insuring that the sum of the squared deviations from the trend surface is a minimum. Each original observation is considered to be the sum of a deterministic polynomial function of the geographic coordinates plus a random error. The polynomial can be expanded to any desired degree, although there are computational limits because of rounding error. The unknown coefficients are found by solving a set of simultaneous linear equations which include the sums of powers and cross products of the X, Y, and Z values.

The elevation z at any point (x,y) on the surface is given by an equation in powers of x and y

- e.g. a linear equation (degree 1) describes a tilted plane surface:

$z = a + bx + cy$

- e.g. a quadratic equation (degree 2) describes a simple hill or valley:

$z = a + bx + cy + dx^2 + exy + fy^2$

The trend surfaces created from the above equations are shown in the figure 2.

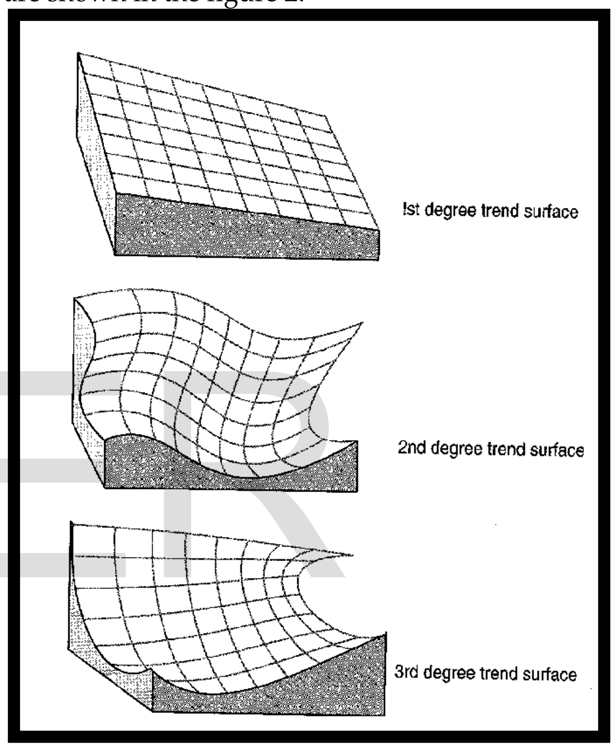

Fig.2. Trend surfaces created using polynomial equations

Once the coefficients have been estimated, the polynomial function can be evaluated at any point within the map area. It is a simple matter to create a grid matrix of values by substituting the coordinates of the grid nodes into the polynomial and calculating an estimate of the surface for each node. Because of the least-squares fitting procedure, no other polynomial equation of the same degree can provide a better approximation of the data.

iii) Splines

Spline is an interpolation method that estimates values using a mathematical function that minimizes overall surface curvature, resulting in a smooth surface that passes exactly through the input points.

Given n+1 distinct knots x_i such that

$x_0 < x_1 < ..... < x_{n-1} < x_n$

With n+1 knot values y_i we are trying to find a spline function of degree n, $S(x)$ can be given as in equation (2)

$$S(x) = \begin{cases} S_0(x) & x \in [x_0, x_1] \\ S_1(x) & x \in [x_1, x_2] \\ \vdots & \\ S_{n-1}(x) & x \in [x_{n-1}, x_n] \end{cases} \quad (2)$$

Where, each $S_i(x)$ is a polynomial of degree k.

Using polynomial interpolation, the polynomial of degree n which interpolates the data set is uniquely defined by the data points. The spline of degree n which interpolates the same data set is not uniquely defined, and we have to fill in n-1 additional degrees of freedom to construct a unique spline interpolant.

Theoretically, the sample points are extruded to the height of their magnitude; spline bends a sheet of rubber which passes through the input points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for generating gently varying surfaces such as elevation, water table heights, or pollution concentrations.

iv) Geostatical Methods – Kragging

The theory of Kriging was developed by the French mathematician Georges Matheron based on the Master's thesis of Daniel Gerhardus Krige, the pioneering plotter of distance-weighted average gold grades at the Witwatersrand reef complex. Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain the variation in the surface. Kriging fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location.

Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modelling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when we know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology. Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data (equation (3)):

$$Z(s_0) = \sum_{i=1}^{n} \lambda_i Z(s_i) \quad (3)$$

where:

$Z(s_i)$ = the measured value at the i^{th} location.

λ_i = an unknown weight for the measured value at the i^{th} location.

s_0 = the prediction location.

n = the number of measured values.

In IDW, the weight, λ_i, depends solely on the distance to the prediction location. However, with the Kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

There are two kriging methods: Ordinary and Universal. Ordinary Kriging is the most general and widely used of the kriging methods and is the default. It assumes the constant mean is unknown. This is a reasonable assumption unless there is a scientific reason to reject it.Universal Kriging assumes that there is an overriding trend in the data—for example, a prevailing wind—and it can be modelled by a deterministic function, a polynomial. This polynomial is subtracted from the original measured points, and the autocorrelation is modelled from the random errors. Once the model is fit to the random errors and before making a prediction, the polynomial is added back to the predictions to give meaningful results.

3. DESCRIPTION OF STUDY AREA

The study area selected for the present study is Dakshina Kannada District in Karnataka in India. It is bordered by Udupi District to the north, Chikkamagaluru district to the northeast, Hassan District to the east, Kodagu to the southeast, and Kasaragod District in Kerala to the south. The Arabian Sea bounds it on the west. The geographic co-ordinates of the area are 13° 11′N to 12° 27′N latitude and 74°40′E to 75°40′E longitude. The geography consists of sea shore in the west and Western Ghats in the east. The major rivers are Netravathi, Kumaradhara, Phalguni, Shambhavi, Pavanje and Payaswini which all join Arabian sea. The Dakshina Kannada district has an area 4866 square kilometre. Density of human population is 390 persons per square kilometre. The area receives an annual average rainfall of 4000mm per year. The location map of the study area is given in figure 3.

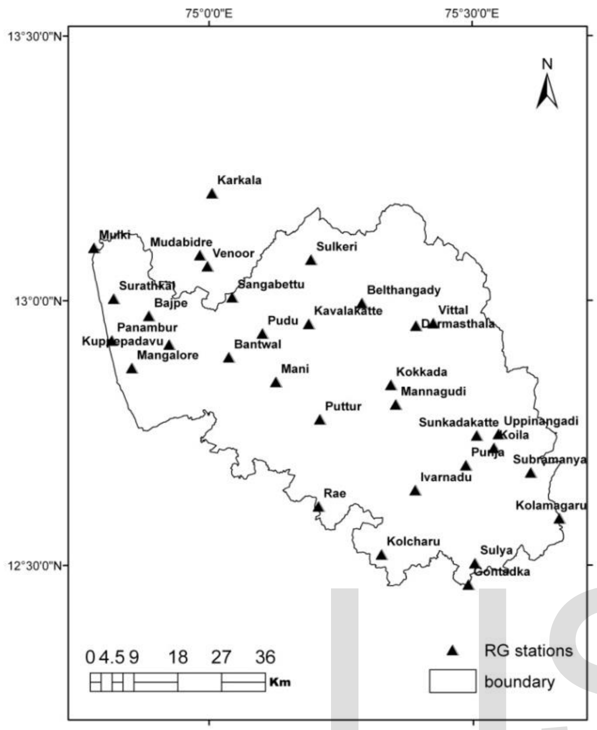

Fig.3 Study Area

4. RESULTS AND DISCUSSIONS

The interpolation of rainfall at unknown points was estimated using different techniques available in the software *ArcGIS®*. The interpolation was carried out using *IDW, Spline, Trend Surface and Krigging* techniques.The performance analysis of these interpolation techniques were carried out based on the Root Mean Square Error (RMSE) produced by them (Refer Table 1). It can be seen from referring to the DEM (Digital Elevation Model) of the area Fig.4), that the highest rainfall receiving stations are located near the mountainous region.

Method		RMSE
IDW		417
SPLINE	REGULARIZED	400.8
	TENSION	395.2
TREND	I	364.3
	II	385.2
	III	443.5
KRIGGING	ORDINARY	372.4
	UNIVERSAL	372.4

Table 1. RMSE of Interpolation Methods

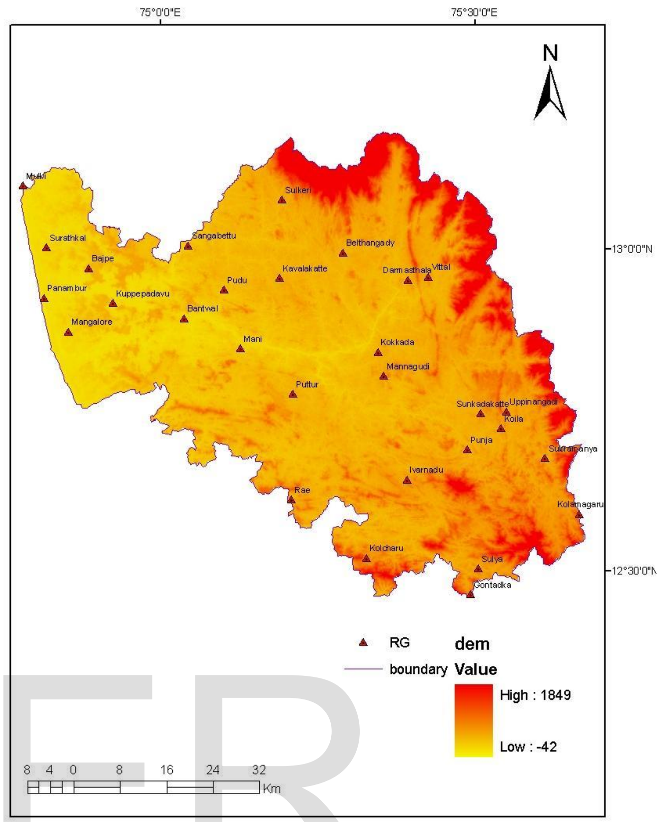

Fig.4 Digital Elevation Model for Dakshina Kannada District

From the results it can be seen that the *Third order Trend Surfac*e produced the largest RMSE error of 443.5 mm and the least was produced by *First order Trend Surface*, 364.3 mm. The *Geo-statistical Krigging* methods also produced comparatively less RMSE of 372.4 mm. But the RMSE can't alone take for deciding the suitable method. It can be seen from referring to the DEM (Digital Elevation Model) of the area Fig.6), that the highest rainfall receiving stations are located near the mountainous region. Also the interpolated surface produced by the *Krigging* method is smooth and realistic compared to the surface produced by the first order trend surface. So based on the RMSE produced and the interpolated surface created, it can be concluded that *Krigging* is the best suitable method for the study area, Dakshina Kannada district.

5. CONCLUSION

The present study aimed at understanding the spatial and temporal pattern of rainfall in the Dakshina Kannada district in Karnataka. The spatial pattern is obtained from the interpolation. The result shown that, the *first order polynomial trend surface* has the least RMS error. But when considering the topography or altitude, the *Krigging* produced the best results compared to others. So based on the RMSE and the interpolated surface produced, it can be concluded that *Krigging* is the best suitable method for the study area ie.Dakshina Kannada district.

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