Analysis of Spatial Interpolation Techniques for Rainfall Data using Various Methods: A Case Study of Bisalpur Catchment Area

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***Abstract*— Distribution of rainfall plays an important role in understanding hydrological processes. Hydrological Modeling using spatial interpolation technique is performed to study hydrological process which is essential for water resource management.**

Spatial Interpolation techniques are performed on rainfall data to predict the unspecified values in Bisalpur Catchment. Chronological Rainfall data are available for numerous rain gauge stations, which are used to perform spatial interpolation to generate layer of rainfall distribution. There are several interpolation techniques in GIS such as simple mathematical models (e.g. Thiessen polygons, Natural Neighbor, Inverse Distance Weighting, Trend, Spline and complex models like geo-statistical methods, such as Kriging, Topo to raster etc.).The results of the study found that among these methods, the geo-statistical interpolation method give better results than other mathematical models because it is based on the spatial variability of data.

Keywords*— Rainfall variability, Spatial analysis, Interpolation, Kriging

1. INTRODUCTION

Rainfall patterns are changing worldwide due to climate change therefore study of Hydrological processes has become essential for water resource management. Distribution of rainfall plays an important role in understanding hydrological processes. To perform hydrological modeling spatial interpolation of rainfall data is a key parameter.

The current research focused on various GIS techniques for spatial interpolation of rainfall data with respect to spatial distribution of the rainfall in the Bisalpur catchment area. The Bisalpur catchment area spread over the six districts of Rajasthan i.e. Tonk, Ajmer, Bhilwara, Rajasamnd, Chittorgarh and Udaipur and one district of Madhya Pradesh, Neemuch. The Geographic Information System (ArcGIS) are used for the estimation of the spatial distribution.

The accuracy assessment was implemented using Cross Validation (CV) on the interpolated rainfall surface using Root Mean Square Error (RMSE), Variance (VAR), Correlation Fractional Bias (FB), and Factor of Two (FA2). Ten rainfall stations were randomly selected for validation. The results were calculated for these stations to pick the most appropriate method which gives greater accuracy.

ArcGIS spatial Analyst extension provides a toolset for analysis & modelling spatial data. A set of sample points representing changes in landscape, population, rainfall or environment can be used to visualize the continuity & variability of observed data across a surface through the use of interpolation tools. These changes can be extrapolated across geographical space so that morphology & characteristics of these changes can be described. The ability to create surface from sample data makes interpolation both powerful & useful (By Colin Childs, ESRI Education Services).

2. STUDY AREA

The aim of the study is to improve interpolation accuracy of the spatial rainfall distribution in the ArcGIS by using the different interpolation techniques. The Bisalpur catchment area is located between latitudes 24 º 16′ to 26 º 30′ N and longitudes 73 º27′ to 75 º 28′ E.. Rainfall data is collected for Ajmer, Bhilwara, Chittorgarh, Rajsamand, Tonk & Udaipur rain gauge stations. Remote sensing Landsat7 data is acquired from the USGS (Landsat.org).

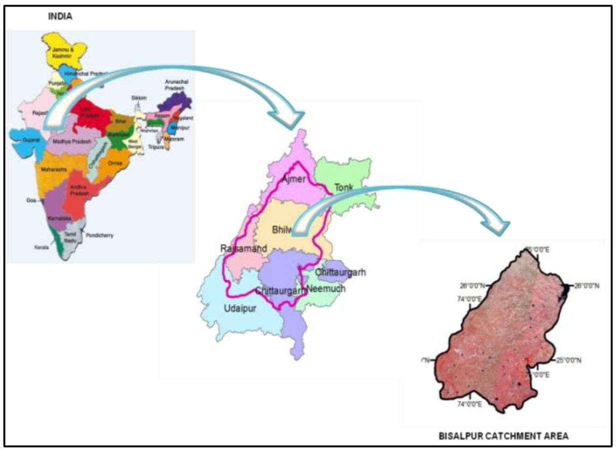


Figure 1. Study Area

Bisalpur dam was constructed near Tonk in the mid – 1990s across the Banas River, the largest river of Rajasthan. It is multipurpose gravity dam which fulfills both drinking and irrigation water needs. It supply drinking water to towns such as Jaipur, Tonk, Chaksu, Ajmer, Beawar, Malpura, Dudu and nearby rural area. The increasing population and urbanization have put tremendous pressure on water resources. Thus the study of Hydrological processes in catchment area is essential for water resource management.

3. METHODOLOGY

The above spatial interpolation techniques were implemented in ESRI's ArcGIS software using Spatial Analyst Tool. The tool offers several interpolation techniques for generating surface grids from point data. Each method uses a different approach for determining the output cell values. The rainfall data from various rainfall stations for the year 2008 was converted into point layer. The point layer was re projected to the same projection as the other dataset. (Geographic,WGS84). The abnormal rainfall data values were removed. Various GIS techniques for spatial interpolation of rainfall data are performed to predict the unknown rainfall values in Bisalpur catchment area. The output was than clipped with the study area boundary. Rainfall chronological data are available at rain gauge stations which are used to perform spatial interpolation to generate surface of rainfall distribution. 75 rain guage stations data were analyzed to generate the result.

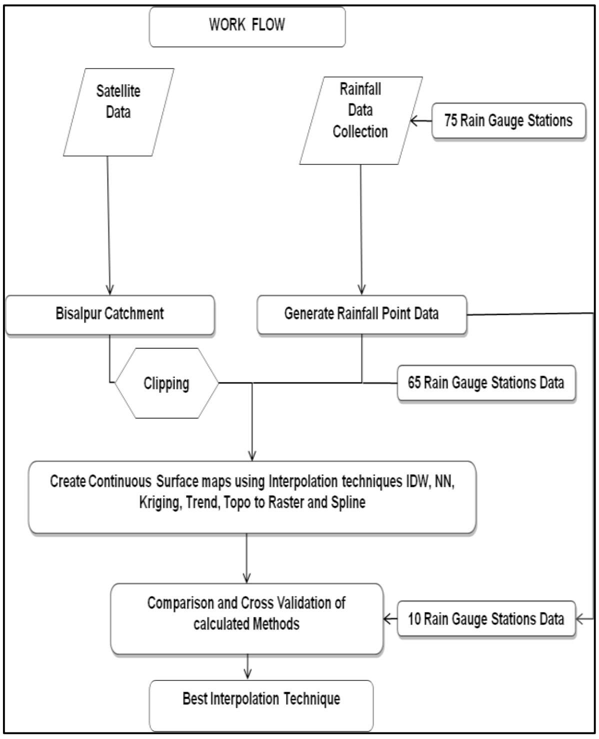


Figure 2: Methodology

A. Data Collection:

Rainfall data for Bisalpur catchment area is collected from Water Resources Department, Government of Rajasthan. Four months rainfall (June to July) data was recorded for the year 2008 of 75 raingauge stations covering Ajmer, Bhilwara, Tonk, Chittorgarh, Udaipur, Rajsamand districts of Rajasthan.

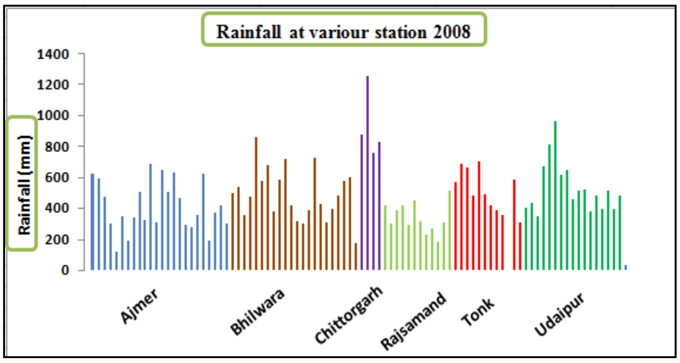


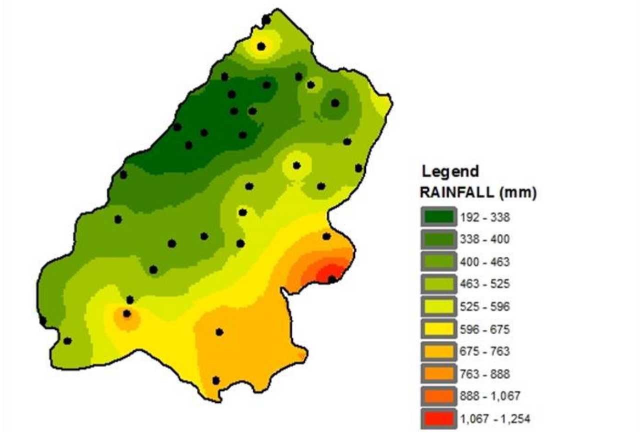
Figure 3: Rainfall recorded at various rain gauge stations from June to Sept of 2008.

4. RESULTS & DISCUSSION:

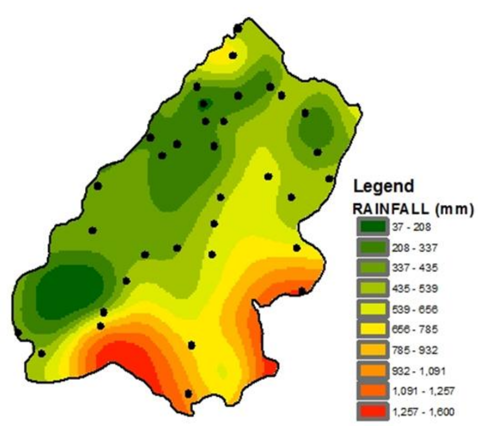
The thematic maps generated by various methods are shown in figure 4(a) & 4(b) which depicts a continuous rainfall surface. Red colour shows high rainfall whereas low rainfall is illustrated by shades of green colour. The different models are compared with each other through a validation procedure to pick the most appropriate method which gives greater accuracy in the validation set. The cross validation was performed using 10 known rainguage stations which were selected randomly on study area. Pixel values of 10 station were recorded in all six interpolation techniques. Predicted values so obtained were further validated using RMSE, VAR, COR, FB, FA2.

TABLE 1 PREDICTED VALUES OF SIX INTERPOLATION TECHNIQUES FOR TEN STATIONS

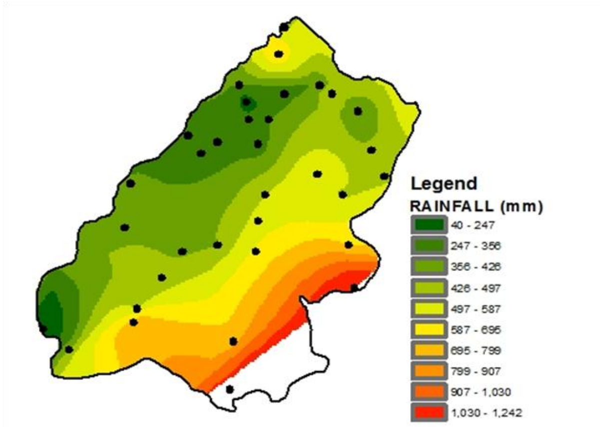
S.NO.	Station	Rainfall	Trend	Top to Raster	Spline	Natural Neghour	Kriging	IDW
1	Mangaliawas	324	375.91	528.57	692	534.24	531.24	507.96
2	Chotisadri	826	602.5	749.77	736.8	793.92	765.1	649.59
3	Dabla	389	484.59	414.74	420.8	415.98	415.98	368.6
4	Begohi	523	474.58	531.11	273.9	482.15	554.24	567.42
5	Raipur	377.5	442.4	389.91	390.1	389.44	393.22	395.49
6	Sawar	627	563.26	459.75	355.6	441.77	415.27	470.72
7	Sambugarh	300.9	418.64	308.58	282.1	299.63	300.17	303.9
8	Hameergarh	723	550.33	584.84	573	598.25	589.55	518.5
9	Barisadari	875	651.23	857.13	993.6	–	876.97	697.92
10	Chilkawas	311	474.75	460.97	467.3	415.38	489.73	505.73



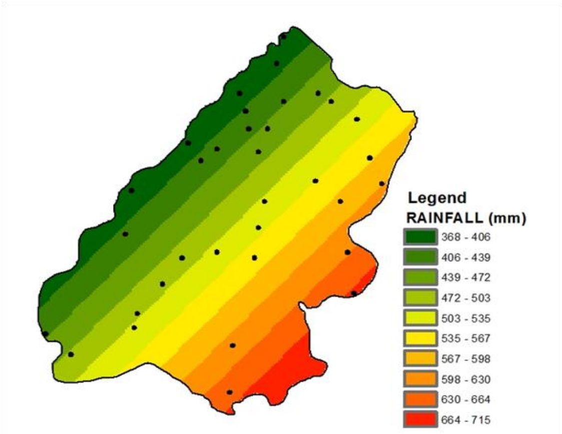
IDW



SPLINE

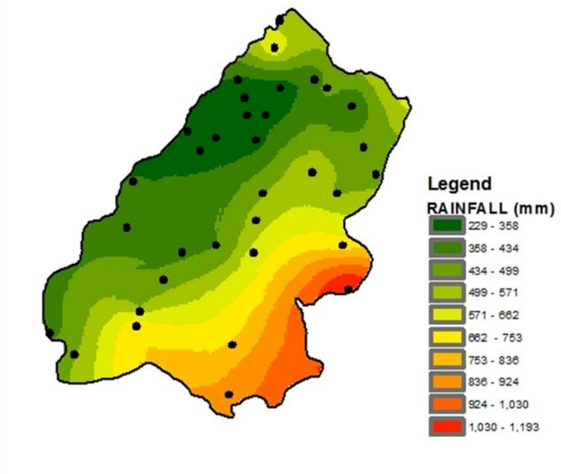


NATURAL NEIGHBOR

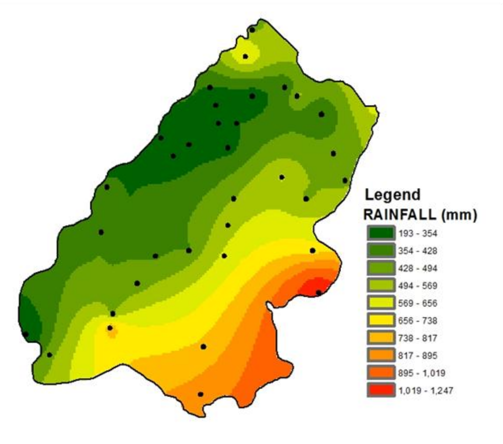


TREND

Figure 4(a): Mathematical Models of interpolation technique at various rainguage stations.



KRIGING



TOPO TO RASTER

Figure 4(b): Geo-Statistical Models of interpolation technique at various rainguage stations.

B. Cross Validation:

In the study RMSE, VAR, COR, FB, FA2, was used to predict the performance of six interpolation techniques. Cross validation was performed using observed values of ten known rainfall data selected randomly on study area with the predicted values of the same from various interpolation methods.

TABLE 2 COMPARISON OF SIX INTERPOLATION TECHNIQUES USING CROSS VALIDATION

S.NO.	INTERPOLATION METHODS	RMSE	VAR	COR	FB	FA2
1	TOPO TO RASTER	**108.848**	**114.733**	**0.861**	**-0.002**	**100.000**
2	KRIGING	113.687	119.451	0.843	-0.017	**100.000**
3	TREND	138.913	144.258	**0.931**	0.046	**100.000**
4	IDW	142.550	147.106	0.780	0.057	**100.000**
5	SPLINE	184.825	194.586	0.629	0.017	90.000
6	NATURAL NEIGHBOR	215.009	212.644	0.397	0.151	88.889

- *Correlation Coefficient (R) :*

This measure defines the relationship between the observed and predicted values. It varies from 0 to ±1. The value of R close to 0.1 implies a good agreement between the observed and predicted values. It is represented in Equation 1

$$R = \frac{\sum_{i=1}^{n}\left(C_{o_i}-C_o\right)\left(C_{p_i}-C_p\right)}{\sigma_{C_o}\times\sigma_{C_p}} \qquad (1)$$

Where

Mean $C_o = \frac{1}{n}\sum_{i=1}^{n} C_{o_i}$ and Standard Deviation

$$\sigma_{C_o} = \sqrt{\frac{1}{n}}\ \sum_{i=1}^{n}(C_{o_i} - C_o) \qquad \text{(Observed)}$$

Mean $C_p = \frac{1}{n}\sum_{i=1}^{n} C_{p_i}$ and Standard Deviation.

$$\sigma_{C_p} = \sqrt{\frac{1}{n}}\ \sum_{i=1}^{n}(C_{p_i} - C_p) \qquad \text{(Predicted)}$$

Here Trend and Topo to Raster R value is near to 0.1

- *Fractional Bias:*

The bias is normalized to make it dimensionless. The fractional bias (FB) varies between +2 and -2 and has an ideal value of zero for an ideal model. The FB is given by

$$FB = 2\times\left(\frac{C_o - C_p}{C_o - C_p}\right) \qquad (2)$$

Fractional bias, as could be seen clearly, is symmetrical and bounded. A value of +2 indicates extreme over prediction and a value of -2 indicates extreme under prediction. In these methods Topo to Raster value is most ideal.

- *Factor of Two:*

The factor of two (FA2) is defined as the percentage of the predictions within a factor of two of the observed values. The ideal value for the factor of two should be 1 (100%).

$$FA2 = \text{Fraction of data which } 0.5 \le C_p / C_o \le 2.0 \qquad (3)$$

- *Root Mean Square Error (RMSE):*

It is frequently used to measure the difference between values predicted by a model and the values actually observed.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i-1}^{n}\left(C_{p_i} - C_{o_i}\right)^{2}} \qquad (4)$$

The RMSE error is minimum in Topo to Raster.

5. CONCLUSIONS

The result showed that the RSME values of the six methods were in the order Topo to Raster < Kriging < Trend < IDW < Spline < Natural Neighbor. Variance was minimum in Topo to Raster. Highest correlation was found in Trend followed by Topo to Raster also Fraictional Bais is near to ideal in Topo to Raster. Thus we can conclude that Topo to Raster produced the most accurate interpolated results. (RMSE = 108.848, Var = 114.733, corr = 0.861, FB = -0.002, FA2(%) = 100 This method was chosen as the most reliable model for interpolation. On the contrary, the worst performance has been observed with Natural Neighbor. The kriging method was next to Topo to Raster. So we can say geo-statistical methods are best fitted in our study.

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