Modeling Spatial Variability of Precipitation over a Catchment

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Abstract* - Catchment is defined as an area of land draining into a stream or water course. Rainfall over a given catchment is not uniform and has spatial and temporal variation. Various methods have been proposed in the recent past to determine this variation. Whatever might be the method involved, the primary theme of any method is to convert point rainfall found at rainfall gauge station into mean precipitation and produce the results in a graphical format giving the distribution of rainfall over a given catchment area under consideration. To find the distribution of rainfall, methods such as Theissen polygons, kriging, spline surfaces etc. are proposed and are being implemented. Each method has its respective pros and cons and selection of a particular method depends on convenience and degree of accuracy required. After the collection and analysis of data, results are established by using different methods mentioned above and comparison is done.

***Key Terms* -** Theissen polygons Method, Annual Precipitation, GIS Technique and Kriging

I. INTRODUCTION

Management of the quantity & Quality of Runoff from catchment is a complex task, which over the last few year has become important to the community. This community awareness has increased the need for managers to get the information relevant to the response of the system vested in their control (By James E.et.al 1998). The influence of catchment scale on hydrologic response and its importance in rainfall-runoff modeling has been recognized since the early 1960s (Minshall, 1960; Amorocho, 1961). Qualitatively it has been recognized that as the spatial scale of the catchment increases, the catchment tends to attenuate the complex, local patterns of runoff generation and water fluxes. As pointed out by Amorocho (1961), at large catchment scales the runoff generation becomes somewhat insensitive to rainfall intensity changes recorded at individual gages and the catchment-scale rainfall-runoff response appears to be governed by macroscale catchment characteristics. These observations have stimulated hydrologists' attempts to define what is meant by "large catchment scales" and to develop a consistent theory for analyzing catchment responses at different scales. Ideally, models that fully replicate the processes and their spatial and temporal variability should be used. However, in practice this does not occur because many processes are so complicated and interrelated that a full description may be impossibly complex and even when a process can be described concisely and completely, the volume of calculations involved may be prohibitive. Also, the data available to define the model control parameter values are limited in both spatial and temporal dimensions. As a result, simplifying assumptions are made and the real situation is idealized. Alternative idealizations result in the emphasis of different processes and require different magnitudes of computational effort. Consequently, instead of one model of reality, alternative models with differing degrees of complexity and computational effort may be developed.

a. THEISSEN POLYGON METHOD FOR PRECIPITATION

The Thiessen polygon method, put forward by Thiessen (1911), is another widely-used interpolation algorithm. In this study, the Thiessen polygons were firstly generated using the spatial analyst tool of ArcGIS and manually overlapped with the delineated sub watershed. Mapping point data usually involves some sort of interpolation. There are many point-interpolation methods out there (contours, IDW, TIN, tension spline, kriging, trend surface, etc.) as well as non-interpolation methods for displaying point values (proportionally-sized circles). The Thiessen Polygon method is an interpolation method commonly used for precipitation, but can be used on other point datasets. The approach is based on defining the area closer to a gauge than any alternate gauge and the assumption that the best estimate of rainfall on that area is represented by the point measurement at the gauge. Because the basis of the model is the geometry of the catchment and the gauge locations, implementation of Theissen polygons in a GIS environment is not difficult. However, an impact of the use of Theissen polygons is the development of discontinuous surfaces defining the rainfall depth over the catchment. Theissen Polygon Method for Precipitation is given below

$$\overline{P} = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + \ldots + P_n A_n}{A_1 + A_2 + A_3 + \ldots + A_n} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i}$$

Whereas,

$\overline{P}$ is the weighted average, P's are measurements, and A's are areas of each polygon.

b. KRIGING METHOD

Kriging or Gaussian process regression is a method of interpolation for which the interpolated values are modelled by a Gaussian process. In probability theory and statistics, a Gaussian process is a statistical distribution where observations occur in a continuous domain, e.g. time or space. Kriging is an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. Kriging is based on regionalized variable theory, which assumes that the spatial variation in the data being modelled is homogeneous across the surface. That is, the same pattern of variation can be observed at all locations on the surface. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points. Kriging is unique among the interpolation methods in that it provides an easy method for characterizing the variance, or the precision, of predictions.

c. SPLINE METHOD

Spline is a numeric function that is piecewise defined by polynomial functions, and which possesses a high degree of smoothness at the places where the polynomial pieces connect. Spline interpolation is a form of interpolation where the interpolant is a special type of piecewise polynomial called a spline. Spline interpolation is often preferred over polynomial interpolation because the interpolation error can be made small even when using low degree polynomials for the spline. Spline is originally developed for ship-building in the days before computer modelling

II. CATCHMENT DESCRIPTION AND DATA

The selected catchment area located in Warangal district of Telangana state. The catchment area covers nine mandals (District) such as Atmakur, Dharmasagar, Duggondi, Geesugonda, Hanamkonda, Hasanparthy, Sangem, Shayampet and Warangal. Nine Rain gauge stations are located under Warangal district, from there 12 year (2001-2012) rainfall data has been obtained for the study. Satellite image of the catchment is shown in the figure. The catchment area is 1156.23 Sq.KM (As calculated from Google earth pro).

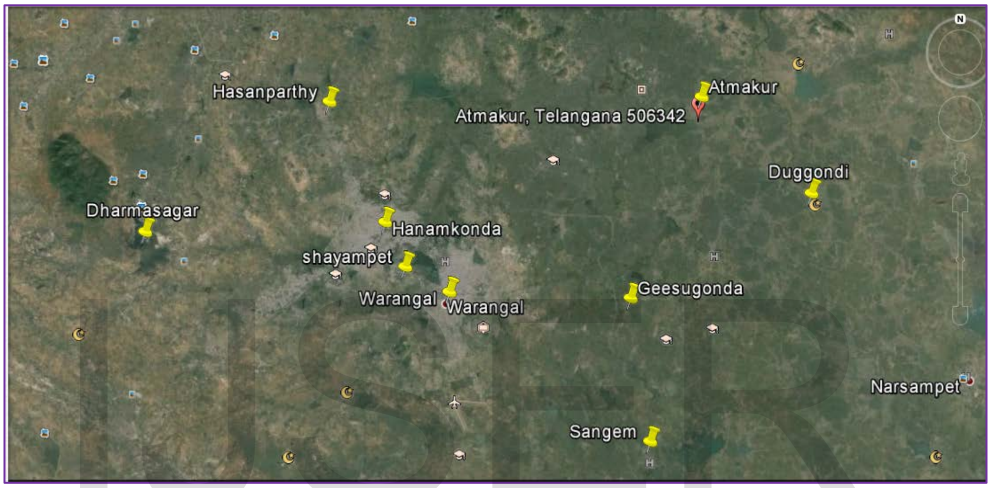


Fig no.1. Location of the Catchment

III. LITERATURE REVIEW

F.F. Zhao a et.al(2011)-The preliminary results from this study suggest that more accurate information of rainfall distribution in a catchment can help to improve daily water balance modelling. The study also showed that the spatial distribution of runoff is controlled by the spatial rainfall variability on a wet day and by the soil moisture distribution on a dry day.

Giha LEE et. al (2009)-This paper aims to investigate the influence of input uncertainty due to spatial variability of rainfall data on both global and internal catchment. The rainfall-runoff transformation conducted by the KWMSS (Kinematic Wave Method for Subsurface and Surface Runoff) is based on the assumption that each element is covered with a permeable soil layer. Even less spatially-distributed rainfall scenarios than the original data could provide acceptable runoff simulation results. Computational tracer method can show the potential stream flow origin in time and space by using a spatiotemporal record matrix.

By James E (1998) -James E. Ball considered the Upper Parramatta River catchment, which is located in the western suburbs of Sydney, Australia. Theissen Polygons, Inverse Distance Weights, Kriging & Spline surfaces methods are used for analyzing the catchment data. All these techniques are used for converting point rainfall found at rain gauge stations into mean precipitation. Rainfall-Runoff Model is based on the RAFTS software package (WP Software 1995). The spatial rainfall distributions obtained from the alternative models are compared and results will be established graphically.

IV. MODEL ANALYSIS

Warangal District, Mean Rainfall vs Year Bar chart (which represent maximum and minimum rainfall occurred in the year)

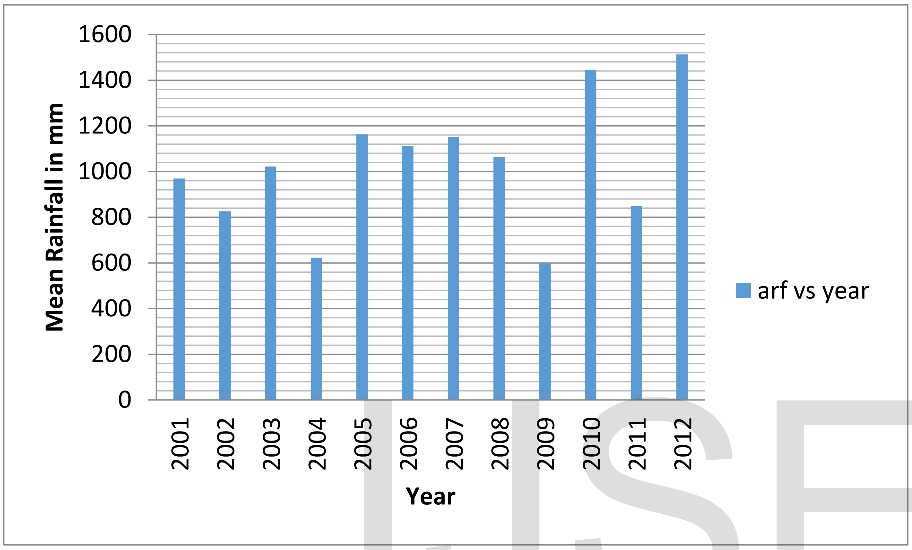
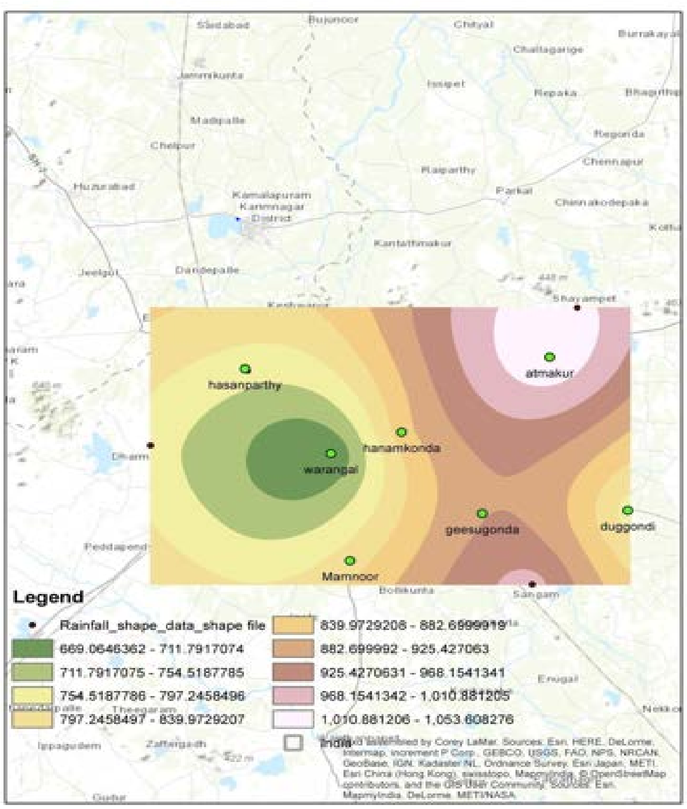


Table No.1 Rainfall data NOB & ARF

Year	NOB	ARF
2001	183	969.8
2002	245	825.9
2003	184	1022
2004	243	623
2005	246	1162.9
2006	365	1112
2007	365	1150.3
2008	366	1065
2009	365	599.6
2010	365	1445.7
2011	365	850
2012	366	1513.4
	SUM	**12339.6**
	MEAN	**1028.3**

NOB- Number of Observation, ARF- Annual Rainfall mm



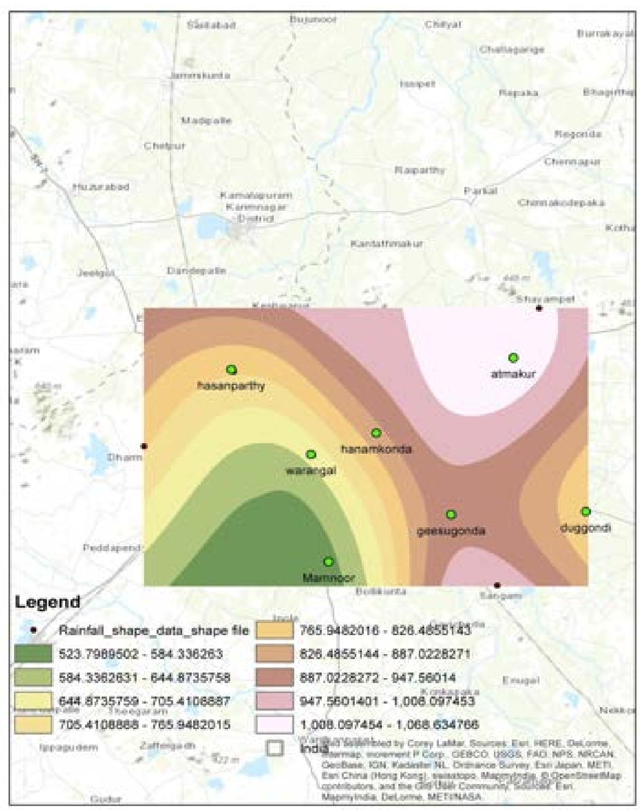


Fig. No. 2 Model output From Kriging Method

Fig.No.3 Model output From Spline Method

V. INTERPOLATING SURFACE IN ArcGIS Spatial Analyst By Using **THIESSEN POLYGON METHOD**

The distribution of rainfall, method such as Theissen polygons, kriging, spline surfaces etc. are proposed and are being implemented. Each method has its respective pros and cons and selection of a particular method depends on convenience and degree of accuracy required.

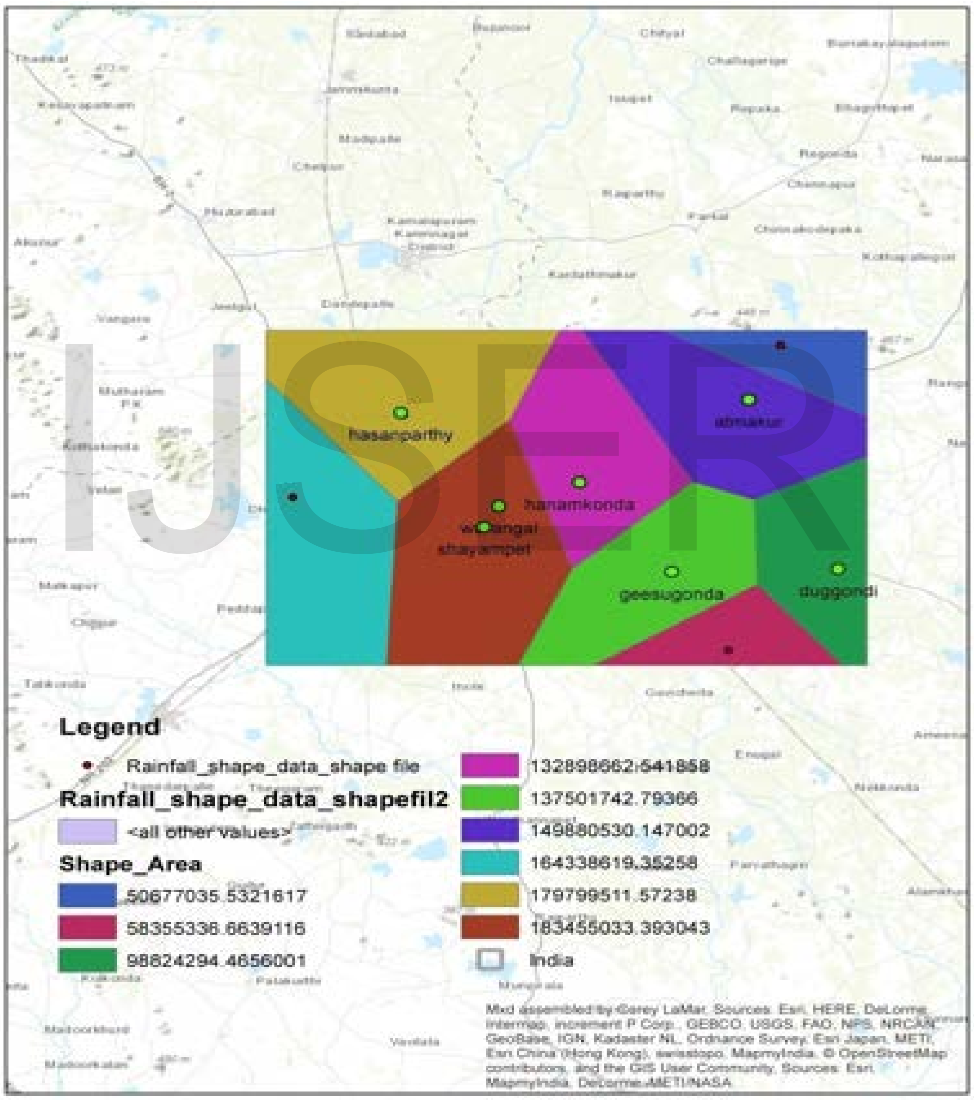


Fig. No. 4. Rainfall Distribution map by using Thiessen Polygon Method

Comparison of various Models

The objective of the comparative analysis is to determine the most adequate rainfall interpolation technique for the catchment. Three different spatial interpolation methods are applied to know the rainfall distribution pattern. To compare all the models, we have to choose a labelled point in the catchment. By removing data at any of rain gauge station , the rainfall pattern is again drawn by using all the methods .Then, relative errors are calculated for original data and data obtained after removing rainfall data at any rain gauge station

Relative error is given by

$$\frac{(New\ Value - Original\ Value)}{Original\ Value} \text{X } 100$$

Table no.2. Relative Error of different Methods

Items	**Kriging**	**Spline**	**Thiessen**
New Value	829.74	596.91	787.92
Original	820.56	566.179	145.55
Relative error	1.12%	5.43%	441%

VI. CONCLUSION

A number of alternative models for describing the spatial distribution of rainfall using hydro - informatics tool, particularly GISs, have been applied to a catchment located in the Warangal district. The alternative spatial rainfall models considered were Thiessen polygons and surfaces based on inverse distance kriging, and spline functions. Analysis of the predicted spatial distributions of rainfall for both artificial and real events resulted in the model based on a kriging providing the more accurate prediction with the Thiessen polygons providing the worst prediction.

VII. REFERENCE

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