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Evaluation of Three Geostatistical Interpolation Methods for the Estimation of Average Daily Rainfall

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Authors' contributions

This work was carried out in collaboration between both authors. Author RED designed the study, collected the data used, performed the geo statistical analysis and wrote the first draft of the manuscript. Author FBW managed the literature searches and the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

This study focuses on evaluating the results from three geostatistical interpolation methods used for the estimation of average daily rainfall in ILWIS 3.7. Rainfall data from nine (9) gauging points over the Upper Dep River Basin, North Central Nigeria were used.The total catchment area is 6076 km^2. The moving average method, ordinary kriging technique and nearest point or Thiessen method were used for the interpolation. The rainfall values used were for five (5) days in the same month where rainfall data for at least six (6) of the nine (9) gauging points were recorded, since rain did not fall on the whole the catchment on the same day. The results obtained from the different geostatistical methods used were different but closely similar with the moving average method recording the highest rainfall values for all interpolations. The techniques behind the methods were evaluated and discussed based on the results obtained. From the results it was observed that the moving average method calculated half of the maximum rainfall within the catchment and assigned that value for the average rainfall while in the Thiessen polygon method, the results obtained were similar to the arithmetic average of the rainfall values with all zero points counted as one point. The work demonstrated that remote sensing and GIS techniques are fast in the estimation of average

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rainfall over a catchment area and the estimated rainfall data for any point within the catchment can be obtained from the output raster maps. It is recommended for GIS users to choose the geostatistical method that best suits their purpose.

Keywords: Average rainfall; geostatistical; interpolation; moving average; Kriging; nearest point.

1. INTRODUCTION

The average rainfall over an area in many instances is considered as the main input in a watershed modelling process [1]. Rainfall data is often required for the estimation of streamflow because of the difficulty in continuous direct measurement using current meter especially during extreme weather conditions [2,3]. They are also utilised to predict the rate of accumulation of groundwater, irrigation planning as well as to develop water quality and ecological models for simulation [4].

For a large watershed one rain gauge station is often not enough to generalise or estimate the rainfall value for the whole catchment. Therefore to estimate average rainfall over a large area there is the need to engage a network of rain gauges to get values before an average could be obtained for the catchment. For general hydro meteorological purposes, [5] suggests 600 - 900 km^2 minimum rain gauge densities of precipitation network per station for flat regions of temperate, mediterranean and tropical zones and 100-250 km^2 for mountainous regions of temperate, mediterranean and tropical zones.

Several methods have been used for the estimation of average rainfall over a catchment. The most commonly used manual methods are the station average technique, Thiessen polygon method, the Isohyetal method and the areal rainfall-distance method [2,5,6].

Bayraktar et al. [7] used the percentage weighting polygon (PWP) method which is a manual method similar to Thiessen polygon method to estimate the average areal rainfall (AAR) in Southeastern Anatolia Region, Turkey. In the method the study area was divided into subareas by considering the rainfall percentages obtained at three adjacent station locations to provide a more reliable and flexible value than the Thiessen polygon procedure where the values for the subareas remain the same. The PWP method yielded 13.5% smaller AAR value among the other conventional methods.

More recently there are methods that make use of computer software and geographic information system analyses and techniques. [8] used the Inverse Distance Weighted (IDW), the Spline and the Kriging methods to interpolate rainfall for small urban sub catchments. They observed that the Spline and Ordinary Kriging techniques gave results with comparable accuracy for individual storm events while the IDW method was observed to have the lowest estimation error and highest model efficiency for aggregated storm events considering the three methods.

This paper is aimed at using some geostatistical methods to estimate the average rainfall over the upper Dep River catchment and to analyze the theories or logic behind the methods so that suitable recommendations can be made. It appears no analysis of this nature has been done for the catchment using either this technique or any other technique.

1.1 Theory of Geostatistical Analysis

The HELP menus of ILWIS 3.7 and ArcGIS 9.3 define geostatistical analysis as the interpolation of sample points taken at different locations in a landscape to create a continuous surface [9,10]. The location coordinates of the sample points are collected where the measurements of some phenomenon such as radiation, an oil spill, pre cipitation or elevation heights have been taken. The values from the measured locations are used to predict values for every location in the entire landscape. There are two interpolation techniques in geostatistical analysis namely, deterministic and statistical. While the deterministic techniques use mathematical functions for interpolation, geostatistical techniques rely on both statistical and mathematical methods for surface creation and assessment of the uncertainty of the predictions [10]. All methods rely on the similarity of nearby sample points to create the surface. Some of the point interpolation techniques include, nearest neighbour or thiessen map, moving average, trend surface, moving surface, kriging and cokriging algorithms (ordinary, simple, universal, indicator, anisotropic, probability and disjunctive). In all the methods, a point map is required as input and a raster map is returned as output.

Techniques applied in some of the geostatistical interpolation methods as obtained from ILWIS 3.7 Academic MENU are summarised below:

i. Moving average geostatistical method in ILWIS 3.7 Academic - The moving average geostatistical method is a point interpolation operation that requires a point map as input and produces a distributed raster map as output. The weight functions, which ensure that points close to an output pixel obtain larger weights than points which are farther away, are user-specified.
ii. The Kriging method is also a point interpolation process which interpolates a surface from point values. The weight factors in Kriging are determined by using a user-specified semi-variogram model, the distribution of input points, and are calculated in such a way that they minimize the estimation error in each output pixel. The method is similar to the Moving Average operation with the estimations being weighted average of the input point values. The ordinary kriging method was used with the 'spherical' semi-variogram model.
iii. In the nearest point operation, also called Nearest Neighbour or Thiessen method, each pixel in the output map is assigned a class name, identifier, or value of the nearest point, according to Euclidean distance. The process produces a Thiessen polygon map assigning similar values for every point within a polygon.

1.2 Study Area

The study area, shown in Fig. 1, is the upper part of the Dep River Basin in North Central Nigeria with a catchment area of 6076 km^2. The average annual rainfall over the catchment for the year 2009 was 1368 mm [11].

2. MATERIALS AND METHODS

2.1 Rainfall Data Collection

Rainfall data were collected for the month of August 2009 for nine (9) rain gauges set up at different locations in the upper Dep River basin. The rain gauge locations were based on accessibility as most of the areas within the inner parts of the catchment were inaccessible because they were close to the rivers and dense bushes with no settlements and access roads.

The coordinates and elevations of the locations are shown in Table 1.

The point rainfall values collected over the catchment were assessed and only days with rainfall data for at least six (6) of the nine (9) points were used.

Table 2 contains the selected daily rainfall data for the month of August 2009.

2.2 Average Rainfall Estimation

The rain gauge locations over the catchment are as shown in Fig. 1. The values were plotted in ILWIS 3.7 and the following methods used to interpolate the precipitation point values to distributed values:

- Moving average technique: Inverse Distance was used with the default weight exponent of 1.0 accepted for the analysis. Limiting distance of 35 km was used and this was based on the distance between the farthest gauge points.
- Kriging method: Ordinary kriging method was used and other default settings were accepted.
- Nearest point or Thiessen method: Spherical distance was used and the precision of 0.1 accepted, which is the default.

The average rainfall values were estimated for each of the days and methods were recorded.

3. RESULTS AND DISCUSSSION

The number of gauges (9) used in relation to the total area of the catchment (6067 km^2) gave the rain gauge density of 675 km^2 of precipitation area per gauge, which is adequate for the study area which has elevations ranging from of 1519 m at the headwaters to 126 m at the hydrometric station (outlet) with a substantial part of the area at higher elevations.

The pictorial view of the distribution of monthly rainfall for August 2, 2009 after interpolation using the moving average, kriging and nearest neighbor (Thiessen) geostatistical methods are shown in Figs. 2a, 2b and 2c respectively.

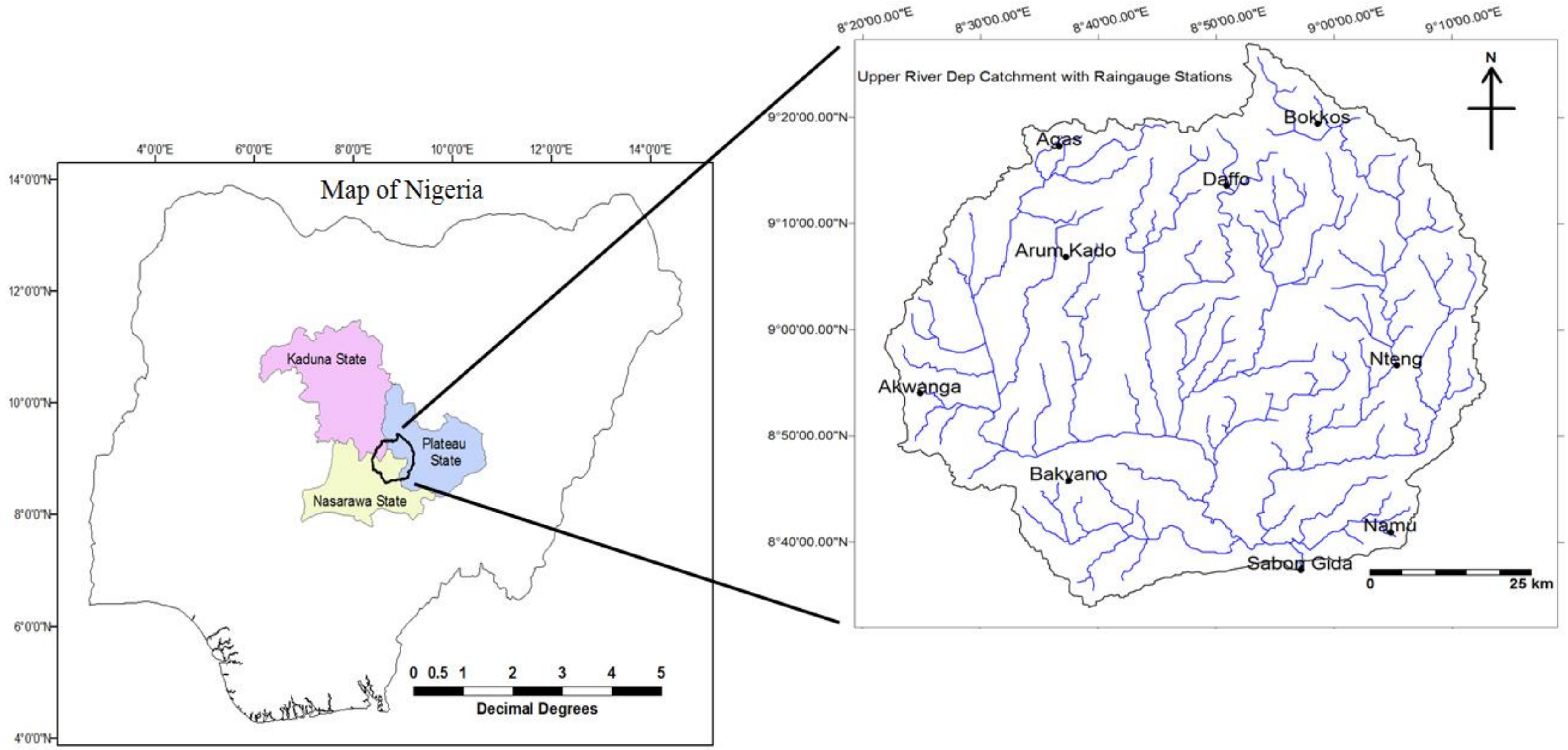

Fig. 1. Study area showing locations of rain gauges

Table 3 shows the estimated average rainfall obtained from interpolation methods used.

The average rainfall values for each of the methods and days selected depends on the points at which rain fell for the day. The rainfall variability maps for the moving average method are as shown in Fig. 3. The maps show the spread of rainfall within the catchment after interpolation using the moving average method.

The results indicate that the moving average method seems to be calculating half of the maximum rainfall within the catchment and assigns that value for the average rainfall as shown in Table 4.

What happens in reality is that a value is assigned to each of the pixels with the pixel closest to the gauging point having the closest value to the value at the point of measurement and the lowest value is assigned to the farthest pixel from the point of measurement. These values are all added up and divided by the total number of the pixels to give the value of the average rainfall.

In the Thiessen polygon method, the results obtained were observed to be similar to the arithmetic average of the rainfall values with all zero points counted as one (compare the values of the Thiessen interpolation in Table 2 to the average values in Table 5).

The software's values from the Thiessen interpolation were obtained by constructing the Thiessen polygons for each of the points and for each of these points the rainfall value is multiplied by the area of the polygon. The values of the products are then summed up and divided by the catchment area to give the average rainfall.

Table 1. Coordinates and elevations of rain gauge locations

S/No	Station name	Northings (Decimal degrees)	Eastings (Decimal degrees)	Elevation (m)
1	Bakyano	8.7641	8.6266	258
2	Akwanga	8.9008	8.4167	434
3	Arum Kado	9.1145	8.6213	520
4	Daffo	9.2266	8.8487	1303
5	Agas	9.2886	8.6122	638
6	Sabon Gida	8.6231	8.9531	130
7	Bokkos	8.9789	9.3226	1341
8	Nteng	8.9449	9.0887	295
9	Namu	8.6833	9.0805	177

Table 2. Selected daily rainfall data (in mm) collected in August 2009

Date	Bokkos	Daffo	Arum Kado	Akwanga	Namu	Bakyano	Nteng	Dep	Agas
2/8/2009		86.8	19.2	40	16.4		22.8	16.5	41.7
13/8/2009		26.9	51.2		18.2	16.7	25.4		20
16/8/2009	4.1	52	8	53	11.5		11.1		
19/8/2009	30.2		9.6		13.5	42.2	4.9	18.9	3.6
27/8/2009		8.8	13.6		7.9	31	37.4		34.2

Table 3. Estimated average rainfall (in mm)

Date / Method	02/08/2009	13/08/2009	16/08/2009	19/08/2009	27/08/2009
Moving Average	43.3	25.6	26.5	21.1	18.7
Ordinary Kriging	32.77	19.89	20.01	14.81	15.61
Thiessen Polygon	30.4	22.6	20.0	15.4	19.0

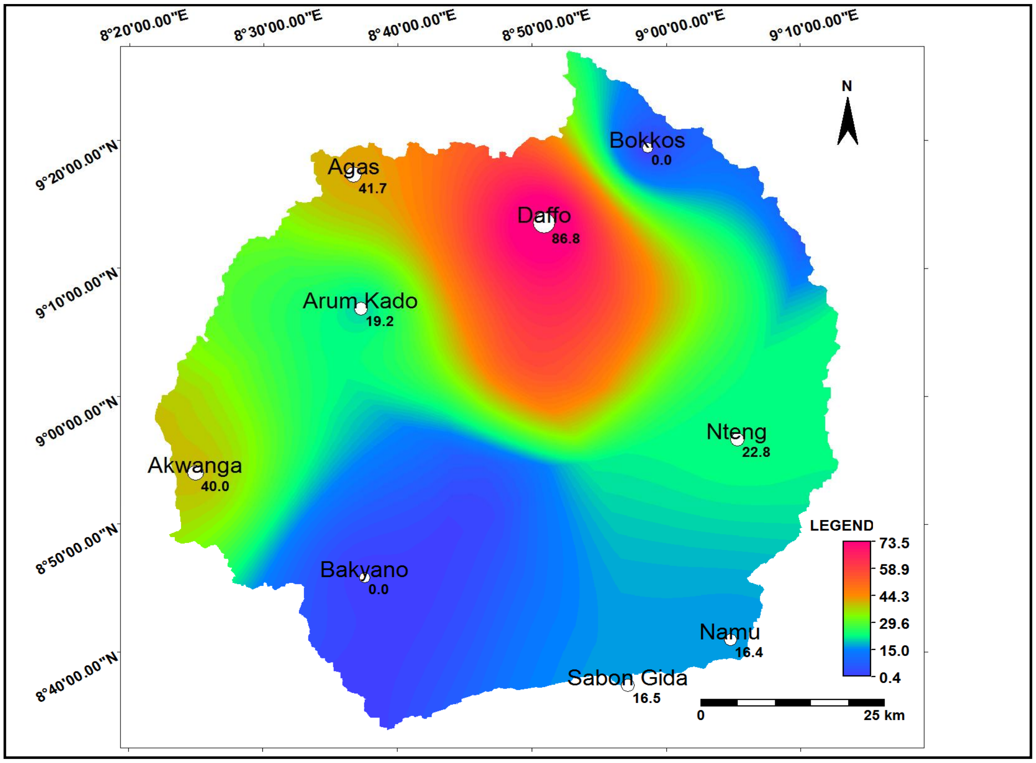

Fig. 2a. Map showing the distribution of rainfall using moving average method in mm

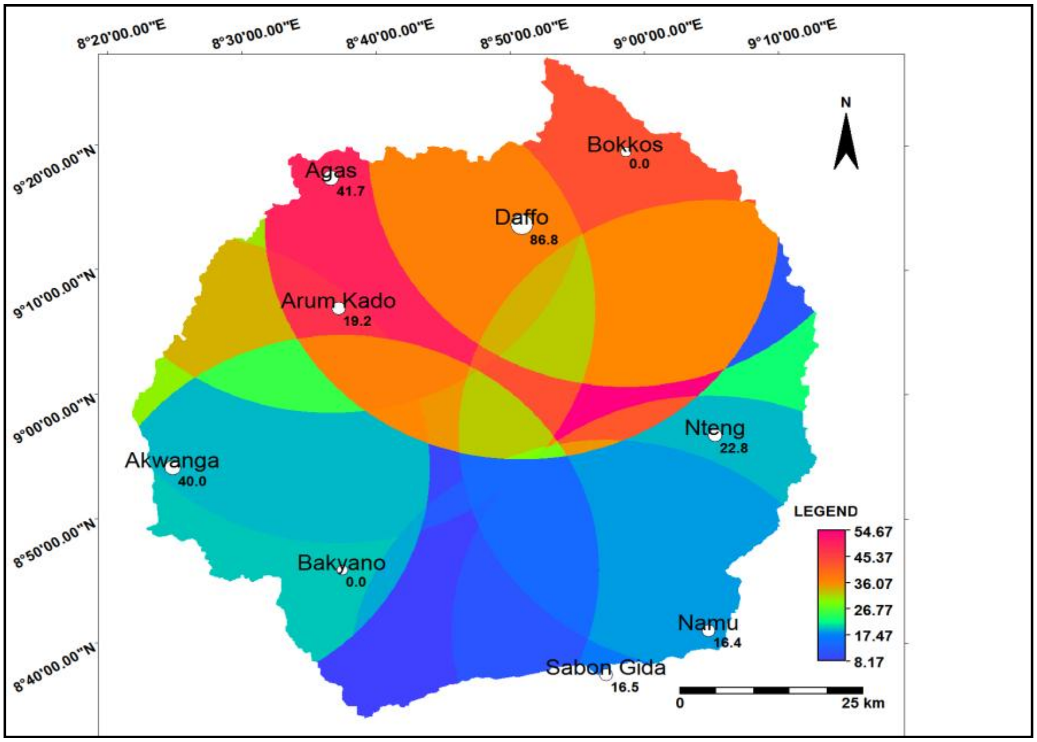

Fig. 2b. Map showing the distribution of rainfall using ordinary Kriging method in mm

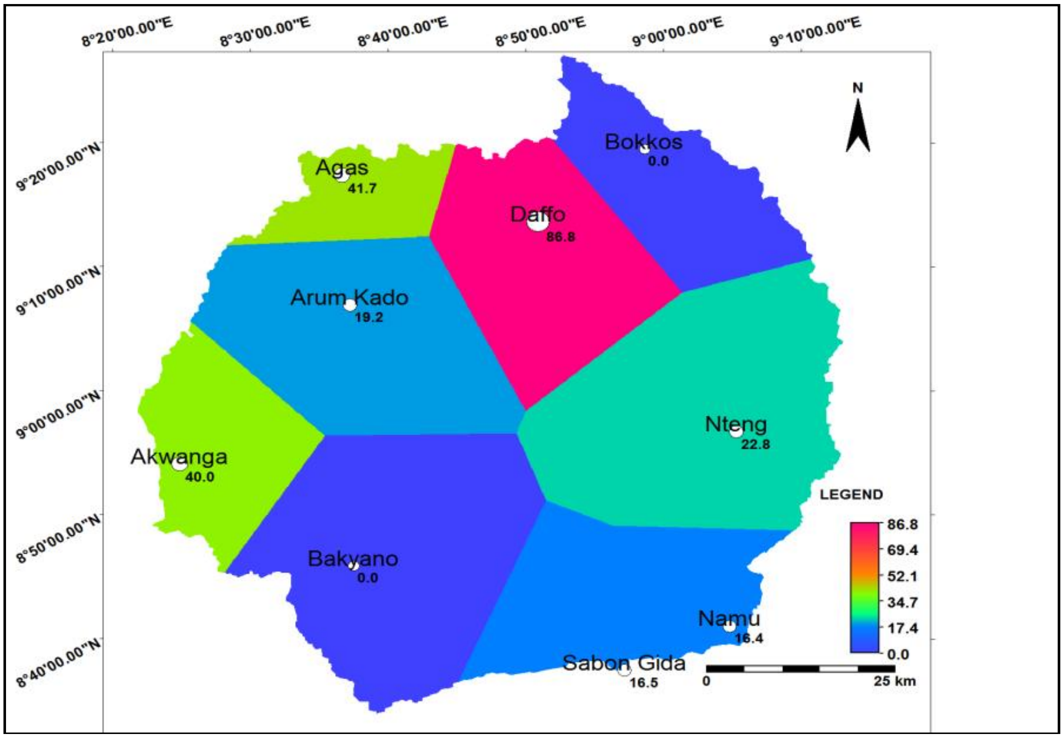

Fig. 2c. Map showing the distribution of rainfall using Thiessen polygon method in mm

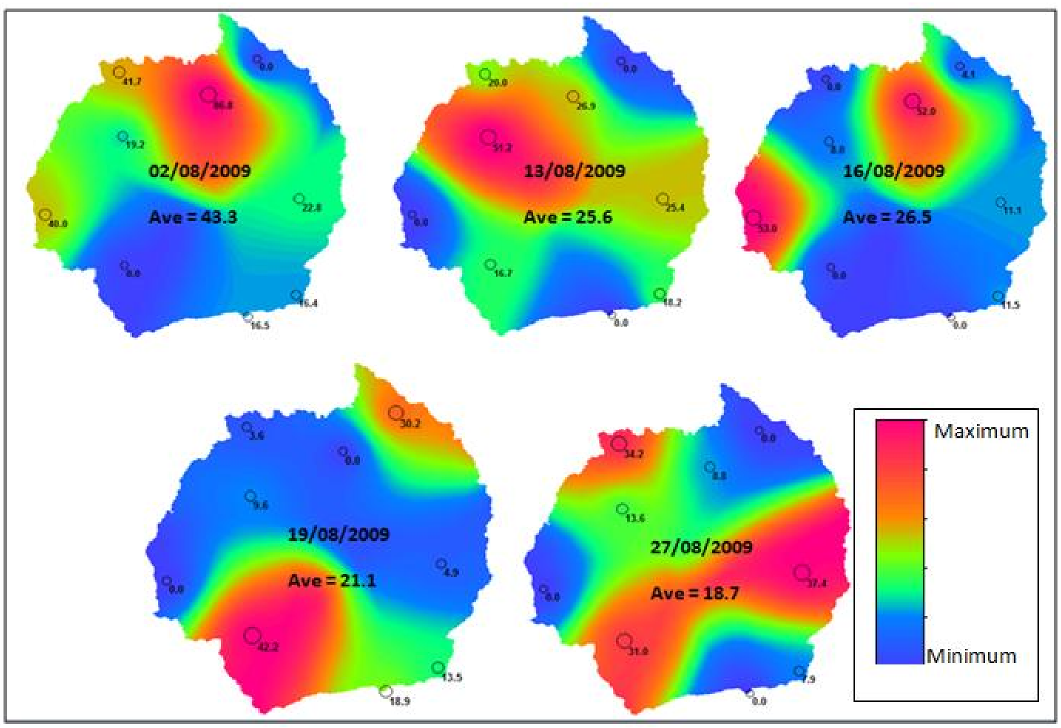

Fig. 3. Map showing the variation of rainfall over the catchment from moving average interpolation

Table 4. Comparison of average rainfall from moving average interpolation with the maximum rainfall in mm

Date	02/08/2009	13/08/2009	16/08/2009	19/08/2009	27/08/2009
Minimum	0	0	0	0	0
Maximum	86.7	51.2	53	42.2	37.4
Average	43.3	25.6	26.5	21.1	18.7

Table 5. Comparison of average rainfall from Thiessen polygon interpolation in mm

Date	02/08/2009	13/08/2009	16/08/2009	19/08/2009	27/08/2009
	0	0	0	0	0
	16.4	16.7	4.1	3.6	7.9
	16.5	18.2	8	4.9	8.8
	19.2	20	11.1	9.6	13.6
	22.8	25.4	11.5	13.5	31
	40	26.9	52	18.9	34.2
	41.7	51.2	53	30.2	37.4
	86.8			42.2	
Sum	243.4	158.4	139.7	122.9	132.9
Average	**30.4**	**22.6**	**20**	**15.4**	**19**

4. CONCLUSION AND RECOMMENDATIONS

Geostatistical analysis is very important in the estimation of average rainfall. It makes the estimation faster, easier and less cumbersome. Though the methods produced varying results due to different theories employed in the interpolation, they are still closely related. Since the process by which each of the methods calculate average rainfall are available in the MENU of the different GIS softwares, the end use of the result will determine the type of method that any user will adopt. From the geostatistical analysis carried out and the results obtained, the rainfall data for any point within the catchment can be obtained from the maps produced.

From the foregoing, it is recommended for GIS users to choose the geostatistical method that best suits their purpose.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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