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A COMPARATIVE STUDY OF DIFFERENT INTERPOLATION METHODS FOR RAINFALL DISTRIBUTION MAPPING USING REMOTE SENSING AND GIS TECHNOLOGIES IN PURULIA DISTRICT

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Abstract

The eastern plateau of India mainly is characterized by harsh climatic condition with poor water condition and agricultural under development. Purulia, the study area is one of the parts of this plateau. Therefore undulating topography, soil infertility, water scarcity, soil erosion, deforestation and concentrated rainfall distribution may need the proper management for agricultural development. In this area most of the people are tribal communities, agriculture is the main livelihood of those people. The agricultural system of this plateau is mainly depending on rainfall. But now the erratic distribution of rainfall becomes a major cause of crop failure. Due to this a brief knowledge about rainfall distribution is needed to achieve sustainability in agricultural production. On this view it is aim to get an idea about the rainfall distribution pattern in the study area by using spatial interpolation technique to estimate the values of unknown points with the help of known sample points. Therefore the different interpolation techniques like, Inverse distance weighted (IDW) interpolation, Natural Neighbor Interpolation Technique, Kriging Interpolation Technique and GIS techniques are used to fulfill the objectives. Here also shows the relationship between elevation and seasonal rainfall distribution and preparing different rainfall distribution maps. Finally the spatial analysis of rainfall distribution on Purulia district has been reflected by the interpolated weekly maps (week 22 to week 30) and the scatter diagram which represented the elevation wise rainfall distribution over the area. In this study, RMSE is detected by the use of cross-validation method. As the absolute error test is the primary procedure of RMS error test, hence in this case RMSE measurement is preferred for the comparative studies of interpolation technique. Finally it can be conclude that RMSE of Natural Neighbor technique as the most preferable technique for spatial interpolation measurement of rainfall data.

Keywords: Harsh climate, Water scarcity, Agriculture, Seasonal rainfall, Interpolation techniques, GIS.

Introduction

In India much of the eastern plateau is characterized by poor agriculture development because of its harsh climatic condition and poor water resource. In these areas the biophysical environment is characterized as drought prone, heterogeneous in terms of micro-topography and accessibility, and suffering soil degradation problems. It may cause of deforestation and intensive agriculture pattern in this area. The physio-climatic conditions, viz., low rainfall, less number of rainy days, high temperature, light textured soil in uplands and less vegetation cover have caused serious soil moisture conservation problem in the entire Purulia district as a part of eastern plateau. In Purulia district 85% of the average annual rainfall is concentrated between 15th June and 15th October with an average of 8-20 rainy days per month. The remaining period is almost dry with 0 mm to 50 mm of average precipitation.

Paddy is the major crop in the eastern plateau region. However, because of lack of assured irrigation facilities in this region, rice-farming is almost completely dependent on rainfall. The distribution of rainfall in this region is also highly variable over time and space. This variability, together with high soil percolation and runoff rates, has resulted in high variability in rice productivity. Among various climatic variables, precipitation is the one that is essentially required for a number of applications like natural resource management, agriculture management, irrigation scheduling, ecosystem modeling, and hydrological modeling. Understanding of its temporal and spatial distribution is also important for undertaking climate change impact studies on various systems [1].

Ethnically, the eastern plateau lies in the so-called tribal belt of the eastern India. Individuals from tribal and scheduled castes represent around 40% of the total population of Purulia district and 90% of the inhabitants maintain their livelihood through agriculture. The most effective way to develop the area is to develop the agricultural systems. The agricultural system of the eastern plateau region is basically rain-fed in nature and therefore, crop production in India is highly depending on rainfall. But now the erratic distribution of rainfall becomes a major cause of crop failure. For this reason, having a brief knowledge of the rainfall distribution patterns of this region is an important aspect to achieve sustainability in agricultural production. Therefore, it is very essential to get an idea about the rainfall distribution pattern in the study area by using spatial interpolation technique to estimate the values of unknown points with the help of known sample points. Spatial interpolation methods are techniques that predict the value at a given location by using values from known sample points. Weather data are generally recorded at point locations, so estimating data values at other locations requires some form of spatial interpolation [8]. Y. Jantakat and S. Ongsomwang, 2011[4], used spatial interpolation techniques based on 11 semi-variogram models of 4 main sub-types of co--kriging with 3 topographical variables: elevation, longitude and latitude. The main aim of this study was to select the best interpolation models from co-kriging technique on mean monthly rainfall and mean monthly temperature. Geographical Information System, statistical interpolation techniques have been used in this study for mapping climatic data. Y. Hong et al., 2005, [3] used spline interpolation techniques to develop a gridded climatic database for China at a resolution of 0.01° in latitude and longitude. A. Dewi et al., 2000, examined statistical approaches for interpolating climatic data over large regions, providing a brief introduction to interpolation techniques for climate variables of use in agricultural research, as well as general recommendations for future research to assess interpolation techniques.

Geographic information system (GIS) and modeling are becoming powerful tools in agricultural research and natural resource management. Especially in developing countries, there is a need for accurate and inexpensive quantitative approaches to spatial data acquisition and interpolation (Mallawaarachchi et al., 1996). Many kinds of geographic data are often collected at irregular intervals e.g. ground water data, elevation data etc. require a great deal of effort. At the same time, it is not possible to make such measurements at all the desired places and hence there is often a need to estimate values for locations where there are no measurements. S. Naoum and I. K. Tsanis, 2004, developed a GIS –based Decision Support System (DSS) to select the appropriate interpolation technique used in studying rainfall spatial variability in Switzerland. GIS is one such tool, which statistically estimates such survey to maximize the amount of information. This information is based on the fact that objects that are near are more important than those that are far away. On this view the main objective of the study is to estimate the rainfall distribution pattern of the study area using different interpolation techniques. Another aim of this study is to find out the relationship between elevations and seasonal average rainfall.

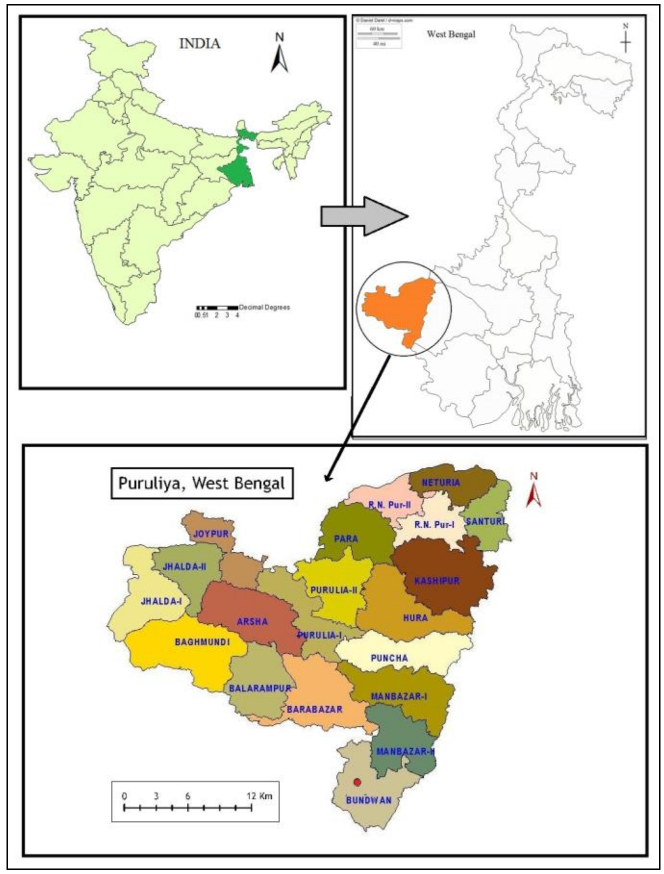

Figure 1: Location of the Study area

Study Area

The study area (Figure 1), Purulia district is located in the western most part of West Bengal, belonging to the eastern plateau region of India. It is surrounded by Paschim Medinipur, Bankura and Burdwan districts of West Bengal and Dhanbad, Bokaro, Hazaribagh, East and West Singhbhum of Jharkhand state. The areal extent of the district is 22° 42’ 19” N to 23° 42’ 00” N and 85° 49’ 19” E to 86° 54’ 25” E. The total area of the district is 6259 sq. km. Regionally the area is a part of Chotanagpur Gneissic Complex of Eastern Indian Peninsular Shied, lying to the north of Singhbhum Craton. Dunn & Dey (1942) first described the complex as largely a product of replacement origin. The area is mostly covered by soil and represents undulating topography with moderate to gentle slopes. Climatically, the area is subtropical and sub-humid, with hot wet summers and cool dry winters. It has an annual average precipitation of 1393 mm, annual mean temperature of 25.6° C and mean summer and mean winter temperature of 29.0° C and 21.3° C respectively. About 82% of the annual rainfall occurs within the monsoon period, which lasts roughly from June to September. Average annual rainfall varies between 1100 and 1500 mm.

Database and Methodology

A. Data Source

In this study, Remote Sensing and GIS technologies were used to achieve the mentioned objectives. Secondary rainfall data were collected from "Weekly Rainfall Probability for Selected Stations of India, Volume – II, India Meteorological Department, Division of Agricultural Meteorology, Pune (Edition – 1, 1995)". Elevation information was derived from ASTER DEM and CARTOSAT DEM. Survey of India topographic map sheets of the district Purulia at 1: 50, 000 scales pertaining to the study area was used.

Ancillary data

Table 1: Ancillary data used

Ancillary Data	**Climatic Data**	Government of India's Weekly Rainfall Probability for selected Stations of India, IMD, Division of Agricultural Meteorology, Pune
	Topographical Maps	SOI Toposheets of Purulia – at scale 1:50,000 (Toposheets 73 I)
	FAO- State map to digitized the state boundaries of Bihar, West Bengal and Jharkhand	

Table 2: Characteristics of Digital Elevation Model

DEM/ Characteristics	ASTER	CARTOSAT
Resolution	90 m	30 m

B. Methodology

Geo-Statistical Approach of Interpolation

Interpolation is a mathematical function that estimates the values at locations where no measured values are available. Spatial interpolation is widely used for creating continuous data when data are collected at discrete locations (i.e., at point). Interpolation methods can also be described as "global" or "local". Global techniques (e.g. inverse distance weighted averaging) fit a model through the prediction variable over all points in the study area. Local techniques, such as splining, estimate values for an unsampled point from a specific number of neighboring points.

I. Applying Kriging Interpolation Technique

Kriging is based on a concept of random functions: the surface or volume is assumed to be one realization of a random function with a certain spatial covariance (Journel and Huijbregts 1978; Matheron 1971).

Estimation of a semi-variogram γ (h) defined as:

$$\gamma(h) = \frac{1}{2}Var[\{z(r+h) - z(r)\}] \approx \frac{1}{(2N_h)}\sum_{(ij)}^{N_h}[z(r_i) - z(r_j)]^2$$

It is related to the spatial covariance C (h) as γ (h) = C (0) – C (h) (4) where C (0) is the semi-variogram value at infinity (sill). The summation in Equation runs over the number N_h of pairs of points which are separated by the vector h within a small tolerance _h (size of a histogram bin).

In this study, Kriging interpolation techniques were applied on weekly average rainfall data of 263 rain gauge stations of West Bengal, Bihar and Jharkhand for 9 SMW using Arc Map 9.3 software. The rainfall distribution map of 9 SMW were generated by the help of kriging interpolation technique those gives the idea of the rainfall distribution pattern of the unknown point using known point. The area of interest was clipped out from prepared large kriging map using vector boundary file of the study area.

II. Local neighbor approach

Applying IDW Interpolation Technique

Inverse distance weighted interpolation (IDW) is one of the simplest and most readily available methods. It is based on an assumption that the value at an unsampled point can be approximated as a weighted average of values at points within a certain cut-off distance, or from a given number m of the closest points (typically 10 to 30). Weights are usually inversely proportional to a power of distance (Burrough 1986; Watson 1992) which, at an unsampled location r, leads to an estimator.

$$F(r)=\sum_{i=1}^{m} w_1 z(r_1)=\frac{(\sum_{i=1}^{m} z(r_i)/|r-r\int}{\sum_{j=1}^{m} 1/|r-r\int}$$

Where p is a parameter (typically p=2; for more details on the influence of this parameter see Watson 1992).

Applying Natural Neighbor Interpolation Technique

Natural Neighbor uses a weighted average of local data based on the concept of natural neighbor coordinates derived from Thiessen polygons (Boots, Chapter 36) for the bi-variate, and Thiessen polyhedra for the tri-variate case (Watson 1992). The value in an unsampled location is computed as a weighted average of the nearest neighbor values with weights dependent on areas or volumes rather than distances. The number of given points used for the computation at each unsampled point is variable, dependent on the spatial configuration of data points. The rainfall distribution maps of 9 SMW were generated by the help of Natural Neighbor interpolation technique using Arc Map 9.3 software.

Evaluation of the accuracy of spatial interpolation techniques

The cross-validation technique was achieved by removing data from one observation point at a time (j), taken from all of the available observation points in the data set and then estimating the value of the removed observation point data using the data from the remaining (n − 1) observation points. This technique is used to evaluate how well the neighboring stations estimate the missing value. The accuracy of spatial interpolation techniques was evaluated by using the following two statistical indicators.

Absolute error (AE), based on actual and estimated rainfall values at the base station. Several researchers (e.g. Chang 2004; Kane ski & Malignant 2004; Ahrens 2006) have recommended these two measures for comparison of spatial predictions of interpolation models for testing data.
Formula of absolute error is given bellow:

$$AE=\sum_{i=1}^{n}|\hat{\varphi}_i-\varphi_i|$$

Where *n* is the total number of observations, $\hat{\varphi}_i$ is the estimated value and φ_i is the actual value of the observation.

The root mean square error (RMSE) is given by

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{\varphi}_i-\varphi_i)^2}$$

Where *n* is the total number of observations, $\hat{\varphi}_i$ is the estimated value and φ_i is the actual value of the observation.

The AE and RMSE were used as indicators of the magnitude of extreme errors. Lower AE and RMSE values indicate greater central tendencies and generally smaller extreme errors. In this comparative study the best suitable spatial interpolation techniques were determined based on Root Mean Square error.

Relation between Seasonal rainfall data and elevation:

In this study, relationship between seasonal rainfall and elevation of the area has shown using scatter plot. Seasonal rainfall distribution of 5 weather stations of Purulia district has been calculated by the help of following formula.

Seasonal average rainfall =

$$\frac{\text{Average rainfall of the station of week 22} \times 7 + \text{week 23} \times 7 + \ldots\ldots\ldots\ldots\ldots \text{week 30} \times 7}{\text{No of total week (9)}}$$

Table 3: The table shows the relationship between Seasonal rainfall and Elevation

Stations	Seasonal average rainfall	Aster Elevation (m)	Cartosat Elevation (m)
Purulia	409.6	248	200.5
Raghunathpur	364	176	73
Barabazar	394.8	213	149
Jhalda	440.45	287	287.5
Manbazar	412.22	176	73

Results and Discussion

Since the failure and success in agricultural production is highly depend on the distribution of rainfall, Purulia district of West Bengal has been chosen as the study area. The area is a subject of low agricultural productivity due to scarcity of rainfall. The area of interest covered entire Purulia district, which demarcated by strictly using GIS platform. Location map of the 262 weather stations of West Bengal, Bihar and Jharkhand were prepared to estimate the rainfall distribution pattern of the study area. Every station was plotted based on provided latitude and longitude values in the hand book of "Weekly Rainfall Probability for Selected Stations of India, Volume – II, India Meteorological Department, Division of Agricultural Meteorology, Pune (Edition 1)". There were used two types of digital elevation model (DEM) data because, to investigate whether the horizontal resolution of DEM data would have any impact on the accuracy of areal rainfall interpolation. The DEM maps of the study area clipped out using boundary vector map of the study area. Derived elevation maps of the study area from Aster DEM and Cartosat DEM is shown in Figure 4.

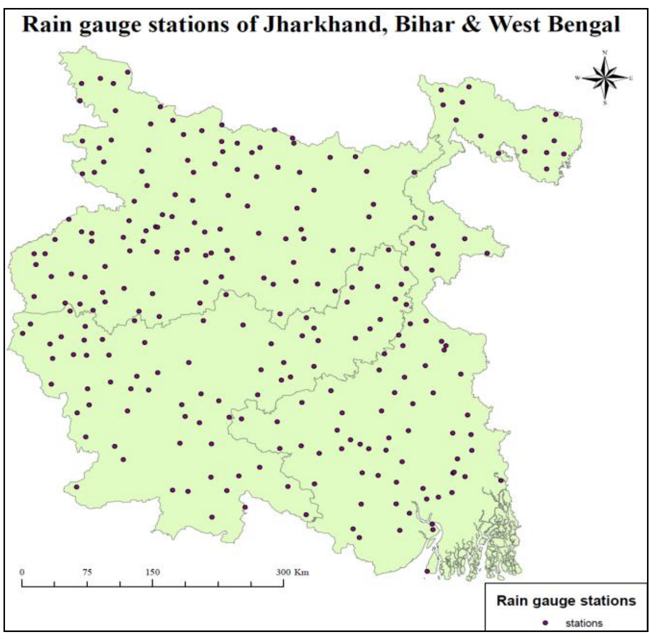

Figure 3: Rain gauge stations of Jharkhand, Bihar and West Bengal

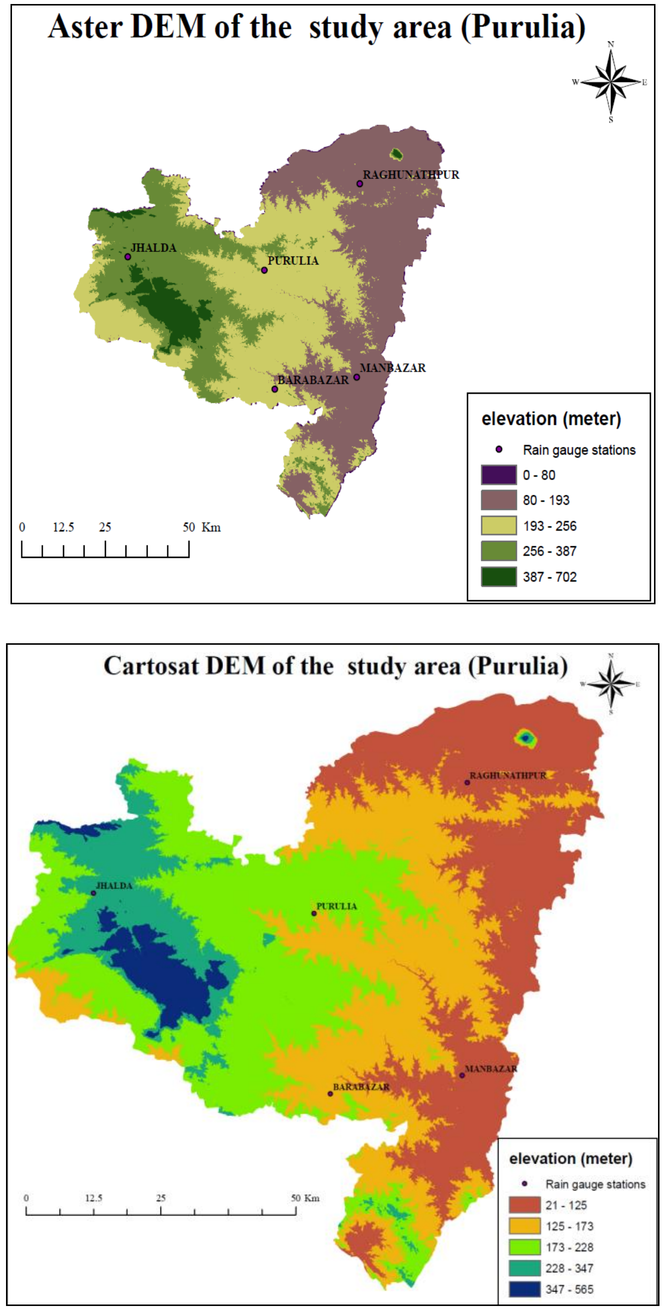

Figure 4: Aster DEM and Cartosat DEM of the study area

Relationship between seasonal average rainfall and elevation:

The relationship between the seasonal average rainfall of each rainfall station of the study area and its elevation which were derived from two different sources of DEM were showed by the scatter plots. The figure shows that the average annual rainfalls tend is to increase with increasing observed elevations. Scatter plot shows the relationship between the seasonal average rainfalls and mean elevation of the study area.

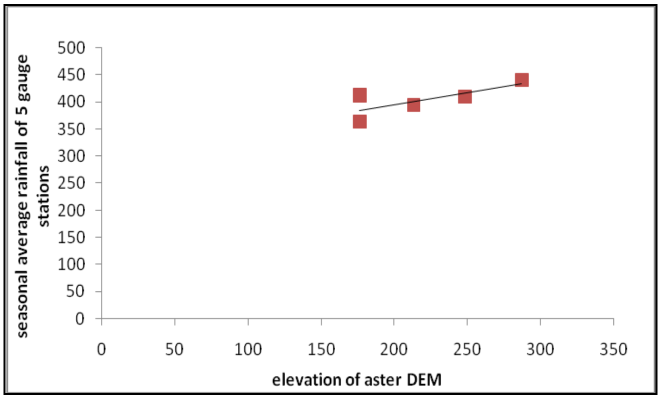

Figure 5: Scatter plot shows the Relationship between the seasonal average rainfalls of each station of Purulia district with the elevation

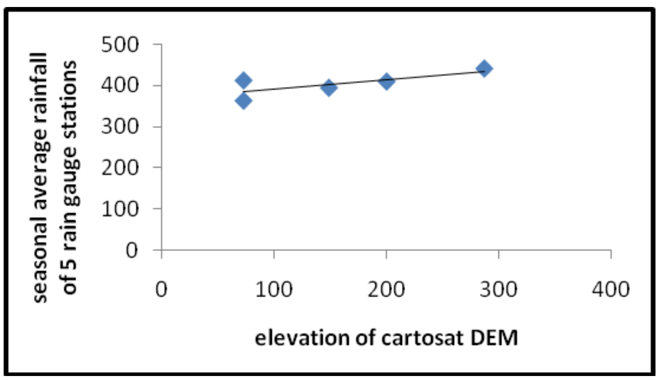

Figure 6: Scatter plot shows the Relationship between the seasonal average rainfalls of each station of Purulia district with the elevation

The Scatter plot of the Figure 5 shows the relationship between the estimated mean elevation of rain gauge stations of the study area which were derived from the low resolution Aster DEM with the seasonal average rainfall of the rainfall of the rain gauge stations of the study area. The scatter plot of the Figure 6 shows the relationship between the estimated mean elevations of rain gauge stations of the study area which were derived from the high resolution Cartosat DEM with the seasonal average rainfall of the rain gauge stations of the study area. It is find out that the amount of rainfall was increased with increasing elevation, except Manbazar station. Though the estimated mean elevation of the Manbazar station is low but the amount of the average rainfall is high.

Areal rainfall estimations using three spatial interpolation techniques:

Three spatial interpolation techniques were used in this study. Out of three techniques kriging is geo-statistical approach and IDW and Natural Neighbor are deterministic approach. Kriging is based on a concept of random functions. In ordinary kriging the weights are based not only on the distance between the measured points and the prediction location, but also on the overall spatial arrangement among the measured points and their values.

Inverse Distance Weighting (IDW) allows the user to control the significance of known points upon the interpolated values, based upon their distance from the output point. In Natural Neighbor interpolation technique the value in an unsampled location is computed as a weighted average of the nearest neighbor values with weights dependent on areas or volumes rather than distances.

In this study Kriging, IDW and Natural Neighbor spatial interpolation techniques were used on weekly average rainfall data of 262 rain gauge stations for the period of nine standard meteorological week (SMW) using Arc MAP 9.3 software. The spatial interpolation maps of the study area was obtained by clipped out the Purulia district using vector boundary file from interpolation map of West Bengal, Bihar and Jharkhand. The use of three spatial interpolation techniques are shown weekly basis in below.

On examining three interpolation techniques maps of 22 Standard Meteorological Week (SMW), it was noted that in Kriging and Neighbor interpolation techniques the average rainfall started increasing gradually from North- West to South East. There is some difference showed in case of IDW technique. Low average rainfall showed in near to Purulia and Raghunathpur weather stations.

The interpolation maps of average weekly rainfall at the 23 SMW showed that the average rainfall distribution was gradually increased from West to East according to Kriging and Natural Neighbor techniques. But, according to the IDW technique, average rainfall distribution increased from North -West to South-East. The average rainfall was increased around Purulia, Raghunathpur and Manbazar weather stations.

The average rainfall distribution of the area on 24 SMW was increase in eastern part of the study area. Low average rainfall was occurred in Western and Northern parts of the study area. Three interpolation techniques have showed more or less same rainfall distribution pattern. Raghunathpur and Jhalda weather stations were became the subject of low average rainfall where as high average rainfall showed in the surrounding parts of the Purulia Weather station.

On examining the interpolation maps of the average rainfall distribution of 25 SMW, it was showed that the average rainfall started decreasing eastward. Maximum Rainfall occurred in the middle part of the study area. According to Kriging and Natural

Neighbor spatial interpolation techniques maximum rainfall was showed in Purulia weather station and its surrounding area. But, uneven rainfall distribution pattern was showed in IDW spatial interpolation map.

The average rainfall distribution of the period of 26 SMW is shown on the above figures. On examining the rainfall distribution, we find out that the average rainfall of 26 SMW increased gradually from Eastern to Western parts of the study area and the average weekly rainfall on the 26 SMW decreased southward and northward. There have not huge difference in average rainfall distribution among the prepared interpolation maps using Kriging, IDW and Natural Neighbor interpolation.

On examining the above shown average rainfall distribution maps of 27 SMW, it is find out that the gradual increase in the rainfall was from the Eastern part to Western part of the study area. Two average rainfall decrement trends were find out in Northern and Sothern part of the study area.

On examining the rainfall distribution, it is find out that the average rainfall distribution of 28 SMW according to Kriging and Natural Neighbor spatial interpolation techniques were increased gradually from North- Eastern to South-Western parts of the study area. According to IDW spatial interpolation technique, it showed that the average rainfall distribution was gradually increased from north- eastern to North- Western part of the study area.

On viewing the above showed spatial interpolation maps of the average rainfall distribution, it was noted that the average rainfall distribution was gradually increased from Eastward to North-Westward. Generated interpolation maps using Kriging and Natural Neighbor spatial interpolation techniques have given more or less same output. But, in IDW, the gradual increment of average rainfall distribution trends has broken in northern and middle part of the study area.

On examining the above figure it comes out that the north-eastern part of the study area was the subject of low average rainfall distribution. The average rainfall was increased gradually westward and south- eastward of the study area. Middle portion of the study area became a subject of moderate average rainfall distribution. Used two spatial interpolation techniques, Kriging and Natural Neighbor, out of three were provided more or less same output. The obtained output from IDW spatial interpolation techniques quit different.

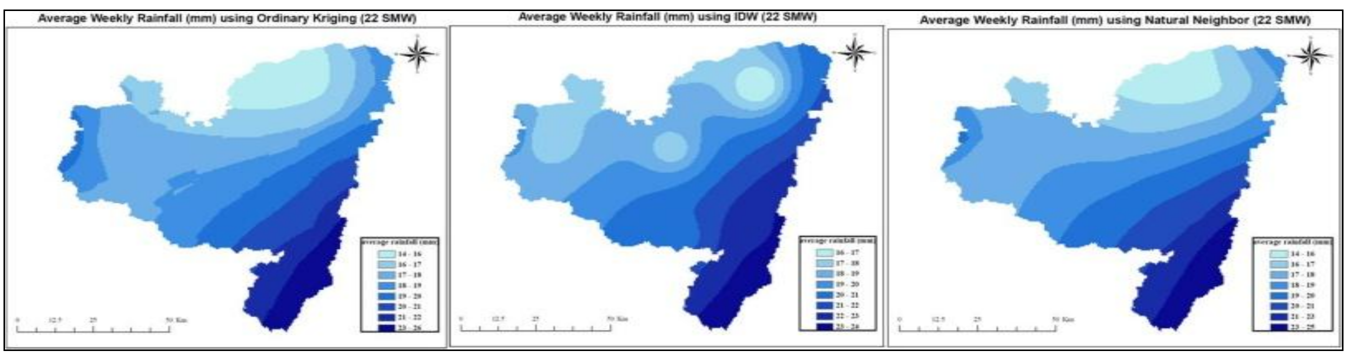

Figure 7: Average weekly rainfall distribution of 22 SMW

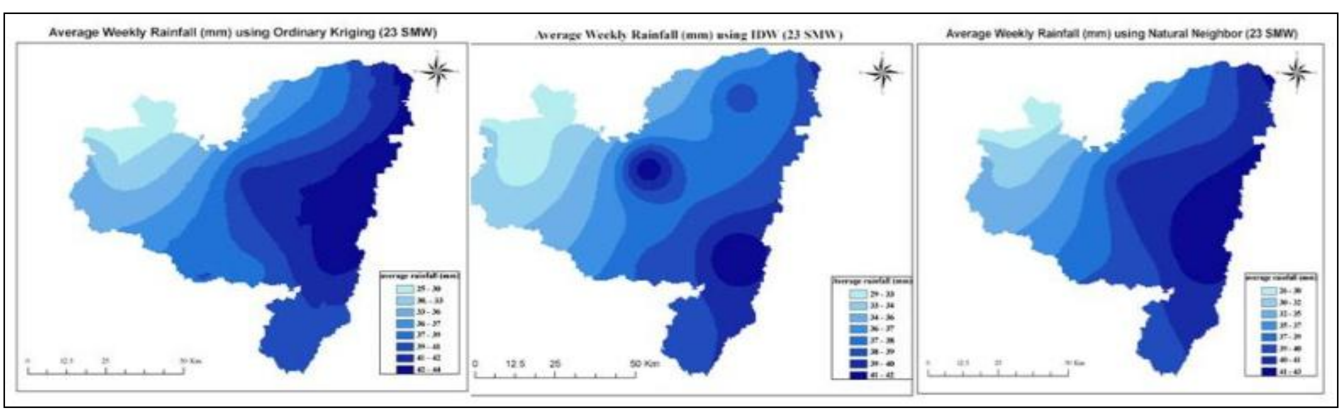

Figure 8: Average weekly rainfall distribution of 23 SMW

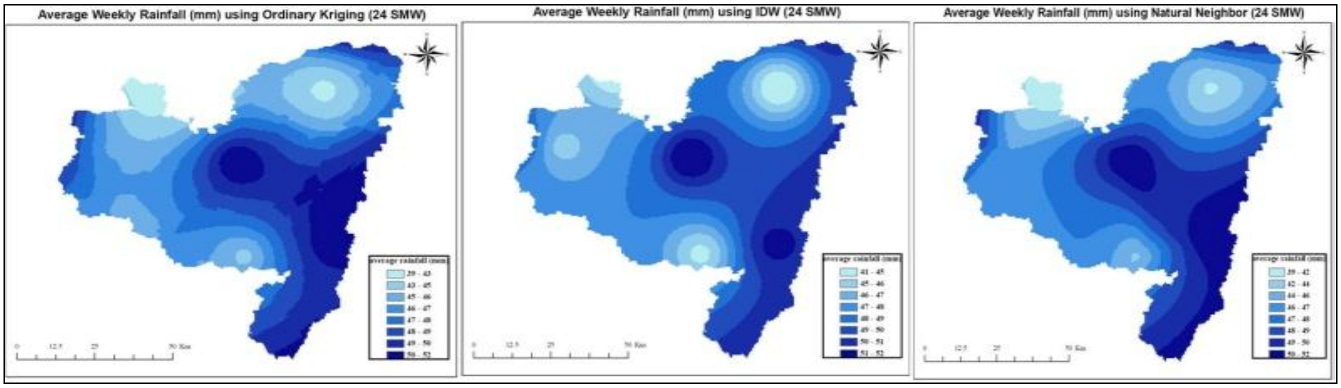

Figure 9: Average weekly rainfall distribution of 24 SMW

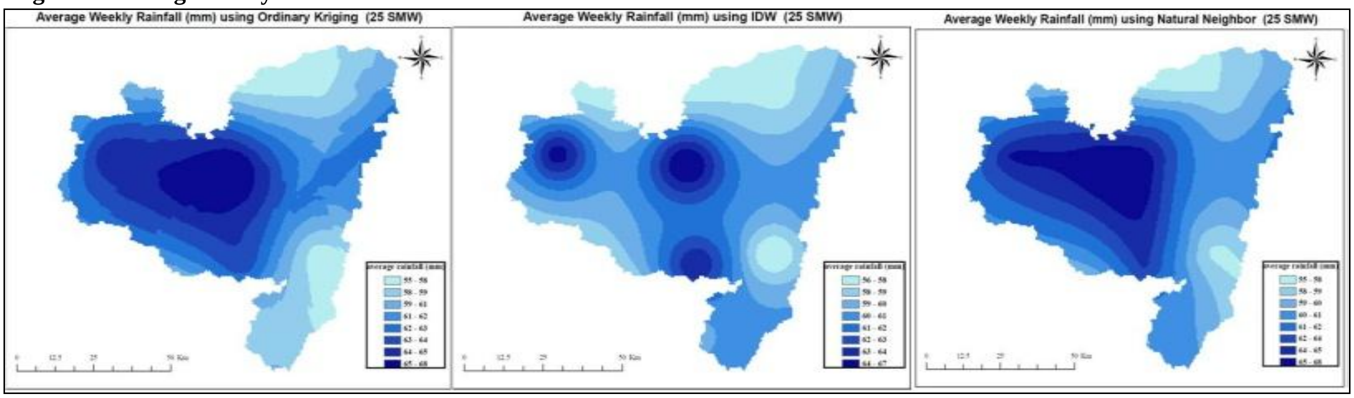

Figure 3: Average weekly rainfall distribution of 25 SMW

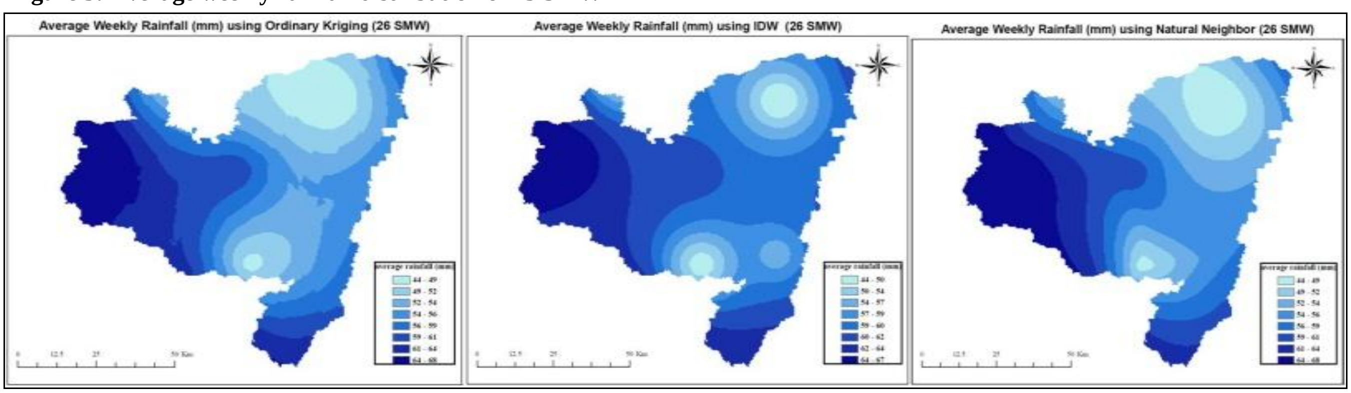

Figure 4: Average weekly rainfall distribution of 26 SMW

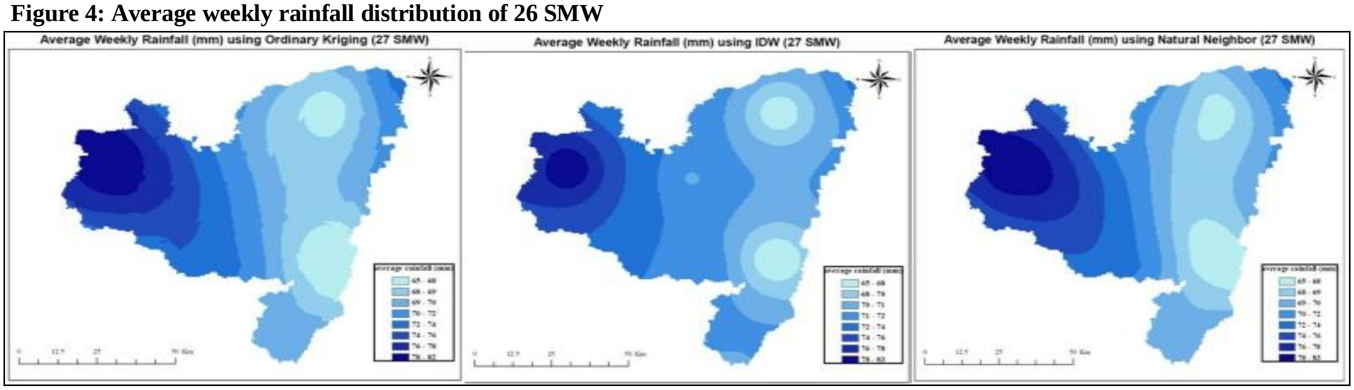

Figure 5: Average weekly rainfall distribution of 27 SMW

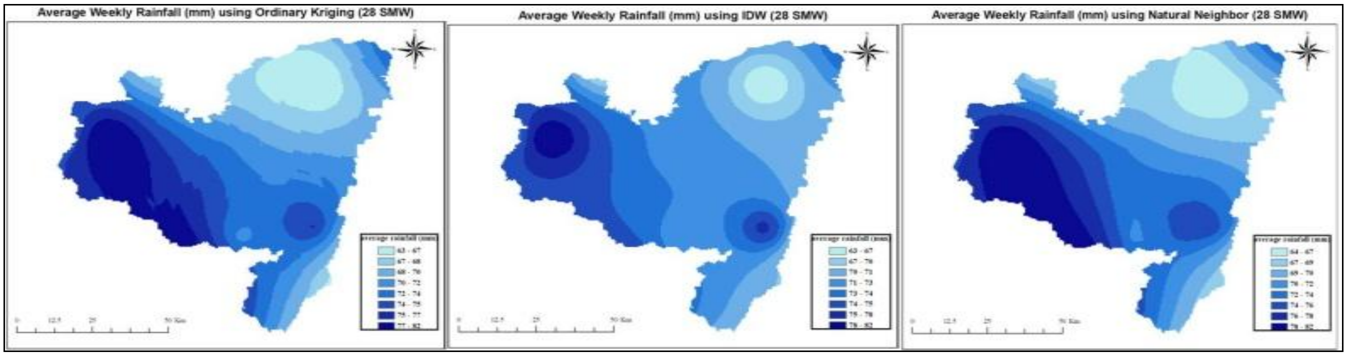

Figure 13: Average weekly rainfall distribution of 28 SMW

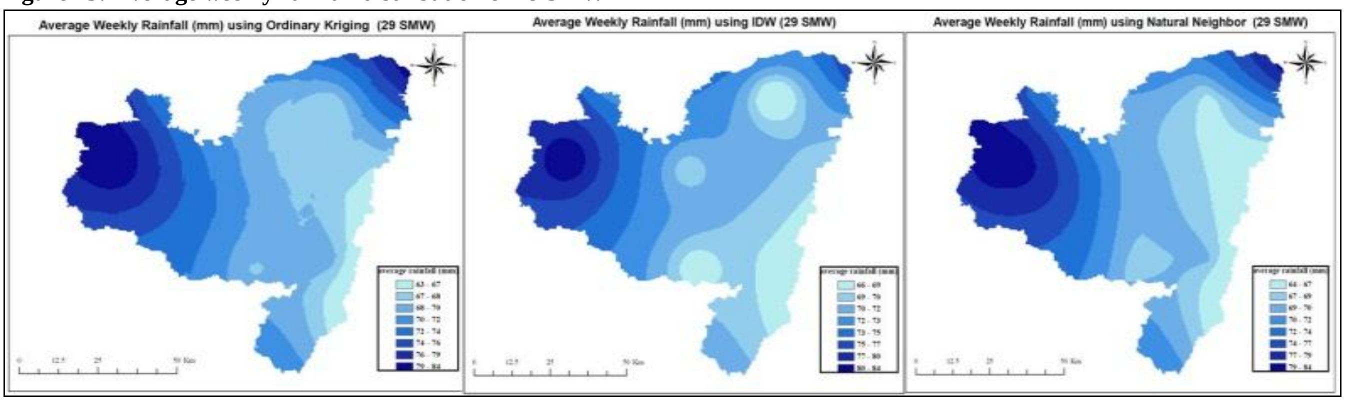

Figure 6: Average weekly rainfall distribution of 29 SMW

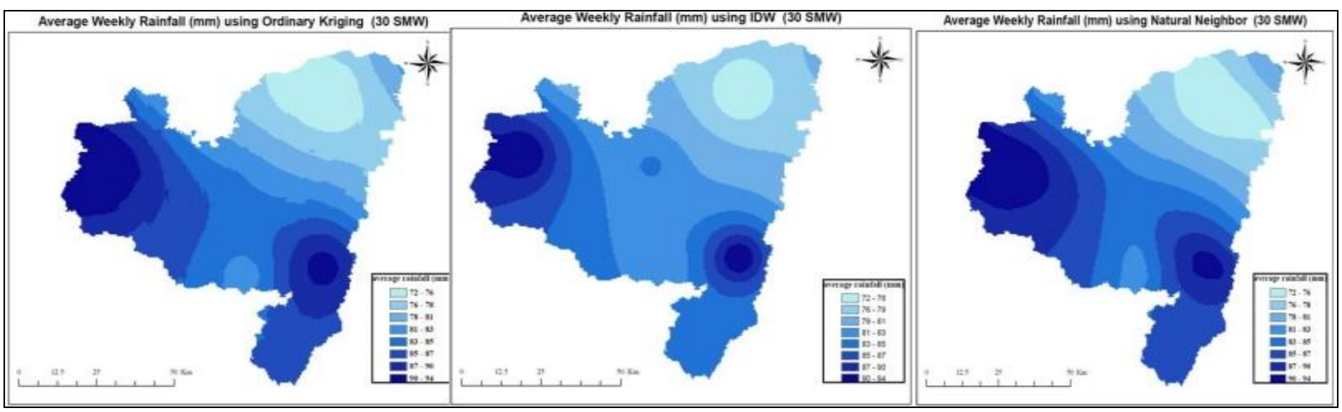

Figure 7: Average weekly rainfall distribution of 30 SMW

Evaluation of the accuracy of spatial interpolation techniques:

One of the main aims of this study is to estimate weekly average rainfall at each station was removed at each time and the remaining data were used to estimate the missing one by applying spatial interpolation techniques. Absolute error (AE) and Root Mean Square error (RMSE) in each technique were calculated to identify the best suitable interpolation techniques among kriging, IDW and Natural Neighbor. The Actual error and RMS error of every interpolation techniques like, kriging, IDW and Natural Neighbor were calculated for nine weeks, then average RMS error of nine SMW for each technique were calculated in this study. Table 5 has shown the RMS error of the used spatial interpolation techniques like, Kriging, IDW and Natural Neighbor spatial interpolation techniques of the study area in Standard Meteorological week.

Absolute error and RMS error:

On examining the above table, the RMS error is quite low in Natural Neighbor spatial Interpolation technique among the three spatial interpolation techniques. Therefore, it can be concluded that the Natural Neighbor spatial interpolation technique is the best suitable spatial interpolation technique on the given rainfall dataset.

Table 4: Weekly absolute & RMS error of three interpolation techniques

Interpolation Method	SME 22		SMW 23		SMW 24		SMW 25		SMW 26	
	AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
IDW	12.42	2.74	18.01	3.94	20.82	5.06	25.62	6.16	45.45	11.17
Kriging	12.78	2.64	10.57	2.59	20.69	5.24	24.91	6.33	50.51	11.09
Nearest Neighbor	10.93	2.22	15.56	3.59	19.97	4.68	26.74	6.69	45.03	10.64

Interpolation Method	SMW 27		SMW 28		SMW 29		SMW 30	
	AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE
IDW	21.77	5.21	24.26	5.95	22.35	5.15	29.24	7.01
Kriging	25.13	6.89	22.94	6.01	43.06	10.57	119.14	24.79
Nearest Neighbor	20.61	4.98	27.27	6.26	23.89	5.82	27.99	6.37

RMS Error of IDW = 5.82
RMS Error of KRIGING = 8.8
RMS Error of NATURAL NEIGHBOR = 5.69

Conclusion and Recommendations

The study based on the method used here is adequate to integrate a climatic database in a GIS context. Spatial analysis (spatial interpolation) of climatic data (weekly average rainfall) is demonstrated to be useful to predict the unknown quantities of rainfall based on known points. The method applied here could be useful for the specialists as an alternative and reliable approach to predict rainfall from the interpolated surface created by using three major types of interpolation techniques (IDW, Ordinary Kriging, Natural Neighbor) in a GIS context. A comparative analysis of the best fitted technique too was studied, applicable for the prediction of rainfall distribution with the help of Absolute Error & Root Mean Square Error (RMSE) measurement. The spatial analysis of rainfall distribution on Purulia district has been reflected by the interpolated weekly maps (week 22 to week 30) and the scatter diagram which represented the elevation wise rainfall distribution over the area. In the comparative study, RMSE is detected by the use of cross-validation method. The sum of RMS error of week - 22 to week - 30 of Inverse Distance Weighted method was found to be 5.82 mm, the RMS error of ordinary kriging was 8.8 mm and the RMS error of Natural Neighbor interpolation technique was 5.69 mm. As the absolute error test is the primary procedure of RMS error test, hence in this case RMSE measurement is preferred for the comparative studies of interpolation technique. As the RMSE of Natural Neighbor technique was detected to be the smallest between the other techniques thereby it can be concluded as the most preferable technique for spatial interpolation measurement of rainfall data.

Acknowledgments

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