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Rainfall Distribution and its Spatial and Temporal Variability Over Damodar Basin under Climate Change Scenario (1901-2002)

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Abstract: *Change in rainfall pattern is one of the most critical factors in determining the impact of climate change. It can adversely affect the socio-economic development of any region. Therefore, the study aims to examine the spatial and temporal rainfall variability and trend during a span of 102-year-period (1901-2002) over the Damodar River Basin. Various spatial and statistical methods have been applied to analyse the spatial and temporal variability of rainfall. ArcGis was used to show the spatial rainfall distribution using Kriging interpolation method. Mean, Standard Deviation, Co-efficient of Variation were used to show the variability of the rainfall. Non-parametric Mann-Kendall test was used to determine whether there is any positive or negative trend in the rainfall data with their statistical significance. Sen's slope estimator was also used to determine the magnitude of trend. The result of the analysis show that the annual rainfall was decreasing being statistically significant at 95% confidence level in north western part of the basin with maximum decrease at Giridih Districts (-2.09mm/year) and minimum decrease at Bokaro (-1.11mm/year) district. The basin receives maximum rainfall during monsoon period which contribute 80.96% to the annual rainfall. The increasing trend of rainfall was observed during post-monsoon season. This study provides the information on rainfall trend on long-term basis and the impact of climate change on different parts of the basin which will be very useful for water resource management, agriculture and economic development of the region.*
Keywords: *Damodar River Basin, Mann-Kendall test, Sen's Slope, Kriging estimator, Rainfall, Trend Analysis.*

I. Introduction:

Rainfall is one of the climatic variables that affect both the spatial and temporal patterns on water availability (De Luis et al., 2000; Kampata et al., 2008; Ngongordo 2006). Rainfall Variability in space and time has significant effects on socio-economic and ecological conditions of any region. The intergovernmental panel on climate change predicts that during the next decade billions of people in developing countries will face changes in rainfall patterns that will contribute to severe water shortage or flooding (FAO 2008). The study of the rainfall variability and its trends is a good tool for the policy makers for agricultural planning, water resource assessment, hazard mapping, flood frequency analysis etc.

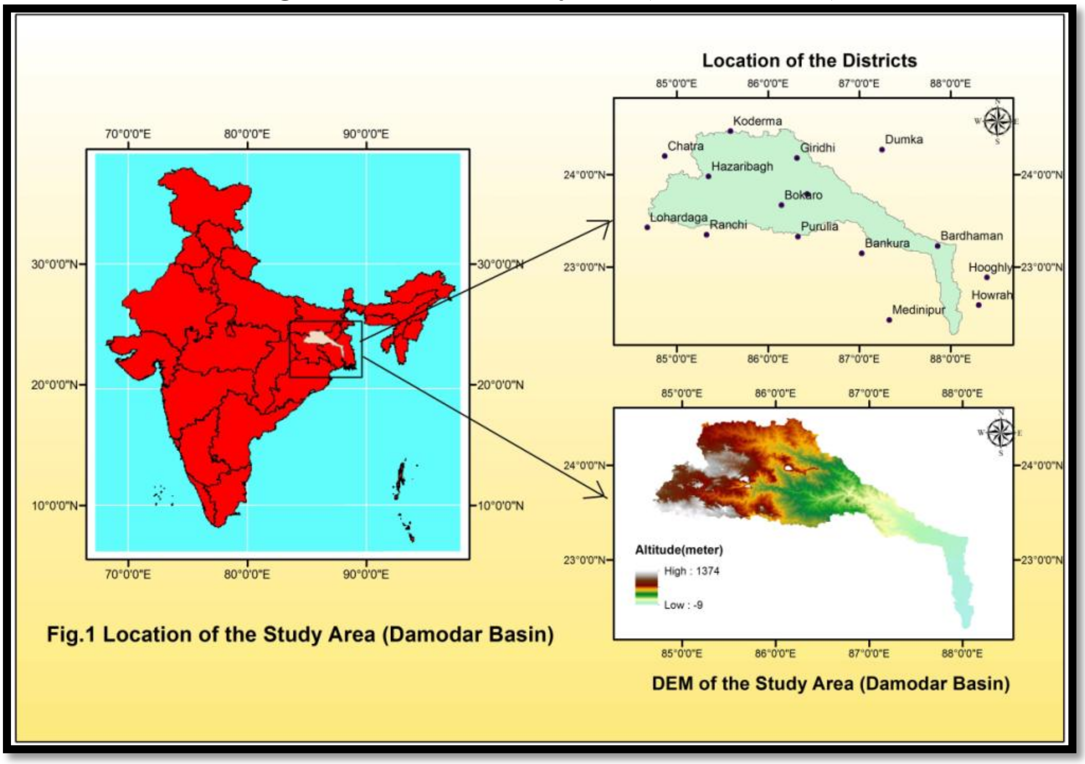
Several studies have been conducted by various researchers in order to know the spatial and temporal variability of rainfall. Bartolini et al., (2009) studied the inter-annual precipitation variability in the European Alps and reported that the Alps are the region with the highest inter-annual variability in winter precipitation in Europe. Wang and Xu (2014) found a descending trend in annual precipitation in Haihe River Basin,China. Nichols and Lavery (1992) found increasing summer rainfall in eastern Australia during 1950s. Loureiro et al., (2015) found highly heterogeneous rainfall behavior with temporal variability in the Tocantins- Araguaia hydrographic region, Brazil. Declining rainfall trends for the period of 1911-1980 over 28 meteorological stations in Nigeria was found by Adefalalu (1986). The increasing rainfall in the southern river basin and decreasing rainfall in the northern river basin of china has been reported by Chen et al., (2011).Spatial and seasonal differences in rainfall trend were observed on Canadian prairies (Akinremi et al. 2001). Archer and Fowler (2004) have studied variation of precipitation in spatial and temporal scale in the upper Indus Basin and reported that winter precipitation is highly correlated spatially across the basin and over the last century, there is no statistically significant long term trend in annual or seasonal precipitation time series. Krishnakumar et al. (2008) studied temporal variation in monthly, seasonal and annual rainfall over Kerala, India and revealed the significant decrease in southwest monsoon rainfall while increase in post monsoon season. Parthasarathi and dhar (1975) reported that the rainfall over India was increased from 1431mm to 1960mm. Wadood and Kumari (2009) noticed a considerable increase in average monthly maximum rainfall pattern with high variability in recent decades in Jharkhand, India. Nandargi and Mulye (2014) studied the spatial and temporal analysis of rainfall over Jharkhand, India for the period of 100 years (1901-200).Upadhaya (2014) made an attempt to study the variability of rainfall in Rajasthan, India for the period of 50 years (1960-2009). Kusre and Singh (2012) conducted the study of rainfall distribution in spatial and temporal time scale in Nagaland, India. The analysis showed that wide variation exists in the rainfall amounts with variation from 159mm to 2123mm.

All the above studies show the rainfall variation and trend analysis in different parts of the world, in India and different parts of the India. However the information regarding the rainfall trends and its variability over Damodar Basin is limited. Damodar River is mainly rain fed river and about 80% of the annual discharge occurs during monsoon season (June to September). There is considerable agriculture in this region which is also depends upon the monsoonal rainfall and river water. Understanding the fluctuation of rainfall in this region is very crucially important to study the change of hydrologic regime and the management of their water resources. Hence in this paper an attempt has been made to find out the long-term variability of rainfall both temporal and spatial scale over 16 districts that covers (fully/partially) entire Damodar basin for better understanding of rainfall variation, water resource management, flood control measures etc.

II. Study Area

The Damodar River lies between 23° 30' N and 24° 19' N latitudes and 85° 31' E and 87° 21' E longitudes and originates from the palamu hills of Chotonagpur at an elevation of about 610m above mean sea level. Total area of the basin is about 23,370.98 km^2 spreading in the states of Jharkhand (73.7%) and West Bengal (26.3%) Majumder et al.,(2010). Damodar Basin is fully and partially spread across Hazaribagh, Koderma, Ramgarh, Giridih, Dhanbad, Bokaro, Chatra, Palamu, Ranchi, Lohardaga and Dumka Districts of Jharkhand and Bardhaman, Hooghly, Howrah, Purulia and Bankura districts of West Bengal. The Basin is Characterize by moderate winter and hot and humid summer. The basin experiences mainly four distinct seasons namely, Winter (January-February), Pre-Monsoon (March-May), Monsoon (June-September) and Post-Monsoon (October- December). Due to the influence of seasonal and varying topographic features, some of the areas of Damodar Basin receive higher amounts of rainfall and some of areas experiences low rainfall.

Fig.1: Location of the Study Area (Damodar Basin)



III. Methodology

In this study, the spatial and temporal variability of the rainfall over damodar basin is examined for the period of (1901-2002). The rainfall data collected from the Indian meterological department (IMD) and Indian water portal (www.indiawaterportal.org /met_data). The general characteristics of the rainfall over damodar river basin are analyzed by computation of mean monthly, seasonal and annual standard deviation and co-efficient of variation. The Following formula has been used for determining Mean, Standard Deviation and Co-efficient of Variation.

$$\text{Mean } (\bar{x}) = \frac{\sum_{i=1}^{n} xi}{N}$$

Where, N= total number of observations, xi= ith values of x- variables.

$$\text{Standard Deviation}(\sigma) = \sqrt{\frac{\sum_{i=1}^{n}(xi - \bar{x})^2}{N}}$$

Where, N=number of observations, x= observations or values, $\bar{x}$= Mean

Co-efficient of variation = $\frac{\text{Standard Deviation}}{\text{Mean}} \times 100$

The spatial distribution of mean monthly, seasonal and annual rainfall variability is studied with the help of Kriging Interpolation Method using ArcGis software. There are many parametric and non-parametric methods for identifying the long term rainfall trend. In case of parametric test the data should be followed in a particular distribution. While in a non-parametric, the time series data used should be independent and allows the outliers present in the data (Lanzante, 1996). In the present study, one of the most popular non-parametric test called mann-kendall test (Mann 1945; kendall, 1975) was adopted for monotonic trend detection in rainfall time series.

The Kriging Method

Kringing is a geo-statistical procedure that generates an estimated surface from scattered sets of point with Z values. It involves an interactive investigation of the spatial behavior of the phenomenon before generating the output surface. It has been considered as a highly recommended spatial interpolation method in GIS (Griffith 1992; Oliver and Webster 1990). Kringing is a two step process which includes semi variance estimation and interpolation. Semi variance can be estimated from the sampling data using the following formula.

$$\vec{\gamma}\,(\vec{h}) = \frac{1}{2n}\sum_{i=1}^{n}\{\,Z\,(\vec{xi}) - Z\,(\vec{xi} + \vec{h})\}^2$$

Where,

$\vec{x}$ and $\vec{h}$ are two dimensional location and distance, n= number of pairs of the data points separated by distance h or distance range (h-d/2, h+d/2) if a distance interval d is used.

Various mathematical models e.g. linear, circular, spherical, exponential and Gaussan (McBratney and Webster 1986) procedures can be fitted in order to describe the way semi-variance changes continuously with the lag. Once the semi-variance estimation step is finished, the fitted semi variance can be used to determine the weights need for interpolation. The following formula has been used to determine the interpolated value at an unvisited/unsampled location.

$$\hat{Z}\,(\overrightarrow{x0}) = \sum_{i=1}^{N} \lambda i\, Z\,(\overrightarrow{xi})$$

Where, $(\overrightarrow{x0})$= prediction location, Z $(\overrightarrow{xi})$ = measured value at the ith location, N= number of measured value.

Mann-Kendall Trend Analysis

The Mann-Kendall test is a non-parametric statistics test widely used by the researchers for analyzing trends in data over time. The Mann-Kendall test can be used with data sets which include irregular sampling intervals and missing data (Gilbert, 1987).

In The Mann-Kendall Statistic, (S) measures the trend in the data. Positive values indicate an increase over time, whereas negative values indicate a decrease over time. The first step is to determine the sign of the difference between consecutive sample results. Sign (xj-xk) is an indicator function that results in the values -1, 0, or 1 according to the sign of xj-xk where j>k, the function is calculated as follows:

$$\text{Sign}\,(xj - xk) = \begin{bmatrix} 1 & \text{if } xj - xk & > 0 \\ 0 & \text{if } xj - xk & = 0 \\ -1 & \text{if } xj - xk & < 0 \end{bmatrix}$$

In the Mann-Kendall statistic, (S) is defined as the sum of the number of positive differences minus the number of negative differences as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sign}\,(xj - xk)$$

In the case of non-monotonic character of trends in the data, Kendall (1975) described a normal approximation test that can be used for the datasets that have more than 10 values. The procedure is as follows.

• S will be calculated using the above formula
• Variance of S, VAR(S), is to be calculated by the following equation:

$$VAR(S) = \frac{1}{18} = [n\,(n-1)\,(2n+5) - \Sigma\, t(t-1)\,(2t+5)]$$

Where, n is the length of data set and t is the extent of any given tie or the number of data value in a group of determination.

• Normalized test statistic (Z) is calculated using the following equation:

$$Z = \frac{S-1}{\sqrt{VAR(S}} \quad \text{if } S > 0 \qquad\qquad Z = \frac{S+1}{\sqrt{VAR(S}} \quad \text{if } S < 0$$

$$Z = 0 \text{ if } S = 0$$

. The probability density function for a normal distribution is given by the following equation:

$$f\,(z) = \frac{1}{\sqrt{2\pi}}\, e^{\frac{z^2}{2}}$$

Decide on a probability level of significance (95% typically).

- The trend will be treating as decreasing if the Z value is negative and the calculated probability is greater than the level of significance.
- The trend will be increasing if the Z value is positive and the calculated probability is greater than the level of significance.
- If the calculated probability is less than the significance level, there is no trend.

Sen's Slope:
Sen (1968) proposed a formula for identifying the slope of a linear trend.

$$Qi = \frac{Xj - Xk}{j-k} \text{ for } I = 1, \ldots, N$$

Where, xj and xk represents data values at times j and k (j > k), respectively. The median of the N values of Qi is Sen's estimator of slope. The Sen's estimator is calculated by the following equation:

$$Q_{med} = Q\,(n+1)/2 \qquad \text{if N is odd}$$
$$Q_{med} = [Qn/2 + Q\,(n+2)/2\,)]/2 \qquad \text{if N is even}$$

For identifying the true slope of the trend, Q_{med} will be tested by two-sided test at 100 (1-α) % confidence interval.

IV. Result and Discussion

Rainfall Characteristics of Damodar Basin:

Rainfall characteristics of Damodar River Basin are presented in the table no. 1 and fig no.2

Table 1: Mean monthly, seasonal and annual rainfall statistics over Damodar Basin (1901-2002)

Month/Season	Rainfall (mm)	standard deviation	Coefficient of Variation	% Contribution to annual rainfall
January	15.87	2.66	16.75	1.17
February	29.03	2.44	8.41	2.13
March	26.43	6.66	25.18	1.94
April	29.26	14.51	49.58	2.15
May	53.92	24.79	45.97	3.96
June	205.55	30.67	14.92	15.09
July	311.76	12.66	4.06	22.89
August	353.40	14.35	4.06	25.94
September	232.14	24.61	10.60	17.04
October	90.84	23.89	26.30	6.67
November	10.11	3.85	38.04	0.74
December	3.90	0.89	22.71	0.29
Winter(Jan-Feb)	44.90	4.40	9.81	3.30
Pre-Monsoon(Mar-May)	109.61	45.46	41.47	8.05
Monsoon(June-sep)	1102.84	48.13	4.36	80.96
Post Monsoon(Oct-Dec)	104.85	27.84	26.55	7.70
Annual	1362.21	114.42	8.40	100

The mean annual rainfall of the Damodar Basin is 1362.21mm with standard deviation of 114.42mm based on 102 years consequent data from 16 districts. The analysis of mean monthly rainfall of Damodar Basin shows that rainfall during August is the highest (353.40mm) which contributes 25.94% to the annual rainfall followed by July (311.76mm), September (232.14mm) and June (205.55mm). Least amount of rainfall is observed during December (3.90mm), November (10.11mm) and January (15.87mm).

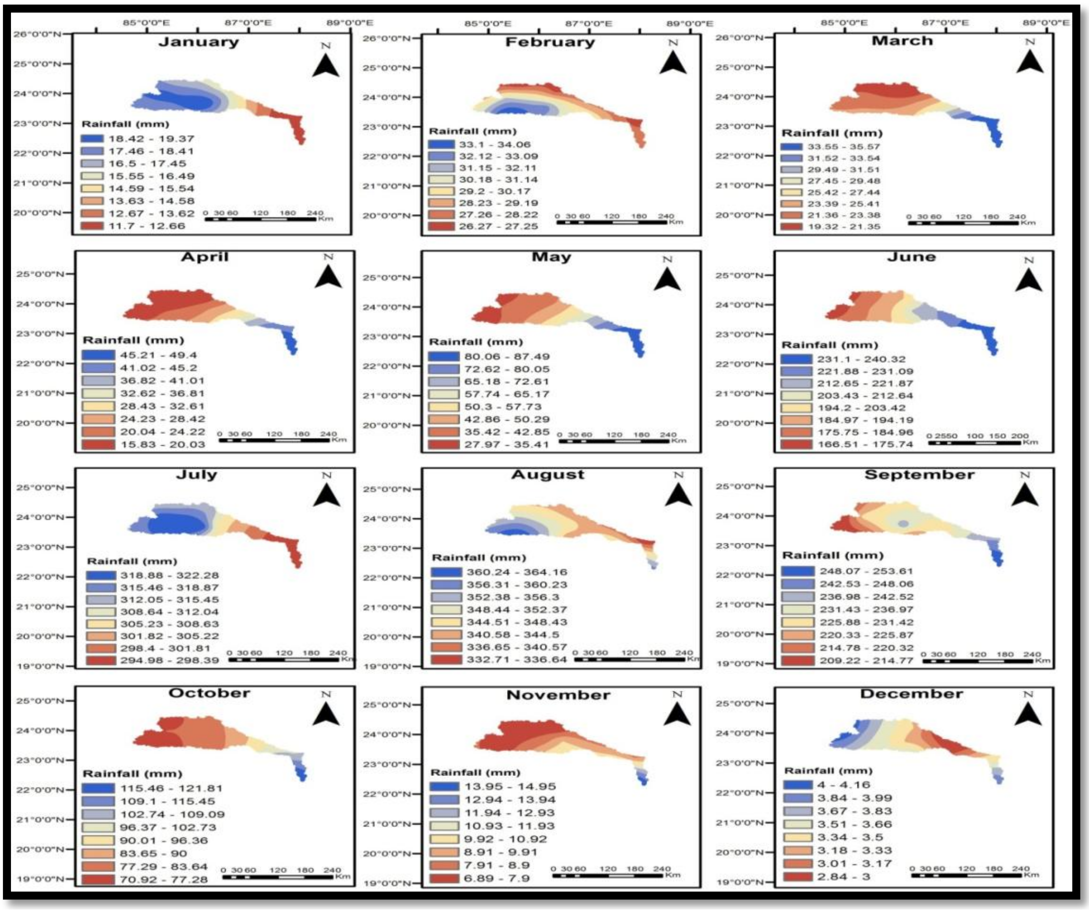


Fig 2: Monthly Mean Rainfall Distribution over Daomdar River Basin (1901-2002)

From monthly rainfall distribution map, it can be said that upper basin mainly gets maximum rainfall during December, January, February, July and August and the lower part of the basin gets maximum rainfall during the rest of the month. Due to the heavy rainfall during July and August, the basin experiences heavy flood. Medium rainfall can be seen in the middle part of the basin. Seasonal shift of the rainfall is clearly identified from the monthly distribution map.

The Seasonal Pattern of Rainfall:

As we have discussed that the basin experiences four distinct season namely, Winter (January-February), Pre-Monsoon (March-May), Monsoon (June-September) and Post-Monsoon (October- December). Mean rainfall in winter season varies from 37.78mm in Dumka to a maximum of 51.87mm in Bokaro. The average winter rainfall of the basin is 44.90mm with standard deviation of 4.40mm. Winter rainfall contributes only 3.30% to the annual rainfall. The spatial distribution of the winter rainfall shows that the rainfall is less than 40mm in the south eastern part of the basin while north western part of the basin receives higher amount of rainfall ranges from 46.54mm to 51.85mm. In Pre-monsoon season, mean rainfall varies from 51.79mm in Palamu to 185.82mm in Medinipur. The average rainfall in pre-monsoon season is 109.61mm with standard deviation of 45.46mm which contribute 8.05% to the annual rainfall. This season is characterized by cyclonic storms originating over the Bay of Bengal. Middle and southern part of the basin is mostly influenced by thunderstorm associated with rain during this season. This climatic phenomenon generally called as norwester or "Kal Baisakhi". During this season, north western part of the basin receives low rainfall ranges from 66.45mm to 108.71mm while south eastern part of the basin gets higher amount of rainfall ranges from 140mm to 172mm. The Basin receives maximum rainfall during monsoon season which contribute 80.96% to the annual rainfall. The rainfall varies from 1049 mm in Palamu to 1208mm in Howrah. This season has the maximum number rainy days. The spatial distribution of the monsoon rainfall shows that middle and south eastern part of the basin gets maximum rainfall ranges from 1105mm to 1147mm. Rainfall gradually decreases from middle to the north western part of the basin. During Post-Monsoon or retreating of south west monsoon season the average rainfall of the basin is 104.85mm with standard deviation of 27.84mm which contribute 7.70% to the annual rainfall of the basin. In this period north eastern part of the basin gets maximum amount of rainfall ranges from 110mm to 112mm. and the rainfall gradually decreases from the middle to the western part of the basin.

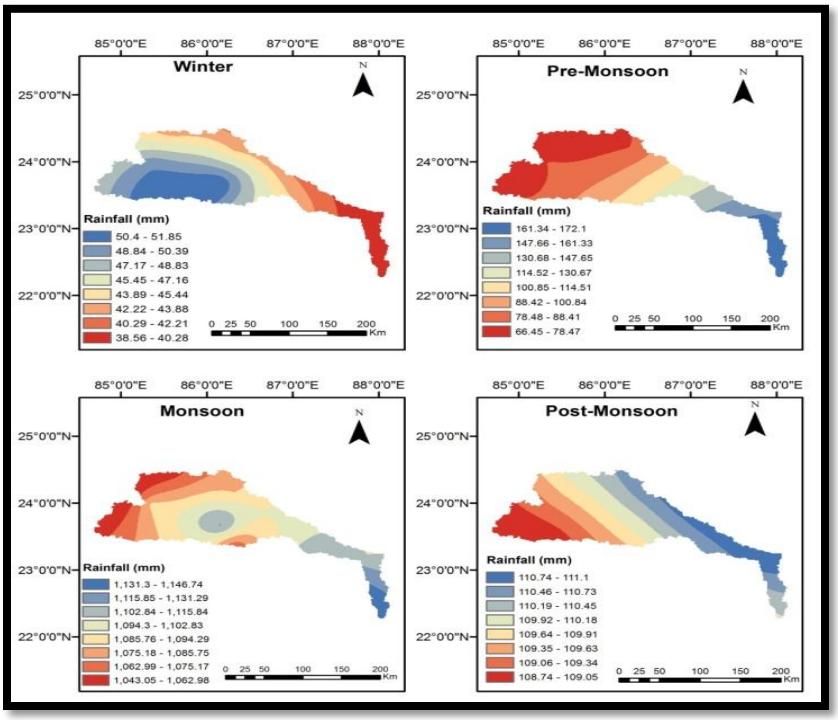


Figure 3: Spatial Distribution of the Mean Seasonal Rainfall over Damodar Basin (1901-2002)

Annual Pattern of rainfall:

Spatial distribution of the mean annual rainfall is shown in the fig no.4, which shows the decreasing trend of rainfall is found in the north western part of the basin. south eastern part of the basin gets maximum rainfall (>1400mm) and middle part of the basin gets moderate rainfall which varies from 1340mm to 1400mm.

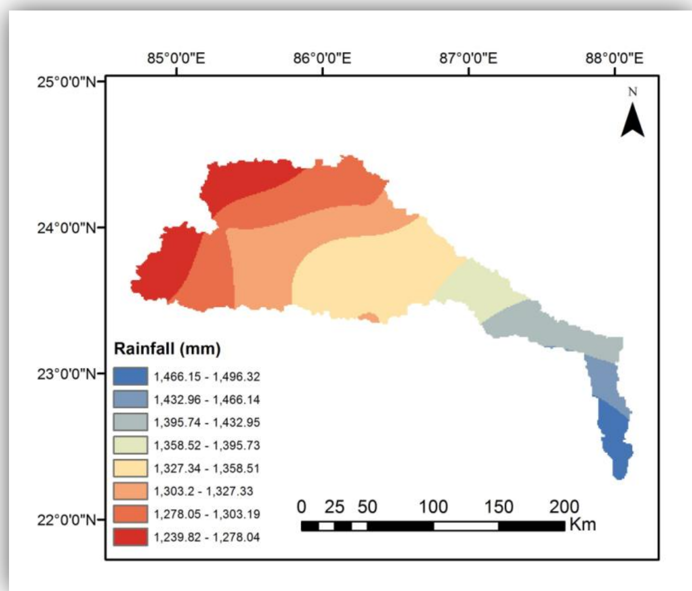


Figure 4: Spatial Distribution of the Mean Annual Rainfall over Damodar Basin (1901-2002)

Spatial variability of the Rainfall:

In order to know the spatial variability of the rainfall in Damodar River Basin, Co-efficient of variation (CV) has been calculated using mean monthly and annual rainfall values. It is observed that co-efficient of variation is less than 22.63% during Monsoon season which indicates very less variability. On the contrary Post-Monsoon season has significant variability. In this period co-efficient of variation varies from 65% to 77%. During winter season, south eastern part of the basin has higher variability of rainfall as the CV varies from 70% to 74% and western part of the basin has less rainfall variability which indicates the consistent rainfall during this period. In Pre and Post-Monsoon period north western part of the basin has the higher variability of the rainfall as the CV varies from 50% to 70%. The CV of the annual rainfall ranges from 14% to 22%. From the annual spatial variability map, it is observed that annual rainfall variability is higher in the north western part of the basin while it is lower in the south eastern part of the basin.

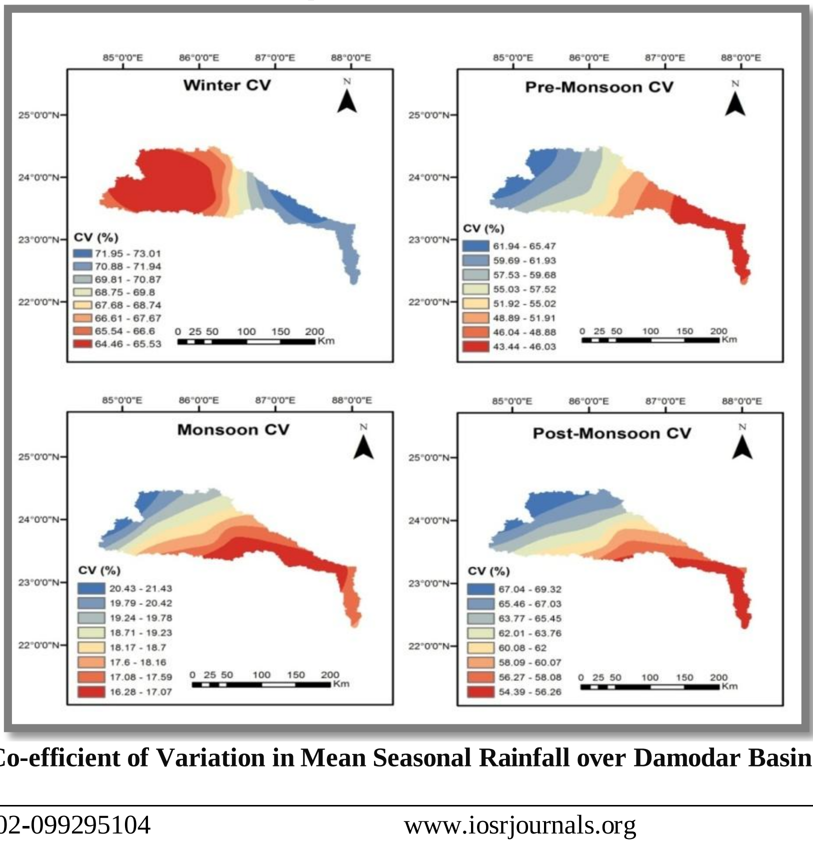


Figure 5: Co-efficient of Variation in Mean Seasonal Rainfall over Damodar Basin (1901-2002)

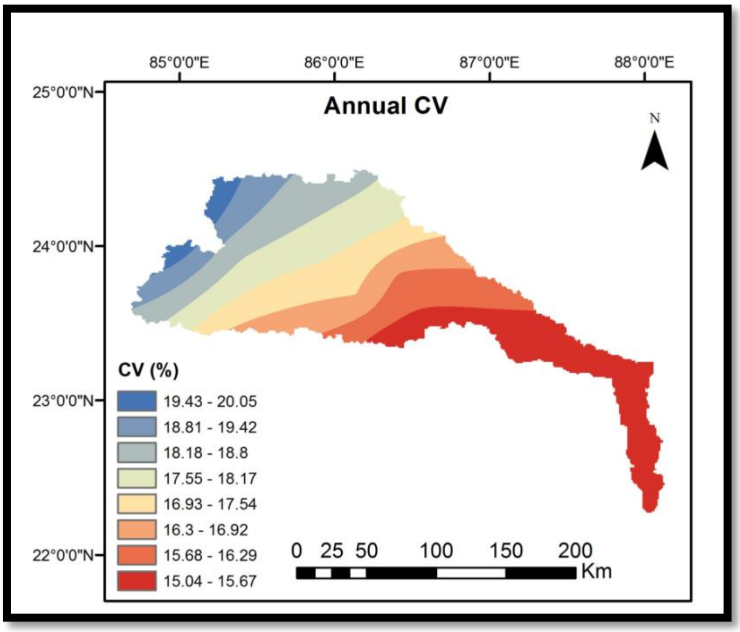


Figure 6: Co-efficient of Variation in Mean Annual Rainfall over Damodar Basin (1901-2002)

Temporal Variability of the Mean monthly, Seasonal and annual Rainfall:

In the present study, trend analysis for mean monthly, seasonal and annual rainfall in Damodar Basin has been carried out with 102 years rainfall data from 1901-2002. Mann-Kendall and Sen's Slope estimator were used for the determination of trend.

In the non-parametric Mann-Kendall test, the trend of rainfall has been calculated for each district individually with Sen's magnitude of slope (Q). In the Mann-Kendall test the Z statistics revealed the trend of the series for 102 years for individual 16 districts that cover the entire basin.

The trend analysis revealed that statistically insignificant (95% confidence level) negative trends of the mean annual rainfall appear in Bankura, Bardhaman and Purulia, districts of West Bengal while Bokaro, Chatra, Dhanbad, Dumka, Giridih, Hazaribagh, Koderma, Lohardaga and Ranchi districts of Jharkhand showed a statistically significant decreasing trend at 95% confidence level. The value ranges from -1.11mm/year to -2.09mm/year. The maximum decreasing trend is found at Giridih district (-2.09mm/year) and the minimum is found at Bokaro district (-1.11mm/year). Z values for Hooghly, Medinipur and Howrah districts of West Bengal showed an insignificant increasing trend.

Table 2: District-wise mean annual rainfall trends using Mann-Kendall test and Sen's slope methods (1901-2002).

	Mann-Kendall trend							Trend (At 95% level of signifcance)
District Name	First Year	Last Year	n	Mean Annual Rainfall	Test Z	Sen's Slope(Q)	Prop.	
Bankura	1901	2002	102	1411.34	-0.51	-0.35	0.6950	No Trend
Bardhaman	1901	2002	102	1417.08	-0.74	-0.53	0.7704	No Trend
Bokaro	1901	2002	102	1357.84	-1.68	-1.11	0.9535	Decreasing
Chatra	1901	2002	102	1211.05	-1.95	-1.62	0.9744	Decreasing
Dhanbad	1901	2002	102	1340.93	-1.97	-1.41	0.9756	Decreasing
Dumka	1901	2002	102	1345.93	-2.68	-2.17	0.9963	Decreasing
Giridih	1901	2002	102	1300.32	-2.67	-2.09	0.9962	Decreasing
Hazaribagh	1901	2002	102	1305.13	-1.83	-1.54	0.9664	Decreasing
Hooghly	1901	2002	102	1540.86	1.12	1.00	0.8888	No Trend
Howrah	1901	2002	102	1602.46	1.54	1.50	0.9382	No Trend
Koderma	1901	2002	102	1255.67	-2.44	-2.01	0.9927	Decreasing
Lohardaga	1901	2002	102	1294.56	-1.93	-1.60	0.9732	Decreasing
Medinipur	1901	2002	102	1569.70	1.23	1.02	0.8907	No Trend
Palamu	1901	2002	102	1224.72	-1.99	-1.73	0.9767	Decreasing
Purulia	1901	2002	102	1318.25	-1.17	-0.77	0.8790	No Trend
Ranchi	1901	2002	102	1299.50	-1.74	-1.24	0.9591	Decreasing

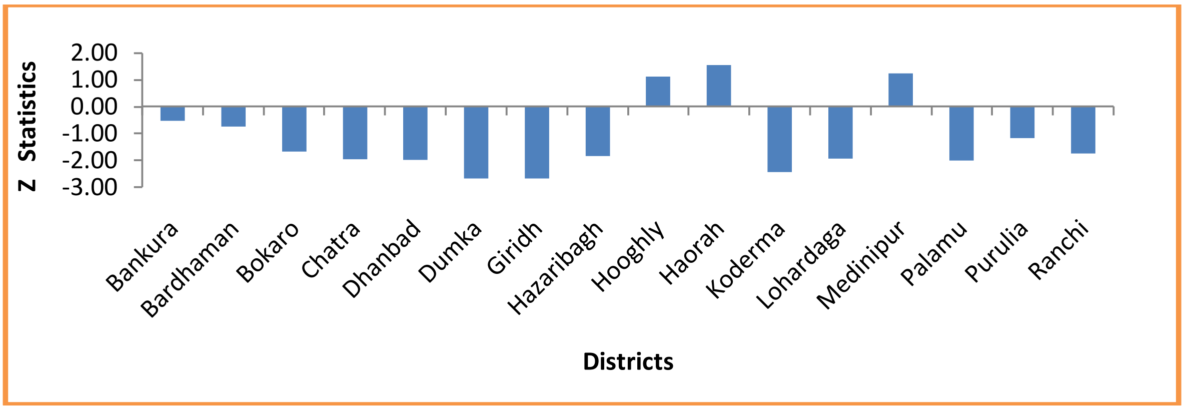


Figure 8: Trend of Z for individual Districts for 102 years.

The rainfall during February shows statistically significant decreasing trend at 95% confidence level. Rainfall during October shows increasing trend which is statistically significant at 95% confidence level. Rainfall in the months of January, April, May, September, November and December also shows increasing trends but all are statistically insignificant. Rainfall in the months of March, June, July and August shows insignificant decreasing trends.

Table 3: Mean Monthly rainfall trend using Mann-Kendall and Sen's slope (1901-2002).

	Mann-Kendall trend						Trend (At 95% level of signifcance)
Month	First Year	Last Year	n	Test Z	Sen's Slope(Q)	Prop.	
January	1901	2002	102	1.55	0.96	0.9394	No trend
February	1901	2002	102	-1.79	-1.99	0.9633	Decreasing
March	1901	2002	102	-0.79	-0.62	0.7852	No trend
April	1901	2002	102	0.31	0.33	0.6217	No trend
May	1901	2002	102	0.72	1.15	0.7642	No trend
June	1901	2002	102	-0.88	-4.75	0.8106	No trend
July	1901	2002	102	-0.82	-3.89	0.7939	No trend
August	1901	2002	102	-1.58	-7.73	0.9429	No trend
September	1901	2002	102	0.87	3.42	0.8078	No trend
October	1901	2002	102	1.65	4.58	0.9505	Increasing
November	1901	2002	102	1.22	0.21	0.8888	No trend
December	1901	2002	102	0.20	0.00	0.5793	No trend

Increasing rainfall trend with statistically significant at 95% confidence level is found during Post-Monsoon Season and the rest of the season has statistically insignificant negative trends. While, determining the impacts of climate change, only post-monsoon season will be significantly considered and the contribution in other seasons are insignificantly considered.

Table 4: Seasonal rainfall trends using Mann-Kendall and Sens's slope (1901-2002)

	Mann-Kendall Trend						Trend (At 95% level of signifcance)
Season	First Year	Last Year	n	Test Z	Sen's Slope(Q)	Prop.	
Winter	1901	2002	102	-0.94	-1.44	0.8264	No Trend
Pre-Monsoon	1901	2002	102	-0.17	-0.37	0.5675	No Trend
Monsoon	1901	2002	102	-1.50	-13.99	0.9332	No Trend
Post-Monsoon	1901	2002	102	1.75	5.04	0.9599	Increasing

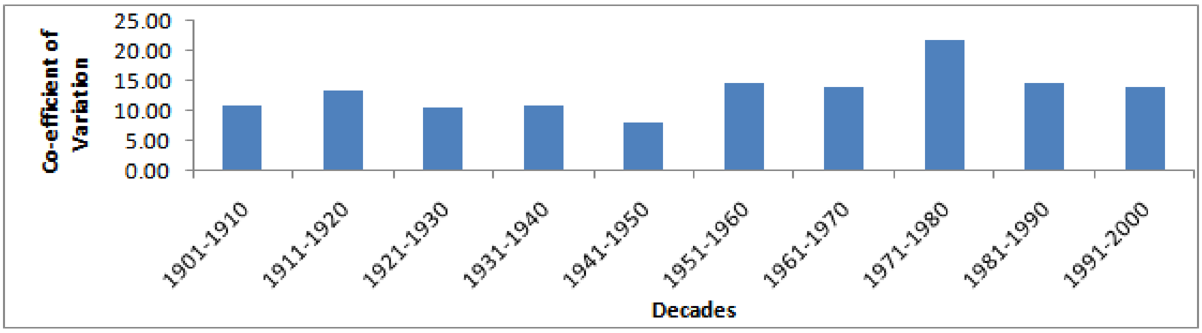


Figure 9: Decadal Co-efficient of Variati on in Damodar Basin (1901-2002)

From the decadal Co-efficient of Variation (CV) graph, it can be observed that CV fluctuates in different decades. The highest CV (21.92%) was recorded in the 8th decade (1971-1980) and the lowest CV (8.09%) is found in the 5th decade (1941-1950).

V. Conclusion

In this study, the spatial and temporal variability of the rainfall has been investigated for the period of 1901-2002 with the help of the different statistical techniques. The main conclusions can be summarized as follows.

- Rainfall over Damodar basin is not uniformly distributed in all seasons. It varies from place to place.
- Large portion of the upper basin experiences statistically significant decreasing rainfall at 95% confidence level.
- Only three districts namely, Medinipur, Howrah, Hooghly experiences statistically insignificant increasing rainfall trend which is located at the lower part of the basin.
- Rainfall mainly decreased in the month of February while it increased in the month of October. During monsoon season (June-September) the basin experiences floods due to heavy rainfall.
- The highest rainfall variability is seen during 1971-1980.
- Result of the Mann-Kendall and Sen's Slope are quite similar to each other.

The trends and variability of rainfall indicating the impacts of climate change which can have adverse impact on socio-economic development of the study area. Proper mitigation measures are required to minimize the climatic impacts. Therefore the result from the study can be useful tool for the management of water resource and economic development of the region.

Acknowledgements

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