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Spatial and Temporal Trends of Monthly, Seasonal and Annual Precipitation in Districts of Jharkhand in India

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SSM, BD and JSC designed the study, performed the statistical analysis. Author SSM wrote the first draft of the manuscript. Authors AKS and BPB did analyses of the study and managed literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Characterization of spatial variability and temporal trends in precipitation in a changing climate is vital to assess climate-induced changes to support adequate agricultural planning and water resources management strategies for the future. In this context, spatial and temporal variability in the precipitation over Jharkhand state in Eastern plateau and hill region is investigated. Spatial distribution of precipitation was mapped using 'ordinary kriging' geostatistical interpolation technique. A comprehensive precipitation trend and periodic analysis at the monthly and seasonal scale on a 40 year data series (1975-2014) for 18 locations in Jharkhand are presented using Mann-Kendall and Sen's slope methods. The seasonal and annual precipitation showed large spatial variability across the Jharkhand. Although, the spatial distribution of monsoon and annual precipitation are roughly similar, annual precipitation varied considerably in space due to the variations induced by pre-monsoon and winter precipitation. The statistical analysis revealed predominantly decreasing trends, both at the annual and seasonal scale. July precipitation showed significantly decreasing trend (-3.17 to -6.21 mm/year) in large number of districts (15), while the

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trend in May and other ‘monsoon’ months was not significant. Over the reference period, the negative trends in monsoon, winter and annual precipitation were significant for 61, 67 and 50% of the total districts analyzed with rate of decrease for monsoon and annual precipitation in the range of -5.3 to -13.0 and -5.3 to -15.9 mm/year, respectively. In view of the rainfall dependence of the agriculture in the state and decreasing trends of precipitation, the information presented in this paper can supports further climate change risk assessment and vulnerability adaptation planning.

Keywords: Precipitation; trend analysis; spatial variability; Mann-Kendall test; kriging.

1. INTRODUCTION

Impact of climate change is a growing concern worldwide. According to the Intergovernmental Panel on Climate Change [1], future climate change is likely to affect agriculture, increase the risk of hunger and water scarcity, and lead to more rapid melting of glaciers. One of the most important necessities of research into climate change is to analyze and detect historical changes in the climatic system [2]. Changes in precipitation pattern can effect human health, ecosystems, plants, and animals. Within the vast subject area of climate change, the changing pattern of precipitation is a topic that deserves urgent and systematic attention [3]. Precipitation is severely affected by the climate change [4] and accurate characterization of precipitation trends over a region is important in many applications relating to water resource management, agricultural planning and irrigation management [5]. Number of hydrologic and ecologic studies recognize the importance of characterizing the temporal and spatial variability of precipitation [6,7].

Over the past few decades, a number of methods have been proposed for modeling the spatial distribution of precipitation. Conventional techniques such as Thiessen polygons, the isohyetal method, and inverse distance weighting (IDW) were used for interpolation of rainfall data until the late 1980s [8,9]. Geostatistics is one of the recent interpolation technique that provides a set of statistical tools for spatial interpolation and analyzing spatial variability. Geostatistical methods like kriging and co-kriging have been increasingly used to map the variability parameters like precipitation [6,7], crop evapotranspiration [10], groundwater table and hydro-geochemical processes [11] and climatic parameters [12].

In recent past, many researchers have focused on analyzing precipitation trends over a geographical region. The fourth IPCC reported temporal and spatial variation in precipitation trends throughout the latter half of the century across Asia [13]. Studies on yearly and seasonal trends in precipitation at global and local scales reveal trends over many regions of the world [14,15,16,17]. Number of studies analyzed temporal trends in precipitation at global, national and basin scale. Toward the upper end of the spatial scale, [1,18] reported that mean annual land-surface precipitation over the 20th century increased by 7%–12% in the middle and high latitudes (30˝–85˝) of the Northern hemisphere, but only by 2% for latitudes ranging from 0˝ to 55˝S. Applicability of these results at local scale is limited as both increases and decreases are expected at the regional and continental scales [3]. Analysis of precipitation trends over India revealed no significant trend for annual, seasonal, or monthly precipitation, however the trends varied over the meteorological sub divisions [19,20,21]. Previous studies have also shown significant trends in precipitation patterns over some pockets of India [22,23]. Large scale spatial variability in the precipitation trends necessitates analysis of precipitation patterns at local scale.

A variety of statistical methods have been applied in studies to detect trends and other changes in hydrologic and climatic variables at different temporal scales. Both nonparametric (Mann–Kendall test) and parametric (linear regression analysis) procedures have been used to detect the annual and seasonal trends in precipitation. The parametric Spearman’s rho test was also been used in many studies to assess the trends in hydrological variables [24, 25]. Sen’s non-parametric estimator of slope has been frequently used to estimate the magnitude of trend, whose statistical significance was assessed by the Mann–Kendall test [22]. The rank-based non-parametric Mann-Kendall (M-K) statistical test [26,27] is used to assess the significance of trends in hydro-meteorological time series such as water quality, streamflow, temperature and precipitation. The non-parametric tests are preferred as they are more suitable for non-normally distributed data, which are frequently encountered in hydro-meteorological time series [28].

Jharkhand is one of the states in Eastern Plateau and Hill Region of India where agricultural production is largely from rainfed areas and agricultural output is primarily governed by timely availability of water. Precipitation remains the most critical input to agriculture as about 80% of the population is dependent upon rainfed agriculture and agricultural productivity of the state as a whole is very low (< 1 ton/ha) [29]. In the rainfed condition success or failure of crops, is closely linked with precipitation pattern. Uncertainty and uneven temporal and spatial distribution of precipitation is creating longer dry spells evoking drought conditions [30]. Many other studies showed that the Jharkhand is in precarious situation due to its high climate sensitivity and vulnerability, combined with low adaptive capacity. The study of precipitation trends is critically important for Jharkhand whose food security and economy are dependent on the timeliness of the precipitation. Attempts have been made in the past to determine trends in the precipitation at national and regional scales. In the present study, a much detailed view has been taken to assess the presence of linear monotonic trends in the temporal structure of precipitation and to quantify the trend statistics on monthly, seasonal and annual scales for 18 districts of Jharkhand covering all the three agro-climatic regions.

2. MATERIALS AND METHODS

2.1 Study Area

The present study was carried out for the Jharkhand state in the eastern plateau and hill region of India (Fig. 1). The state is bounded by 21º95' to 25º45'N latitude and 83º35' to 87º95'E longitude and has a total geographical area 79714 sq km. It is a part of greater Mahanadi river basin and comprises of the Chotanagpur Plateau, which forms a part of Deccan bio-geographic province. The state is characterized by a broad range of elevations and has series of four plateaus with different elevation above mean sea level (amsl). The highest plateau lies in the west known as Western or Higher Ranchi Plateau located at 760 to 1100 m amsl. Major land uses in the state include forest and grassland. As per the land use statistics of 2006 (Ministry of agriculture, GOI) about 29.27% of the area was under forest and only 22.29% of the total geographical area was under different crops. The state falls under the tropical monsoon climatic region. The average temperature of the state is 25ºC, which varies greatly because of varying altitudes of different plateaus. The average temperature of the higher Ranchi plateau region is below 23ºC, in the eastern part it is slightly above 26ºC while rest of the state records average annual temperature between 23 and 26ºC. The average annual precipitation in the state is 1400 mm and it varies from 1200 mm to 1800 mm across the three agro-climatic regions of the state. In some years there are distinct 'dry' spells during monsoon season.

2.2 Data and Methods

In this study, monthly precipitation data of 40 years (1975-2014) for 18 locations (districts) covering all the three agro-climatic regions over entire state was considered. The data records for the period of 1975 to 2001 were obtained from India Meteorological Department (IMD) available at http://www.indiawaterportal.org/met_data/. Monthly precipitation data records for the period of 2002 to 2009 for all the districts were obtained from the Directorate of Economics and Statistics, Government of Jharkhand and the data for rest of the period (2011 to 2014) was obtained from Customized Precipitation Information System (CRIS) of IMD (http://hydro.imd.gov.in/). The acquired data was processed for homogeneity and quality control. Homogeneity testing in this study followed an absolute method described by [16], in which the time series must pass two separate tests (a t-test and modified Ward's test) to be included for subsequent analysis. To detect monotonic trends, monthly precipitation values were added to generate the annual and seasonal precipitation. Precipitation time series of pre monsoon (March, April and May), monsoon (June, July, August and September) and winter (November, December, January and February) seasons were compiled for analysis from the monthly data.

2.3 Mapping Spatial Variability in Precipitation

Climatic variables such as precipitation are highly influenced by local and synoptic-scale meteorological processes. Therefore, assessing the spatial variability of observed values of variables is very demanding. The seasonal and

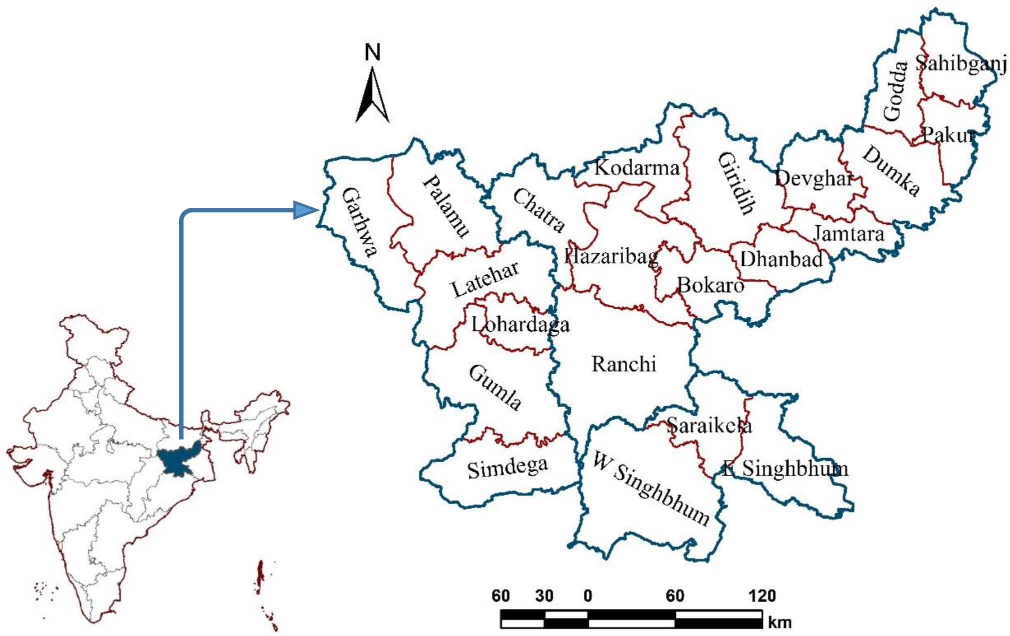

Fig. 1. Location and the district map of Jharkhand

annual precipitation values for all the districts and the base map of the Jharkhand were projected to WGS_1984 projection system with the ground distance represented in meters. Kriging interpolation technique was used to interpolate the point values of precipitation over the Jharkhand state. Kriging was selected as it is most robust and is frequently used to account for data fluctuations and consideration of a global trend [31,32,33]. Ordinary Kriging considers only the effect of the space coordinates on point precipitation values distributed over space. To make a prediction of precipitation at a particular point, ordinary kriging uses the fitted semivariogram model and the values of precipitation at neighboring stations. In this study, spherical semivariogram model was used as it is one of the most widely used semivariogram models [34,35] and is commonly available in many geostatistical software packages [36,37]. Prior to semivariogram fitting and actual kriging, an exploratory data analysis was carried out to ascertain the normality in data, data trend and presence of any outliers. The accuracy of prediction was assessed in terms of mean error (ME) and Root Mean Squared Error (RMSE). The geostatistical analysis extension module of ArcGIS 9.3 was used for analysis and development of precipitation variability maps for seasonal and annual precipitation over the state of Jharkhand.

2.4 Mann-Kendall Test

Methods used in trend detection are broadly categorized as parametric and non-parametric methods. Many studies have advocated the use of non-parametric methods of trend detection. Mann-Kendall test is a non-parametric statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. The Mann-Kendall test confirm the existence of a positive or negative trend for a given confidence level [27]. This test was found to be an effective tool for identifying trends in hydrologic and other related variables, resistant to the effect of extreme values. Major advantage of Mann-Kendall test is that it is free from statistical distributions which are required for parametric method. The Mann-Kendall test applied in this study is a rank-based method for evaluating the presence of trends in time series data, without specifying whether the trend is linear or nonlinear. The data are ranked according to time, and then each data point is compared to all the data points that follow in time. The null hypothesis (H0) for the Mann-Kendall test is that there is no trend there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis (H1), which assumes increasing or decreasing monotonic trend. The Mann-Kendall statistic S of the series x is given by [26,27]:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i)$$

Where, *sgn* is the signum function. The variance associated with S is calculated from [26,27];

$$V\,(S) = \frac{n\,(n-1)\,(2n+5) - \sum_{k=1}^{m} t_k\,(t_k - 1)\,(2t_k + 5)}{18}$$

Where, m is the number of tied groups and t_k is the number of data points in group k. In cases where the sample size n > 10, the test statistic Z(S) is calculated from;

$$Z\,(S) = \begin{cases} \frac{S-1}{\sqrt{V\,(S)}}, & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{V\,(S)}}, & if\ S < 0 \end{cases}$$

Here Z follows standard normal distribution. A positive value of Z indicates increasing (upward) trend and negative value indicate decreasing (downward) trend. A significance value α is utilized for testing either an upward or downward trend in a two sided test. If the Z value is greater than $Z_{\alpha/2}$, then null hypothesis (H0) is rejected at α level of significance. Trends are considered significant if |Z(S)| are greater than the standard normal deviate $Z_{(1-\alpha/2)}$ for the desired value of α. In this study significance is tested at α values of 0.1, 0.05 and 0.001.

2.5 Sen's Slope Estimator

The Theil–Sen's slope estimator has been widely used for determining the magnitude of trend in hydro-meteorological time series [38,39]. True slope in time series data (change per unit time) is estimated by procedure described by [38], in case the trend is linear. The Sen's estimator is considered more robust than the least-squares method due to its relative insensitivity to extreme values and better performance even for normally distributed data. The magnitude of trend is predicted by the Sen's slope (Q_i) of all data pairs as calculated by;

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1, 2, \ldots, N,$$

where x_j and x_k are data values at time j and k (j > k) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as;

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd,} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even.} \end{cases}$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

3. RESULTS AND DISCUSSION

3.1 Spatial Variability

The exploratory data analysis performed on the point precipitation data for all the time series revealed that the data are normally distributed and free of outliers. It was observed from the fitted semivariogram that ordinary kriging resulted in r^2 values of the fitted spherical semivariogram ranging from 0.71 to 0.95 with optimal values of model parameters (Table 1). The estimated values of the R^2 and RMSE for all four time series were well within the acceptable range. The observed point precipitation data for pre-monsoon, monsoon, winter and annual scales were subjected to ordinary kriging analysis to develop spatial variability maps.

Spatial distribution maps for pre-monsoon, monsoon, winter and annual precipitation are presented in Fig. 2. The seasonal precipitation follows a systematic pattern of spatial correlation. In general south-east and north-east parts of the Jharkhand have higher average pre-monsoon precipitation. Major part of the state gets 110-170 mm of winter rains with district located in north-eastern parts (Pakur, Dumka, Jamtara and Sahebganj) receiving comparatively higher winter season precipitation (140-170 mm). Annual precipitation gradually decreased from south-east to north-west direction. The region comprising Garwa, Palamu, Chaatra and Latehar districts is the low precipitation region in the state. Since, monsoon is the major contributor to annual precipitation, the spatial distribution of monsoon precipitation closely resembled that of annual precipitation.

3.2 Monthly Precipitation Trends

The Mann-Kendall (MK) test was applied on a monthly scale to detect trends in the precipitation series in different districts and the values of the

Mann-Kendall statistic and Sen's slope (January-December) are presented in Table 2. Changes in trends of observed monthly precipitation have been evident. Analysis revealed mix of positive and negative trends in monthly precipitation time series for different districts. Monthly analysis of district level precipitation indicated that majority of the districts have no statistically significant change in months of May, June, August, September and October (Table 2). The months of January, April, July and December exhibited significant decreasing (negative) trends with the respective Sen's slope varying between -0.06 to -0.47, -0.18 to -0.73, -0.96 to -6.29 and 0.0 to -0.02 among all the districts. Particularly notable are the months July and December for which decreasing trend was observed in 15 and 16 districts out of 18 districts studied and the trend was statistically significant at 5% level of confidence.

Table 1. Parameters of the fitted semivariogram model and cross-validation statistics

Time series	Semivariogram model parameters (Spherical)			Prediction accuracy (Cross validation statistics)	
	Nugget	Sill	r^2	R^2	RMSE
Pre-monsoon	13	2112	0.95	0.809	1.1
Monsoon	2823	19170	0.76	0.814	10..1
Winter	81	1623	0.78	0.825	1.9
Annual	4400	49900	0.85	0.830	12..2

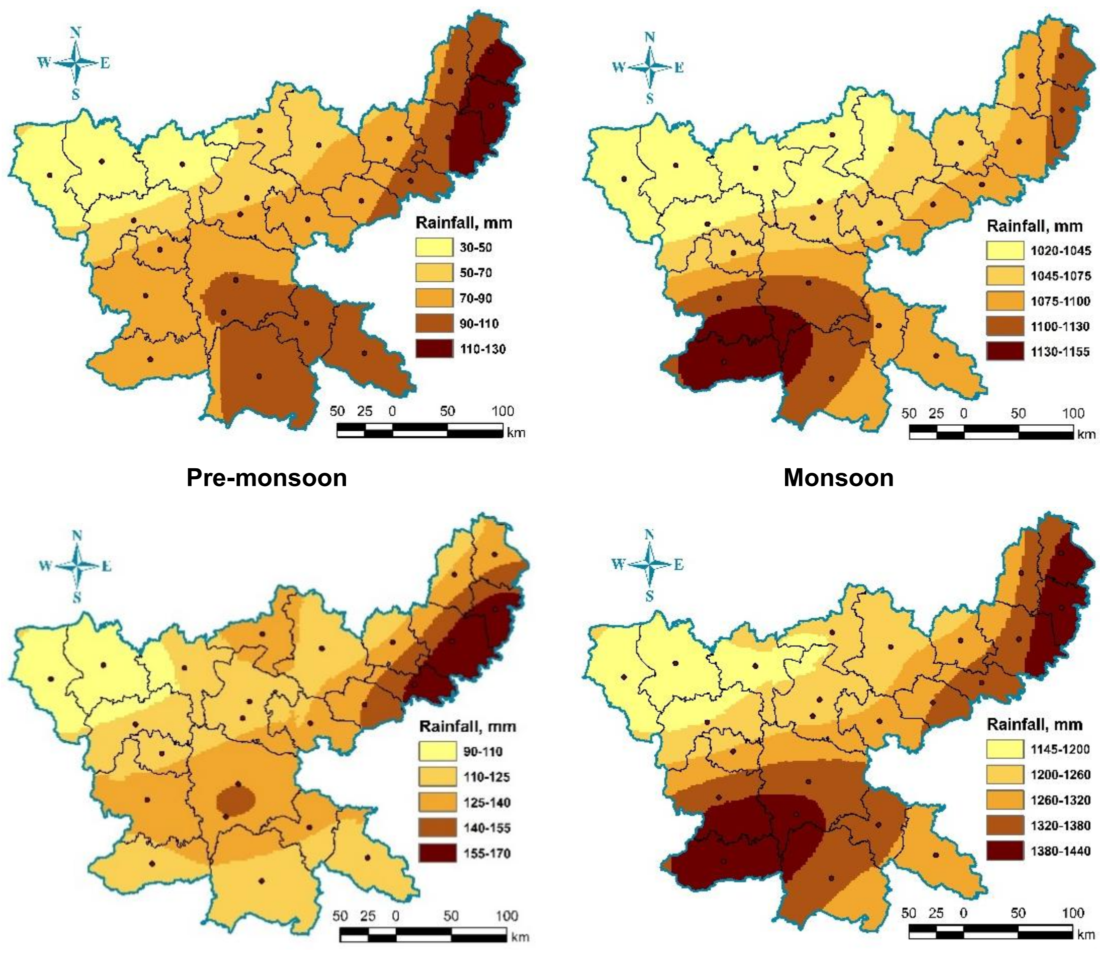

Fig. 2. Seasonal and annual spatial distribution of precipitation over Jharkhand

Table 2. Mann-Kendall test statistic (Z) and the Sen's Slope (Q) results for the monthly precipitation time series

District	Statistic	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Bokaro	Test Z	-1.56	-1.85	-1.90	-2.21	0.15	-0.85	-2.78	-0.14	-0.22	0.34	-2.04	-2.54
	Signific.		+	+	*			**				*	*
	Q	-0.23	-0.41	-0.15	-0.57	0.11	-1.09	-3.80	-0.11	-0.31	0.23	-0.09	0.00
Chattra	Test Z	-2.93	-2.70	-2.32	-2.90	0.00	-0.55	-3.48	-0.73	-1.13	0.34	-3.49	-3.30
	Signific.	**	**	*	**			***				***	***
	Q	-0.47	-0.41	-0.24	-0.43	0.00	-0.77	-5.71	-1.09	-1.49	0.23	-0.09	-0.02
Deoghar	Test Z	-2.52	-2.19	-2.20	-3.49	-0.40	-1.01	-2.64	-0.24	-0.87	0.43	-2.45	-3.92
	Signific.	*	*	*	***			**				*	***
	Q	-0.25	-0.38	-0.27	-0.66	-0.24	-1.80	-4.42	-0.25	-1.07	0.39	-0.09	-0.02
Dhanbad	Test Z	-2.04	-2.13	-2.06	-2.35	-0.68	-1.41	-2.39	-0.36	-0.10	-0.17	-2.54	-2.54
	Signific.	*	*	*	*			*				*	*
	Q	-0.27	-0.44	-0.23	-0.70	-0.41	-1.76	-3.42	-0.42	-0.14	-0.10	-0.17	0.00
Dumka	Test Z	-1.93	-2.13	-2.03	-2.21	-0.33	-0.86	-3.87	-0.02	-0.56	-0.19	-1.03	-2.28
	Signific.	+	*	*	*			***					*
	Q	-0.34	-0.38	-0.20	-0.29	-0.08	-1.20	-5.58	-0.02	-0.66	-0.08	-0.04	-0.01
E Singhbhum	Test Z	-0.85	-1.31	-2.01	-1.76	0.92	0.50	-0.66	0.01	0.01	0.99	-0.57	-0.96
	Signific.			*	+								
	Q	-0.06	-0.35	-0.49	-0.73	0.71	0.72	-0.96	0.09	0.02	0.69	-0.01	0.00
Gharwa	Test Z	-2.33	-1.58	-1.68	-3.73	-1.22	-2.09	-4.18	-0.62	-1.62	-0.38	-3.69	-3.16
	Signific.	*		+	***		*	***				***	**
	Q	-0.46	-0.23	-0.11	-0.32	-0.14	-2.80	-6.21	-0.75	-1.46	-0.27	-0.09	-0.02
Giridih	Test Z	-2.22	-1.20	-2.04	-1.07	0.58	-0.41	-2.74	0.36	-0.94	0.10	-1.88	-2.87
	Signific.	*		*				**				+	**
	Q	-0.26	-0.28	-0.16	-0.28	0.19	-0.55	-4.30	0.55	-1.34	0.13	-0.05	0.00
Godda	Test Z	-2.45	-2.99	-2.30	-3.04	-1.12	-1.22	-2.04	-0.10	-1.41	-0.65	-2.55	-3.28
	Signific.	*	**	*	**			*				*	**
	Q	-0.24	-0.30	-0.26	-0.56	-0.65	-1.23	-3.17	-0.21	-1.47	-0.46	-0.11	-0.02
Gumla	Test Z	-2.32	-1.81	-0.42	-0.98	1.72	-0.82	-3.71	-1.79	-0.56	1.47	-0.57	-1.99
	Signific.	*	+			+		***	+				*
	Q	-0.29	-0.32	-0.04	-0.18	0.35	-1.06	-5.42	-2.90	-0.66	0.83	-0.02	-0.01
Hazaribagh	Test Z	-1.59	-2.05	-2.41	-2.82	-0.77	-1.50	-3.20	-0.03	-0.64	0.38	-1.44	-2.82
	Signific.		*	*	**			**					**

District	Statistic	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
	Q	-0.25	-0.40	-0.25	-0.56	-0.24	-1.94	-4.87	-0.04	-1.11	0.33	-0.04	-0.02
Koderma	Test Z	-2.65	-3.48	-1.92	-2.62	-0.49	-0.64	-3.11	-0.16	-1.41	0.14	-3.18	-2.97
	Signific.	**	***	+	**			**				**	**
	Q	-0.39	-0.51	-0.18	-0.44	-0.17	-0.80	-4.34	-0.25	-1.75	0.12	-0.12	-0.01
Lohardaga	Test Z	-2.71	-2.02	-1.60	-2.02	0.91	-0.66	-4.28	-1.20	-0.22	0.80	-1.18	-2.59
	Signific.	**	*		*			***					**
	Q	-0.39	-0.37	-0.09	-0.31	0.30	-0.88	-5.41	-1.76	-0.47	0.47	-0.05	0.00
Pakur	Test Z	-1.40	-2.09	-1.62	-1.12	0.09	0.70	-0.58	1.82	0.09	0.37	-3.04	-4.12
	Signific.		*						+			**	***
	Q	-0.10	-0.28	-0.14	-0.21	0.10	0.93	-1.05	2.09	0.07	0.24	-0.19	-0.02
Palamu	Test Z	-2.80	-1.88	-1.69	-2.49	-1.20	-1.41	-3.90	-0.15	-0.92	0.00	-2.52	-2.92
	Signific.	**	+	+	*			***				*	**
	Q	-0.43	-0.34	-0.10	-0.32	-0.21	-1.99	-5.87	-0.24	-0.90	0.00	-0.06	-0.01
Ranchi	Test Z	-2.17	-1.12	-0.79	-2.16	0.48	-0.06	-3.20	-1.04	0.13	0.57	-0.92	-1.45
	Signific.	*			*			**					
	Q	-0.30	-0.30	-0.07	-0.48	0.16	-0.06	-4.10	-1.37	0.25	0.41	-0.08	0.00
Sahebganj	Test Z	-2.22	-1.81	-1.89	-2.72	-0.51	-0.96	-2.25	0.76	-0.48	1.13	-3.12	-3.82
	Signific.	*	+	+	**			*				**	***
	Q	-0.20	-0.23	-0.16	-0.73	-0.46	-1.54	-3.79	1.18	-0.84	1.10	-0.16	-0.02
W Singhbhum	Test Z	-1.33	-2.25	-1.11	-0.45	1.44	1.11	-1.85	-0.62	0.43	1.25	-2.24	-2.61
	Signific.		*					+				*	**
	Q	-0.12	-0.46	-0.14	-0.18	0.74	1.21	-3.21	-0.91	0.51	0.96	-0.16	0.00

*+, *, ** and *** implies Z statistic is significant at 10, 5, 1 and 0.1 % level of significance respectively*

Although large number of districts recorded significant decreasing trend, the quantitative decrease (mm/year) in the precipitation of the December, as indicated by Sen's slope, was very small. The Sen's slope estimates for July month time series of the Palamu and Gharwa districts was decreasing at relatively faster rate of -5.8 and -6.2 mm/year implying a substantial decrease of 232 and 248 mm precipitation, respectively, over the period 1975-2014. The variations in July precipitation for districts with most significant decreasing trends and the corresponding Sen's slope line (Ranchi, Dumka, Gharwa, Chhatra, Lohardaga and Gumla) during 1975–2014 illustrated in Fig. 3 depicts the pronounced variability and decreasing precipitation trend for July.

A synoptic view of the precipitation trends for the months from May to October over the districts of Jharkhand state are presented in Fig. 4. Although, increasing trend of monthly precipitation was observed for some months in some districts, this positive change was not statistically significant (Table 2). Considering the monsoon period, except July, no significant trend was recorded in the precipitation time series of June, August and September. Interestingly, October was the month which recorded positive, but non-significant, trends over all the districts of Jharkhand, followed by May which showed non-significant increasing trend in nine districts. Gumla, West Singhbhum, East Singhbum and Lohardaga districts showed rising trends for both the time series of May and October. This highlights the widening of precipitation distribution pattern over these districts. The temporal pattern of variations in the May and October precipitation of Gumla and West Singhbhum are illustrated in Fig. 5.

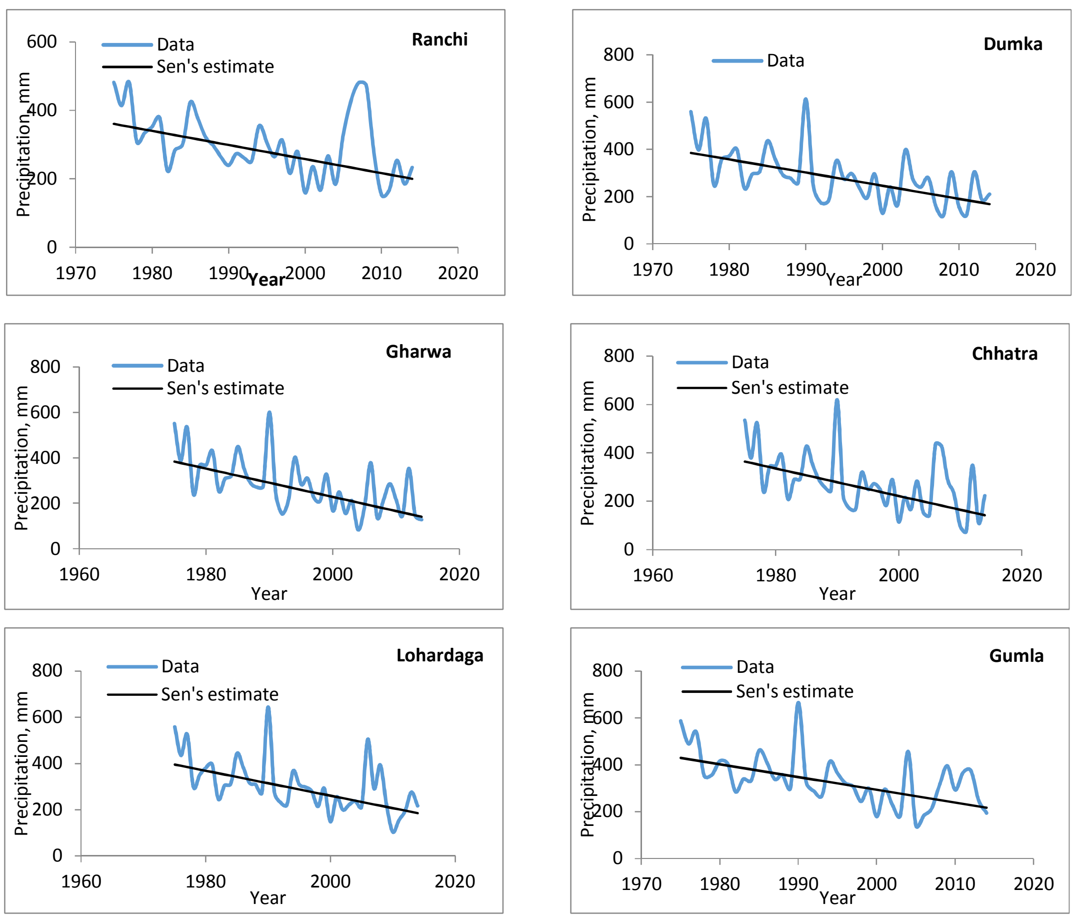

Fig. 3. Figure Variations of 'July precipitation' in districts with most significant decreasing trends during 1975–2014

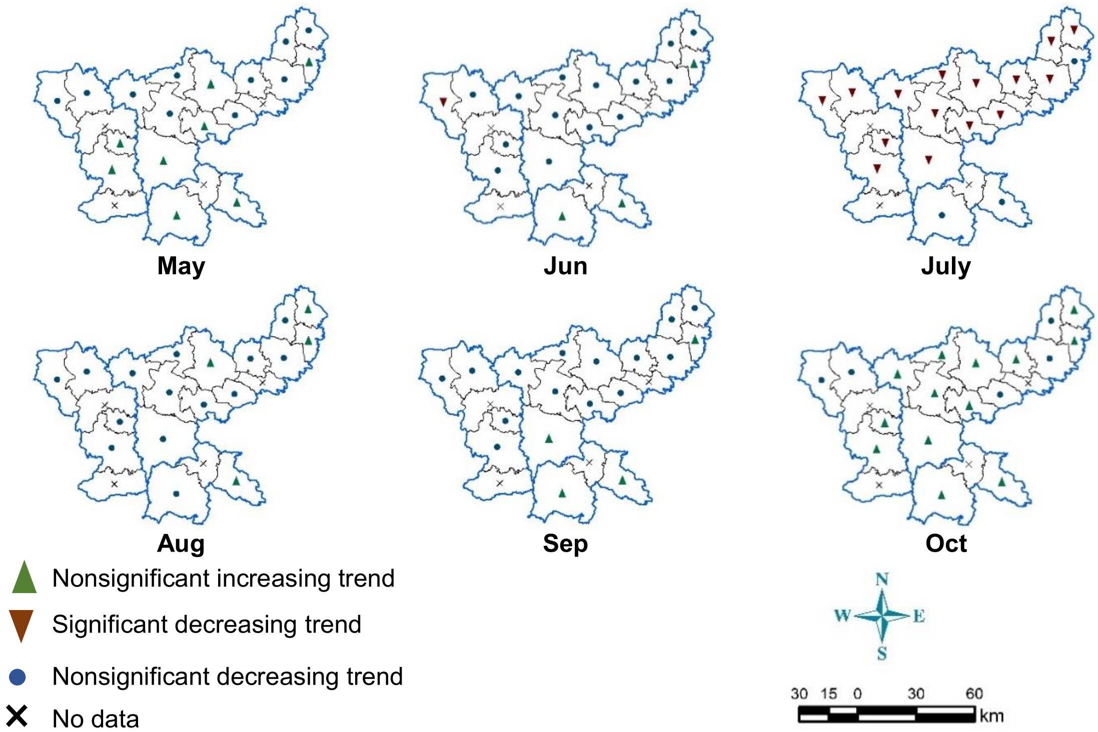

Fig. 4. Trends in monthly time series of precipitation for different districts of Jharkhand

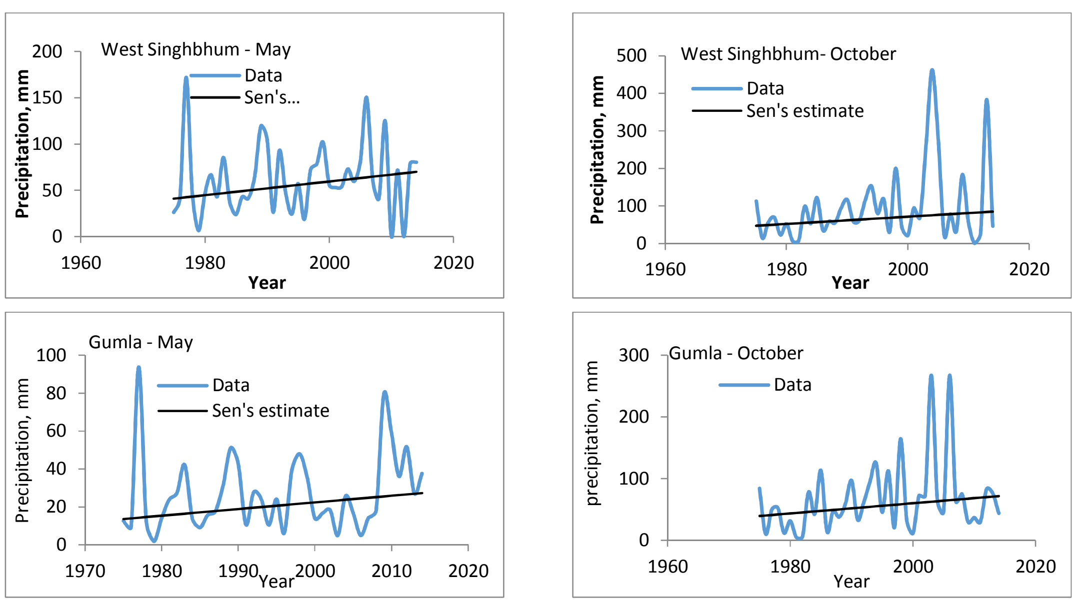

Fig. 5. Variations of monthly precipitation time series (May and October) in districts with increasing trends during 1975–2014

3.3 Seasonal and Annual Trends

A long-term annual and seasonal data series of precipitation for 40 years was studied to detect trends in Jharkhand. The magnitude of the trend in the time series was determined using the Sen's slope estimator. The Mann-Kendall statistics, its significance and estimate of Sen's slope are presented in Table 3. Seasonal time series of precipitation for pre-monsoon, monsoon and winter also showed decreasing trends over 15 districts of the Jharkhand over the period of

1975-2014. We found that the precipitation is stable in pre monsoon (Mar-Apr-May) and that it weakly decreased at range of -0.01 to -1.68 mm/year. Five districts depicted statistically significant decrease in precipitation during pre-monsoon season.

Table 3. Mann-Kendall test statistic (Z) and the Sen's slope (Q) results for the seasonal and annual precipitation time series

District	Statistic	*Pre Monsoon*	*Monsoon*	*Winter*	*Annual*
Bokaro	Test Z	-1.17	-1.69	-2.53	-2.20
	Signific.			*	*
	Q	-1.16	-5.82	-1.20	-5.31
Chattra	Test Z	-2.07	-2.78	-3.81	-3.11
	Signific.	*	**	***	**
	Q	-1.01	-9.89	-1.73	-12.20
Deoghar	Test Z	-1.42	-2.11	-2.61	-1.88
	Signific.		*	**	
	Q	-1.14	-6.30	-0.86	-6.06
Dhanbad	Test Z	-1.84	-2.09	-2.53	-1.48
	Signific.		*	*	
	Q	-1.68	-6.04	-1.20	-5.57
Dumka	Test Z	-2.89	-2.82	-1.49	-2.91
	Signific.	**	**		**
	Q	-1.11	-10.21	-0.78	-10.84
E Singhbhum	Test Z	-0.83	0.20	-0.71	0.73
	Signific.				
	Q	-0.62	1.23	-0.35	3.45
Gharwa	Test Z	-2.93	-4.23	-2.52	-4.30
	Signific.	**	***	*	***
	Q	-1.00	-12.97	-1.35	-15.85
Giridih	Test Z	-0.62	-1.76	-1.48	-0.97
	Signific.				
	Q	-0.32	-5.67	-0.76	-2.72
Godda	Test Z	-1.90	-2.25	-3.10	-1.78
	Signific.		*	**	
	Q	-1.37	-5.35	-0.76	-4.90
Gumla	Test Z	-0.40	-3.36	-2.38	-2.94
	Signific.		***	*	**
	Q	-0.22	-11.23	-0.86	-9.80
Hazaribagh	Test Z	-1.98	-2.67	-2.23	-2.41
	Signific.	*	**	*	*
	Q	-1.51	-9.08	-1.06	-9.38
Koderma	Test Z	-1.44	-2.48	-3.68	-2.69
	Signific.		*	***	**
	Q	-0.88	-8.39	-1.48	-9.53
Lohardaga	Test Z	-0.19	-2.71	-1.61	-2.11
	Signific.		**		*
	Q	-0.16	-10.19	-0.82	-7.95
Pakur	Test Z	0.00	0.44	-2.89	1.07
	Signific.			**	
	Q	-0.01	1.89	-0.79	3.15
Palamu	Test Z	-3.04	-3.20	-2.48	-3.23
	Signific.	**	**	*	**
	Q	-1.24	-10.83	-1.22	-12.92
Ranchi	Test Z	-1.01	-1.69	-1.92	-1.36
	Signific.				
	Q	-0.68	-6.27	-0.73	-4.73
Sahebganj	Test Z	-0.89	-1.29	-2.54	-0.27
	Signific.			*	
	Q	-0.65	-3.88	-0.85	-1.62
W Singhbhum	Test Z	0.22	-0.41	-1.78	0.31
	Signific.				
	Q	0.22	-2.14	-0.91	1.41

*+, *, ** and *** implies Z statistic is significant at 10, 5, 1 and 0.1 % level of significance, respectively*

Monsoon season, which is the main crop growing season of Jharkhand, also showed decreasing trend in 16 districts with 11 of them showing significant decreasing trend at 5% level of confidence. There was pronounced decrease in the monsoon precipitation in all the districts, except East Singhbhum and Pakur, with precipitation decreasing at a rate of -2.14 (West Singhbhum) to -12.97 (Gharwa) mm/year. Although the monthly time series of precipitation for October showed positive trend for many of the districts, the winter season (Oct-Nov-Dec-Jan) precipitation exhibited decreasing trend over all the 18 districts analyzed, with 12 of them showing statistically significant negative trend. The trend of precipitation in four districts with most significant decreasing trends in winter precipitation are illustrated in Fig. 6. Compared to monsoon season, the magnitude of change in pre-monsoon and winter seasons was quite small; as precipitation in these seasons is much smaller than in the monsoon season.

Annual precipitation in 15 districts showed decreasing trend with the trend in 9 of the districts being statistically significant. The districts of Gharwa and Palamu displayed the faster decrease rate of -15.85 and -12.92 mm/year in the precipitation. On annual basis the non-significant positive trends were detected for East Singhbhum, West Singhbhum and Pakur districts with the increase rate of 3.45, 3.15 and 1.41 mm/year. Variations of annual precipitation time series with corresponding Sen's slope lines in four districts with most significant negative trends during 1975–2014 are presented in Fig. 7. No significant change was observed in seasonal and annual precipitation in case of East Singhbhum, Giridih, Ranchi and West Singhbhum districts. A synoptic view of the trends in seasonal and annual precipitation of districts of Jharkhand are presented Fig. 8.

As stated earlier, agriculture in Jharkhand depends largely on precipitation. Particularly July precipitation is crucial for land preparation and nursery growing for the paddy. The State is a mono- cropped region with paddy as a main kharif season crop (June to November). Any delay or reduction in the July precipitation severely affects the paddy production from the state. The analysis showed that the annual precipitation in the district of Chaatra, dumka, Garwa and Palamu is decreasing at faster rate of -10.84 to -15.85 mm/year. If the decreasing trend of monsoon and winter season precipitation continues, the water availability for the Rabi season will reduce and the production of vegetable s and fruits may be adversely affected. After kharif season, a very small portion of net sown area (17%) is brought under Rabi crops. As per the estimates of Central Ground Water Board

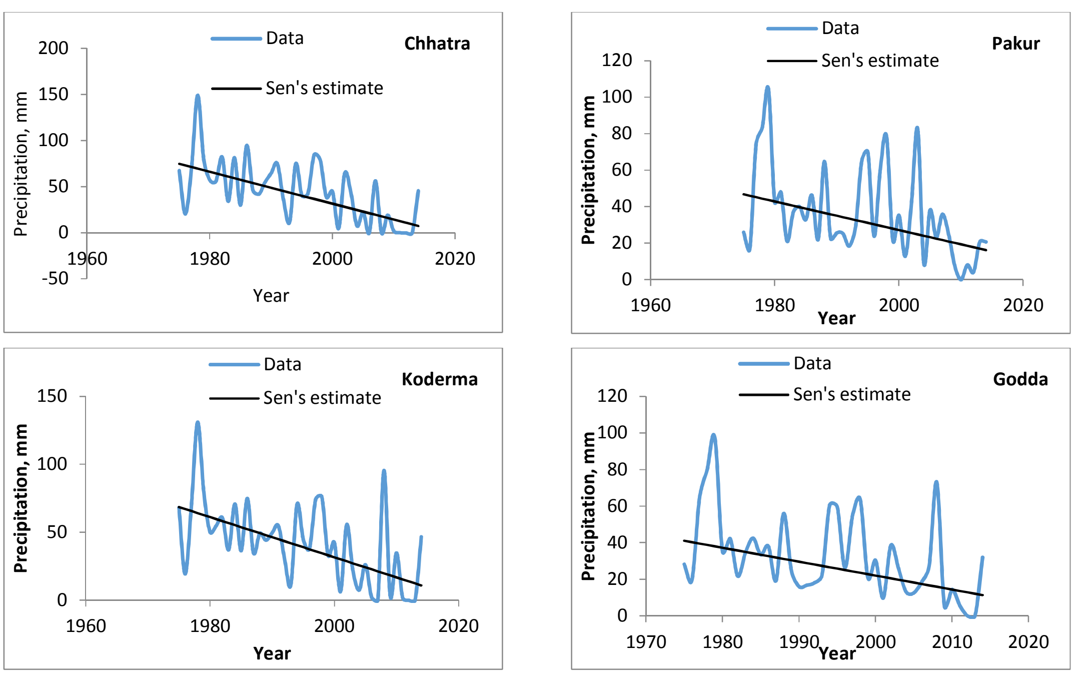

Fig. 6. Variations of 'winter precipitation' time series in districts with most significant negative trends during 1975–2014

(CGWB), total net annual ground water available in the state is, 5.25 BCM out of which, only 1.06 BCM (20%) is currently being utilized. The recurrent poverty does not allow the famers to opt for groundwater pumping infrastructure and the irrigated area in the state remains at 12.77% of the net sown area.

Given cognizance to the recent reports of climate change and its extreme variability, an understanding of temporal and spatial characteristics of rainfall is crucial to planning and management of water resources. This research highlighted the trends in the monthly, seasonal and annual trends in the precipitation over the districts of Jharkhand, an Indian state in the Eastern Plateau and Hill Region of the India. Large number of districts depicted the decreasing trend in the July rainfall. The region comprising of northern Jharkhand showed significant decreasing or decreasing trends in pre-monsoon, monsoon and winter season rainfall. Several factors can be responsible for this upsetting fact. Many researchers have showed the positive correlation between forest area and rainfall amount [40,41]. The increase in forest area induces the rising of rainfall and the reduction of temperature and evaporation [40]. In case of Jharkhand, uncontrolled mining has not only converted the forests in to wastelands, but also affected the wildlife and the livelihood of the tribal communities. According to the Union Ministry of Environment and Forests, between 1985-2004, more than 9,000 hectare of forest land had been diverted for mining in the state.

Worldwide, rainfall patterns are being moved in new directions by climate change [42]. Communities who live in marginal lands and whose livelihoods are highly dependent on optimality of rainfall are among the most vulnerable communities to climate change. The variability in rainfall trends can also be linked to the long term changes in other climatic parameters over the Eastern Plateau and Hill Region. Many indigenous and traditional peoples of the region are among those who are at greatest risk. Assessment Report of IPCC (2007) mentioned that greenhouse-gas emissions from human activity particularly from burning fossil fuels for energy are changing the Earth's climate [42]. Owing to its large scale thermal power production plants, Jharkhand is also among the largest states that contribute to greenhouse gas emissions. The main source of increasing carbon dioxide is burning of fossil fuels, especially coal, through thermal power plant. More than 7 million tonnes of carbon dioxide is emitted per year from

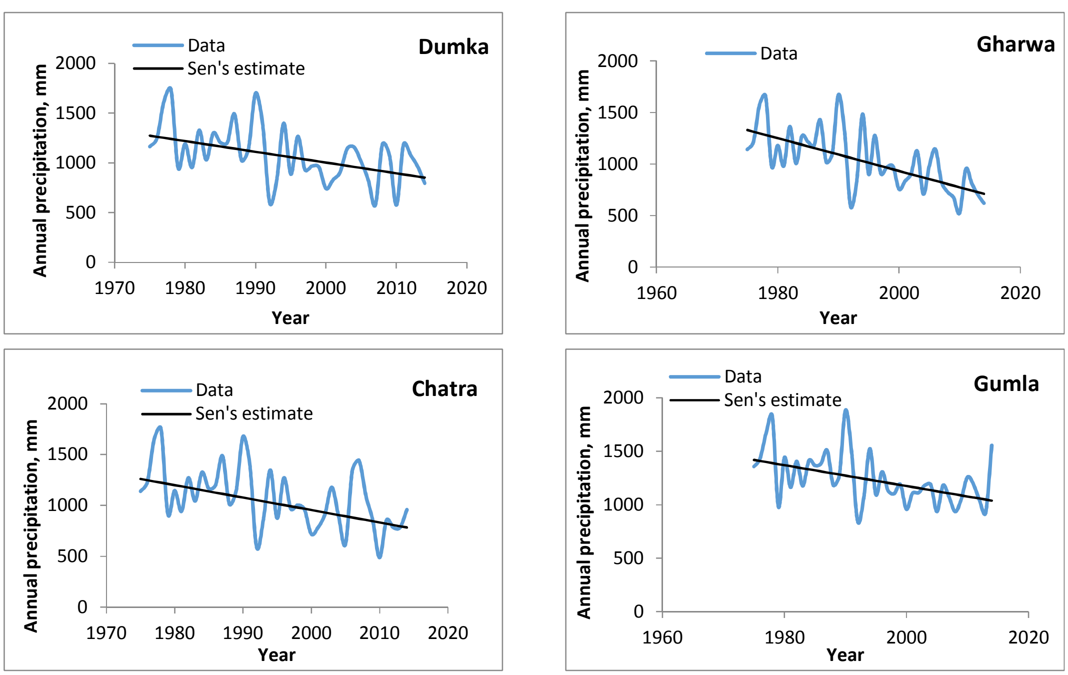

Fig. 7. Variations of 'annual precipitation' time series in districts with most significant negative trends during 1975–2014

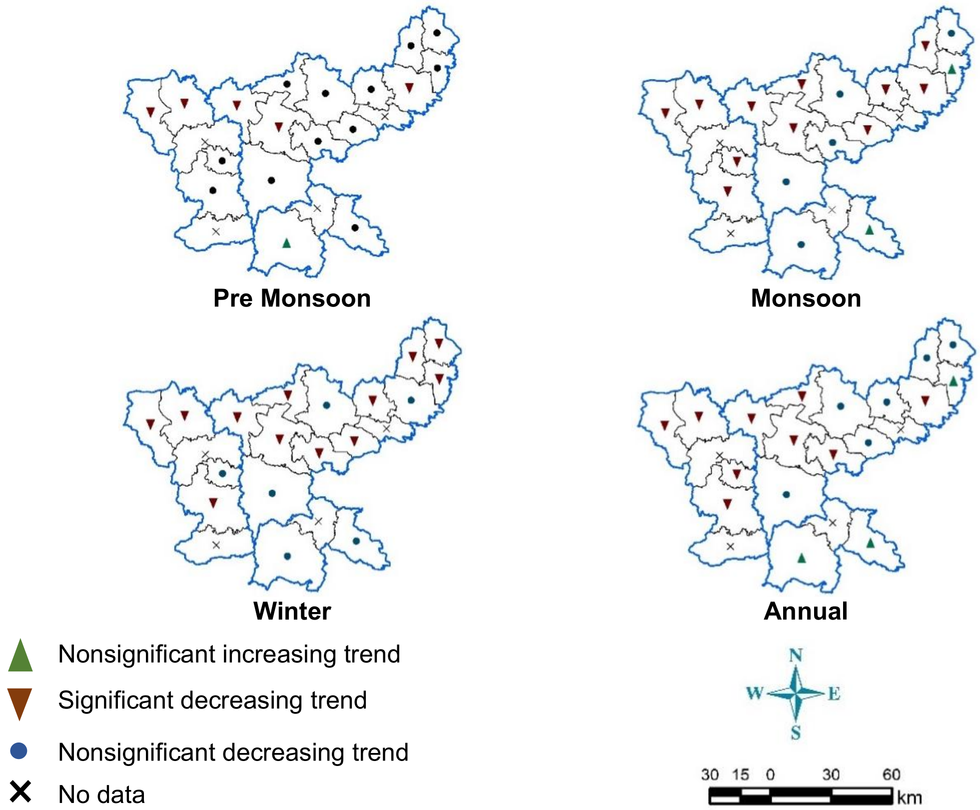

Fig. 8. Seasonal and annual trends in precipitation for different districts of Jharkhand

power plants in Jharkhand. This calls for effective implementation of National Solar Mission of government of India, which aims to promote the development and use of solar energy for power generation and other uses with the ultimate objective of making solar energy competitive with fossil based options.

In the events of abundant or scanty rainfall, agriculture is the first sector to be affected, because of its critical dependence on rainfall and stored soil water. A better alternative to mitigate the impacts of changing rainfall patterns (increasing or decreasing) is construction of small and medium dams in the Jharkhand. The undulating topography of the Jharkhand is more favorable for large scale construction of small and medium dams. In the events of reduced rainfall, the reservoirs of these dams will meet out the agricultural, domestic and industrial water demands, while in the event of heavy rainfall, they can attenuate the peak discharge from the rivulets, thereby reducing the adverse impacts of floods. Small water harvesting structures like *dobha* or check dams have limited scope in achieving these twin objective of water supply and flood moderation. Large scale demonstrations on efficient techniques like drip and sprinkler irrigation systems needs to be carried out to promote the wider adoption among the farming community. These efficient and water saving technologies can play a key role in climate proofing of the region and will help to overcome the whims of variable rainfall. The findings in this study stress that, given the precipitation dependence of agriculture and the decreasing trends in the precipitation in most of the districts, more number of irrigation schemes including lift irrigation and providing access to groundwater would be effective in damping-off of the effects of decreasing precipitation in future.

4. CONCLUSION

The present examined the trends of monthly, seasonal and annual precipitation in Jharkhand state located in the eastern plateau and hill region of India using Mann-Kendall test and Sen's slope for a precipitation time series (1975-2014) of 18 districts of the state. The results revealed there was a significant decreasing trend in the precipitation for most in the districts. The time series of May, June, August, September and October precipitation did not show statistically significant trend. However, the precipitation trends in other months showed significant decrease for some districts, with July showing the largest decline in precipitation over the study period. Seasonal analysis shows that in the pre-monsoon season, precipitation decreased over 5 river districts; in the monsoon season, precipitation decreased over 11 districts; in the winter season, precipitation decreased over 12 districts while on annual basis the significant decreasing trend was observed in 9 districts of the Jharkhand. The rate of decrease in winter season precipitation is slightly higher than the decrease rate observed for pre-monsoon precipitation. Furthermore, the results of the spatial distribution of the precipitation trends showed that annual precipitation trends were entirely negative at all the districts except for the districts located in the South-eastern regions of Jharkhand state. If the decreasing trends combined with large variability continues at the prevailing rates, this can severely affect the agriculture in the years to come. This necessitates immediate attention to irrigation and water resource planning with special focus on building irrigation infrastructure in the state to impart resilience against the precipitation deficits in future. Further research is required to analyze the impacts of decreasing precipitation trends on agriculture and ecosystems which can provide appropriate framework for policy makers and planners in helping them take proactive measures in the context of climate change.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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