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Spatiotemporal Trend Analysis of Rainfall Data in Bihar using Non-Parametrical Tools

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ABSTRACT

Rainfall is the most fundamental physical parameter which determine the environmental condition in a particular region. It is a vital role in determining the amount of water available to meet various demands such as agriculture, domestic water supply, industrial and hydrological power generation. Hence, this study aimed to investigated the annual and seasonal rainfall trend analysis at six districts of Bihar during the period from 1981 to 2020. To illustrate the methodology, non-parametric statistical approaches such as Mann-Kendall (MK) test, Sen's slope estimator and Innovative Trend Analysis (ITA) were performed to detect the rainfall trends. According to descriptive analysis of rainfall patterns, coefficient of variation (CV) indicated the moderate variation in annual and monsoon rainfall while in winter, pre-monsoon and post-monsoon rainfall showed higher variation at all six spatial horizons during 1981-2020. The results of the nonparametric tests exhibited statistically significant increasing trend in pre-monsoon rainfall except Rohtas district. During the annual, monsoon and post-monsoon rainfall, the most of the districts showed decreasing non-significant trends but some showed increasing non-significant trends. The magnitude of the significant increasing trends of rainfall varied maximum at Nalanda district (1.38 mm/year) to a minimum at Aurangabad district (0.854 mm/year). The ITA plots were also clearly visualized that the pre-monsoon rainfall exhibits increasing trend during last 40 years. In conclusion, the findings from this investigation may give a clear and useful information regarding annual and seasonal rainfall patterns in different spatial distributions especially in agro climatic zone-III of Bihar.

Keywords Trend analysis, Spatiotemporal, Rainfall, MK test, Sen's slope.

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INTRODUCTION

Global climate change and its influence on patterns of weather parameters viz., rainfall, temperature, relative humidity and wind speed is apparent, and a serious threat to the sustainability and stability of any sectors. The impact of climate change is directly in terms of extreme events such as flood, drought, water resources (hydrology) and crop production. Rainfall is the most fundamental physical parameter which determine the environmental condition of a particular region which plays a vital role in determining the amount of water available to meet various demands such as agriculture, domestic water supply, industrial, and hydrological power generation. In India, agriculture sector is highly rainfall dependent because of two-thirds of India's agriculture areas are under rain-fed condition. Therefore, too much or too little rain can have an injurious effect on agriculture growth and high spatial and temporal variability of rainfall can play a significant impact on economy of the country. A proper assessment of likely incidences of rainfall patterns would be helpful to the planners in the disaster adaptation and mitigation strategies. In eastern part of India, Bihar is a state where erratic nature of rainfall and dependence of farming on rain water are the major issues that affect farming to large extent. Recurrent drought or floods at different places are some of the key constraint often faced by the farmers (Shankar *et al*. 2009). Therefore, extensive study on climate change or, more particularly, on rainfall trend analysis is very much needed to a better decision-making and understanding of the rainfall trend in the changing environment. Several approaches are present in the literature for the assessment of the trends. Both Parametric and non-parametric statistical tests have been used to assess trends in hydro-metrological parameters in India (Duhan and Pandey 2013, Jain *et al*. 2013, Kumar *et al*. 2010). However, Mann-Kendall (MK) test and Sen slop estimator are most widely used (Dabanlı *et al*. 2016, Öztopal and Sen 2017, Tosunoglu and Kisi 2017). Hence, the present study has been planned for a systematic trend detection of the annual and seasonal (winter, pre-monsoon, monsoon and post-monsoon) rainfall at different spatial distributions of Bihar using Mann–Kendall trend test, Sen slop estimator and Innovative trend analysis (ITA) methods.

MATERIALS AND METHODS

Study area

Bihar state is situated at the eastern part of India and lies between latitude 24°-27° N and longitude 82°-88° E with a total geographical area of 94,163 sq km (ParthSarthi and Singh 2013). The climatic condition has subtropical to sub humid type with average annual rainfall of about 1235 mm, out of which 75% rainfall occurs during the south west monsoon period (June to September). Every year, the state has been experiencing flood and drought due to high spatial and temporal fluctuation of Indian Summer Monsoon Rainfall (ISMR). The plain of Bihar is categorized into three agro-climatic zones viz., Zone-I (North-West Alluvial Plains), Zone-II (North-East Alluvial Plains) and Zone-III (South Alluvial Plains). In this study, total six districts of agro climatic Zone-III (South Alluvial Plain) viz., Patna, Nalanda, Bhojpur, Rohtas, Jehanabad and Aurangabad have been considered which are represented in Fig. 1.

Source of data

Source of data used for the current study has been downloaded from NASA prediction of worldwide energy resources (https://power.larc.nasa.gov/data-access-viewer/). Gridded data sets (0.5^o latitude x 0.5^o longitude spatial resolution) of monthly rainfall (mm) from the period January, 1981 to December, 2020 has been recorded. Further, time series were segregated into five data sets viz. annual and seasonal as characterized by the India Meteorological Department (IMD) guidelines: Annual, winter (Dec–Feb), pre-monsoon (Mar–May), monsoon (Jun-Sept), and post-monsoon (Oct-Nov).

Trend analysis

Statically, a trend can be defined as a significant +/- changes in a random variable over time and estimated by using statistical parametric and non-parametric tests. In this study, non-parametric statistical methods have been employed to trends analysis of rainfall parameter. There are three statistical techniques such as Mann-Kendall (MK) test, Sen slop estimator, and Innovative trend analysis (ITA) have been used and whole procedures were carried out and run the analysis on R programming.

Mann-Kendall (MK) test

Mann Kendall test (Mann 1945) has been used for

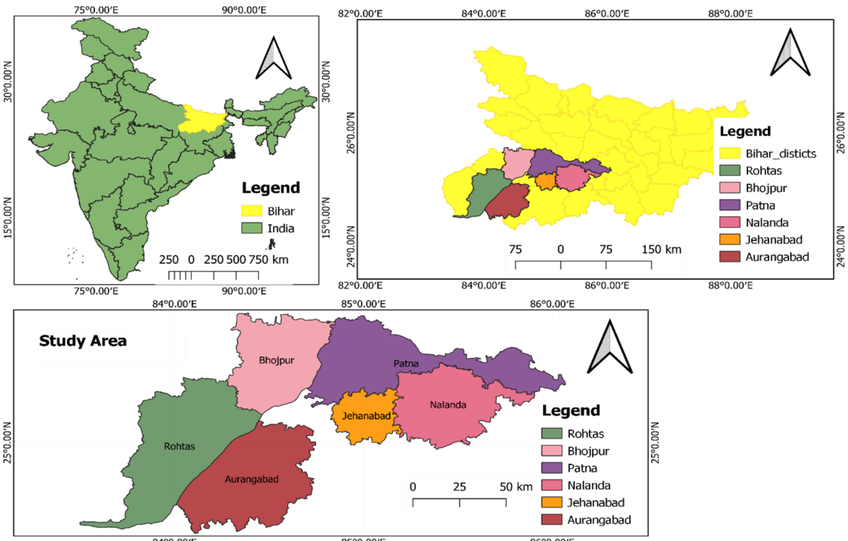


Fig. 1. Study area of agro climatic Zone-III, Bihar, India.

the identifying trends in the spatiotemporal data. It is a statistical non-parametric test widely used in trend analysis for climatological studies. The advantage of non-parametric test over parametric test, it does not require the data to be normally distributed. The MK test statistics (S) for rainfall can be computed as follows.

Null hypothesis (H_0): Three is no trend

Alternative hypothesis (H_1): Three is presence of trend

The Mann-Kendall test statistic (S):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(X_j - X_k), \qquad (1)$$

where n is the number of the data points, X_j is the observed value at time j and X_k is the observed value at time K. The value of $\operatorname{sgn}(X_j - X_k)$ is computed as follow:

$$\operatorname{sgn}(X_j - X_k) = \begin{cases} +1, & (X_j - X_k) > 0 \\ 0, & (X_j - X_k) = 0 \\ -1, & (X_j - X_k) < 0 \end{cases} \qquad (2)$$

For large samples (n >10), the test is conducted using a normal approximation (Z statistics) with the mean and the variance as follows:

$$E(S) = 0, \qquad (3)$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)\right], \qquad (4)$$

where q is the number of tied (zero difference between compared values) groups and t_p is the number of data values in the p^{th} group .Test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{Var(S)} & \text{if } S>0 \\ 0 & \text{if } S=0 \\ \frac{S+1}{Var(S)} & \text{if } S<0 \end{cases} \qquad (5)$$

A statistically significant trend is evaluated using the Z value which positive value of Z indicates an increasing trend and its negative value a decreasing trend. Null hypothesis (H_0) is tested at 5% level of significance ($Z_{0.05}$=1.96).

Sen's slope estimator

To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method has been used. The Sen's method (Sen,1968) can be used in cases where the trend can be assumed to be linear.

$$Q = \text{Median}\left(\frac{X_j - X_k}{j-k}\right) \qquad (6)$$

Table 1. Descriptive statistical trend analysis of rainfall data.

Season	Aurangabad Mean (mm)	Aurangabad Standard deviation	Aurangabad CV (%)	Bhojpur Mean (mm)	Bhojpur Standard deviation	Bhojpur CV (%)
Annual	1037.56	187.40	18.06	997.04	199.08	19.97
Winter	35.65	26.97	75.67	31.76	23.94	75.38
Pre-monsoon	57.25	29.19	50.99	56.37	32.02	56.81
Monsoon	888.83	181.56	20.43	858.48	194.33	22.64
Post-monsoon	55.84	46.75	83.73	50.44	43.52	86.29

where X_j is the observed value at time j and X_k is the observed value at time K. Q is a magnitude of trend estimate. Sen's slope indicates an increasing trend for positive value and a decreasing trend for negative value in the time series data.

Innovative trend analysis (ITA)

The concept of Innovative trend analysis (ITA) was firstly proposed by Sen (2011) for the detection of trends in time series data. In this approach, the observed values of time series are equally divided into two parts and both the sub-series are arranged in ascending order and presented on the X and Y-axis. If the time series data are fall on the 1:1 (45◦) line that means no trend. Further, the time series data that fall in the upper triangular 1:1 line portrays an increasing trend, while the time series data that fall in the lower triangular 1:1 line indicated a decreasing trend. The Innovative Trend Analysis method can be expressed as follow:

$$T = \frac{1}{n} \sum_{i=1}^{n} \frac{10(\bar{Y}-\bar{X})}{n} \qquad (7)$$

where T is the indicator of trend having the positive values that represent the increasing trend, while the negative values represent the decreasing trend. Y^{-} and $X^{-}$are the mean of the first sub-series and second sub-series respectively. Furthermore, n is the collected data products.

RESULTS AND DISCUSSION

Rainfall variability

Rainfall variability pattern over 1981 to 2020 at six districts of agro-climatic zone-III of Bihar using mean, standard deviation and coefficient of variation (CV) have been computed which are represented in Tables 1 to 3. The coefficient of variation (CV) indicated that the inter-annual variability of post-monsoon (76.83 to 86.29%) was higher than that of other seasons rainfall while lowest variability was observed in annual (16.99 to 19.97%) rainfall. At spatial horizons, the higher variability of rainfall was observed at Bhojupr and Jehanabad districts. The average annual (1042.51 mm), winter (36.15 mm) and monsoon (888.83 mm) rainfall were observed higher at Patna, Rohtas and Aurangabad districts, respectively. During average pre-monsoon (68.07 mm) and post-monsoon (59.58 mm) rainfall were observed higher at Patna district. Overall, the rainfall variability was higher in winter, pre-monsoon and post-monsoon while

Table 2. Descriptive statistical trend analysis of rainfall data.

Season	Jehanabad Mean (mm)	Jehanabad Standard deviation	Jehanabad CV (%)	Nalanda Mean (mm)	Nalanda Standard deviation	Nalanda CV (%)
Annual	1002.88	200.25	19.97	1003.82	191.51	19.08
Winter	31.16	23.33	74.86	30.10	21.73	72.18
Pre-monsoon	59.28	33.60	56.68	64.61	35.83	55.45
Monsoon	860.69	195.98	22.77	855.99	188.45	22.02
Post-monsoon	51.76	43.46	83.98	53.12	42.37	79.77

Table 3. Descriptive statistical trend analysis of rainfall data.

	Patna			Rohtas		
Season	Mean (mm)	Standard deviation	CV (%)	Mean (mm)	Standard deviation	CV (%)
Annual	1042.51	177.15	16.99	1022.04	184.22	18.02
Winter	33.87	24.03	70.97	36.15	27.24	75.35
Pre-monsoon	68.07	32.51	47.75	53.28	27.39	51.41
Monsoon	880.99	173.67	19.71	878.88	177.02	20.14
Post-monsoon	59.58	45.77	76.83	53.73	44.88	83.53

the rainfall variability was moderate in annual and monsoon rainfall at all six districts.

Non-parametric trend analysis

In this section, non-parametric methods have been applied for rainfall trends analysis at different locations of Bihar. The results of the Mann–Kendall test and Sen's slope estimate reported in Tables 4 and 5. Positive and negative values indicated the increasing and decreasing trends respectively. The results of ITA plots for pre-monsoon rainfall are represented in Figs. 2 - 4. The data points falling in the upper triangle indicates increasing trend, and falling in the lower indicates decreasing trend.

The results of the Mann–Kendall test with Sen's slope estimator at the spatial distribution of temporal trends of pre-monsoon rainfall showed statistically significant increasing trends excepts Rohtas district, while in annual, monsoon and post-monsoon rainfall showed non-significant mixed increasing and decreasing trends during 1981-2020. Similarly, in winter rainfall was also observed non-significant trend but showed decreasing trends at all six districts. The magnitude of the significant increasing trends of rainfall was observed the highest in pre-monsoon season at Nalanda district (1.38 mm/year) and the lowest at Aurangabad district (0.854 mm/year). In the case of annual, winter and monsoon rainfall the magnitude of the Sen's slope estimate was observed the highest at Aurangabad district with the changes rate of 1.387 mm/year, -0.362 mm/year and 1.383 mm/year, respectively. Similarly, in post-monsoon rainfall, the rate of change was observed the highest increasing rate at Nalanda district (0.167 mm/year) and the lowest at Rohats district (-0.177 mm/year). From Figs. 2 - 4, it can be visualized that the pre-monsoon rainfall for all six districts exhibits increasing trends during 1981-2020. Therefore, based on the above trends analysis, it can conclude that Bihar is vulnerable to rainfall variability due to impact of climate change. The significant increasing trends of pre-monsoon rainfall may help in early *kharif* crops cultivation and reduce the requirements of irrigation. The annual, monsoon and post-monsoon periods clearly showed non-significant mixed trend which may create difficulties in the agriculture sectors,

Table 4. Non-parametric statistical trend analysis of rainfall data. NS and * indicates the non-significant and significant at 5% respectively.

	Non-parametric tests					
	Aurangabad		Bhojpur		Jehanabad	
Season	MK test (Z value)	Sen's slope estimate	MK test (Z value)	Sen's slope estimate	MK test (Z value)	Sen's slope estimate
Annual	0.338NS	1.387	-0.291NS	-1.078	-0.175NS	-0.945
Winter	-0.967NS	-0.362	-0.990NS	-0.321	-0.920NS	-0.315
Pre-monsoon	2.108*	0.854	2.272*	0.933	2.412*	1.128
Monsoon	0.454NS	1.383	-0.618NS	-1.210	-0.548NS	-0.984
Post-monsoon	-0.128NS	-0.071	-0.175NS	-0.080	0.105NS	0.059

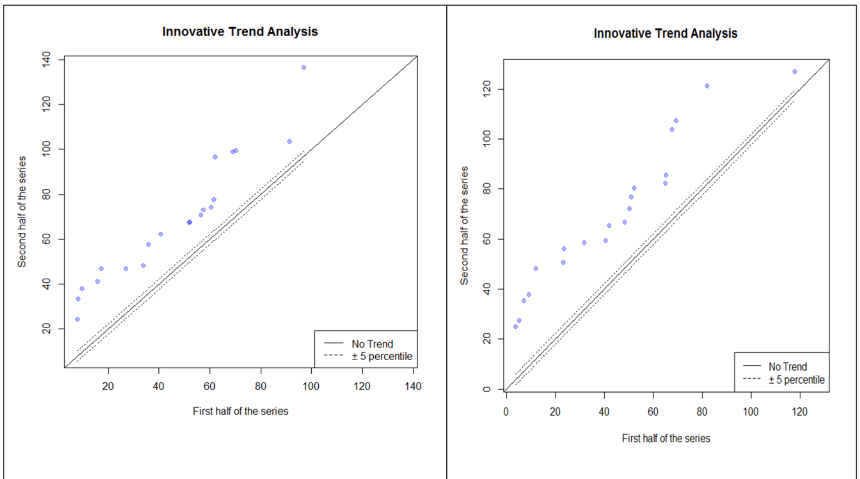
Table 5. Non-parametric statistical trend analysis of rainfall data.

	Non-parametric tests					
	Nalanda		Patna		Rohtas	
Season	MK test (Z value)	Sen's slope estimate	MK test (Z value)	Sen's slope estimate	MK test (Z value)	Sen's slope estimate
Annual	0.105NS	0.207	0.408NS	1.195	0.524NS	1.329
Winter	-1.084NS	-0.315	-1.177NS	-0.418	-0.955NS	-0.326
Pre-monsoon	2.808*	1.385	2.7846*	1.272	1.736NS	1.679
Monsoon	-0.361NS	-0.530	0.000NS	-0.022	0.384NS	0.636
Post-monsoon	0.361NS	0.167	0.571NS	0.222	-0.408NS	-0.177

industrial and domestic water supply.

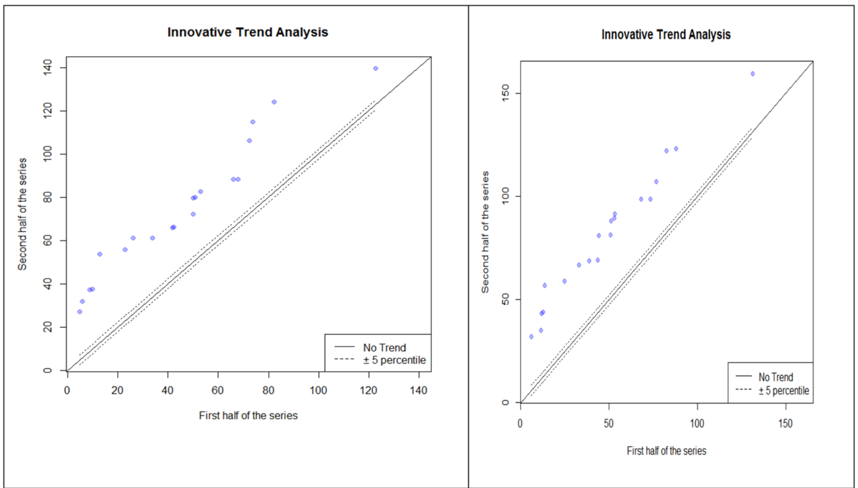
CONCLUSION

In this study, non-parametric approaches MK test, Sen's slope estimator and Innovative trend analysis have been used to trends analysis of annual and seasonal (winter, pre-monsoon, monsoon and post-monsoon) rainfall at six districts of agro-climatic zone-III, Bihar. Total 40 years of monthly rainfall data has been recorded for trends analysis. The descriptive distributions of rainfall were showed the moderated variation in annual and monsoon rainfall while in winter, pre-monsoon and post-monsoon rainfall were showed higher variation in all six spatial horizons. The results of the Mann-Kendall test with Sen's slope estimator and ITA showed the significant increasing trends in pre-monsoon rainfall excepts Rohtas district, while in annual, monsoon and post-monsoon rainfall were showed the non-significant mixed increasing and decreasing trends. In case of winter rainfall, non-significant decreasing trends were observed at all six districts. The magnitude of the significant increasing trends of rainfall varied maximum at Nalanda (1.38 mm/year) to a minimum at Aurangabad (0.854 mm/year). During annual, winter and monsoon rainfall, the magnitude of the Sen's slope estimates were observed the highest at Aurangabad district with the changes



Results of ITA for pre-monsoon rainfall at Aurangabad district	Results of ITA for pre-monsoon rainfall at Bhojpur district

Fig. 2. ITA trend plots of rainfall data during 1981-2020.



Results of ITA for pre-monsoon rainfall at Jehanabad district	Results of ITA for pre-monsoon rainfall at Nalanda district

Fig. 3. ITA trend plots of rainfall data during 1981-2020.

rate of 1.387 mm/year, -0.362 mm/year and 1.383 mm/year, respectively. Overall, in conclusion, the findings from this investigation may give a clear and useful information regarding the annual and seasonal rainfall patterns in different spatial horizons of Bihar. The significant increasing trend of pre-monsoon rainfall may helpful in early *kharif* crops cultivation, reduce the requirements of irrigation digester management and decision makers for agricultural sectors.

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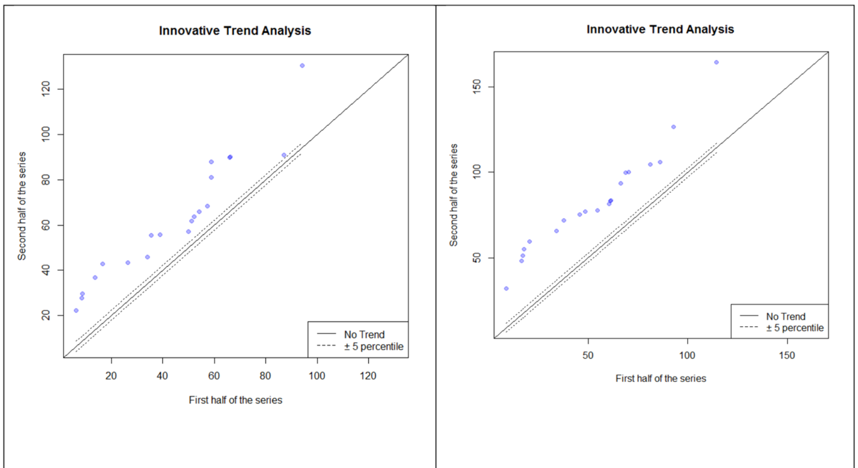

Results of ITA for pre-monsoon rainfall at Rohtas district	Results of ITA for pre-monsoon rainfall at Patna district

Fig. 4. ITA trend plots of rainfall data during 1981-2020.

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