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District wise spatiotemporal analysis of precipitation trend during 1900-2022 in Bihar state, India

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सार – किसी क्षेत्र में वर्षा जल संसाधन की उपलब्धता निर्धारित करने में महत्वपूर्ण भूमिका निभाती है जबकि वर्षा के स्थानिक-कालिक वितरण का अध्ययन सूखा, बाढ़ आदि जैसे वर्षा से जुड़े जोखिमों के प्रबंधन में मदद करता है। यह अध्ययन बिहार, भारत में 1900-2022 की अवधि के लिए बिहार के जिलेवार वर्षा डेटा का उपयोग करके किया गया है। अध्ययन के प्रमुख निष्कर्ष बताते हैं कि बेगूसराय और जहानाबाद जिलों को छोड़कर मॉनसून ऋतु और वार्षिक वर्षा का CV और SD मध्यम श्रेणी में हैं; हालाँकि, मॉनसून पूर्व, सर्दियों और मॉनसून के बाद की ऋतु के लिए CV सभी जिलों के लिए उच्च थे। वर्षा की बढ़ती प्रवृत्ति विश्लेषण से कुछ जिलों को छोड़कर या तो कोई प्रवृत्ति नहीं या नकारात्मक प्रवृत्ति का संकेत मिलता है, और हाल के वर्षों में लगभग सभी जिलों में नकारात्मक प्रवृत्ति देखी गई है। वर्षा में एकरूपता को समझने के लिए, मान-केंडल परीक्षण के माध्यम से वर्षा सांद्रता सूचकांक (PCI) और इसके प्रवृत्ति विश्लेषण किया गया। पीसीआई विश्लेषण से पता चलता है कि वार्षिक वर्षा अनियमित रूप से वितरित होती है और मॉनसून वर्षा समान रूप से वितरित होती है। वार्षिक वर्षा में उच्च असमानता मानसून के बाद के PCI योगदान के कारण है। बिहार के दक्षिणी, सुदूर उत्तरी और मध्य भागों में पीसीआई प्रवृत्ति सकारात्मक पाई गई, जबकि बिहार के सुदूर पश्चिमी जिलों जैसे औरंगाबाद, भोजपुर, बक्सर, रोहतास और सुदूर पूर्वी जिलों जैसे पूर्णिया, कटिहार, अररिया और सुपौल में नकारात्मक प्रवृत्ति पाई गई।

ABSTRACT. Precipitation over a region plays vital role in determining availability of water resource whereas study of spatiotemporal distribution of rainfall helps in managing precipitation associated risks like drought, flood *etc*. The present study is carried out in the state of Bihar, India using District-wise rainfall data of Bihar for period 1900-2022. Major findings of study indicate that CV and SD of monsoon season and annual rainfall are in a moderate range except for districts Begusarai and Jahanabad; however, CVs for pre-monsoon, winter and post-monsoon seasons were high for all the districts. Innovative trend analysis of the rainfall indicates either no trend or a negative trend except in few districts, and in recent years the negative trend is observed in almost all the districts. To understand homogeneity in rainfall, the precipitation concentration index (PCI) and its trend analysis performed through Mann-Kendall test. PCI analysis indicates irregularly distributed annual and uniformly distributed monsoon rainfall. High inhomogeneity in annual rainfall is due to the post-monsoon PCI contribution. PCI trend was found positive in the southern, extreme northern, and central parts of Bihar, whereas extreme west districts of Bihar like Aurangabad, Bhojpur, Buxar, Rohtas and extreme eastern districts like Purnia, Katihar, Araria and Supaul had negative trend.

Key words - Rainfall, Precipitation concentration index, Innovative trend analysis, Mann kendall test.

1. Introduction

The observed rainfall pattern changes and their consequence on water resource availability are one of the most important climate change associated problems of the era. Due to these observed changes and their impact on alterations in the hydrological cycle, various research has been carried out on spatiotemporal changes in rainfall and the subsequent outcomes on the management of water resources for irrigation in agriculture, flood, or drought management in recent times (Gu *et al*., 2017; Mall *et al*., 2019). This change pattern study is carried out by various researchers in the world (De Luis *et al*., 2000; Hulme *et al*., 1998; Chaubey *et al*., 2022) and finding of these studies indicates an increase in the contribution of extreme events to accumulated precipitation (Alexander *et al*., 2006; Haider *et al*., 2020; Min *et al*., 2011; Tabari, 2020). Climate change and global warming impacts on the intensity and duration of precipitation; these impacts are evident in the form of long-dry spell, extreme event with high precipitation intensity causing floods or less precipitation leading to droughts (Ford & Labosier, 2017; Zaman *et al*., 2020; Chaubey & Mall, 2023).

Finding of the studies carried out on India's precipitation distribution also showed variability in the rainfall on different temporal and spatial scales (Kripalani *et al*., 2003; Sahai *et al*., 2003; Mall *et al*., 2006), high variability in rainfall distribution over space has been indicated. Regions like Western Ghats, Sub-Himalayan areas in North East receive annual rainfall more than 200 cm. and regions like northern part of Kashmir, West Rajasthan and Punjab receives annual rainfall less than 50 cm. An increasing trend in the frequency of extreme precipitation was observed in the central part of India by Goswami *et al*. (2006). According to Krishnamurthy *et al*. (2009) statistically significant increasing trends is observed for extremes over many parts of India whereas decreasing trends has been observed in some parts of India only. These extreme events show the percentage contribution of rainfall in annual and seasonal rainfall in few days only. Changing rainfall concentrations may cause floods and droughts like situation and further leads to pressure on water resources **(**Zhang *et al*., 2009). Oliver in 1980 introduces the concept of Precipitation Concentration Index (PCI) to study the rainfall concentration and this index was further used to characterize homogeneity in monthly, seasonal and annual rainfall by many researchers (De Luis *et al*., 2011 & 2010; Apaydin *et al*., 2006; Michiels *et al*., 1992), There are number of studies carried out on the evaluation of PCI across the world like Spain and China *etc*. by De Luis *et al*. (2011), Xuemei *et al*. (2011), Adegun *et al*. (2012), Iskander *et al*. (2014), Benhamrouche *et al*. (2015), Gocic *et al*. (2016), Al-Shamarti (2016) and Nery *et al*. (2017). However, only a few studies on PCI are available in India, regional level studies are available by Patel and Shete (2015) and Valli *et al*. (2013) in north Gujarat and Andhra Pradesh, respectively.

In the present study, spatiotemporal rainfall concentration distribution is studied for Bihar state in India using district-wise monthly rainfall data from 1901-2022. To study the long-term changes in seasonal and annual rainfall, trends in the PCI have been analysed using Mann-Kendall test.

2. Study area, dataset used and methodology

2.1. *Study area*

Bihar is situated in the eastern part of the country. Topographically, the state is divided into sub-Himalayan foothills, Indo-Gangetic plains, and the southern plateau zone. The annual mean rainfall of Bihar is 1098.9 mm; however, the monsoon rainfall mean is 938.7 mm, with coefficients of variation of 18.2 and 19.3, respectively. (Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/04(2020)/28). The southwest monsoon season contributes 86% of the rainfall in the state during South West monsoon season (June to September), about 2% rainfall received in the winter season (December, January, and February), about 6% in the pre-monsoon season (March-May), only 6% in the post-monsoon season (October and November).

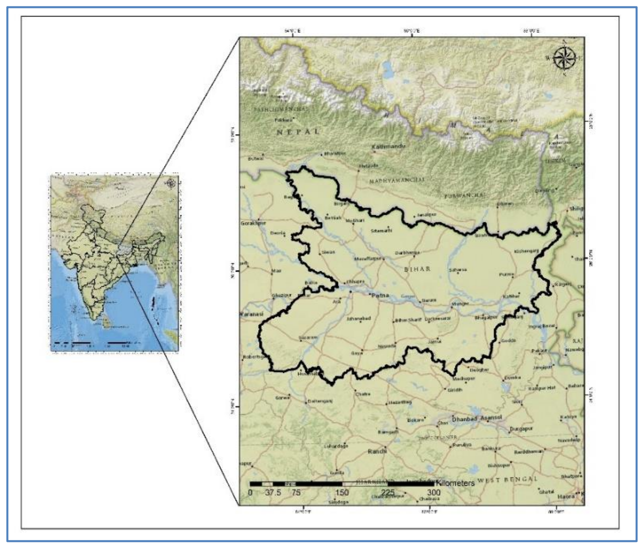


Fig. 1. Study Area Bihar, India.

2.2. *Dataset used and methodology*

To study the spatiotemporal variability of rainfall, a monthly rainfall data for all districts of Bihar state for the period 1901-2022 was used (Source: India Meteorological Department).

According to the study made by Alsubih *et al*. (2021) the temporal dynamics of rainfall makes variation of rainfall in its intensity, frequency, pattern and distribution over an area. There are various methods to check the temporal variability of rainfall over an area, which include the standard deviation, coefficient of variation (CV), precipitation concentration index, *etc*. where coefficient of variation (CV) evaluates the seasonal and annual rainfall dynamics of long-period rainfall (Belay *et al*., 2021) and the extent of rainfall dynamics is classified as high (CV >

30), moderate (20 < CV < 30) and low (CV < 20) Hare (2003). Hence, higher the value of CV higher the dynamics of rainfall in the study area and vice versa. The precipitation concentration index (PCI) evaluates the rainfall seasonal and annual distribution over time. In the present study, the monthly, seasonal and annual averages, standard deviation, and coefficient of variance of the monthly rainfall are calculated using R software.

The seasonal and annual precipitation concentration index was calculated for each district to understand the heterogeneity in seasonal and annual precipitation. Using meteorological standards, the year has been divided into four seasons, *viz*., winter (January to February), pre-monsoon (March to May), monsoon (June to September), and post-monsoon (October to December), and further PCI was calculated using the following equations proposed by Oliver (1980):

$$PCI_{Annual} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100$$

$$PCI_{Winter} = \frac{\sum_{i=1}^{2} p_i^2}{\left(\sum_{i=1}^{2} p_i\right)^2} \times 16.67$$

$$PCI_{Pre-monsoon} = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p_i\right)^2} \times 25$$

$$PCI_{Monsoon} = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p_i\right)^2} \times 33.33$$

$$PCI_{Post-monsoon} = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p_i\right)^2} \times 25$$

where p_i is the monthly precipitation in i^{th} month and 100, 16.67, 25, 33.33 is percentage of season duration in annual.

According to Oliver (1980),

(*i*) PCI ≤ 10: Uniform distributed precipitation

(*ii*) 11 ≤ PCI ≤ 15: Moderate distributed precipitation

(*iii*) 16 ≤ PCI ≤ 20: Irregular distributed precipitation

(*iv*) PCI ≥ 20: Strongly Irregular distributed precipitation

Trend Analysis

Mann Kendall Test: The trend which is significant change in climatic data over time is primarily studied by parametric and non-parametric test. In this study statistical significance trend analysis of Precipitation Concentration Index was carried out by Man-Kendall test in The RStudio program.

The Mann-Kendall's (MK) test is a statistical nonparametric test widely used for trend analysis in hydrometeorological time series data (Panda & Sahu, 2019). The trend analysis is proposed by Mann, (1945). The Non parametric Mann Kendall Test does not require the data to be normally distributed also it has less sensitivity towards inhomogeneous time series data. In MK test, the null hypothesis Ho assumes that there is no trend (the data is independent and randomly ordered). The null hypothesis is tested against the alternative hypothesis H1, which assumes that there is a trend. The MK statistic is computed as follows:

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

where, x_j and x_i are annual or seasonal values in years j and i respectively, n is the number of data points, and $sgn(x_j-x_i)$ is calculated as follows:

$$sgn(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases}$$

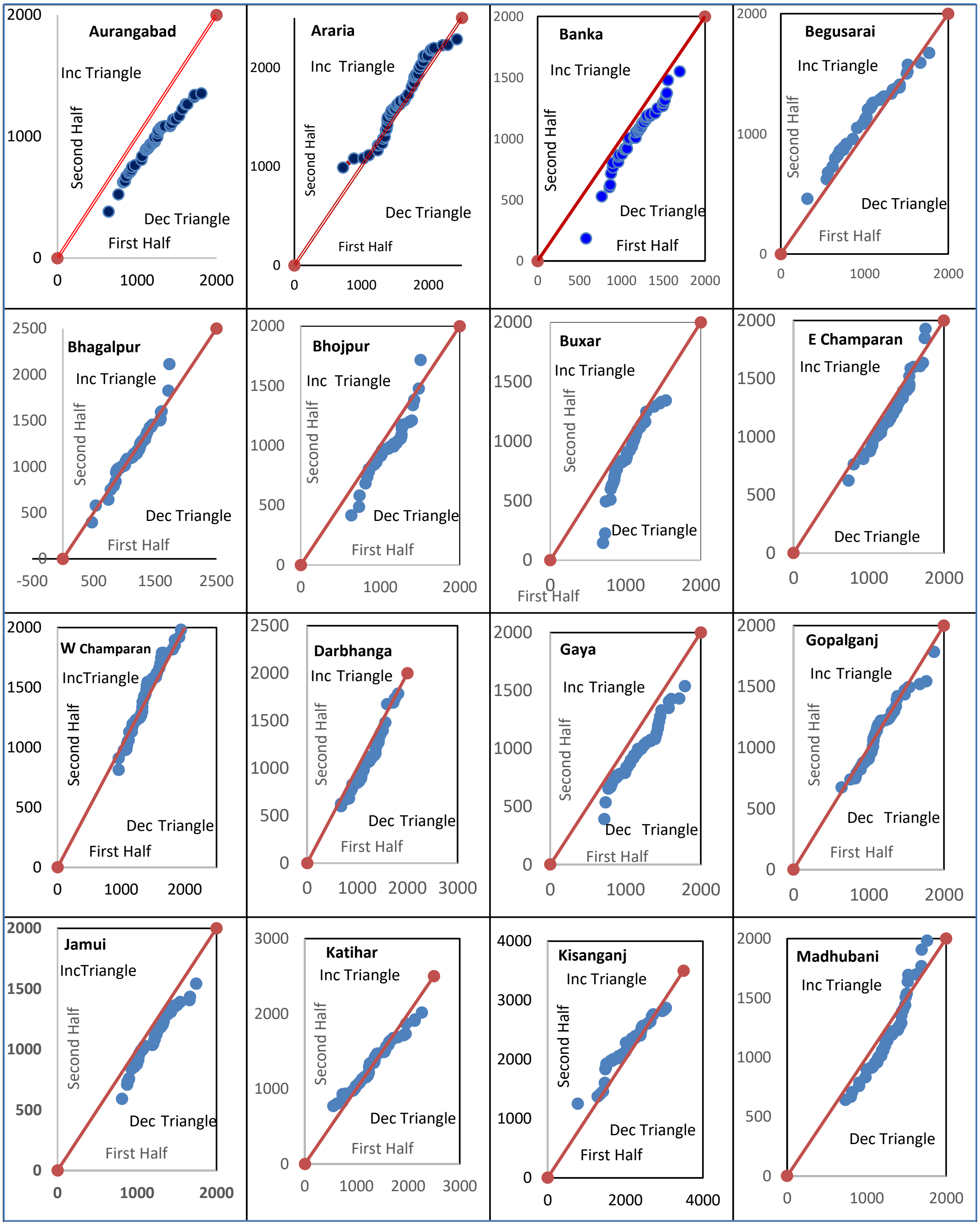
A positive or negative value of S indicates an upward (increasing) or downward (decreasing) trend respectively.

Innovative Trend Analysis (ITA): Trend analysis of hydrological parameters like rainfall using non-parametric tests like the Mann-Kendall (MK) test, Spearman's Rho (SR) test, regression analysis and wavelet analysis are all frequently suggested as classic mathematical methods (Malik *et al*., 2020; Ivanovski *et al*., 2021). To analyze the trend in long-term annual rainfall Innovative Trend Analysis (ITA), introduced by Şen (2012). ITA is carried out in various studies across the world (Gumus *et al*., 2022), in the ITA method the long period data is divided into two halves and independently arranged in ascending order. The first half is plotted on the x-axis of the cartesian coordinate system and the second half on the y-axis, where the vertical and horizontal axes should be the same range of duration. The time series is declared trendless if the data points lie on a 1:1 straight line in the scatterplot whereas time series depicts a positive or negative trend if the data points are spread above or below a straight line (Şen, 2012). The average difference between Xi and Xj, obtained from the horizontal or vertical distance from a 1:1 straight line, represents the magnitude of the increasing or decreasing trend at each data point.

TABLE 1

Statistical feature of District wise rainfall of Bihar

District	Annual			Winter			Pre-Monsoon			Monsoon			Post Monsoon		
	Mean	St Dev	CV	Mean	St Dev	CV	Mean	St Dev	CV	Mean	St Dev	CV	Mean	St Dev	CV
ARARIA	1643	346	21	23	20	86	174	81	46	1356	308	23	90	113	126
AURANGABAD	1068	268	**25**	38	33	88	34	28	83	950	244	26	64	59	92
BANKA	1117	262	23	32	28	88	81	54	67	908	225	25	96	94	98
BEGUSARAI	1079	309	**29**	28	24	86	72	56	79	899	291	**32**	80	84	105
BHAGALPUR	1166	279	24	29	25	87	98	67	69	950	243	**26**	89	89	100
BHOJPUR	1040	226	22	30	28	91	36	31	86	912	204	22	61	62	102
BUXAR	979	253	**26**	30	32	105	29	26	87	855	237	**28**	64	92	143
CHAMPARAN_E	1279	261	20	29	24	83	88	52	59	1091	259	24	72	69	95
CHAMPARAN_W	1400	305	22	32	25	79	108	65	60	1258	288	23	77	66	85
DARBHANGA	1156	285	**25**	24	18	77	91	44	48	968	261	27	73	73	100
GAYA	1051	265	**25**	34	30	88	40	34	85	910	238	26	67	55	82
GOPALGANJ	1143	267	23	27	22	81	58	47	81	986	249	25	72	73	102
JAHANABAD	1009	296	**29**	33	30	89	41	38	92	870	279	32	64	53	83
JAMUI	1136	229	20	34	33	97	72	51	71	941	199	21	89	85	95
KATIHAR	1340	372	**28**	23	22	95	131	77	59	1088	318	29	98	96	98
KHAGARIA	1097	300	**27**	23	22	94	80	52	66	913	261	29	81	81	100
MADHEPURA	1293	307	24	23	21	90	114	66	58	1067	281	26	89	88	99
MADHUBANI	1227	272	22	22	18	83	108	49	45	1026	259	25	72	71	99
MUNGER	1171	263	22	29	25	87	77	53	69	977	236	24	89	85	96
MUZZAFARPUR	1174	303	**26**	27	22	81	79	52	66	991	278	28	89	88	99
NALANDA	988	223	23	29	30	104	46	41	91	848	209	25	65	60	92
NAWADAH	1024	198	19	35	30	86	46	42	91	867	172	20	76	73	95
PATNA	995	243	24	28	27	94	48	43	90	855	221	26	64	59	92
PURNEA	1543	379	**25**	24	23	95	159	81	51	1253	338	27	106	103	97
ROHTAS	1062	266	**25**	37	32	87	35	32	91	928	239	26	62	57	92
SAMASTIPUR	1172	307	**26**	30	28	93	76	51	68	993	291	29	74	79	107
SARAN	1075	238	22	27	23	83	17	5	30	929	234	25	68	71	104
SITAMARHI	1243	312	**25**	27	23	86	105	50	48	1042	296	28	69	66	95
SIWAN	1102	261	24	29	26	90	48	33	69	959	251	26	66	82	125
SUPAUL	1356	332	24	25	21	85	130	68	53	1117	306	27	84	90	107


Aurangabad
Inc Triangle
Dec Triangle
Second Half
First Half
Araria
Inc Triangle
Dec Triangle
Second Half
First Half
Banka
Inc Triangle
Dec Triangle
Second Half
First Half
Begusarai
Inc Triangle
Dec Triangle
Second Half
First Half
Bhagalpur
Inc Triangle
Dec Triangle
Second Half
First Half
Bhojpur
Inc Triangle
Dec Triangle
Second Half
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Buxar
Inc Triangle
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First Half
E Champaran
Inc Triangle
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W Champaran
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Second Half
First Half
Darbhanga
Inc Triangle
Dec Triangle
Second Half
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Gaya
Inc Triangle
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Second Half
First Half
Gopalganj
Inc Triangle
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Jamui
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Katihar
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Kisanganj
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Second Half
First Half
Madhubani
Inc Triangle
Dec Triangle

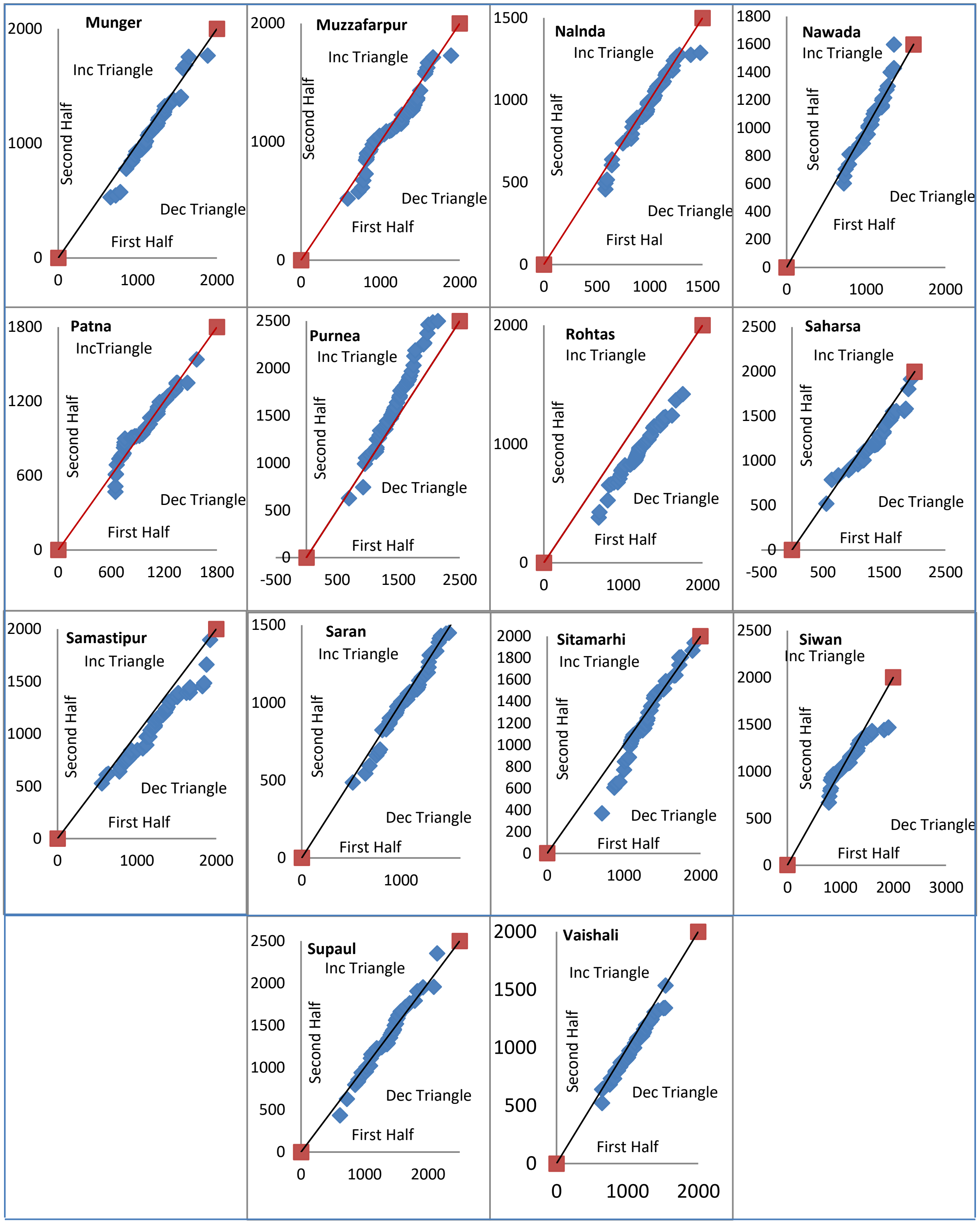

Fig. 2. Trend analysis of district wise annual rainfall data using ITA.

3. Results and discussions

3.1. *District wise rainfall characteristics*

Statistical analysis of long-term district-wise rainfall data for Bihar is presented in Table 1. Annual mean rainfall for the period 1901-2022, with a value >1200 mm, is concentrated in the northern and north-eastern districts of the state, *viz*. Araria, Purnea, E and W Champaran, Supaul, Katihar, Madhepura and Sitamarhi; however, southern and south-west districts like Buxar, Nalanda, and Patna received <900 mm of annual mean rainfall. More than 80% of the rainfall in the state is received during the monsoon (Met Monograph IMD); hence, the mean rainfall value of the monsoon also shows a similar distribution. The coefficient of variation with the annual rainfall for all the districts found in the moderate range only has values in the range of 20-30. The coefficient of variation for the monsoon rainfall is also in the moderate range except for the districts Begusarai and Jahanabad; however, CV values for pre-monsoon, winter rainfall and post-monsoon rainfall are high for all the districts.

3.2. *Trend analysis of district wise long-term rainfall data*

Trend analysis of district-wise long-term rainfall data is depicted in Fig. 2. Analysis of the data indicates that no trend has been found in the districts of Araria, Bhagalpur, Begusarai, East and West Champaran, Darbhanga, Katihar, Munger, Muzzafarpur, Nalanda, Nawada, Kisanganj, Patna, Saharsa, Saran, Sitamarhi, Supaul Gopalganj and Vaishali. A significant decreasing trend was observed in Aurangabad, Banka, Gaya and Rohtas; however, the rainfall for Bhojpur, Buxar and Jamui was also in the decreasing triangle, but the points were concentrated near the no trend line. Rainfall for Madhubani was lying near no trend line, but in a positive triangle, only Purnea shows an increasing rainfall trend in recent years. The rainfall of the South West monsoon season was also analyzed and the results were found in line with the annual rainfall analysis; hence, separate figures are not included in the study. The trend in the district-wise rainfall shows either no trend or a negative trend except in one district and the negative trend in recent times is found in almost all the districts. The decrease in monsoon rainfall trend for Bihar state is also reported by Zakwan and Ara, 2019 in his study conducted with the monthly met subdivision rainfall for the duration 1950-2016 using non parametric and parametric trend analysis. Kumar *et al*. (2010). in his study using all India met sub divion monthly dataset reported negative southwest monsoon trend for Bihar.

3.3. *PCI for annual rainfall*

The average precipitation concentration index of long-term rainfall data for each district for annual, winter, pre-monsoon and post-monsoon data is tabulated in Table 2. The average annual PCI for districts varies from 21 to 27, *i.e*., strongly irregularly distributed rainfall. The winter rainfall was in the range of 12-14, which lies in the moderately distributed rainfall; pre-monsoon rainfall PCI ranges from 15-19, *i.e*., irregular distribution; post-monsoon PCI values were in the range of strongly irregular distribution, with values of 20-23, whereas monsoon PCI values for most of the districts were found in the uniform distribution. Since monsoons contribute to 85% of the annual rainfall, the uniform distribution of south-west monsoons supports the uniform distribution of rainfall in Bihar. Hence, high inhomogeneity in annual rainfall may be due to post-monsoon PCI contribution and interannual variability of rainfall is very high because of the major contribution of south-west rainfall. The variability found in the analysis of the coefficient of variation also supports the lower variation in the south-west monsoon and the high CV in post-monsoon rainfall. The high annual PCI values for Bihar state were also reported by Zakwan and Ara (2019).

District wise categorical PCI distribution is depicted in the Table 3 where all the districts are in the strongly irregular distribution category for annual and post monsoon rainfall all districts have moderately distributed precipitation in winter rainfall season, for pre monsoon 12 of 36 districts were in moderate and 24 districts in irregular distributed precipitation. Whereas in monsoon which contributes 85% of total annual rainfall 27 of 36 districts were had uniform distribution and remining 09 districts were had moderate distributed precipitation.

Table 4 represents the temporal and seasonal variability of PCI across the districts of Bihar using MK Test. The significant change in the PCI were found for few districts only where Banka and Munger shows significant increasing trend and Purnea had significant decreasing trend in annual PCI. Again Banka, Bhagalpur and Munger had significant increasing trend in monsoon rainfall also with the values 2.5, 2.2 and 2.2 respectively and Begusarai and Khagaria had significant decrease in monsoon PCI with -0.2 and -2.4 values. Spatial distribution of PCI trend indicates that the positive trend (both significant and nonsignificant) is mainly distributed in the southern, extreme northern and central part of Bihar whereas extreme western districts of Bihar like Aurangabad, Bhojpur, Buxar, Rohtas and extreme eastern districts like Purnia, Katihar, Araria and Supaul had negative trend (both significant and nonsignificant). The increasing trend areas may requires the attention of water resource in these areas.

TABLE 2

District-wise Average PCI for Annual, Winter, Pre-monsoon and Post Monsoon

District	Annual	Winter	Pre-Monsoon	Monsoon	Post Monsoon
Aurangabad	25	12	17	10	20
Banka	21	14	15	10	21
Begusarai	25	13	17	12	22
Bhabhua	25	13	17	11	21
Bhagalpur	22	13	16	10	21
Bhojpur	25	12	17	11	21
Buxar	27	13	19	11	21
E Champaran	23	13	15	10	20
W Champaran	23	13	16	10	21
Darbhanga	23	13	16	10	21
Gaya	24	12	17	10	20
Gopalganj	24	13	17	10	21
Jahanabad	24	13	18	10	21
Jamui	22	13	16	10	21
Katihar	21	14	17	10	22
Khagaria	24	14	17	11	22
Kisanganj	22	14	15	10	22
Lakhisarai	23	14	18	10	23
Madhepur	22	13	17	10	21
Mdhubani	23	13	15	10	21
Munger	22	13	15	10	21
Muzzafarpur	23	12	16	10	21
Nalanda	24	13	17	10	21
Nawada	23	13	17	10	21
Patna	24	12	16	10	21
Purnea	21	14	16	10	22
Rohtas	25	12	16	11	21
Saharsa	22	14	16	10	22
Samastipur	23	13	15	10	21
Saran	24	12	17	10	21
Sitamarhi	23	13	16	10	21
Shekhpura	27	14	19	12	22
Seohar	24	14	17	11	22
Siwan	25	12	17	11	21
Supaul	22	13	16	10	22
Vaishali	24	12	17	10	20

TABLE 3

District wise distribution of PCI in Bihar

PCI Distribution	Annual	Winter	Pre Monsoon	Monsoon	Post Monsoon
	Districts				
Uniform distributed precipitation	Nil	Nil	Nil	Aurangabad, Banka, Bhagalpur, E and W Chmparan, Darbhanga, Gaya, Gopalganj, Jahanabad, Jamui, Katihar, Kisanganj, Lakhisarai, Madhepura, Madhubani, Munger, Muzzafarpur, Nalanda, Nawada, Patna, Purnea, Saharsa, Samastipur, Saran, Sitamarhi, Supaul, Vaishali (27)	Nil
Moderate distributed precipitation	Nil	All	Banka, Bhagalpur, E Chamaparan, W Champaran, Kisanganj, Madhubani, Munger, Patna, Purnea, Samastipur, Sitamarhi, Supaul (12)	Begusarai, Bhbhua, Bhojpur, Buxar, Khagaria, Rohtas, Shikhpura, Seohar, Siwan (09)	Nil
Irregular distributed precipitation	Nil	Nil	Aurangabad, Begusarai,Bhabhua, Bhojpur, Buxar, Darbhanga, Gaya, Gopalganj, Jahanabad, Jamui, Katihar, Khagaria, Lakhisarai, Madhepur, Muzzafarpur, Nalanda, Nawada, Rohtas, Saharsa, Saran, Sheikhpura, Seohar, Siwan, Vaishali (24)	Nil	Nil
Strongly Irregular distributed precipitation	All	Nil	Nil	Nil	All

TABLE 4

District wise and season wise trend analysis of PCI using Man Kendall Test

District	Annual		Winter		Pre-Monsoon		Monsoon		Post Monsoon	
	z	p value	z	p value	z	p value	z	p value	Z	p value
ARARIA	-0.9	0.4	-2.1	**0.0**	-1.0	0.3	-0.4	0.7	-1.9	**0.0**
AURANGABAD	-1.3	0.2	1.1	0.3	1.1	0.3	-1.3	0.2	0.4	0.7
BANKA	2.1	**0.0**	0.7	0.5	0.1	0.9	2.5	**0.0**	0.6	0.6
BEGUSARAI	-1.2	0.2	-1.2	0.2	-0.9	0.4	-0.2	**0.0**	-1.3	0.2
BHAGALPUR	0.9	0.4	-1.1	0.3	-2.3	0.6	2.2	**0.0**	-0.5	0.6
BUXAR	-0.5	0.6	-0.8	0.4	2.1	**0.0**	-1.0	0.3	0.3	0.7
CHAMPARAN_E	0.3	0.7	-1.9	0.1	-0.5	0.6	0.7	0.5	-1.4	0.2
CHAMPARAN_W	-1.5	0.1	-2.0	**0.0**	0.0	1.0	0.5	0.6	-0.6	0.6
DARBHANGA	-0.8	0.4	-0.6	0.5	0.1	0.9	-0.3	0.8	0.5	0.6
GAYA	-1.2	0.2	-0.9	0.4	0.2	0.8	-1.7	0.1	-0.4	0.7
GOPALGANJ	-0.5	0.6	-1.9	0.1	-1.4	0.2	0.7	0.5	-1.3	0.2
JAMUI	1.3	0.2	-0.5	0.6	2.4	**0.0**	0.6	0.5	1.5	0.1
KATIHAR	-1.9	0.1	-2.7	**0.0**	-0.6	**0.0**	-0.6	0.5	0.5	0.3
KHAGARIA	-1.3	0.2	-1.9	0.1	-1.1	0.3	-2.4	**0.0**	0.2	0.8
KISHANGANJ	0.6	0.5	-1.7	0.1	-1.3	0.2	0.0	1.0	0.0	1.0
MADHUBANI	0.6	0.6	-0.8	0.4	0.0	1.0	0.2	0.8	0.9	0.4
MUNGER	2.2	**0.0**	-0.9	0.3	0.9	0.3	2.2	**0.0**	1.1	0.3
MUZZAFARPUR	-0.5	0.6	-1.3	0.2	-1.2	0.2	0.1	0.9	-0.3	0.8

TABLE 4 (*cont.*)

District	Annual		Winter		Pre-Monsoon		Monsoon		Post Monsoon	
	z	p value	z	p value	z	p value	z	p value	Z	p value
NALANDA	0.8	0.4	-0.1	0.9	1.8	0.1	0.6	0.5	0.0	1.0
NAWADAH	-0.1	0.9	-0.9	0.3	1.1	0.3	0.3	0.8	0.8	0.4
PATNA	0.6	0.5	0.5	0.3	1.7	0.1	-0.5	0.6	1.0	0.3
PURNEA	-2.5	**0.0**	-1.5	0.1	-0.9	0.4	-1.7	0.1	-0.6	0.6
ROHTAS	-0.2	0.8	0.5	0.6	0.5	0.6	-0.4	0.7	1.8	0.1
SAMASTIPUR	-0.4	0.7	-1.0	0.3	-0.5	0.6	0.5	0.6	0.5	0.6
SARAN	0.3	0.8	-1.4	0.2	1.1	0.3	0.7	0.5	-0.3	0.8
SITAMARHI	-1.0	0.3	-1.8	0.1	0.0	1.0	-0.1	1.0	0.0	1.0
SIWAN	0.6	0.6	-1.7	0.1			0.7	0.5	-0.4	0.7
SUPAUL	-0.8	0.4		0.1	-0.2	0.8	-1.1	0.3	0.5	0.6
VAISHALI	0.6	0.6	-0.5	0.6	1.4	0.2	1.4	0.2		

4. Conclusion

Bihar is an agriculture-dependent state where only 57 percent of the agricultural area is irrigated, 30 percent of the irrigation is canal water-dependent, and about 63 percent is tubewell-dependent (BAMETI.org). Bihar is an agricultural state hence information derived through the spatial and temporal distribution of rainfall will be useful for agricultural irrigation scheduling, flood frequency analysis, water resource management, studying the impacts of climate change on rainfall distribution and other environmental aspects (Michaelides *et al*., 2009, as cited in Ngongondo *et al*., 2011). In the present study, district-wise rainfall data of Bihar for the period 1900-2022 was analysed with statistical tests like CV, standard deviation, and ITA for trend analysis. The precipitation concentration index and its trend were also analysed to understand change in the spatiotemporal distribution of rainfall concentration. The major findings of the study indicate: The coefficient of variation of the annual rainfall and monsoon rainfall was found in the moderate range for all the districts except for Begusarai and Jahanabad; however, CV values for pre-monsoon, winter rainfall and post-monsoon rainfall were found high for all the districts. Trend analysis of district wise rainfall using ITA indicates either no trend or a negative trend except in one or two districts, and the negative trend was observed in recent two decades in almost all the districts.

Precipitation concentration index analysis indicates strongly irregularly distributed annual rainfall, whereas uniform distribution in monsoon rainfall but high inhomogeneity in annual rainfall is found due to post-monsoon PCI contribution, and interannual variability of rainfall is very high because of the major contribution of south-west monsoon rainfall in annual rainfall.

The spatial distribution of the PCI trend indicates a positive trend in the southern, extreme northern, and central parts of Bihar, whereas extreme western districts of Bihar like Aurangabad, Bhojpur, Buxar, Rohtas and extreme eastern districts like Purnia, Katihar, Araria and Supaul had a negative trend.

The findings on trend analysis and homogeneity as well as spatiotemporal distribution of rainfall provide useful information for decision-makers and planners to design appropriate plans to deal with the adverse hydrometeorological conditions *viz*. floods, droughts, deficit rainfall, *etc*. This information is useful in hydrological, water resource, and environmental management programs.

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References

Adegun, O., Balogun I. and Adeaga, O., 2012 "Precipitation Concentration Changes in Owerri and Enugu, Hydrology for Disaster Management", *Special Publication of the Nigerian Association of Hydrological Sciences*., 383-391.

Alexander, L. V., Zhang, X., Peterson, T., C., Caesar, J., Gleason, B. and Klein Tank, A., M., G., 2006, "Global observed changes in daily climate extremes of temperature and precipitation", *Journal of Geophysical Research: Atmospheres*, **111**, D5, 5109. doi : https://doi.org/10.1029/2005JD006290.

Al-Shamarti, H. K. A., 2016, "The variation of annual precipitation and precipitation concentration index of Iraq", *Journal of Applied Physics*, (IOSRJAP) e-ISSN: 2278-4861., **8**, 4, 3, 36-44 doi : 10.9790/4861- 0804033644.

Alsubih, Majed, Mallick, Javed, Talukdar, Swapan, Salam, Roquia, Alqadhi, Saeed, Fattah, Md and Thanh, Nguyen., 2021, "An investigation of the short-term meteorological drought variability over Asir Region of Saudi Arabia", *Theoretical and Applied Climatology*. **145**. doi : 10.1007/s00704-021-03647-4.

Apaydin, H., Erpul, G., Bayramin, I. and Gabriels, D., 2006, "Evaluation of indices for characterizing the distribution and concentration of precipitation: A case for the region of Southeastern Anatolia Project, Turkey", *Journal of. Hydrology***, 328**, 726-732.

Belay, A., Demissie, T., Recha, J. W., Oludhe, C., Osano, P. M., Olaka, L. A., Solomon, D. and Berhane, Z., 2021, "Analysis of Climate Variability and Trends in Southern Ethiopia" *Climate* , **9**, 96. doi : https://doi.org/10.3390/cli9060096.

Benhamrouche, A., Boucherf, D., Hamadache, R., Bendahmane, L., Martinvide, J. and Teixeira, J., 2015, "Spatial distribution of the daily precipitation concentration index in Algeria", *Natural. Hazards Earth System Science*, **15**, 617-625. doi : 10.5194/nhess-15-617-2015.

Chaubey, P. K. and Mall, R. K., 2023, "Intensification of extreme rainfall in Indian river basin: Using bias corrected CMIP6 climate data", *Earth's Future*, **11, 9**, e2023EF003556.

Chaubey, P. K., Mall, R. K., Jaiswal, R., and Payra, S., 2022, "Spatio-Temporal Changes in Extreme Rainfall Events Over Different Indian River Basins", *Earth and Space Science*, **9, 3**, e2021EA001930.

De Luis, M., Raventos J, González-Hidalgo JC, Sánchez JR and Cortina J, 2000, "Spatial analysis of precipitation trends in the region of Valencia (East Spain)", *International Journal of Climatology* **20**, 1451-1469.

De Luis, M., Brunetti, M., Gonzlez-Hidalgo, J. C., Longares, L. A. and Mart´ın-Vide, J., 2010, "Changes in seasonal precipitation in the Iberian Peninsula during 1946-2005", *Global Planet. Change*, **74**, 27-33.

De Luis, M., Gonz´alez-Hidalgo C. J., Brunetti M and Longares L. A., 2011, "Precipitation concentration changes in Spain 1946-2005", *Natural Hazards and Earth System Sciences*, **11**, 1259-1265.

Ford, T. W. and Labosier, C. F., 2017, "Meteorological conditions associated with the onset of flash drought in the eastern United States", *Agricultural and forest meteorology***, 247**, 414-423.

Gocic, M., Shamshirband, S., Razak, Z., Petković, D., Ch, S. and Trajkovic, S., 2016, "Long-term precipitation analysis and estimation of precipitation concentration index using three support vector machine methods", *Advances in Meteorology*.

Goswami, B. N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan and P. K. Xavier., 2006, "Increasing trend of extreme rain events over India in a warming environment", *Science*, **314**, 1442-1445.

Gu, X., Zhang, Q., Singh, V. P. and Shi, P., 2017, "Changes in magnitude and frequency of heavy precipitation across China and its potential links to summer temperature", *Journal of Hydrology*, **547**, 718-731.

Gumus, V., Avsaroglu, Y., and Simsek, O., 2022, "Streamflow trends in the Tigris river basin using Mann− Kendall and innovative trend analysis methods", *Journal of Earth System Science*, **131**, 1, 34.

Haider, H., Zaman, M., Liu, S., Saifullah, M., Usman, M. and Chauhdary, J. N., 2020, "Appraisal of climate change and its impact on water resources of Pakistan: a case study of mangla watershed", *Atmosphere*, **11**, 10, 1071. doi : https://doi.org/10.3390/atmos11101071.

Hare, W., 2003, "Assessment of Knowledge on Impacts of Climate Change, Contribution to the Specification of Art, 2 of the UNFCCC". WBGU

Hulme, M., Osborn, T. J. and Johns, T. C., 1998, "Precipitation sensitivity to global warming: comparison of observations with HADCM2 simulations", *Geophysical Research Letters*, **25**, 3379-3382.

Iskander, S. M., Rajib, M. A. and Rahman, M. M., 2014, "Trending regional precipitation distribution and intensity: Use of climatic indices", *Atmospheric and Climate. Science*. **4**, 385-393.

Ivanovski, K., Hailemariam, A. and Smyth, R., 2021, "The effect of renewable and non-renewable energy consumption on economic growth: Non-parametric evidence", *Journal of Cleaner Production*, **286**, 124956, ISSN 0959-6526, doi : https://doi.org/10.1016/ j.jclepro.2020.124956.

Kendall, M.,1976, "Time series", Griffin, Londan.

Kripalani R. H., Kulkarni A., Sabade S. S., Khandekar, M. L., 2003, "Indian monsoon variability in a global warming scenario", *Natural Hazards*, **29**, 189-206.

Krishnamurthy, C. K. B., Lall, U. and Kwon, H. H., 2009, "Changing frequency and intensity of rainfall extremes over India from 1951 to 2000", *Journal of Climate*, **22**, 18, 4737-4746.

Kumar V., Jain, S. K. and Singh, Y., 2010, "Analysis of long-term rainfall trends in India", *Hydrological Science Journal*, **55**, 4, 484-496.

Kumar, V. and Jain, S. K., 2010, "Trends in seasonal and annual rainfall and rainy days in Kashmir Valley in the last century", *Quaternary International*, **212**, 64-69.

Malik, .A., Kumar A.,, Ahmed, A., Chow Ming Fai, Afan, H., Sefelnasr, A., Sherif, M. and El-Shafie, A., 2020, "Application of non-parametric approaches to identify trend in streamflow during 1976–2007 (Naula watershed)", *Alexandria Engineering Journal*, **59**, 3, 1595-1606, ISSN 1110-0168, https://doi.org/10.1016/j.aej.2020.04.006.

Mall, R. K., Gupta, A., Singh, R., Singh, R. S., & Rathore, L. S., 2006, "Water resources and climate change: An Indian perspective", *Current Science*, **90(12)**, 1610–1626

Mall, R. K., Srivastava, R. K., Banerjee, T., Mishra, O. P., Bhatt, D., & Sonkar, G., 2019, "Disaster Risk Reduction Including Climate Change Adaptation Over South Asia: Challenges and Ways Forward", *International Journal of Disaster Risk Science*, **10(1)**, 14–27, https://doi.org/10.1007/s13753-018-0210-9

Mann, HB., 1945, "Nonparametric tests against trend", *Econometrica* **13**, 245-259.

Met Monograph No.: ESSO/IMD/HS/Rainfall Variability/04(2020)/28

Michaelides, Silas, Tymvios, Filippos and Michaelidou, T., 2009, "Spatial and temporal characteristics of the annual rainfall frequency distribution in Cyprus*", Atmospheric Research*, **94**. 606-615. 10.1016/j.atmosres.2009.04.008.

Michiels, P., Gabriels, D. and Hartmann, R., 1992, "Using the seasonal and temporal precipitation concentration index for characterizing monthly rainfall distribution in Spain", *Catena*, **19**, 43–58.

Min, S. K., Zhang, X., Zwiers, F. W., and Hegerl, G. C., 2011, "Human contribution to more-intense precipitation extremes". *Nature,* **470**, 7334, 378-381.

Nery, JT., Carfan, AC., Martin-Videz J., 2017, "Analysis of Rain Variability Using the Daily and Monthly Concentration Indexes in Southeastern Brazil", *Atmospheric and Climate Science*, **7**, 176-190

Ngongondo, C, Xu CY, Gottschalk L, Alemaw, B., 2011, "Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region", *Theoretical and Applied Climatology.* **106**, 79-93

Oliver, J. E., 1980, "Monthly precipitation distribution: a comparative index", *Professional Geographer,* **32**, 300 -309.

Panda, A., and Sahu, N., 2019, "Trend Analysis of Seasonal Rainfall and Temperature Pattern in Kalahandi, Bolangir and Koraput Districts of Odisha, India", Atmospheric Science Letters, **20**, e932.https://doi.org/10.1002/asl.932

Patel, N., R and Shete D., T, 2015, "Analyzing Precipitation Using Concentration Indices for North Gujarat Agro Climatic Zone, India, Proc. Int. Conf. on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015)" *Science Direct, Aquatic Procedia* **4**, 917-924

Sahai, A. K., Pattanaik, D. R., Satyan, V. and Grimm Alice, M., 2003, "Teleconnections in recent time and prediction of Indian summer monsoon rainfall", *Met Atmospheric Physics*, **84**, 217–227.

Şen, Z., 2012, "Innovative trend analysis methodology. Journal of Hydrologic Engineering", **17**, 9, 1042–1046. Available from: https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Tabari, H., 2020, "Climate change impact on flood and extreme precipitation increases with water availability". *Scientific reports*, **10**, 1, 13768.

Valli, M., Shanti, SK., Murali and KIV, 2013, "Analysis of Precipitation Concentration Index and Rainfall Prediction in various Agro-Climatic Zones of Andhra Pradesh", *Journal of Environment Science*. **2**, 5, 53-6.

Xuemei, L., Fengqing, J., Lanhai, L., Guigang, W., 2011, "Spatial and temporal variability of precipitation concentration index, concentration degree and concentration period in Xinjiang, China", *International Journal of Climatolology,* **31**, 1679-1693.

Zakwan, M., and Ara, Z., 2019, "Statistical analysis of rainfall in Bihar. Sustainable Water Resources Management, 5, 1781-1789.

Zaman, M., Ahmad, I., Usman, M., Saifullah, M., Anjum, M.N. and Khan, M.I., 2020, "Event-based time distribution patterns, return levels, and their trends of extreme precipitation across Indus Basin" *Water*, **12**, 12, 3373.https://doi. org/10.3390/w12123373.

Zhang, Q., Xu, C-Y, Gemmer, M., Chen, Y. D. and Liu, C-L., 2009, "Changing properties of precipitation concentration in the Pearl River basin, China", *Stochastic Environmental Research and Risk Assessment (SERRA),* **23**, 377-385.