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Trend analysis of monthly and seasonal rainfall of IARI research farm (New Delhi)

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सार – जलवायु परिवर्तन से वर्षा चक्र पर असर पड़ने की संभावना है जिससे दुर्लभ जल संसाधनों, बाढ़ और सूखे की घटनाओं के प्रबंधन में अनिश्चितता बढ़ सकती है। इसे ध्यान में रखते हुए गैर-प्राचलिक मान-केंडल (MK) परीक्षण और सेन के ढलान अनुमानक दृष्टिकोण का उपयोग करके IARI अनुसंधान फार्म (नई दिल्ली) के वर्षा डेटा का विश्लेषण किया गया। दीर्घकालिक वर्षा डेटा (1991-2020) के विश्लेषण से पता चलता है कि IARI में 802 मिमी की सामान्य वार्षिक वर्षा और जून (82 मिमी), जुलाई (219.7 मिमी), अगस्त (239.8 मिमी), सितंबर (117.8 मिमी) के लिए सामान्य मासिक वर्षा होती है, जबकि शेष महीनों के लिए 4.2 से 33.9 मिमी तक वर्षा होती है। इसके अलावा, मॉनसून पूर्व (63.3 मिमी), मॉनसून (639 मिमी), मॉनसून पश्चात (32.5 मिमी) और शीत ऋतु (40.8 मिमी) के लिए सामान्य ऋतुनिष्ठ वर्षा, इसके अलावा फसल ऋतुओं के लिए 680.2 मिमी (खरीफ), 142.8 मिमी (रबी) और 149.6 मिमी (ज़ैद)। एमके और सेन के ढलान दृष्टिकोण ने मासिक, जलवायु और फसल ऋतुओं पर लागू किया, जिसने 1991-00, 2001-10 और 2011-20 की अवधि के बीच मासिक और ऋतुनिष्ठ वर्षा प्रवृत्तियों (बढ़ती/ घटती) में अंतर परिवर्तिता का संकेत दिया। इसके अलावा, मार्च, अप्रैल, जुलाई, मॉनसून पूर्व और रबी फसल ऋतु के लिए क्रमशः 0.22, 0.23, 0.34 और 0.30 के ZMK के साथ महत्वपूर्ण वृद्धि की प्रवृत्ति देखी गई। अंततः यह निष्कर्ष निकाला जा सकता है कि चार महीने (जून-सितंबर) के मॉनसून ऋतु के दौरान सामान्य वार्षिक वर्षा का लगभग 80 प्रतिशत हिस्सा फसलों के लिए उपयोग किया जा सकता है, रेखीय जल संचयन संरचनाओं में संरक्षित किया जा सकता है या भू जल पुनर्भरण के लिए इस्तेमाल किया जा सकता है।

ABSTRACT. Climate change is likely to impact rainfall patterns leading to higher uncertainty in management of scare water resources, flood and drought events. Keep this in view the rainfall data of IARI research farm were analyzed using non-parametric Mann-Kendall (MK) test and Sen's slope estimator approaches. Analysis of long-term rainfall data (1991-2020) indicated that IARI receives a normal annual rainfall of 802 mm and normal monthly rainfall for June (82 mm), July (219.7 mm), August (239.8 mm), September (117.8 mm), while for remaining months varies from 4.2 to 33.9 mm. Moreover, normal seasonal rainfall for pre-monsoon (63.3 mm), monsoon (639 mm), post-monsoon (32.5 mm) and winter (40.8 mm), besides this for cropping seasons, 680.2 mm (kharif), 142.8 mm (rabi) and 149.6 mm (zaid). The MK and Sen's slope approach applied to monthly, climatic and cropping seasons indicated intra variability in monthly, and seasonal rainfall trends (increasing/ decreasing) among the period of 1991-00, 2001-10 and 2011-20. Also, significant increasing trend were observed for March, April, July, pre-monsoon and rabi crop season with ZMK of 0.22, 0.23, 0.34 and 0.30, respectively. Overall, it can be concluded that the about 80% of normal annual rainfall during monsoon season of four months (June-September) can be used by crops, conserved in lined water harvesting structures or used for groundwater recharge.

Key words – Agriculture, Climate, Rainfall, Mann-Kendall, Sen's slope.

1. Introduction

Climate is a complex system comprising many variables, including rainfall, temperature, atmospheric pressure, and humidity. The effects of global warming have led to significant changes in climate patterns around the world (Abbass *et al*., 2022; New *et al*., 2001). Consequently, it has become increasingly important to study long-term changes in climatic variables to detect climate change. Recent studies have shown that global climate changes can lead to alterations in rainfall patterns, which can affect the availability of water, increase the risk of droughts and floods, and impact agriculture and other related sectors (Datta and Behera, 2022; Pal *et al.,* 2017; Trenberth. 2011). Changes in rainfall patterns have been observed in many river basins across the world (Giri *et al*., 2015; Nnaji *et al*., 2016; Belayneh *et al*., 2016; Zakwan and Ara, 2019). Rainfall is a critical climatic element since it provides the primary source of freshwater on Earth. Recent studies suggest that the frequency of extreme rainfall events is increasing, while the frequency of moderate events is decreasing (Arvind *et al*., 2017; Pandey *et al*., 2018).

Several studies have examined the trend in rainfall patterns across different parts of Asia. For instance, Goswami *et al*. (2006) found that total annual precipitation is declining in central India, while Bhatla and Tripathi (2014) reported a decrease in the frequency of infrequent rainfall events in Varanasi, India. Jain and Kumar (2012) analyzed rainfall trends for various river basins in India and reported a decreasing trend of rainfall for most basins. However, some basins showed increasing rainfall trends. The agricultural sector in India, which is a significant contributor to the country's economy, is highly dependent on rainfall patterns, which significantly affect agricultural productivity (Modarres and Da Silva, 2007; Kumar and Gautam, 2014). The timely availability of adequate amounts of water and a conducive climate is essential for the agriculture and related sectors, food and energy security and overall economy of any region (Panda and Sahu, 2019). In India, the southwest (SW) monsoon accounts for about 80% of the total precipitation over the country. Changes in the pattern, frequency, and variability of SW monsoons can significantly impact agricultural production, water resources management, and the overall economy of the country (Sinha and Srivastava, 2000; Seo and Ummenhofer, 2017). Thus, studying rainfall variability and trends is critical for better water resource management, irrigation and agricultural activities.

The dependence of the agricultural sector on rainfall persists in many parts of the world, despite the development of new irrigation techniques. Therefore, it is essential to conduct a long-term analysis of rainfall patterns and their variability. Alterations in the rainfall patterns can have significant implications for the livelihoods of people, particularly in agricultural countries such as India. With the advent of rapid climate change, it has become even more crucial to investigate the trends in rainfall. The primary aim of this study is to explore the monthly and seasonal variability of rainfall trends at the IARI research farm in New Delhi, India. This involves an assessment of the rainfall trend and variability, and an understanding of the uncertainties associated with rainfall patterns. This knowledge will aid in the better management of agriculture, irrigation, storage and groundwater recharge and other water-related activities.

2. Data and methodology

2.1. *Study area and metrological data*

The Indian Agricultural Research Institute (IARI) is located in the National Capital Territory of Delhi in the Indo-Gangetic alluvial plains (Fig. 1). The geological formation mainly consists of unconsolidated alluvial and colluvial materials, such as fine sand and clay, with nodular calcareous formations found locally. It is divided into two major geomorphic units: sloping piedmont plain in the south and alluvial plain in the central and northern parts. Flood irrigation practice is predominantly used on the IARI farm for experiments on different types of crops in different seasons, with groundwater as the primary source. Groundwater exists under both unconfined and semi-confined conditions. Over the last few decades, excessive pumping of groundwater has resulted in a significant decrease in the water table, dropping from approximately 2 meters in the 1980s to 10-12 meters in 2003 in the central area (Tyagi and Datta, 2010). The monthly rainfall data from 1991 to 2020 for IARI research farm (New Delhi) was collected from the Division of Agricultural Physics, ICAR-IARI, New Delhi.

2.2. *Climate of the study area*

New Delhi, India is situated in the agro-climate zone of the "Trans-Gangetic plains," where the climate is semi-arid and sub-tropical. The summers are hot and dry, with maximum temperatures ranging from 41 °C to 46 °C in May and June. In contrast, January is the coldest month, with minimum temperatures ranging between 4 °C to 7 °C. The temperature gradually increases from February until it peaks in June, after which it reduces significantly due to the arrival of southwest monsoon rain. During June, the mean open pan evaporation rate reaches its highest point, with a recorded value of 12.88 mm per day, while in January; it is at its lowest, with a recorded value of 0.6 mm per day. The evaporation rate follows the same trend as that of temperature during this period. The

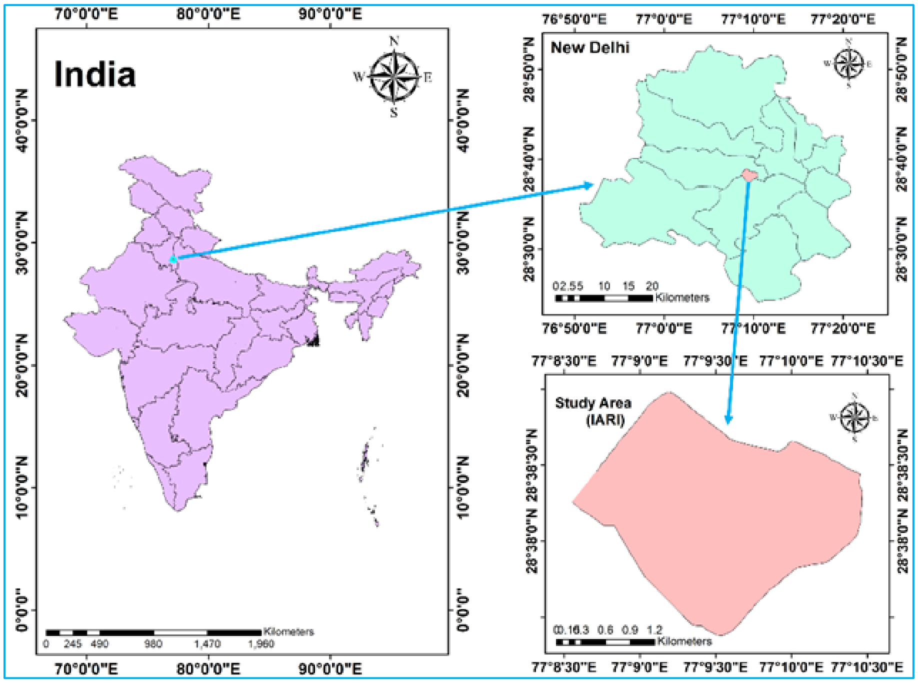

Fig. 1. Map of Indian Agricultural Research Institute (IARI), New Delhi

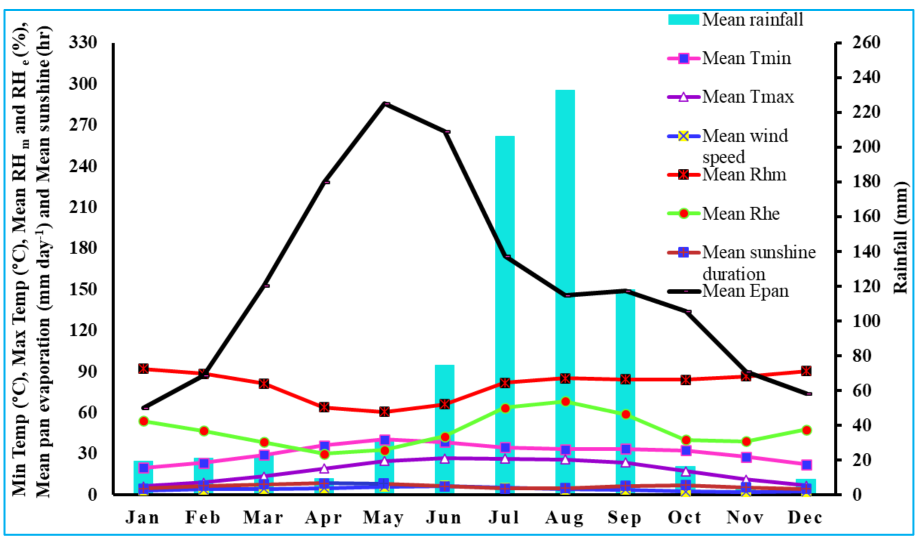

Fig. 2. Mean monthly meteorological data for 1984-2020

average annual rainfall in Delhi is about 750 mm, with 74% of it received during active southwest monsoon months, such as July, August, and September. The wettest months are July and August, with sporadic winter rains between September and February, varying in depth, intensity, and duration. The mean wind speed ranges from 3.5 km/hr in October to 6.4 km/hr in April, and winter showers are generally associated with storms having high wind speed. The mean relative humidity (RH) is at its maximum (up to 98%) during the monsoon season, while it is at its minimum of 40 to 45% during summer months.

In the IARI research farm study area, the mean annual temperature recorded at a nearby observatory was 24 °C, with June being the hottest month (mean maximum temperature of 45 °C) and January being the coldest (mean minimum temperature of 7 °C). The mean annual rainfall, based on a 30-year record (1991-2020), was

802.17 mm, with 80% of the annual rainfall received during the monsoon (June-September) and the rest in winter, with occasional summer rain accompanied by hail storms. The mean monthly climatic parameters of IARI research farm are presented in Fig. 2.

2.3. *Non-parametric statistical test*

Nonparametric statistical methods are commonly used to evaluate changes in hydroclimatic parameters over time and space. These methods are typically less sensitive to outliers and other forms of non-normality than parametric methods and are often based on measures of monotonic linear dependence (Davis 1986; Lanzante, 1996). The Sen's slope estimator, which is a non-parametric method, can be combined with other methods such as the Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) to determine the statistical significance of trends. The MK test is also less sensitive to extreme events and missing data points (Partal and Kahya, 2006). The MK statistic is given by:

Let X_1, X_2,…, X_n represent n data points, where X_j represents the data point at time j. Then, the MK (S) is given by:

$$S = \sum_{k-1}^{n-1} \sum_{j-k+1}^{n} \text{sign}\left(X_j - X_k\right) \tag{1}$$

$$\text{sign}\left(X_j - X_k\right) = \begin{cases} 1 \text{ if } X_j - X_k > 0 \\ 1 \text{ if } X_j - X_k = 0 \\ -1 \text{ if } X_j - X_k < 0 \end{cases} \tag{2}$$

The S statistic therefore represents the number of positive differences minus the number of negative differences found in analyzed time series. Under the null hypothesis (H_o) of that there is no trend in the data no correlation between considered variable and time, each ordering of the data set is equally likely. Under this hypothesis the statistic S is approximately normally distributed with the mean $E(S)$ and the variance Var (S) as follows:

$$E(S) = 0 \tag{3}$$

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

where n is the length of the times-series, t_p is the number of ties for the pth value and q is the number of tied values *i.e.*, equals values. The second term represents an adjustment for tied or censored data. The standardized test statistic Z is given by:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\text{Var}(S)}} \text{ if } S > 0 \\ 0 \quad \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\text{Var}(S)}} \text{ if } S < 0 \end{cases} \tag{5}$$

The Z value is a statistical measure used to determine whether a time-series has a statistically significant trend. It tests the null hypothesis that there is no trend and a positive Z value indicates an increasing trend, while a negative Z value indicates a decreasing trend. To test for either an increasing or decreasing monotonic trend at a significance level of p, the null hypothesis is rejected if the absolute value of Z is greater than $Z(1-p/2)$, where $Z(1-p/2)$ is obtained from the standard normal cumulative distribution tables. In this study, significance levels of 0.05 and 0.1 were applied, and the p-value for each analyzed time-series was calculated. Sen's slope was calculated to determine the magnitude of change observed over time (Yu *et al.*, 1993). This method estimates the slope of the overall trend shown by rainfall by taking the median value of the slope estimates for all possible pairs of years. The sign of Sen's slope indicates the direction of the trend. We used Sen's slope estimator to provide an estimate of the trend's magnitude, which is calculated as follows:

$$T_i = \frac{X_j - X_k}{j-k} \quad \text{for } i = 1,2,\ldots,N \tag{6}$$

where x_i and x_j are data values at time j and k ($j > k$) respectively. The median of (β) N values of T_i is the Sen’s slope estimator.

$$\beta = T_{[(N+1)/2]}, \quad \text{if } N \text{ is odd} \tag{7}$$

$$\beta = T_{\{N/2 + T_{[(N+1)/2]}\}}, \quad \text{if } N \text{ is even} \tag{8}$$

Positive value of β indicates an increasing trend and negative value indicates a decresing trend in the time series.

2.4. *Normal monthly, sesonal and annual rainfall*

Normal rainfall was calculated as the average of the consecutive 30-months, seasons or year rainfall series. Rainfall series considered in the present study were

TABLE 1

Range of monthly rainfall

	1991-2000			2001-10			2011-2020			1991-2020		
	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Normal
Jan	72.90	0.00	23.99	41.60	0.00	9.16	64.80	0	28.05	72.90	0.00	20.40
Feb	53.50	4.00	20.23	49.80	0.00	15.61	109.40	0.00	29.70	109.40	0.00	21.85
Mar	40.40	0.00	9.81	54.40	0.00	11.82	201.80	0.00	51.91	201.80	0.00	24.51
Apr	42.40	0.00	7.29	31.00	0.00	7.34	51.80	0.60	14.01	51.80	0.00	9.545
May	49.30	0.00	15.14	136.60	1.60	54.45	79.60	0.00	30.58	136.60	0.00	33.39
June	205.20	28.40	88.97	156.20	4.60	64.82	290.80	12.40	92.59	290.80	4.60	82.13
July	439.10	59.40	189.62	578.60	7.20	180.45	540.90	33.80	289.00	578.60	7.20	219.69
Aug	425.00	85.00	251.79	338.80	66.30	184.01	521.90	98.90	283.15	521.90	66.30	239.77
Sep	232.60	29.80	107.81	314.20	5.40	130.46	237.90	9.80	115.19	314.20	5.40	117.82
Oct	65.80	0.00	19.73	80.60	0.00	12.35	109.00	0.00	30.21	109.00	0.00	20.76
Nov	37.00	0.00	8.14	14.20	0.00	2.84	7.40	0.00	1.74	37.00	0.00	4.24
Dec	68.00	0.00	8.42	21.30	0.00	4.18	66.00	0.00	11.60	68.00	0.00	8.07

TABLE 2

Range of hydrological seasonal precipitation

	1991-2000			2001-10			2011-2020			1991-2020		
Season	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Normal
Winter	85.80	7.00	44.22	30.80	3.20	24.77	150.20	1.40	57.75	150.20	1.40	40.81
Pre-monsoon	103.70	1.10	32.24	167.60	8.80	73.61	254.40	24.20	96.50	254.40	1.10	63.27
Monsoon	897.40	408.70	638.19	894.40	392.40	559.74	1240.80	493.70	780.29	1240.80	392.40	639.01
Post-monsoon	152	0.00	36.39	80.0	0.00	19.37	116.20	2.40	43.55	152	0.00	32.45

monthly, seasonal and annual time series. Normal rainfall may be estimated (Subramanya, 2008) as:

$$N = \frac{\sum_{i=1}^{30} P_i}{30} \tag{9}$$

where P_i is the rainfall in ithunit.

The normanl annual rainfall of the IARI research farm was observed 802.17 mm for the period of 1991-2020.

2.5. *Open-source software for non-parametric statistical analysis*

In present study open-source software were used for non-parametric statistical analysis Python 3.7.14 programming language on Colaboratory online platform (https://colab.research.google.com/) was used for the analysis (Van Rossum and Drake J., 1995). The libraries used for preprocessing, management and analysis of data were Numpy (Harris *et al*., 2020), Pandas (McKinney, 2010) and pymannkendal 1.4.2 (Hussain *et al*., 2019).

3. Results and discussion

Rainfall data of IARI research farm for the duration of 1991-2020 was analyzed to characterize the rainfall and identify its trend. Rainfall data were categorized in four groups, *viz.*, 1991-00, 2001-10, 2011-20 and 1991-2020. Maximum rainfall, minimum rainfall and average rainfall for monthly, climatic seasons (pre-monsoon, monsoon, post-monsoon and winter) and cropping seasons (*rabi*, *kharif* and *zaid*) characteristics are presented in Tables 1, 2 & 3, respectively. It was observed from Table 1 that the

TABLE 3

Range of cropping seasons rainfall 578.60, 521

	1991-2000			2001-10			2011-2020			1991-2020		
Seasons	Max	Min	Ave	Max	Min	Ave	Max	Min	Ave	Max	Min	Normal
Kharif	817.80	420.50	657.92	916.40	309.50	527.09	1349.80	504.70	810.50	1349.80	309.50	680.17
Rabi	262.70	43.60	112.75	169.40	53.80	117.75	298.50	63.40	197.80	298.50	43.60	142.77
Zaid	254.40	29.50	121.21	268.30	13.40	138.43	378.80	54.20	189.09	254.40	13.40	149.58

maximum rainfall (mm) occurred for the months of June- 205.20, 156.20, 290.80; July-439.10, 578.60, 540.90; August- 425, 338.80, 521.90; and September-232.60, 314.20, 237.90 for 1991-00, 2001-10, 2011-20, respectively. Whereas, maximum monthly rainfall for the remaining months ranged from 7.40 to 201.80 mm during 3 decades (1991-2020). Which indicated that the maximum monthly rainfall occurred only during June-September during the study period of three decades. Overall, the maximum monthly rainfall depth (290.80 to 578.60 mm) for the months June- September occurred over a period of 1991-2020. It was also observed that the minimum rainfall depth (4.60 to 66.30 mm) occurred during June to September and normal monthly rainfall for June to September varied from 82.13 to 239.77 mm for the same period (1991-2020). Moreover, the normal rainfall for the remaining months were less than 33.39 mm. The findings emphasize the need for rainwater harvesting, efficient irrigation, and groundwater recharge to manage water availability across seasons. Strategic crop planning and storage infrastructure can help mitigate drought risks and optimize water use. Seasonal rainfall during the monsoon season (June to September) ranging from 408.70 to 897.40, 392.40 to 894, 493.70 to 1240 for 1990-00, 2001-10, 2011-20, respectively (Table 2). While normal rainfall for the monsoon season was 639.07 mm, which is approximately 79.66% of the normal annual rainfall (802.17 mm). Although, rainfall for the remaining seasons (Winter, pre-monsoon and post-monsoon) varied from 85.80 to 152, 30.80 to 167 to 60, and 116.20 to 254.40, for 1991-00, 2001-10 and 20111-20, respectively. It was observed that about 80% of annual rainfall occurred during monsoon season of four months (June-September). Besides its use by the crops in the growing season, there is scope for using this major share of rainfall (80%) in water harvesting structures for its use in irrigation or recharge of groundwater in the region. The data analyses by Rana *et al.* (2012) also indicated that monsoon (June-September) contributes 85.9% of the annual rainfall. While, the contribution of pre-monsoon (March-May), post-monsoon (October-November) and winter rainfall (December-February) to annual rainfall is 5, 3 and 5% respectively.

Crops sown in *rabi* season from October to December (post-monsoon) and harvested in summer from April to June (pre-monsoon). Some of the important *rabi* crops are wheat, barley, peas, gram and mustard. Though these crops are grown in many parts of India, states in the north and northwestern parts of the country, such as Punjab, Haryana, Himachal Pradesh, Jammu and Kashmir, Uttarakhand and Uttar Pradesh, have significant areas under wheat and mustard cultivation. The availability of precipitation during the winter months as a result of western temperate cyclones contributes to the success of these crops. However, maximum monthly rainfall for these months (October -May) were varying from 37 to 72.90 mm, 41.20 to 80.60 mm and 7.40 to 109.40mm, for 1991-00, 2001-10, 2011-2020, respectively. The crop grown in *rabi* season require irrigation to achieve potential farm productivity. Irrigation during these periods can be met from groundwater, and stored surface water (farm pond and canal). *Kharif* crops are planted across India at the beginning of the monsoon season, and they are harvested in September and October. The major crops grown during this season include paddy, maize, jowar, bajra, tur (arhar), moong, urad, cotton, jute, groundnut, and soybean. In some states such as Assam, West Bengal, and Odisha, three crops of paddy are grown in a year: Aus, Aman, and Boro. The *zaid* season is a short summer season that falls between the *rabi* and *kharif* seasons and crops such as watermelon, muskmelon, cucumber, vegetables, and fodder are grown during this period. Sugarcane, on the other hand, takes almost a year to mature. Besides this, during *kharif* season, the rainfall amount varied from 420.50 to 817.80, 309.50 to 915.40, and 504.70 to 1349.80 mm for 1990-00, 2001-10, 2011-20, respectively (Table 3), while normal rainfall for *kharif* season 680.17 mm, which is about 84.79% of normal annual rainfall (802.17). Besides this the normal rainfall

TABLE 4

Mann Kendall test for monthly rainfall

	1991-2000			2001-10			2011-2020			1991-2020		
	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p
Jan	0.13	1.58	0.65	-0.58⁺⁺	-1.57	0.02	0.36	4.11	0.18	0.04	0.03	0.76
Feb	-0.04	-0.07	0.93	0.0	0.00	1.00	-0.07	0.0	0.85	-0.10	-0.19	0.45
Mar	0.22	0.84	0.42	-0.02	0.00	1.00	0.02	0.99	1.0	0.22⁺	0.45	0.09
Apr	-0.06	0.0	0.85	-0.04	0.00	0.93	0.07	0.44	0.86	0.23⁺	0.21	0.08
May	0.15	0.79	0.60	-0.02	-2.87	1.00	0.24	2.27	0.37	0.18	0.80	0.17
June	0.33	7.43	0.21	-0.24	-4.85	0.37	-0.02	-4.17	1.0	-0.03	-0.31	0.80
July	0.16	10.24	0.59	0.11	8.32	0.72	0.2	19.09	0.47	0.21⁺	5.18	0.10
Aug	-0.33	-17.0	0.21	0.42	19.85	0.11	-0.11	-4.23	0.72	0.05	1.10	0.69
Sep	-0.15	-1.57	0.59	0.38	17.03	0.15	-0.02	-5.63	1.00	0.03	0.57	0.80
Oct	0.33	6.24	0.17	-0.11	0.00	0.71	-0.29	-1.83	0.25	0.01	0.0	0.92
Nov	0.02	0.0	1.0	0.22	0.00	0.36	0.47	0.4	0.05	0.01	0.0	0.97
Dec	0.04	0.0	0.92	-0.07	0.00	0.85	0.13	0.07	0.65	0.14	0.0	0.27

Note : ++ is for 0.05 level of significance, + is for 0.1 level of significance

TABLE 5

Mann Kendall test for hydrological seasons rainfall

	1991-2000			2001-10			2011-2020			1991-2020		
	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p
Winter	0.16	1.87	0.59	-0.33	-2.85	0.21	-0.07	-1.46	0.11	-0.01	-0.02	0.96
Pre-monsoon	0.07	0.79	0.86	-0.07	-3.31	0.86	0.42	4.13	0.72	0.34⁺	1.95	0.01
Monsoon	-0.07	-5.55	0.86	0.33	27.18	0.21	0.11	9.82	0.28	0.15	6.85	0.24
Post-monsoon	0.31	3.16	0.24	-0.09	-0.40	0.78	-0.29	-3.2	0.72	0.54	0.11	0.59

Note : ++ is for 0.05 level of significance, + is for 0.1 level of significance

TABLE 6

Mann Kendall test for cropping seasons rainfall

	1991-2000			2001-10			2011-2020			1991-2020		
	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p	Z	S (*β*)	p
Kharif	-0.07	-4.38	0.86	0.24	22.81	0.37	0.11	12.45	0.72	0.14	5.80	0.27
Rabi	0.42	9.45	0.11	-0.24	-7.71	0.37	0.11	1.32	0.72	0.30⁺	3.89	0.02
Zaid	0.24	11.54	0.37	-0.24	-10.52	0.37	0.16	10.27	0.59	0.19	2.81	0.15

Note : ++ is for 0.05 level of significance, + is for 0.1 level of significance

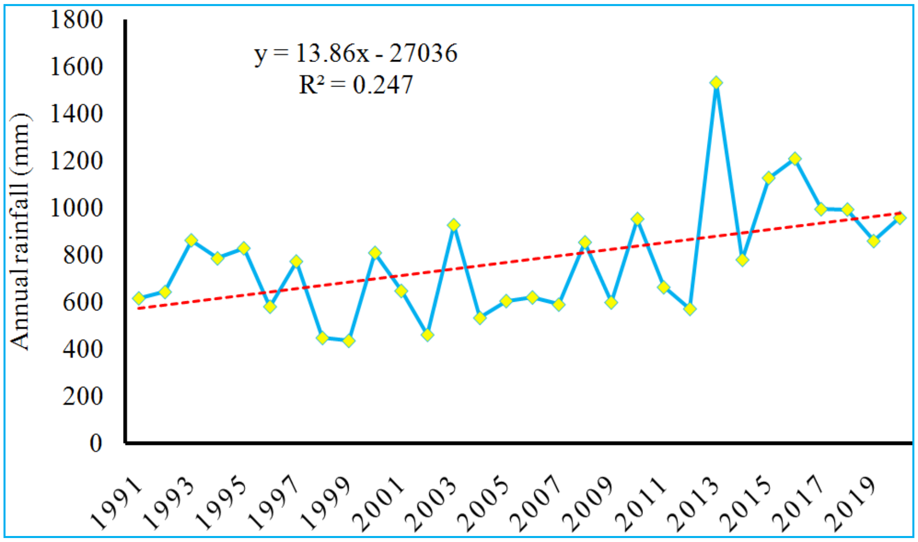

Fig. 3. Time-series of annual rainfall for the period of 1991-2020

for the *rabi* and *zaid* season were 142.77 and 149.58 mm, respectively; which is only 17.79% and 22.38% of normal annual rainfall. So, crop grown in *rabi* and *zaid* seasons would need of supplemental irrigation for enhancing farm productivity (Rana *et al.*, 2014).

The variability in rainfall amount (trend) on monthly, hydrological (climate) and agricultural cropping seasonal basis is calculated individually for each month and seasons using Mann-Kendall test and magnitude of slope is calculated with Sen's slope estimator for a period of 1991-00, 2001-10, 2011-20 and 1991-2020 are presented in Tables 5, 6 & 7, respectively. The statistically significant levels, 0.05 (1%), medium 0.1 (5%) and more than >0.1 (>10%) were used. Table 4 indicated both increasing and decreasing trends highlighting intra variability during 1991-00, 2001-10 and 2011-2020, respectively, excluding July and November months, which indicated only increasing trend. Nonetheless, increasing or decreasing trend were insignificant except for decreasing trend for January of 2001-10, which was significant at 5% probability level. However, the normal monthly rainfall (1990-2020) exhibited increasing trend (positive values of Z_{MK}) except for February and June. Besides this, increasing trend for March, April and July months were observed at 10% level of significance for 1991-2020 (Table 4). Overall positive Z_{MK} values for most of the months and decades indicated increase in annual rainfall depth, which could be observed as an increasing trend with slope 13.87 (Fig. 3). Singh *et al*. (2008) analyzed rainfall variations across nine river basins in northwest and central India and observed an increasing trend in annual rainfall, ranging from 2% to 19% of the mean per 100 years. Similarly, Mirza *et al*. (1998) conducted trend and persistence analysis for the Ganges, Brahmaputra, and Meghna River basins, concluding that precipitation in the Ganges basin remains largely stable.

Under climatic perspective, Indian subcontinent can be considered to have four seasons as pre-monsoon (March-May), monsoon (June-September), Post-monsoon (October-November), winter (December-February). Table 5, showed that the positive Z_{MK} values (increasing trend) for three seasons, *viz.*, winter, pre-monsoon, and post-monsoon for 1991-00; and negative Z_{MK} values (decreasing trend) for the same season of 2001-10. However, for the 2011-20 positive Z_{MK} values for Pre-monsoon and monsoon and negative Z_{MK} values for post-monsoon and winter seasons. Besides this, for the normal seasonal rainfall (1991-2020) decreasing trend form winter season and increasing trend for pre-monsoon, monsoon and post-monsoon. Moreover, increasing trend was significant only for monsoon season at 10% probability level. Kripalani *et al.* (2003) analyzed inter-annual and decadal variability in summer monsoon rainfall over India using observed data spanning 131 years (1871-2001). The rainfall trends for three cropping seasons- *rabi*, *kharif* and *zaid* seasons are presented in Table 6. Trend of cropping seasons also indicated existence of intra variability of rainfall during crop seasons for 1991-00, 2001-10 and 2011. This seasonal variability could be due to monthly rainfall variability (Table 1). For the *kharif* season decreasing trend (1991-00) and increasing trend (2001-10 & 2011-20); *rabi* and *zaid* seasons increasing trend (1991-00 & 2011-20) and decreasing trend (2001-10). Besides this, increasing trend for all cropping seasons were observed for 1991-2020. Although, increasing and decreasing trend for all seasons and periods were insignificant except only for *rabi* season of 1991-2020. Kumar *et al.* (2010) analyzed long-term rainfall trends in India and found no significant trends in annual, seasonal, or monthly rainfall. However, annual and monsoon rainfall exhibited a decreasing pattern, whereas pre-monsoon, post-monsoon, and winter rainfall showed an increasing trend at the national level. Additionally, rainfall decreased in June, July and September but increased in August across the country. The findings suggest that crops grown during the rabi season (October to December) and harvested in the summer (April to June) require supplemental irrigation due to low precipitation during the winter months. For kharif crops, rainfall is higher and more consistent, while zaid crops are grown in a short summer period. The variability in rainfall patterns highlights the need for efficient water management strategies, such as irrigation from groundwater and stored surface water, to enhance farm productivity across different seasons. Additionally, trends in rainfall data show intra-seasonal and inter-decadal variations, with some months experiencing increasing rainfall, while others show a decreasing trend.

4. Conclusions

IARI research farm is susceptible to climate variability and change. Fluctuations or variations in climatic parameters is a recurring phenomenon in region. Rainfall is the most determinant climatic parameters in the area. Present study analyzed time series rainfall data (1991-2020) for monthly and seasonal (climatic and cropping) using nonparametric Mann-Kendall (MK) test and Sen's slope estimator. The rainfall data were categorized in four groups, *viz*., 1991-00, 2001-10, 2011-20 and 1991-2020. It was observed that the IARI farm received a normal annual rainfall of 802.17 mm and normal monthly rainfall for June to September varied from 82.13 to 239.77mm, normal monsoon- 639.01mm, and kharif season- 680.17mm,while for remaining months, climatic and cropping seasons were varying from 4.24 to 33.9mm, 40.81 to63.27mm and 142.77 to 149.58mm, respectively. which indicated that the approximately ~80% and 84.79% of normal annual rainfall (802.17mm) occurred in monsoon season (639.01mm) of four months (June to September) and *kharif* season (680.17mm), respectively. Besides this, trend analysis of monthly and seasonal rainfall indicated intra variability in monthly and seasonal (climatic and cropping) rainfall trend (increasing/ decreasing) among the period of 1991-00, 2001-10 and 2011-20. Although, significant increasing trend were found for march, April, July, Pre-monsoon and *Rabi* season with ZMK of 0.22, 0.23, 0.34 and 0.30, respectively. Overall, it can be concluded that the rainfall events of the monsoon are of a renewable source of fresh water than can be expected to available to conserve in on-farm for multipurpose use and groundwater recharge.

Authors' Contribution

Amit Kumar: Developed the concept, Conducted data preprocessing and analysis, Prepared the initial draft of the manuscript.
A Sarangi: Developed the concept, prepared the initial draft of the manuscript.
D. K Singh: Developed the concept
K. K. Bandyopadhyay: Conducted data preprocessing and Analysis
S. Dash: Conducted data preprocessing and analysis
I. Mani and M. Khanna: Prepared the initial draft of the manuscript.

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