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Extreme rainfall pattern analysis for drought prone Shali reservoir area in West Bengal of India

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सार – वर्षा आवश्यक जल के प्रमुख स्रोतों में से एक है। वर्षा की मात्रा उस क्षेत्र में कृषि और औद्योगिक गतिविधियों को भी निर्धारित करती है। वर्तमान अध्ययन पश्चिम बंगाल के बांकुरा जिले में गंगाजलघाटी ब्लॉक के शाली जलाशय क्षेत्र में वर्षा की प्रवृत्ति की जांच करने के लिए किया गया है। गंगाजलघाटी प्रखंड में सिंचाई का पानी उपलब्ध कराने के लिए शाली जलाशय बनाया गया था। इस क्षेत्र के लोगों के लिए पानी की कमी एक स्थाई खतरा है। यहां फसलों का रोपण और उत्पादन सीमित अवधि में अनियमित वर्षा पर अत्यधिक निर्भर करता है। इस क्षेत्र में लगभग 80-90% **वर्षा सामान्यत: जून से सितंबर तक भारी वर्षा के आगमन तक होती है। इसलिए, इस सूखा प्रवण क्षेत्र में, हर समय वर्षा में परिवर्तन को समझने के लिए वर्षा पैटर्न का विश्लेषण बहुत महत्वपूर्ण है। मासिक और वार्षिक वर्षा के आंकड़े लगभग पिछले** 40 **वर्षों** (1980 **से** 2020) **के क्षेत्र सर्वेक्षणों और माध्यमिक सर्वेक्षणों से लिए गए हैं। मान केंडल (एमके) और सेन के ढलान अनुमान (एसएसई) परीक्षणों को स्थायी प्रवृत्ति को पहचानने के लिए लागू किया गया है और एसएसई परीक्षण का उपयोग मौजूदा प्रवृत्ति और समय के साथ वर्षा में परिवर्तन की सीमा को खोजने के लिए किया गया है। इस अध्ययन क्षेत्र के आसपास के दस वर्षामापी स्टेशनों से वर्षा के आंकड़े लिए गए हैं। सुदूर संवेदी का उपयोग करके संबंधित मानचित्र तैयार किए गए और जीआईएस की क्रिगिंग इंटरपोलेशन तकनीक की मदद से वर्षा वितरण पैटर्न का विश्लेषण किया गया है। वार्षिक एमके परीक्षण एक ऋणात्मक प्रवृत्ति दर्शाता है, लेकिन ऋतुवार एमके परीक्षण मॉनसून के मौसम में धनात्मक प्रवृत्ति दिखा रहा है। एसपीआई परिणाम से पता चला है कि अध्ययन क्षेत्र में पर्याप्त वर्षा नहीं हो रही है, जो कृषि उत्पादकता पर हानिकारक प्रभाव पैदा कर सकती है। यह अध्ययन इस स्थिति से निपटने के लिए उचित सूखा प्रबंधन कार्यक्रम को अपनाने का सुझाव देता है।**

ABSTRACT. Rainfall is one of the major sources of needed water. Rainfall amount also determines the agricultural and industrial activities in the region. The present study has been conducted to examine the rainfall trend in the Shali reservoir area of the Gangajalghati block in Bankura district in West Bengal. The Shali reservoir was made to provide irrigation water in the Gangajalghati block. Water insufficiency is a habitual threat to the people of this area. Here the planting and production of crops highly depend on the constricted period of inconsistent rainfall. About 80-90 % of rainfall usually occurs in this area from June to September until the onset of heavy rains. Therefore, in this drought-prone area, the analysis of rain patterns is very vital to understand the change in rainfall at all times. The monthly and annual rainfall data have been taken from field surveys and secondary surveys for almost the last 40 years (1980 to 2020). The Mann Kendall (MK) and Sen's Slope estimate (SSE) tests have been applied to recognise the standingtrend and the SSE test has been used to discover the existing trend and extent of change in rainfall over time. The rainfall data has been taken from ten rain gauge stations surrounding the study area. The relevant maps were prepared using Remote Sensing and the rainfall distribution pattern was analyzed with the help of the kriging interpolation technique of GIS. The annual MK test shows a negative trend, but the season-wise MK test is showing a positive trend during the monsoon season. The SPI result describes that the study area is not getting adequate rainfall, which may create harmful effects on agricultural productivity. The study suggests taking proper drought management programs to combat this situation.

Key words – Rainfall, Trend analysis, Mann Kendall test, Sen's slope estimator, Standard precipitation index, Interpolation.

1. Introduction

Water is essential for every livelihood and there is no replacement for it. Water is consumed for agricultural activities, industrial purposes, power supply, transportation, domestic purposes, and many other useful activities. Rainfall is the prime source of freshwater worldwide. Consistent with Arvind *et al*. (2017), it plays a major role in the global hydrological cycle. According to the World Meteorological Organization, rainfall distribution is uneven throughout the world. In the year 2020, the annual rainfall was higher than usual in the monsoon-influenced regions like North America, Africa, and South-east Asia. India got maximum rainfall during monsoon in the year 2020 after 1994. Along with State of the Global Climate (2021), for India, 2020 was the wettest monsoon later in 1994 that results in floods in many Indian states. Central Water Commission report 2019-20 shows that India had about 3880 billion cubic meters of annual rainfall. Several studies have chronologically been made to evaluate the trend of rainfall worldwide. Wang *et al*. (2020) studied annual rainfall trends in adelta of the River Yangtze in China. They used monthly rainfall data of 15 stations from 1691 to 2015. The innovation trend analysis method was applied to analyze the trend of monthly rainfall data and Theil-Sen approach and MannKendall (MK) tests were also applied to understand the extent of the trend. The results showed a monotonous trend between 1961 to 2016 and all the trend magnitudes were positive.

Alahacoon and Edirisinghe (2021) studied rainfall trends over Srilanka from 1989 to 2019. They used daily gridded rainfall data from 1989 to 2019. They used the MK test to determine the rainfall trend and Sen's-slopeestimator (SSE) to understand the extent of the trends. They also classified Srilanka into four climatic zones such as (*i*) wet, (*ii*) dry, (*iii*) intermediate, and (*iv*) semi-arid. The result showed that the rainfall in the wet zone has been increased from 1898 to 2019 in every district of Srilanka and all over annual rainfall also increased. Longobardi and Villani (2010) worked on seasonalbesides annual rainfall trends in Italy. They used both the *t* and MK tests to examine seasonal besides annual rainfall data. They found a negative annual rainfall trend but the seasonal trend during summer is showing a positive trend. The result displays a severe trend in the past 30 years. Khan *et al*. (2019) worked on diurnal rainfall data starting from 1951 to 2007 in the Malaysian peninsular. They also incorporated the SSE and MK tests to investigate the change in rainfall. Monte Carlo simulation was also applied to describe the seasonal trend of rainfall based on climatic zones. The overall trend shows no change in annual rainfall. Roy (2013) examined rainfall trends from 1957 to 2006 over the north-eastern portion of Bangladesh. Linear regression model and correlation coefficient have been used to understand the rainfall trends. The result shows a negative association between time and rainfall which means the amount of rainfall is decreasing in the north-eastern region of Bangladesh. The main two factors in reducing rainfall are (a) deforestation and (b) desertification which create ecological imbalances besides climate change.She also stated the impact of low rainfall in the study region. Low rainfall can create a massive ecological imbalance in tea plantations and also soil erosion and landslides. Frazier and Giambelluca (2017) analyzed Hawaiian rainfall from 1920 to 2012. They also used the SSE and MK tests to analyze the data. Results of that period showed that most of the regions follow a negative seasonal rainfall trend. The Hawaiian Islands become drier over the year.

In India, rainfall is the main source of irrigational water, maximum rainfall occurs due to the south-west monsoon. Numerous works have been done on analyzing the rainfall characteristics of India. Saini *et al*.(2020) worked on 117 years of rainfall trends in the west-coast plains and agro-climatic hilly areas of India. According to the Planning Commission of India, this is the 12th agro-climatic area among 15 agro-climatic areas of India. These regions conclude five states of India such as Goa, Maharasthra, Karnataka, Kerala, and Tamilnadu which are confined by the Arabian Sea in the west, and the Western Ghats in the east. Gridded rainfall data of 117 years were obtained from IMD Pune. The MK and linear regression (LR) methods were used to understand rainfall trends. The outcome of the study was a reduction in rainfall in July, winter seasons, and January while an intensifying trend was found from August to September. Nagalapalli *et al*. (2019) analyzed the rainfall trend of the Vaigai river basin, Tamilnadu from 1901 to 2015. They also incorporated the MK and SSE tests to find out the rainfall trends. The Vaigai river basin falls under the Theni district of Tamilnadu. This river provides irrigational water to the Theni district. Theni district faces four seasons that is winter consisting of January and February, pre-monsoon consisting of March to May, south-west monsoon consisting of June to September and north-east monsoon consisting of October to December. The result showed decreasing rainfall trend in June and maximum rainfall occurred in the north-east monsoon season. The study revealed that the Theni district gets maximum rainfall during the north-east monsoon than the south-west monsoon. Because of the presence of the Western Ghats, this area gets plenty amount of rainfall in both the monsoon seasons. Patra *et al.* (2012) detected a rainfall trend over Orissa from 1871 to 2006. They adopted the MK and SSE tests to identify the trends. The study reveals that Orissa gets the highest rainfall during the monsoon. The annual rainfall trend declines from the 1960s to the

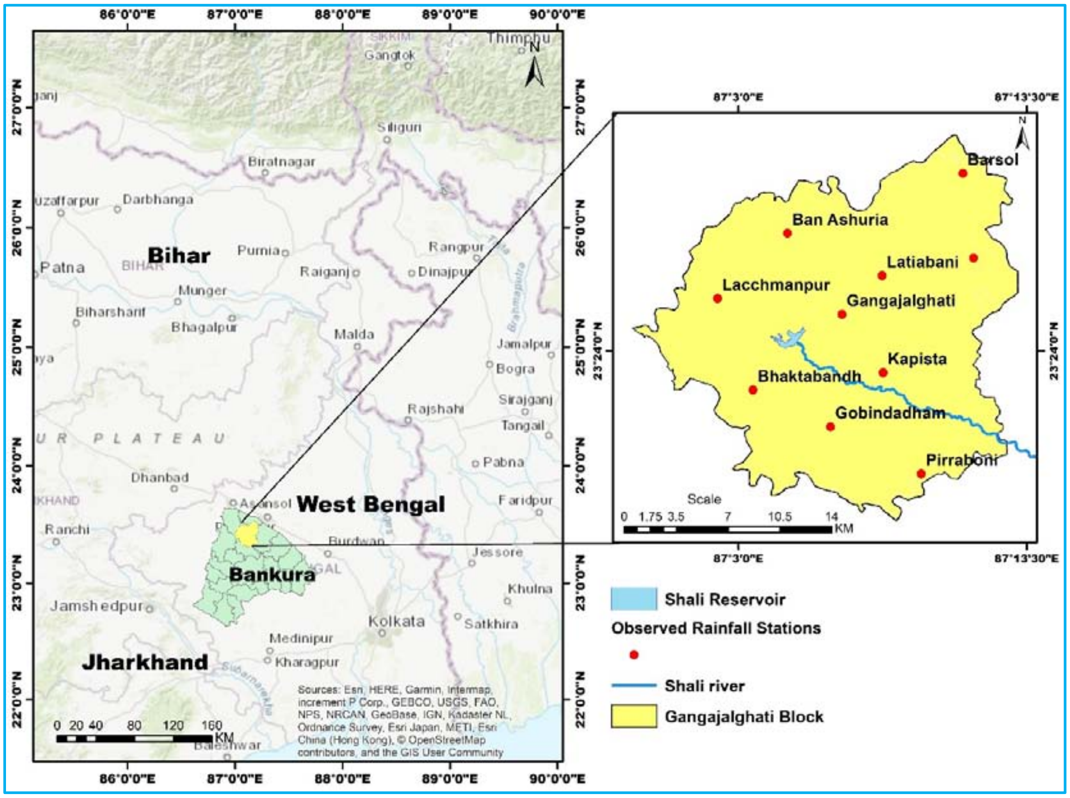

Fig. 1. Map of the location of the selected study area

1980s. All over annual and seasonal trend shows a negative trend in Orissa.

John and Brema (2018) investigated the rainfall trend of the Vamanapuram basin, Kerala. With the help of the MK test, they analyzed the trend of 30 years of rainfall data. The trend analysis showed a positive trend inthe first eight months while a negative trend in the last four months. Kundu *et al*. (2014) worked on rainfall analysis for the whole of India from 1871 to 2011. They studied annual, seasonal, and monthly rainfall trends over 141 years. They also applied the MK and SSE tests to get the trend and its extent. They explored that in 141 years, north-west and peninsular India had a positive trend in July-August than other parts of India. In the north-eastern part of India, the amount of monsoonal rainfall has decreased. Except, the peninsular and north-west portion all over India is facing a reduction in rainfall due to atmospheric circulation, and thereduction of monsoon season rainfall might affect agricultural production.

Taxak *et al*. (2014) examined rainfall data of the Waingana basin from 1901 to 2012. Wainganga is the sub-basin of the Godavari river. Maharashtra, Madhya Pradesh, and parts of Chattisgarh are the main parts of this basin. A negative trend in annual rainfall has been found from the Mann Kendall trend analysis and Sen slopes estimator. An overall decrease has been noticed throughout the region. They also mentioned some probable reasons for it such as global warming, deforestation, and other anthropogenetic activities. Gajbhiye *et al*. (2016) studied 102 years of rainfall data from the Sindh river basin. Sindh river basin covers a major portion of the Madhya Pradesh district. It has a sub-tropical climate, maximum rainfall gets from July to September. The MK and SSE tests have been used to get the trend and its extent. Both positive and negative trend has been found due to unequal sharing of rainfall. Sanikhani *et al*. (2018) observed rainfall patterns of central India (Madhyapradesh and Chattisgarh) from 1901 to 2010. They used the revised MK and SSE tests to signify the rainfall trend. Trend analysis showed no trend in January and October months and the rainfall trend is not similar to all the stations.

All of the above-mentioned literature reviews on rainfall trend analysis have cleared that the MK and SSE tests are the most useful techniques to identify the rainfall trend of a region. In this paper, detailed work has been done on rainfall trend analysis on the Shali reservoir area in West Bengal using about 40 years of rainfall data. The MK and SSE tests have been performed to signify the

Shali reservoir　　Sluice gate of Shali reservoir　　Shali river

Fig. 2. Images of the Shali reservoir system, taken during the field visit

trends. Shali reservoir is located in Bankura district that receives a lesser amount of rainfall than other districts of West Bengal as per India Meteorological Department (IMD) records. Some portions of the Bankura district are considered drought-prone regions. So Standard Precipitation Index (SPI) method has been adopted to identify the inadequate rainfall months and years in the study area.

2. Study area

Shali water reservoir, shown in Figs. 1-2, is a medium irrigation project governed by the Irrigation & Waterways Department, Government of West Bengal, situated in the Gangajalghati block, Bankura district of West Bengal. Gangajalghati block is located in the north-west portion of the Bankura district. This man-made reservoir was formed at the origin of the Shali river. Shali river is a tributary of the Damodar river. This region undergoes the hottest summer and coldest winters and a low amount of rainfall than other districts of West Bengal.

Maximum rainfall occurs during the monsoon. Shali reservoir stores the monsoonal rainfall and provides irrigational water through the Shali river (river lift irrigation technique). The topography of the area is undulating with an average height of around 110 meters and covered with laterite soil. Annual rainfall varies between 700 mm to 1200 mm. The region experiences four distinct seasons, such as winter consisting of January, February; pre-monsoon consisting from March to May; monsoon consisting from June to September; and post-monsoon consisting from October to December is consistent with Halder *et al*. (2020).

3. Data & methodology

The foremost objective of the study was to observe the rainfall trend over the Shali reservoir area. Monthly rainfall data from 1980 to 2020 of ten stations, namely Ban Asuria, Barsol, Bhaktabndh, Gangajalghati, Gobindadham, Kapista, Lachmanpur, Latiabani, Nityanandapur and Pirrabani of Gnagajalghati block were obtainedfrom the IMD website https://www. imdpune.gov.in. The MK and SSE tests have been applied to signify the trend. An interpolation method has been done to observe the distribution of rainfall. SPI was also incorporated to identify rain deficit months.

3.1. *MK test*

The MK test is a non-parametric test that is applied to determine trend detection of time series data like rainfall, temperature, etc. It analyzes the positive or negative trends of the given data. In the MK statistics ‘β’ is calculated using the following equations (1-2) given by Mann (1945) and Kendall (1975).

$$\beta = \sum_{i=1}^{p-1} \sum_{j=i+1}^{p} \operatorname{sgn}\left(P_{rj} - P_{ij}\right) \tag{1}$$

$$\operatorname{sgn}\left(P_{rj} - P_{ri}\right) = \begin{cases} +1, & >\left(P_{rj} - P_{ri}\right) \\ 0, & =\left(P_{rj} - P_{i}\right) \\ -1, & <\left(P_{rj} - P_{i}\right) \end{cases} \tag{2}$$

where, the P_{rj} and P_{ri} are values of consecutive data, and p represents time-series data counts. The positive ‘β’ value represents high tendency and the negative value represents low inclination.

Generally, more than 10 records are used in the MK statistics. The variance of the records has been calculated as follows in equations (3-4).

$$\operatorname{Var}(\beta) = \frac{p(p-1)(2p+5) - \sum_{i=1}^{m} tc_k(k)(k-1)(2k+5)}{18} \tag{3}$$

where, thetc_k is the ties countable for the k^{th}specified sample.

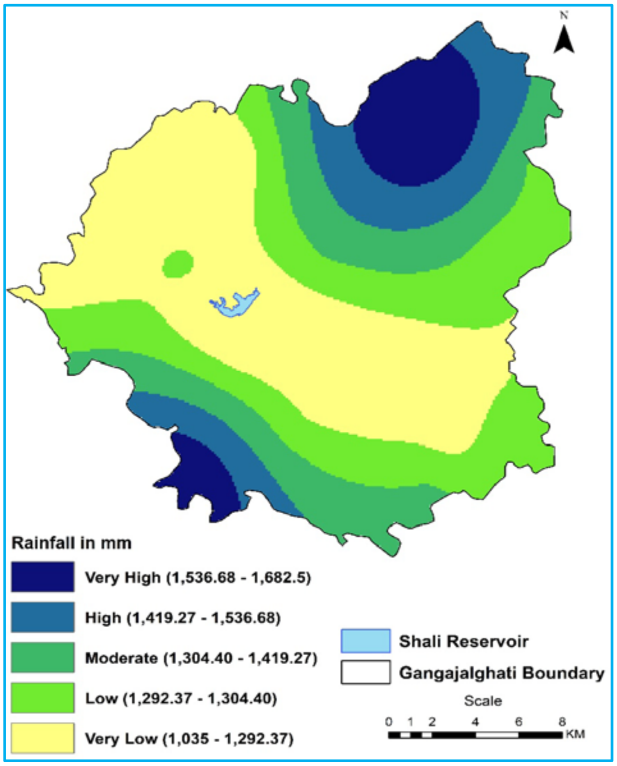

Fig. 3. Annual rainfall distribution of Gangajalghati block from 1980 to 2020

The last step of the MK statistics is to calculate the standard mean deviation *Zc* given in equation (4).

$$Zc = \begin{cases} \dfrac{\beta - 1}{\sqrt{Var(\beta)}}, & \beta > 0 \\ 0, & \beta = 0 \\ \dfrac{\beta + 1}{\sqrt{Var(\beta)}}, & \beta < 0 \end{cases} \tag{4}$$

where an increasing trend means a positive *Zc* value and a decreasing trend means a negative *Zc* value.

3.2. *Sen Slope Estimator*

The Sen slope introduced by Sen (1968) signifies the extent of the trend which is obtained by the MK test. The steps for calculation of Sen slope are as follows in equation (5).

$$Q = \frac{(ri - rj)}{(j - k)} \qquad i = 1, 2, ..., p \tag{5}$$

where *p*denotes sample size, *Q* is the slope, where, *rj* and *ri* denote data values at *j* and *k* (*j*>*k*) times.

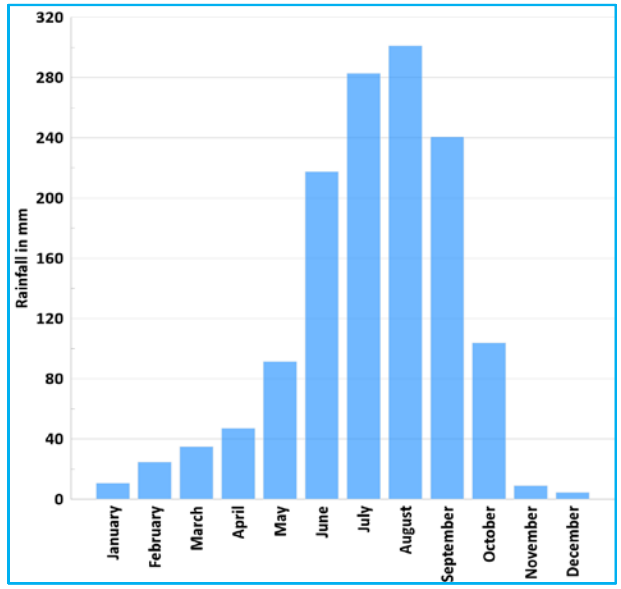

Fig. 4. Monthly mean rainfall of the Gangajalghati block from 1980 to 2020

3.3. *Standard Precipitation Index (SPI)*

The Standard Precipitation Index (SPI) is a statistical method formulated by McKee *et al.* (1993). It analyzes historical rainfall data to compute the degree of wetness. The degree of wetness can be calculated as 3,6,12 and 24 total rainfall data. A 1-month SPI provides short-term weather conditions, three months' SPI specifies seasonal rainfall, six and nine months' SPIs provide a medium trend of rainfall and twelve months' SPI signifies a long-term rainfall pattern as addressed by Khan *et al.* (2008). The SPI is calculated by dividing the standard deviation of the difference between normalized seasonal rainfall and its long-term seasonal mean (equation 6). McKee *et al.* (1993) classified SPI values into seven categories as (a) extremely wetwhen SPI ≥+2.00, (b) very wet when +1.50<SPI<1.99, (c) moderately wet when +1.00<SPI<+1.49,(d) normal when -0.99<SPI<+0.99, (e) moderately dry when -1.00<SPI<-1.49,(f) severely drywhen -1.50<SPI<-1.99 and extremely drywhen SPI ≤-2.00.

$$\text{SPI} = \frac{(r_{ij} - r_{im})}{\sigma} \tag{6}$$

where,r_{ij} denotes seasonal rainfall at i^{th} raingauge station for j^{th} observation, r_{im} denotes a long-term seasonal mean value and σ denotes standard deviation.

3.4. *Kriging interpolation method*

Kriging is a form of regression that delivers a least-squares estimation of data. Kriging applies *z*-scores to

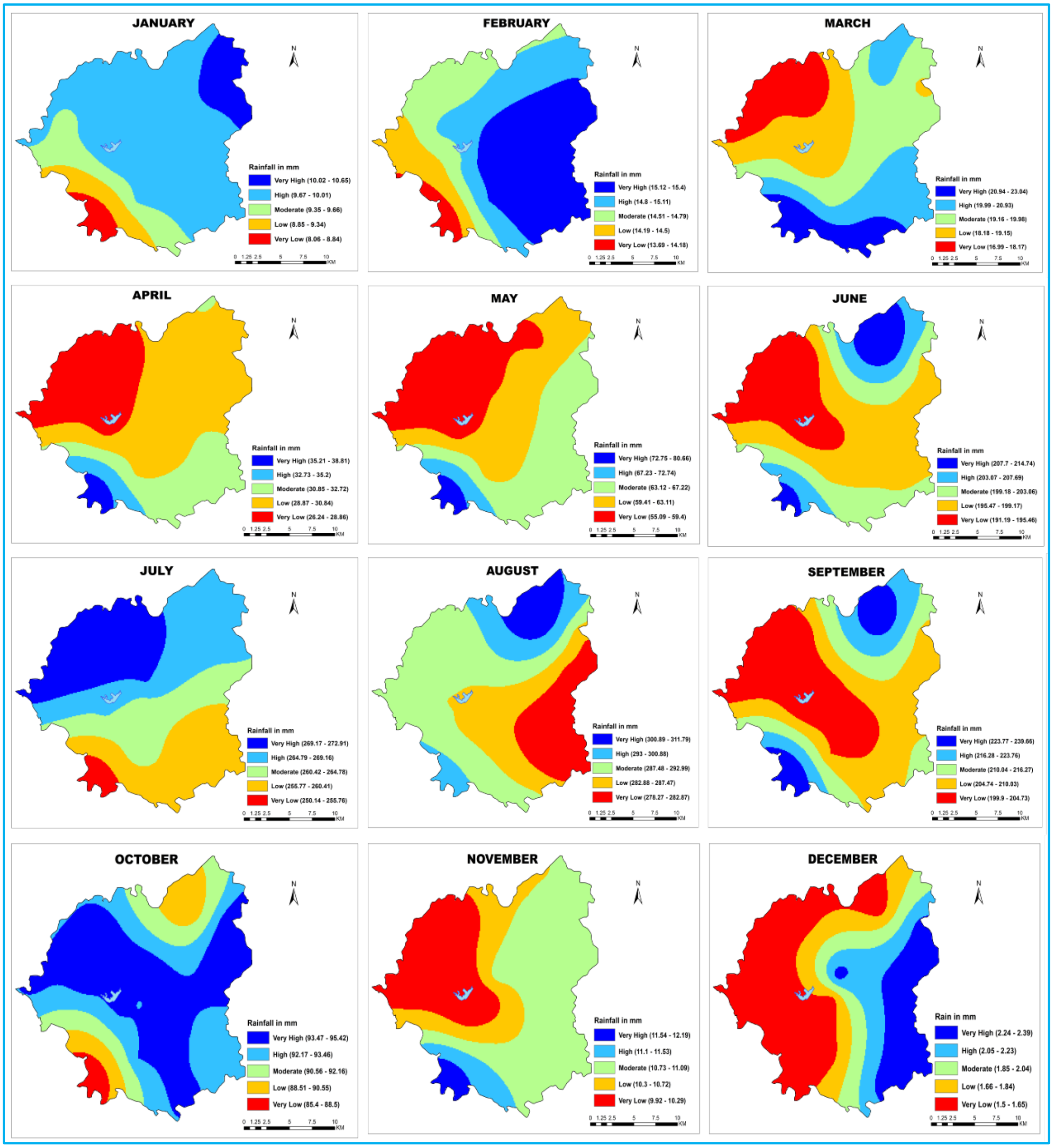

Fig. 5. Monthly rainfall distribution of the Gangajalghati block from 1980 to 2020

create an estimated surface model from a spatial account of a scattered set of considered data points. There are different categories of kriging like regression kriging, cokriging, universal kriging etc. The universal kriging method is more popular than other methods of kriging. This method is purely dependent on geographic locations, a very useful method of applied geography. This method was used by Meng *et al.* (2013) as a GIS software packages.

$$\hat{z}(s_0) = \sum_{i=1}^{n} \lambda_i z(s_i) \qquad (7)$$

where, $\hat{z}(s_0)$ denotes location value s_0 needs an interpolation; $z(s_i)$ denotes sampled values; and λ_i regulated by semi-variogram modelling, denotes weightages to be given to all ungauged locations.

4. Results and discussion

4.1. *Annual rainfall*

Shali reservoir plays an important role in the Gangajalghati block. It stores rainfall and provides irrigational water throughout the season. So it is necessary to study rainfall data of the Gangajalghati block. For this purpose, about 40 years (1980 to 2020) of rainfall data of the ten gram-panchayats of the Gangajalghati block have been collected. Fig. 3 shows the annual mean rainfall distribution pattern of the Gangajalghati block from 1980 to 2020.

The highestgauged rainfall was 1682.50 mm in the year 2007 and the lowest gauged rainfall was 1035.6 mm in the year 1982 and the mean annual rainfall was 1368.37 mm. Fig. 3 has been prepared by the kriging interpolation method, ten main gram panchayats rainfall data of Gangajalghati block has been considered here.

The ten gram panchayats are Ban Ashura, Barsol, Bhaktabandh, Gobindadham, Gangajalghati, Kapisa, Lacchmanpur, Nityanandapur, Latiabani, and Pirraboni. Shali reservoir is situated under Gangajalghati gram panchayat. Here annual rainfall has been categorised into five classes, *i.e*., Very High (1536.68 to 1682.50), High (1419.27 to 1536.68), Moderate (1304 to1419.27), Low (1292 to 1304.40) and Very Low (1035 to 1292.37). In 40 years, maximum annual rainfall occurred in the Barsol gram panchayat area and the minimum rainfall occurred in the Shali reservoir area. So it is clear that the Shali reservoir area got the minimum amount of rainfall than other parts of the Gnagajalghati block, which might affect the water level of the Shali reservoir.

4.2. *Monthly rainfall*

A mean monthly rainfall analysis has been conducted to identify which month had the maximum rainfall throughout the study period (Table 1). The study reveals that maximum rainfall occurred in August at around 300 mm and the minimum rainfall in December at around 4 mm (Fig. 4). The monthly rainfall distribution of the Gangajalghati block from 1980 to 2020 has been created by using the kriging interpolation method, 12 maps have been prepared and shown in Fig. 5 to give a clear view of the month-wise 40 years of rainfall data. The amount of rainfall has been categorised into five groups such as, very high, high, moderate, low and very low. The scale range is not the same for all months, it varies according to monthly rainfall data. For January, the very high rainfall category ranges between 10.19 to 10.65 mm category while very low rainfall ranges between 8.06 to 8.84 mm. In January, the Shali reservoir receives a high amount of rainfall, which is good for irrigation during the winter season. In February, the Shali reservoir received high (14.8 - 15.11 mm) to moderate (14.51 - 14.8 mm) rainfall. From March, the amount of rainfall has decreased in the Shali reservoir area. It falls under the low (18.18 - 19.15 mm) category. In April, the Shali reservoir area receives very low rainfall.

In May, rainfall was found to be increased in the Gangajalghati block, a very high category of around 75 to 80 mm, but the Shali reservoir area had very low rainfall (55 to 58 mm). In June, a rapid increase in rainfall has been found. The very high rainfall category ranges between 207 to 214 mm, whereasthe very lower rainfall group varies between 191 to 195 mm. Though the amount of rainfall increases in June, theShali reservoir gets a lower amount of rainfall than other parts of the Gangajalghati block. The rainfall was foundmore in July than in June. In July, the very high rainfall category fluctuates between 269 to 273 mm, while the very low category varies between 250 mm to 255 mm. Shali reservoir area had high category rainfall which means 264 to 269 mm. In August, the very high rainfall ranges between 300 mm to 312 mm, but very low rainfall ranges between 278 to 282 mm. Though Shali reservoir got a low (282 to 287 mm) amount of rainfall than other parts of Gangajalghati block during August. Since September, rainfall has started to decrease, the very high category ranges between 223 to 240 mm and the very low category ranges between 199 to 205 mm.

Shali reservoir falls under the very low category during September. During October very high rainfall category range decreased to 94 to 96 mm and the very low category to 85 to 88 mm. This time the Shali reservoir area has been found in a very high rainfall category (93 to 96 mm). A rapid decrease in rainfall has been observed during November and December. In November and December,the extremely high and extremely low rainfall category ranges between 11 to 13 mm in November and 2 to 3mm in December whereas 9 to 11 mm in November and 1.5 to 1.7 mm in December. Shali reservoir area had a low and extremely low amount of rainfall in both months (Fig. 5).

4.3. *Seasonal rainfall*

The study area experiences four distinct climatic seasons, such as (a) winter consisting of January to February, (b) pre-monsoon consisting of March to May, (c) monsoon consisting of June to September and (d) post-monsoon consisting of October to December. All seasons are classified into five classes based on the amount of rainfall, such as very high, high, moderate, low and very low (Fig. 6). Class ranges are different in different seasons. In the winter season,thevery high rainfall class varies from 24 to 26 mm whereas the very low rainfall

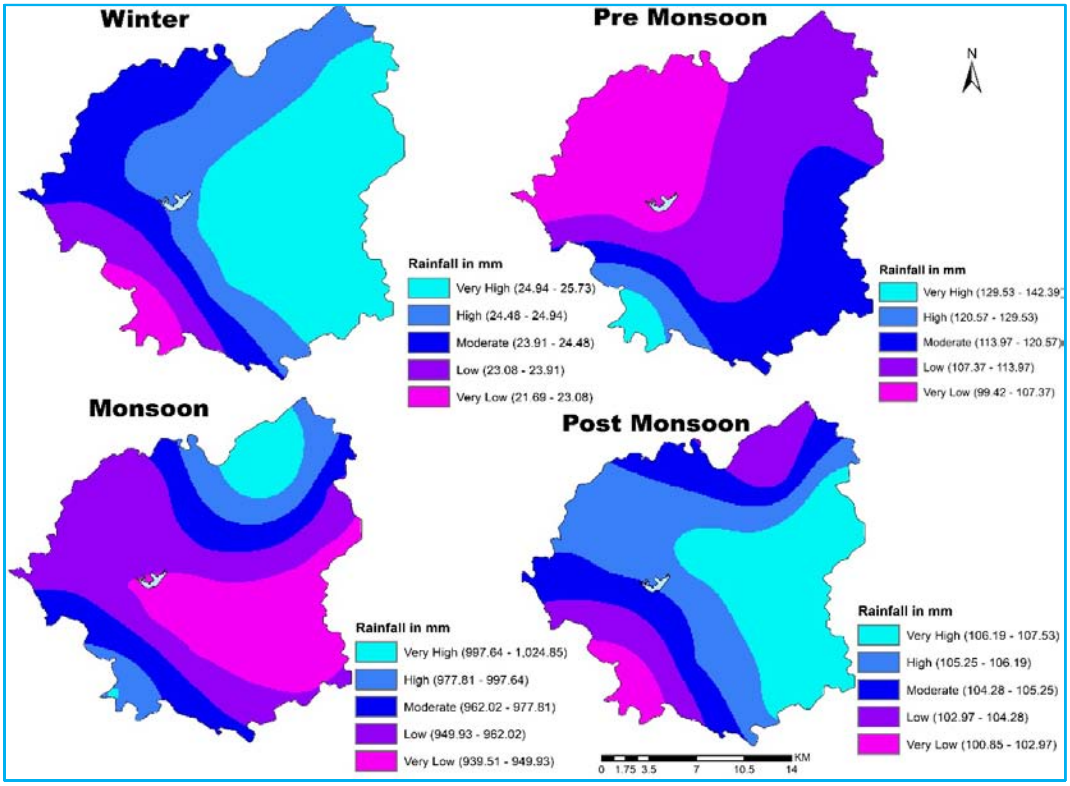

Fig. 6. Seasonal rainfall distribution of Shali reservoir area

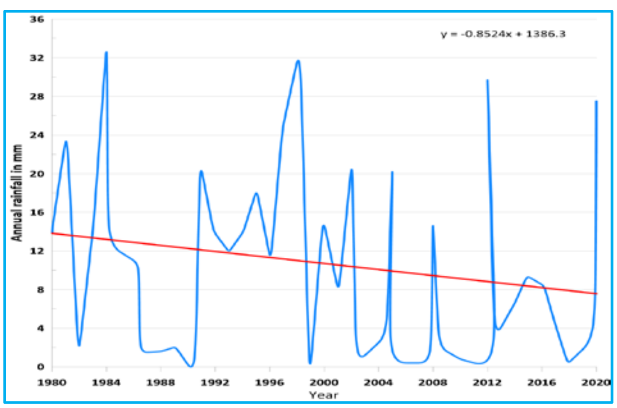

Fig. 7. The annual rainfall trend of the Gangajalghati block from 1980 to 2020

class isbetween 20 to 22 mm. In the winter season, the Shali reservoir area gets a moderate to a high amount of rainfall than other parts of the Gangajalghati block. In the pre-monsoon season, rainfall started to increase. Then the 129 to 140 mm rainfall category isconsidered very high and the 99 to 107 mm rainfall category is very low. In this season,the Shali reservoir had only 99 to 106mm of rainfall which is considered a very low rainfall class. During the monsoon season amount of rainfall has increased. The study area receives the maximum amount of rainfall during the monsoon season with the effect of the south-west monsoon. Monsoonal rainfall is very important for agricultural activities. Shali reservoir was made to store rainfall and provide irrigational water throughout the year but the study reveals that Shali reservoir gets 939 to 950 mm rainfall during the monsoon season which is very low than other parts of the Gangajalghati block. On the contrary, the rainfall has decreased during the post-monsoon season but the Shali reservoir area gets moderate to high rainfall between 104 to 107 mmduring post-monsoon (Table 3).

4.4. *Rainfall trend analysis*

The MK statistics and SSE test have been used to signify the annual, monthly and seasonal rainfall trend of 40 years' rainfall data of the Shali reservoir area. The annual rainfall trend of the Gangajalghati block shows a decreasing trend from 1980 to 2020. (Fig. 7) The maximum and minimum amounts of rainfall have been observed at 1682.5 mm and 1035.6 mm in 2007 and 1982. The mean and standard deviation values of annual rainfall are 1368.37 and 164.93. The CV (coefficient of variance) value is 12.05 %, which indicates less variability in the rainfall amount from 1980 to 2020. The Mann Kendall and Sen Slope Estimator values are -0.59 and -1.48 which also signify a negative trend in annual rainfall during the study period.

TABLE 1

Descriptive statistics for monthly rainfall from 1980 to 2020 of Gangajalghati block

Months	Mean	Standard Deviation (SD)	Coefficient of Variance (CV) in (%)
January	10.69	9.75	91.23
February	24.74	21.60	87.33
March	35.03	27.10	77.35
April	47.04	28.51	60.60
May	91.41	32.44	35.49
June	217.51	82.17	37.77
July	282.85	75.83	26.80
August	301.12	65.63	21.79
September	240.61	72.31	30.05
October	103.77	58.17	56.05
November	9.01	10.96	121.57
December	4.54	7.15	157.29

TABLE 2

MK and SSE values of monthly rainfall from 1980 to 2020 of Gangajalghati block

Months	MK	SSE	Trend type
January	-1.23	-0.43	Negative
February	-1.13	-0.18	Negative
March	-0.7	-1.15	Negative
April	0.79	0.26	Positive
May	0.01	0.003	Low Positive
June	-0.21	-0.27	Negative
July	0.24	0.12	Positive
August	0.44	0.54	Positive
September	0.53	0.37	Positive
October	-0.22	-0.17	Negative
November	0.12	0.003	Low Positive
December	-0.41	0	Negative

TABLE 3

Descriptive statistics for seasonal rainfall from 1980 to 2020 of Gangajalghati block

Season	Mean	Standard Deviation (SD)	Coefficient of Variance (CV) (%)
Winter	35.43	24.79	69.97
Pre-monsoon	173.49	52.12	30.04
Monsoon	1042.10	145.36	13.94
Postmonsoon	117.34	58.77	50.08

TABLE 4

MK and SSE values of seasonal rainfall from 1980 to 2020 of Gangajalghati block

Season	MK	SSE	Trend type
Winter	-1.21	-0.41	Negative
Pre-monsoon	0.03	0.07	Low Positive
Monsoon	0.38	0.78	Positive
Postmonsoon	-0.38	-0.3	Negative

TABLE 5

Classification of category wise SPI values

Extremely wet	:	SPI≥ 2.00
Very wet	:	+1.50<SPI<+1.99
Moderately wet	:	+1.00<SPI<+1.49
Normal	:	-0.99<SPI<+0.99
Moderately dry	:	-1.00<SPI<-1.49
Severely dry	:	-1.50<SPI<-1.99
Extremely dry	:	SPI≤-2.00

In monthly trend analysis, each month rainfall data from 1980 to 2020 have been analysed (Fig. 8). The MK and SSE values of January are -1.23 and -0.43, which determine a negative trend in January rainfall. The amount of rainfallin January is decreasing from 1980 to2020. In February, the MK and SSE values are -1.13 and -0.18, which also signify a negative trend in rainfall. The MK and SSE values in March are -0.7 and -1.15, which define a negative trend but in April the MK and SSE values are 0.79 and 0.26 which signify a positive trend, the amount of rainfall has been increased in April from 1980 to 2020. Whereas, in May the MK and SSE values are 0.01 and 0.003 which represent a very low positive trend. The MK and SSE values of June are -0.21and -0.27, which means a negative rainfall trend during June. While in July, August and September the MK and SSE values are showing a positive trend which means the amount of rainfall has increased in these months from 1980 to 2020. The MK and SSE values of July are 0.24 and 0.12, August are 0.44 and 0.54 and September are 0.53 and 0.37 but in Octoberthe MK and SSE values are -0.22 and -0.17 which determine a negative trend, whereas in November the MK and SSE values are 0.12 and 0.003 which signifya low positive trend. In December the MK trend value is -0.41 which means a negative trend (Table 2).

In this study, the coefficient of variance (CV) is used to measure the variability level of rainfall from 1980 to 2020. Here month-wise CV has been calculated to

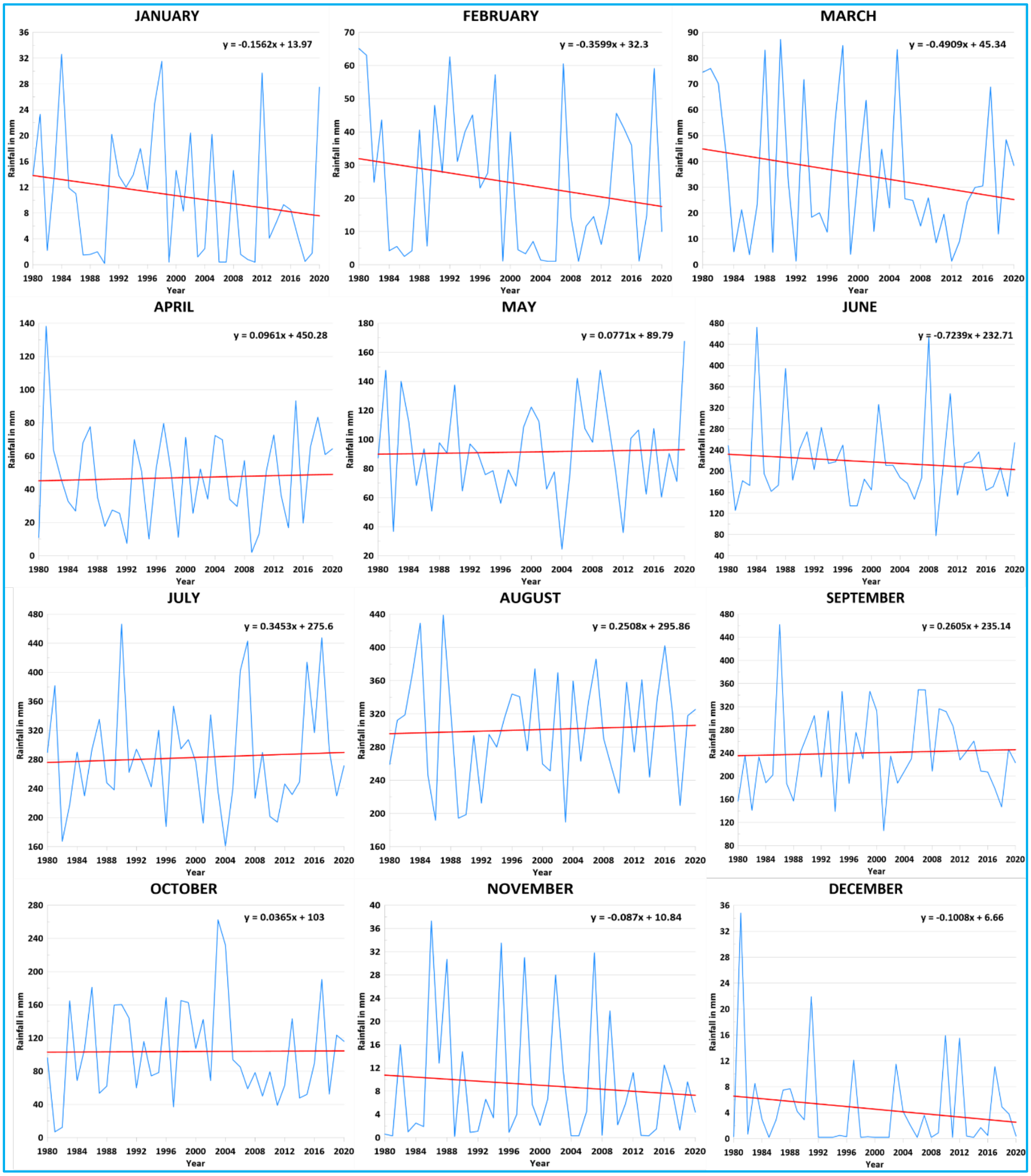

Fig. 8. The monthly rainfall trend from 1980 to 2020 in Gangajalghati block

understand the variability of the rainfall. The result shows maximum variability in December and minimum in August.

The seasonal Mann Kendall and Sen Slope analysis reveals (Fig. 9) that winter (January to February) has anegative trend. The MK and SSE values of winter are -1.21 and -0.41, whereas during the pre-monsoon (March to May) the MK and SSE value are 0.03 and 0.07, which means a very low positive trend but the monsoon (June to September) has a positive rainfall trend. The MK and SSE values of monsoon are 0.38 and 0.78. Again during post-monsoon, the rainfall trend is negative. The MK and SSE values of post-monsoon are -0.38 and -0.3 (Table 4).

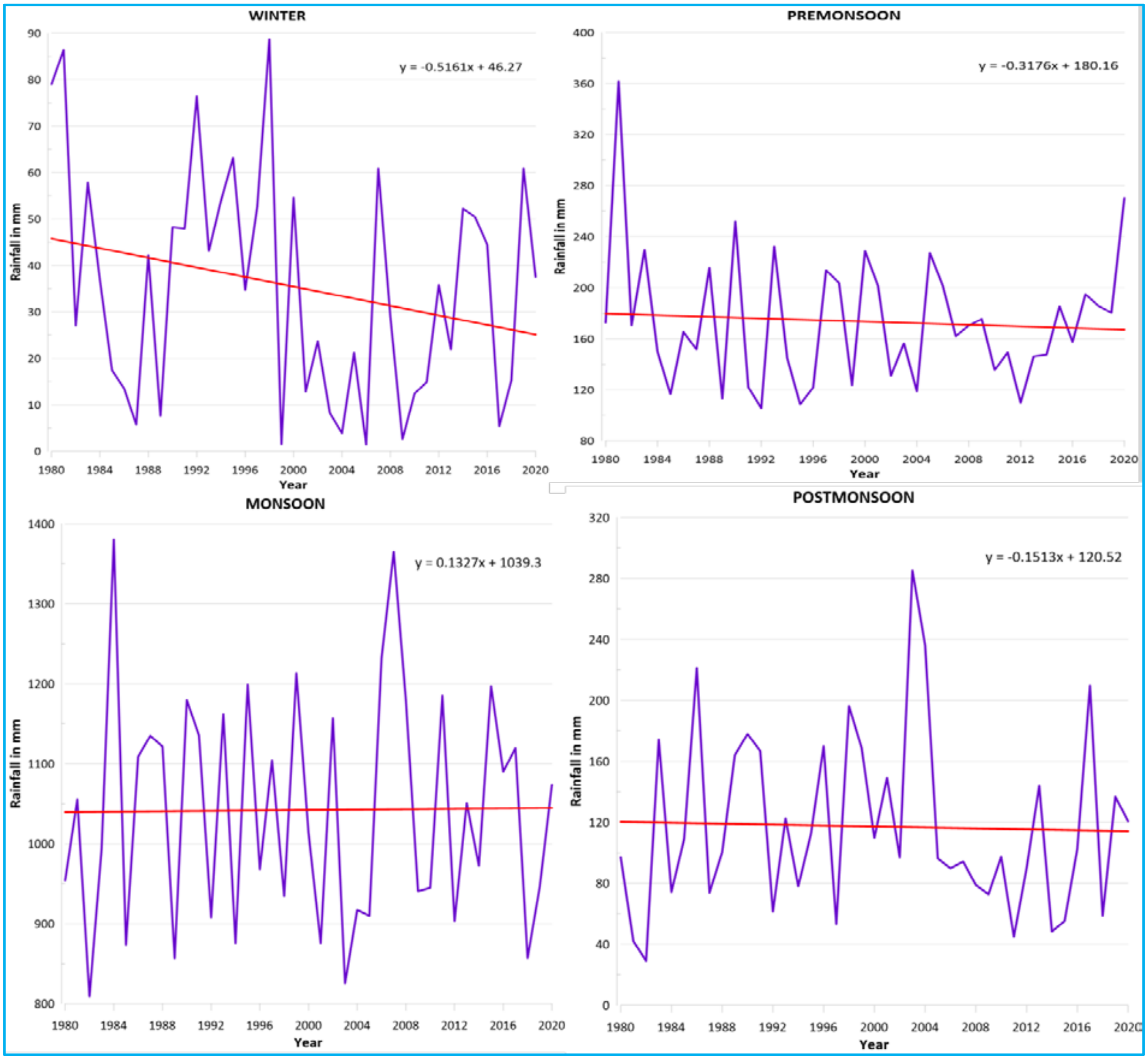

Fig. 9. Seasonal rainfall trend from 1980 to 2020 of Gangajalghati block

4.5. *Rainfall deficiency analysis*

The study area is located in the Bankura district where annual rainfall is insufficient compared to other districts of West Bengal. Some parts of the Bankura district are considered drought-prone regions. So, to identify the degree of wetness SPI has been applied. Here, three months' SPI, six months' SPI, and twelve months' SPI have been incorporated. According to the National Climatic Data Center,three months' SPI measures short-term weather conditions, six months' SPI measures medium-term precipitation, and twelve months' SPI measures long-term precipitation. Based on T.B. McKee *et al*. (1993), the classification of all SPI values has been detailed in Table 5.

The obtained three months' SPI, six months' SPI, andtwelve months' SPI values are listed in Tables 6, 7, and 8, respectively, according to the background colours shown in Table 5.

According to three months' SPI calculations, 1984 had the maximum number of extremely wet months (June, July and August) and the maximum number of extremely dry months in 2010. In the winter season, 1981, 1992 and 1996 had moderate to extremely wet conditions, but 1989, 1999, 2001, 2009, 2014 and 2017 had moderate to extremely dry conditions.

The positive SPI values were found in 1981, 1982, 1983, 1990, 1998, 2005 and 2020 during the pre-monsoon season, whereas 1986, 1987, 1989, 1995 and 1999 were

TABLE6

Three months' SPI values

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1980	NA	NA	0.48	0.10	1.08	1.40	1.53	0.74	-0.19	-0.57	-0.22	0.24
1981	0.12	1.72	1.98	2.03	2.22	0.17	0.09	-0.73	0.05	-0.91	-0.71	-0.80
1982	0.62	0.70	1.06	1.21	0.36	-0.72	-2.00	-1.39	-1.89	-1.44	-1.83	-0.95
1983	-0.46	-0.38	0.92	1.07	1.18	-0.46	-1.16	-0.66	0.02	1.18	0.89	0.97
1984	0.47	0.26	-0.84	-0.99	-1.04	2.29	2.29	2.81	1.05	0.51	-0.62	-0.15
1985	-0.47	-0.15	-0.02	-0.80	-0.07	0.53	0.63	0.54	-0.20	-0.04	-0.34	0.38
1986	-0.86	-0.67	-1.21	-1.07	-0.58	0.06	-0.04	-1.07	-0.65	-0.40	0.91	0.90
1987	1.12	0.23	-1.30	-0.87	-1.59	-2.16	-1.36	0.74	1.59	1.58	0.22	-0.24
1988	0.68	-0.18	0.46	0.07	-1.02	-0.28	-0.61	-0.55	-1.17	-1.18	-0.84	-0.49
1989	-0.22	-1.55	-1.64	-2.56	-0.73	0.10	0.54	0.29	0.44	0.00	0.04	-0.37
1990	0.19	1.06	1.21	1.20	0.55	-0.16	0.93	0.05	0.60	-0.21	0.84	0.37
1991	0.19	-0.09	0.69	0.10	-1.17	-0.94	0.10	0.69	0.95	0.80	0.63	1.51
1992	2.37	2.66	0.18	-0.03	-0.08	0.58	0.80	0.40	-0.20	-0.97	-0.91	-0.37
1993	-0.68	-1.11	-0.58	0.13	-0.40	0.31	-0.24	0.58	1.07	1.48	1.14	0.07
1994	0.53	1.10	0.75	1.19	-0.27	0.89	0.53	0.70	-0.28	-0.97	-1.32	-0.75
1995	-0.08	0.50	0.08	-1.37	-1.70	-1.19	0.23	0.13	0.98	0.92	1.80	1.47
1996	2.08	0.42	-0.01	-0.73	-1.48	0.22	0.04	1.03	0.25	0.34	-0.97	-0.44
1997	-0.17	0.47	0.40	1.43	0.93	0.32	0.00	0.82	1.06	0.56	0.02	0.10
1998	2.00	1.48	1.93	1.12	-0.09	-1.97	-1.66	-1.83	-1.07	-0.18	0.86	1.14
1999	0.14	-1.96	-3.61	-3.51	0.52	0.57	0.85	0.28	0.96	1.23	1.31	0.56
2000	-0.59	0.21	-0.19	0.02	0.16	-0.46	-0.70	-1.57	-0.49	-0.59	0.17	-0.78
2001	-1.47	-1.89	-0.29	-0.10	0.72	1.11	0.41	-0.26	-1.27	-0.95	-0.55	0.07
2002	0.18	-0.13	-0.01	0.42	0.62	1.14	0.28	-0.06	-0.23	-0.22	0.26	-0.34
2003	-0.06	-0.22	0.90	0.82	0.04	0.08	-0.38	-0.45	-1.16	0.47	0.91	1.68
2004	-0.14	-0.57	-0.54	0.23	0.14	0.10	-0.58	0.35	0.67	1.74	1.15	0.93
2005	0.30	0.91	1.61	1.03	0.05	-0.46	-0.18	-0.37	-0.70	0.06	0.56	1.30
2006	-0.60	-0.91	-1.89	-0.72	-0.39	0.28	0.89	0.61	0.96	0.06	0.36	-0.84
2007	-0.85	0.72	1.16	0.92	0.08	-0.55	1.58	1.46	2.40	0.80	0.97	-0.93
2008	0.39	-0.08	-0.43	-0.98	-0.49	0.64	0.79	0.68	0.17	-0.44	-0.67	-0.88
2009	-2.11	-1.86	-0.42	-1.34	1.44	-0.91	-0.45	-0.92	0.40	0.34	-0.01	-0.67
2010	-1.35	-0.51	-0.31	-0.28	-0.17	-0.28	-0.94	-2.13	-2.20	-2.11	-0.81	-0.08
2011	0.55	0.10	-0.78	-0.30	-0.06	1.68	0.83	0.65	-0.73	-0.90	-0.99	-1.15
2012	0.57	0.50	0.18	-0.26	-1.61	-1.83	-1.29	-0.67	-0.01	-0.26	-0.06	0.14
2013	0.98	0.17	-0.74	-0.26	1.07	0.76	-0.19	-0.52	-0.34	1.75	1.78	1.90
2014	-1.63	0.14	0.32	-0.45	-1.61	-1.56	-0.90	-0.58	-0.45	-0.84	-1.16	-1.14
2015	-0.31	-0.27	-0.25	0.62	0.14	0.32	1.11	1.08	0.53	-1.38	-1.75	-1.62
2016	-0.49	0.32	0.30	-0.78	-0.68	-0.60	-0.63	0.39	0.65	0.89	-0.32	-0.95
2017	-1.64	-1.89	-0.61	-0.17	0.62	0.46	1.59	1.51	1.42	1.45	1.41	1.67
2018	0.11	-0.90	-1.69	1.02	0.44	-0.07	-0.81	-0.26	-0.28	-0.76	-1.26	-0.54
2019	0.41	1.25	0.72	0.73	0.43	-1.15	-1.75	-1.87	-0.80	0.40	0.74	0.97
2020	1.00	0.38	1.06	1.20	2.62	1.84	0.04	-0.60	-1.81	-1.00	-1.26	-0.42

TABLE 7

Six months' SPI values

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1980	NA	NA	NA	NA	NA	1.54	1.53	1.09	0.60	0.75	0.43	-0.16
1981	-0.60	0.37	1.13	1.63	2.68	1.14	0.94	0.14	0.08	-0.60	-1.08	-0.33
1982	-0.78	-0.53	-0.19	1.12	0.58	-0.29	-1.40	-1.31	-2.15	-2.50	-2.21	-2.19
1983	-1.52	-1.96	-0.38	0.64	0.75	-0.13	-0.73	-0.27	-0.28	0.10	0.00	0.41
1984	1.11	0.82	0.59	-0.58	-0.80	2.15	2.07	2.71	2.19	2.02	2.07	0.80
1985	0.33	-0.74	-0.34	-0.99	-0.24	0.44	0.34	0.49	0.06	0.38	0.19	-0.10
1986	-0.23	-0.58	-0.18	-1.36	-0.88	-0.40	-0.42	-1.35	-0.61	-0.36	-0.28	-0.19
1987	-0.15	0.82	0.42	0.01	-1.24	-2.85	-1.74	0.30	0.60	0.33	0.66	1.27
1988	1.54	0.06	-0.17	0.28	-1.04	-0.21	-0.66	-0.95	-1.26	-1.31	-1.00	-1.36
1989	-1.23	-1.19	-1.29	-2.04	-1.24	-0.42	-0.02	0.03	0.40	0.33	0.20	0.16
1990	-0.05	0.28	0.19	0.93	0.95	0.33	1.31	0.19	0.42	0.50	0.50	0.60
1991	-0.24	0.68	0.49	0.03	-1.12	-0.73	0.06	0.34	0.39	0.59	0.87	1.53
1992	1.43	1.56	1.47	1.54	1.98	0.56	0.74	0.34	0.08	-0.07	-0.21	-0.43
1993	-1.10	-1.21	-0.81	-0.25	-0.85	0.02	-0.27	0.43	1.09	0.90	1.11	0.90
1994	1.41	1.29	0.25	1.06	0.38	1.12	0.93	0.60	0.20	-0.29	-0.12	-0.63
1995	-1.01	-1.16	-0.82	-1.22	-1.11	-1.31	-0.20	-0.40	0.32	0.77	1.24	1.53
1996	1.40	1.74	1.37	0.95	-1.01	0.12	-0.26	0.64	0.28	0.21	0.32	-0.04
1997	0.21	-0.86	-0.37	1.03	0.89	0.38	0.53	1.11	1.09	0.35	0.62	0.90
1998	1.05	0.45	1.00	1.88	0.83	-0.69	-1.15	-1.93	-2.05	-1.31	-0.85	-0.37
1999	-0.23	0.52	0.58	-2.00	-0.13	0.01	0.27	0.42	1.12	1.43	1.00	1.00
2000	1.01	1.21	0.31	-0.33	0.13	-0.67	-0.77	-1.58	-0.75	-0.98	-1.19	-0.83
2001	-0.79	-0.18	-1.05	-0.59	0.06	0.97	0.31	-0.06	-0.47	-0.38	-0.60	-1.21
2002	-0.94	-0.68	-0.13	0.28	0.35	1.10	0.35	0.11	0.40	-0.01	0.04	-0.44
2003	-0.30	0.10	0.01	0.53	-0.18	0.39	-0.12	-0.50	-1.03	0.02	0.17	-0.01
2004	0.34	0.68	1.49	0.00	-0.22	-0.20	-0.57	0.36	0.61	0.90	0.94	0.95
2005	1.61	1.24	1.48	0.83	0.48	0.31	0.16	-0.41	-0.94	-0.14	-0.01	0.05
2006	-0.11	0.29	0.85	-0.97	-0.79	-0.25	0.64	0.47	0.97	0.64	0.65	0.52
2007	-0.13	0.44	-0.14	0.43	0.37	-0.07	1.84	1.51	2.01	1.65	1.69	1.87
2008	0.74	0.82	-1.26	-0.63	-0.56	0.43	0.48	0.52	0.45	0.24	0.15	-0.24
2009	-0.66	-1.04	-1.22	-1.80	0.73	-1.23	-0.91	-0.39	-0.14	-0.12	-0.81	0.03
2010	0.12	-0.23	-0.96	-0.75	-0.47	-0.53	-1.13	-2.26	-2.13	-2.17	-2.28	-2.09
2011	-1.89	-0.85	-0.59	-0.06	-0.11	1.48	0.69	0.61	0.34	-0.01	-0.03	-1.16
2012	-0.79	-0.86	-1.04	-0.03	-1.04	-1.89	-1.47	-1.24	-0.93	-1.14	-0.65	-0.05
2013	-0.08	-0.12	-0.33	0.26	0.86	0.47	-0.36	-0.17	0.07	1.14	0.77	0.79
2014	1.46	1.65	1.95	-0.93	-1.31	-1.55	-1.15	-1.15	-1.26	-1.29	-1.19	-0.89
2015	-0.93	-1.29	-1.32	0.28	-0.11	0.14	1.26	1.12	0.59	-0.06	0.05	-0.03
2016	-1.47	-1.62	-1.21	-0.98	-0.48	-0.60	-0.97	0.15	0.26	0.19	0.07	0.21
2017	0.64	-0.68	-1.38	-0.67	-0.03	0.18	1.51	1.73	1.49	2.10	2.01	2.03
2018	1.30	1.14	1.32	0.76	-0.05	-0.61	-0.44	-0.17	-0.35	-1.17	-0.96	-0.56
2019	-0.71	-0.73	-0.25	0.64	1.01	-0.91	-1.46	-1.75	-1.40	-0.90	-0.98	-0.27
2020	0.52	0.70	1.25	1.29	2.26	2.24	0.45	0.45	-0.35	-0.70	-1.26	-1.92

TABLE 8

Twelvemonths' SPI values

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1980	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.63
1981	0.69	0.99	0.96	1.19	1.34	0.35	0.23	0.29	0.58	0.04	0.06	0.24
1982	0.10	-0.24	-0.08	-0.21	-0.89	-0.51	-1.47	-1.34	-2.14	-2.09	-2.04	-2.28
1983	-2.21	-2.09	-2.10	-2.06	-1.86	-2.04	-1.53	-1.23	-0.49	0.28	0.23	0.29
1984	0.37	0.28	-0.05	-0.12	-0.30	1.38	2.12	2.50	2.24	1.96	1.95	1.86
1985	1.75	1.72	1.76	1.61	1.92	0.88	0.44	-0.06	-0.14	0.08	0.08	0.07
1986	0.03	0.00	-0.09	-0.01	-0.13	-0.35	-0.45	-1.40	-0.71	-0.80	-0.61	-0.45
1987	-0.47	-0.46	-0.41	-0.39	-0.70	-1.39	-1.21	0.70	0.68	0.30	0.31	0.17
1988	0.16	0.21	0.39	0.32	0.30	1.05	0.74	-0.70	-1.31	-1.32	-1.42	-1.48
1989	-1.45	-1.44	-1.64	-1.72	-1.41	-1.49	-0.84	-0.65	-0.12	-0.14	-0.20	-0.10
1990	-0.11	0.14	0.36	0.54	0.44	0.24	0.84	0.28	0.41	0.82	0.82	0.70
1991	0.76	0.52	0.50	0.40	0.12	0.18	-0.15	0.64	0.52	0.59	0.56	1.20
1992	1.14	1.23	0.98	1.01	1.45	1.61	1.48	1.24	0.79	0.51	0.53	-0.18
1993	-0.27	-0.42	-0.28	-0.20	-0.52	-0.45	-0.94	-0.33	0.69	0.83	0.89	0.86
1994	0.91	1.10	0.99	1.10	1.13	1.28	1.58	1.23	0.23	0.07	-0.03	-0.05
1995	-0.05	-0.18	-0.18	-0.62	-0.51	-1.24	-0.83	-0.98	-0.07	0.47	0.98	0.98
1996	0.95	0.86	0.86	0.95	0.90	1.43	0.86	1.58	0.91	0.53	-0.01	-0.04
1997	-0.08	-0.01	0.04	0.47	0.53	0.07	0.47	0.38	0.82	0.70	0.92	1.03
1998	1.14	1.05	1.31	0.94	0.80	0.49	0.08	-1.13	-1.34	-0.50	-0.60	-0.77
1999	-1.04	-1.08	-1.52	-1.72	-0.94	-0.40	0.01	0.59	1.24	1.08	0.98	0.96
2000	0.93	1.04	1.03	1.18	0.95	0.60	0.26	-0.30	-0.61	-1.20	-1.21	-1.22
2001	-1.21	-1.32	-1.11	-1.13	-1.19	-0.30	-0.34	-0.19	-0.90	-0.64	-0.64	-0.65
2002	-0.50	-0.47	-0.54	-0.33	-0.53	-0.54	-0.40	-0.33	0.26	0.04	0.13	0.11
2003	-0.02	0.09	0.29	0.09	-0.08	-0.28	-0.31	-0.35	-1.02	0.16	0.08	0.13
2004	0.12	0.02	-0.16	-0.04	0.03	-0.17	-0.14	0.65	1.26	0.90	0.89	0.81
2005	0.90	1.01	1.16	1.02	1.00	0.96	1.27	0.50	-0.09	0.12	0.12	0.15
2006	-0.01	-0.18	-0.47	-0.43	-0.31	-0.13	0.34	0.49	1.23	0.38	0.41	0.34
2007	0.32	0.57	0.73	0.65	0.68	0.38	1.17	1.36	1.79	1.84	1.86	1.84
2008	1.85	1.57	1.37	1.33	1.47	1.89	0.81	0.86	-0.06	0.02	-0.06	-0.07
2009	-0.18	-0.20	-0.06	-0.20	0.32	-0.83	-1.08	-0.91	-0.63	-0.61	-0.59	-0.61
2010	-0.60	-0.48	-0.53	-0.37	-1.00	-0.28	-0.65	-1.83	-2.47	-2.60	-2.55	-2.33
2011	-2.27	-2.25	-2.17	-2.06	-2.28	-0.99	-0.69	-0.02	0.03	-0.08	-0.10	-0.29
2012	-0.10	-0.04	-0.12	-0.08	-0.39	-2.00	-1.52	-1.48	-1.34	-1.26	-1.05	-0.97
2013	-1.12	-1.04	-1.02	-1.02	-0.39	0.11	-0.31	-0.24	-0.13	1.25	1.06	0.96
2014	0.91	0.95	1.01	0.79	0.35	0.06	0.42	0.33	0.00	-1.71	-1.70	-1.70
2015	-1.58	-1.64	-1.65	-1.15	-1.25	-0.80	0.27	0.20	0.06	-0.02	-0.02	-0.02
2016	-0.06	0.05	0.07	-0.36	-0.16	-0.37	-1.66	-0.74	-0.24	-0.12	-0.12	-0.14
2017	-0.19	-0.32	-0.28	-0.06	-0.01	0.20	1.42	0.96	0.94	2.04	2.09	2.10
2018	2.02	1.93	1.81	2.09	1.91	1.64	0.68	0.59	0.32	-0.97	-1.05	-0.92
2019	-0.90	-0.58	-0.48	-0.91	-0.61	-1.00	-1.46	-1.79	-1.48	-0.74	-0.64	-0.77
2020	-0.60	-0.82	-0.60	-0.39	-0.09	0.87	0.64	0.74	0.27	-0.23	-0.31	-0.39

considered the driest years. During the monsoon season, 1980, 1984, 2007, 2015 and 2017 were under moderate to extremely wet zone but in1982, 1987, 1998, 2010, 2012 and2019 were found under the rainfall deficit category having negative SPI values.

In the post-monsoon season, the observed intensity of rainfall has been reduced, 1993, 1995, 1999, 2004, 2013 and 2017 had more excessive rainfall than normalatthat time. On the contrary, in 1982, 2010, 2014, 2015 and2020 we have undergone the rainfall scarcity zone. In six months' SPI 1984, 2007 and 2017 were considered the wettest years because of having very wet to extremely wet months. While 1982, 2010 and 2014 were considered drought-prone years due to severely dry to extremely dry conditions.

The six months SPI calculation is that 1988, 1992, 1994, 1996 and 2000 had moderate to extremely wet conditions during winter and 1983, 1989, 1993, 1995 and 2016 were under dry conditions. Low to high positive values have been found in 1981, 1992, 1998 and 2020 during the pre-monsoon season. While 1989, 1995, and 2009 were extreme dry classes. The selected study area obtains the maximum amount of rainfall during the monsoon season, but the six months' SPI result shows that in 40 years, only 1980, 1984, 1997, 2007, 2015 and 2017 received a positive SPI value during the monsoon season. But the number of dry years is more than the wet seasons, *i.e*., 1982, 1987, 1998, 2010, 2012, 2014 and 2019 respectively.

Table 8 shows twelve months,of SPI calculations. Twelve months' SPI describes long-term weather conditions. In the twelve months' SPI calculations, 1984 is considered the wettest year and has extremely wet to very wet months during monsoon and post-monsoon seasons. In contrast, 1992, 1994 and 2007 had extremely wet to moderately wet rainfall during the monsoon to post-monsoon season. The dry monsoon years were 1982, 1983, 2010, 2012 and 2019.

Rainfall deficit months are also noticed in winter and pre-monsoon seasons, 1983, 1989, 1999, 2001, 2011, 2013 and 2015 have experienced moderate dry to extremely dry during winter to pre-monsoon seasons, while 1985, 1992, 2008 and 2018 have undergone moderately wet to severe wet conditions. During the post-monsoon, the rainfall started to decline.

The study shows that during post-monsoon 1988, 2000, 2010, 2012 and 2014 had faced moderate to extremely dry phases and 1984, 2007, 2013 and 2017 had positive SPI values which means moderate wet to extremely wet.

5. Conclusions

Shali reservoir plays a significant character in agricultural advances in the Gangajalghati block. The 40 years'of rainfall data stated that the annual average rainfall of the Gangajalghati block is around 1368 mm and the Shali reservoir got lower rainfall than other parts of the block. From 40 years ofmonthly mean rainfall analysis, it has been found that the amount of rainfall increased from June and reached maximum position during August. After August, the amount of rainfall started to decrease. Monthly rainfall distribution maps visualize that the Shali reservoir has an ample amount of rainfall during January, February, July and October than in other parts of the Gangajalghati block.

The study area experiences four climatic seasons, *i.e*., winter, pre-monsoon, monsoon and post-monsoon, highest rainfall takes place in the monsoon season from June to September. The 40 years' rainfall study clarifies that the Shali reservoir area has a very low amount of rainfall in the monsoon than in other parts of the block, which may cause low agricultural production but in winter and in post-monsoon moderate amount of rainfall occurred in the reservoir area.

The MK and SSE tests have been done to signify the rainfall trends. An annual decreasing trend has been found bythe MK and SSE tests. In the monthly trend analysis, a high positive trend was noticed in April, August and September. Generally, monsoonal rainfall begins in June but the MK test shows a negative trend during June and very low positive trends from Julybut ahigh positive trend in August and September. Again negative trend has been noticed in post-monsoon (October to December). So, a clear view has been found from 40 years of rainfall analysis that the amount of rainfall is increasing during pre-monsoon and monsoon season but in pre-monsoon, the increasing trend is very low. Although, a negative trend has been observed in winter and post-monsoon season. It may affectwinter crop cultivationin the study area.

Also, Standard Precipitation Index gives a broad layout of rainfall deficit years. All the three months, six months and twelve months SPI analyses show that the Gangajalghati block did not get normal rainfall throughout the study period. Therefore, it is advisable to take proper measures to combat this situation. The present study delivers a detailed view of rainfall trends over 40 years of the Shali reservoir area. It is supposed that this study will help similar studies for other regions.

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