RESEARCH PAPER

RAINFALL AND DROUGHT TENDENCIES IN RAJSHAHI DIVISION, BANGLADESH

Md. Abdullah Al Mamun[1], Syed Mahbubur Rahman[2*], Md. Nezam Uddin[3], Md. Sultan-Ul-Islam[4], Khairul Arifin M. N.[5], Syed Mustafizur Rahman[6]

[1]Department of Mathematics, Bangladesh Army University of Engineering and Technology, Natore 6431, Bangladesh
[2]Faculty of Business Administration, American International University-Bangladesh (AIUB), Dhaka 1229, Bangladesh
[3]Institute of Environmental Science, University of Rajshahi, Rajshahi 6205, Bangladesh
[4]Department of Geology and Mining, University of Rajshahi, Rajshahi-6205, Bangladesh
[5]Geosciences Department, Faculty of Science and Information Technology, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia
[6]Geophysics Laboratory, Department of Electrical and Electronic Engineering, University of Rajshahi, Rajshahi 6205, Bangladesh
***Corresponding author:** rahman_s_m@yahoo.com
Received: July 20th, 2020 / Accepted: February 16th, 2021 / Published: April 1st, 2021
https://DOI-10.24057/2071-9388-2020-124

ABSTRACT. Insufficient rainfall results in water shortage and eventually leads to drought. This research has investigated drought by utilizing standardize precipitation index in monthly mean rainfall data for 30 years from 1988 to 2017 in Rajshahi division, a region in the northwestern part of Bangladesh. Estimated indices have identified that the years 1992, 1994, 2006, and 2012 experienced moderate to severe droughts, and the year 2010 suffered from extreme drought. Non-parametric and linear trend analyses have shown that the number of draughts in the study area has been growing. The study area is thus judged as moving forward to experience more droughts from lack of water due to rainfall deficit, especially during monsoon. This region has already started to experience a shortage of rainwater, approximately 18%, in the monsoon season. This shortage is likely to affect the volume of surface water and thus the groundwater recharging, which would distort irrigation for agriculture in the region. This work would therefore assist in policy-making addressing the watering system of the region to ensure smooth agricultural production.

KEY WORDS: Drought, Rainfall, Trends, Rajshahi, Bangladesh

CITATION: Md. Abdullah Al Mamun, Syed Mahbubur Rahman, Md. Nezam Uddin, Md. Sultan-Ul-Islam, Khairul Arifin M. N., Syed Mustafizur Rahman (2021). Rainfall And Drought Tendencies In Rajshahi Division, Bangladesh. Geography, Environment, Sustainability, Vol.14, No 1, p. 209-218 https://DOI-10.24057/2071-9388-2020-124

ACKNOWLEDGEMENTS: We are thankful to the Bangladesh Meteorological Department (BMD) for the data used in this research. We are also indebted to two anonymous reviewers for their comments and suggestions.

Conflict of interests: The authors reported no potential conflict of interest.

INTRODUCTION

Drought is the deficiency of precipitation that results in a disturbance of water cycle and thereby water shortage. The agriculture sector suffers the most due to lack of precipitation and subsequent serious hydrological imbalance, making drought one of the most complex natural hazards (Heim 2002). Bangladesh experiences dry weather because of low precipitation for a period of six months from November to April, and many parts of the country have already experienced an increasing number of droughts with varying severity in recent years (Uddin et al. 2020; Alamgir et al. 2020; Hoque et al. 2020; Adhikary et al. 2013). The northwestern part of the country is highlighted as a severely drought-prone area because of irregularity and high variability in rainfall (Rahman et al. 2020; Uddin et al. 2020; Rahman et al. 2019; Shahid and Behrawan 2008). Agricultural production in the northwest part plays a pivotal role in the overall economy of the country. Most of the surface water bodies including swamps, beals, rivers and canals dry up during the dry season. To meet irrigation approximately 75% of water demand were sourced from groundwater which led to a sharp rise in the ratio of surface to groundwater, as previous literature identified (Shahid and Hazarika 2010; Rahaman et al. 2016; Bari and Anwar 2000), which was not sustainable from both environment and climate change perspectives. A paradigm shift towards a cross-sectoral water management regime is yet to be achieved (Islam et al. 2020), where additional knowledge about the influence of climate variables would play a key role.

The drought of Bangladesh, especially in the northwestern part, has already attracted numerous researchers. Many studies during the last decade have projected that the northwestern part of Bangladesh would become more vulnerable to droughts (Shahid 2011; Shahid and Behrawan 2008). Although there is an agreement about greater agricultural losses from droughts (Ahammed et al. 2020; Alauddin and Sarker 2014; World Bank 2013; Alam et al. 2012), various contributions show different opinions about recent droughts in the region (CEGIS 2013; Miyan 2015; Nury and Hasan 2016), which creates a room for further investigation.

Investigations have been conducted to assess drought severity, vulnerability, historical trend and also to predict using for instance Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index, and analytical hierarchical process (Alamgir et al. 2020; Uddin et al. 2020; Hoque et al. 2020; Ahammed et al. 2020; Miah et al. 2017), However, use of statistical tools is hardly found in the existing literatures, particularly focusing Bangladesh.

SPI, designed by McKee et al. (1993), for the above purposes is relatively simple, can describe drought through water supply condition, and is based on rainfall data alone. It has the strength to be employed for a variety of timescales. SPI is a tool to monitor short-term water supplies to observe soil moisture, which is important for agricultural production, and also to observe groundwater supplies and streamflow in the long run (Hayes et al. 1999). Researchers from several countries including Argentina, Canada, China, Hungary, India, Korea, Spain, Turkey, and the USA, and are using this index to monitor droughts (Nury and Hasan 2016; Quiring and Papakryiakou 2003; Hayes et al. 1999; Wilhite et al. 1985). While several pieces of research utilized SPI, most of the studies have not considered the whole water cycle, instead considered groundwater extraction for irrigation (Rahaman et al. 2016). The amount of water required has rarely been addressed in water management.

In this backdrop, this research, in addition to rainfall, the primary factor in governing drought phenomena (Edossa et al. 2014), intends to investigate the shortage of water supply in northwest Bangladesh. Since rainfall is one of the basic natural resources in the study area, this work reinvestigates recent droughts, trends, and shortage of water from rainfall with the estimation of drought indices using the statistical tools.

MATERIALS AND METHODS

Study area

The study area is Rajshahi division, which is located in the northwestern part of Bangladesh (Fig. 1). Most of the region is low-lying plain land except the uplifted and undulated Barind Tract. It is surrounded by India in the west, Rangpur division in the north, Dhaka division in the east, and Khulna division in the south. The area is lying at the west of the river Jamuna and the north of the river Ganges.

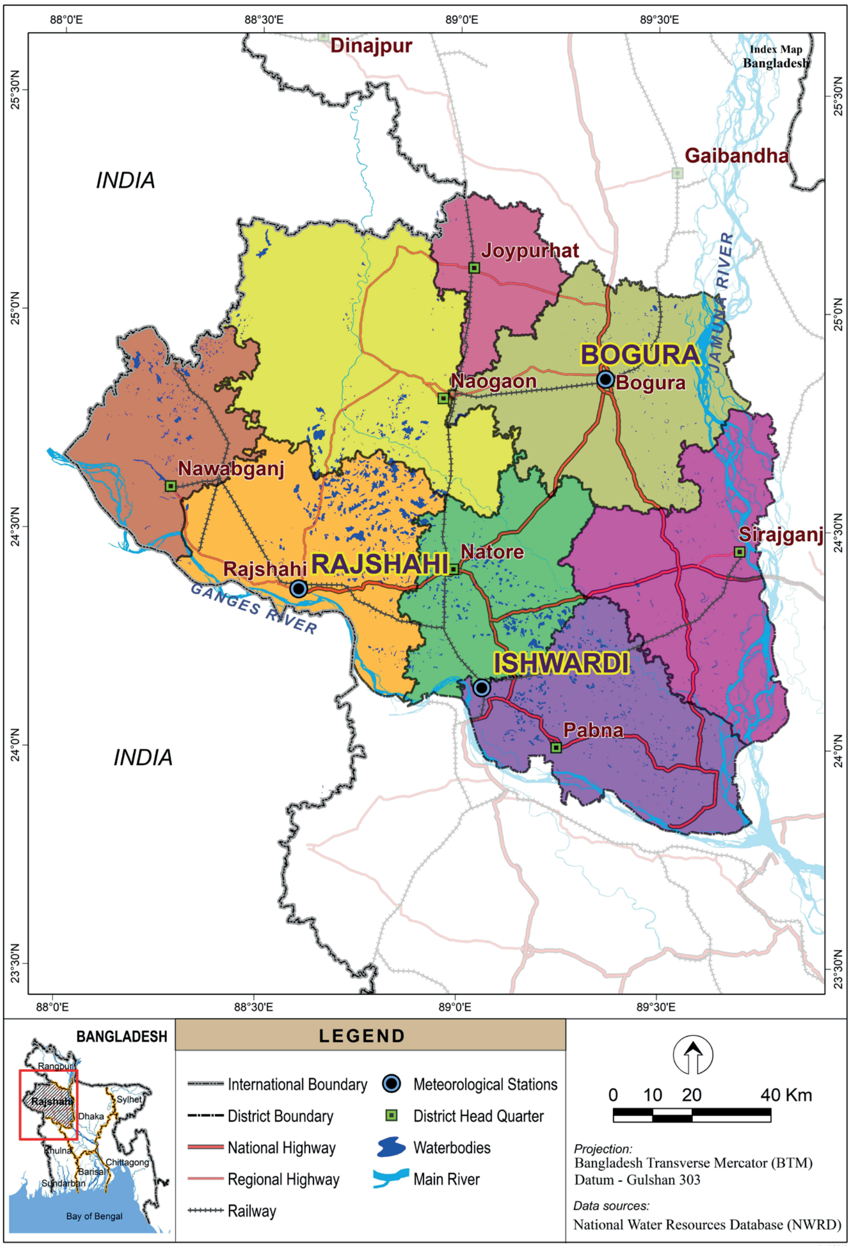

Fig. 1. Location map of the study area

MATERIALS

Daily rainfall data for 30 years from 1988 to 2017 recorded in three meteorological stations in the region namely Rajshahi, Ishwardi, and Bogura (Fig. 1) by the Bangladesh Meteorological Department (BMD) have been used for the analysis.

METHODS

Standardized Precipitation Index (SPI)

SPI conveys the rainfall departure with respect to the rainfall probability distribution function. SPI computation requires long-term rainfall data to determine the probability distribution function which is then transformed to a normal distribution with mean zero and standard deviation of one (Edwards and McKee 1997). It is the fitting of a gamma probability density function and the gamma distribution, g(x) can be written as shown below.

$$g(x) = \frac{x^{a-1} e^{\frac{-x}{\beta}}}{\beta^a \Gamma(a)} \qquad x, a, \beta > 0 \tag{1}$$

where,

$$logmean = \overline{X}_{ln} = \ln(X)$$

$$U = \overline{X}_{ln} - \frac{\sum \ln(X)}{N}$$

$$\beta = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \; and \; a = \frac{\overline{X}}{\beta}$$

The cumulative probability is then can be written as:

$$G(x) = \int g(x)dx \tag{2}$$

Since Equation 1 is undefined at x = 0 (no rainfall event), the cumulative probability can be modified further as written below:

$$H(x) = q + (1-q)G(x) \tag{3}$$

where, q is the probability of zero or for no rainfall.
The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance of one. Transferred Z is said to be SPI (Edwards and McKee 1997). Such approximate conversion given by Abromowitz and Stegun (1965) is as shown below:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) 0 < H(x) \le 0.5 \tag{4}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) 0.5 < H(x) \le 1 \tag{5}$$

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \qquad 0 < H(x) \le 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \qquad 0.5 < H(x) \le 1$$

where,
C_0=2.515517; c_1=0.802583; c_2=0.010328; d_1=1.432788; d_2=0.189269 and d_3=0.001308 (Abramowitz and Stegun 1965).
With the estimated Z or SPI values drought status can be classified as shown in Table 1.

Mann-Kendall Test

The Mann-Kendall (MK) test is used for determining monotonic trends and is based on ranks (Helsel and Hirsch 2002). This is a test for correlation between a sequence of pairs of values. The significance of the detected trends can be obtained at different levels of significance (generally taken as 0.05). It has been suggested by the World Meteorological Organization (WMO) to determine the existence of statistically significant trends in climate and hydrologic data time series. The MK test statistic and the sign function are calculated using the below formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \tag{6}$$

$$sign(x_j - x_i) \begin{cases} +1 x_j > x_i \\ 0 x_j = x_i \\ -1 x_j < x_i \end{cases} \tag{7}$$

where *n* is the number of data, *x* is the data point at times i and j (*j* > *i*). The variance of S is as follows:

$$\text{var}(S) = \left[n(n-1)(2n-5) - \sum_{i=1}^{m} t_i i(i-1)(2i+5)\right] / 18 \tag{8}$$

Where t_i is the number of ties of extent *i*, and *m* is the number of tied groups. For *n* larger than 10, the standard test statistic *Z* is computed as the MK test statistic as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} if \; S > 0 \\ 0 \; if \; S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} if \; S < 0 \end{cases} \tag{9}$$

The presence of a statistically significant trend is evaluated using the *Z* value. Positive values of *Z* indicate upward trends, while negative values show downward trends. To test for either an increase or decrease in monotonic trend (a two-tailed test) at a level of significance, H_0 should be rejected if the $|Z| > Z_{1-\frac{a}{2}}$, where $Z_{1-\frac{a}{2}}$ is obtained from the standard normal cumulative distribution tables. For example, at the significance level, the null hypothesis is rejected if |Z|>1.96. A higher magnitude of *Z* value indicates that the trend is more statistically significant.

Spearman's Rho Test

Similar to MK, the Spearman's Rho (SR) is another rank-based non-parametric statistical test that can also be used to detect a monotonic trend in a time series (Yue et al. 2002; Yenigun et al. 2008). It is a simple test to determine whether a correlation exists between two classifications

Table 1. Drought category according to SPI (McKee et al. 1993)

SPI	Drought category
0 to - 0.99	Mild drought
– 1.00 to -1.49	Moderately drought
– 1.50 to -1.99	Severely drought
– 2.00 to less	Extremely drought

of the same series of observations. The Spearman's Rho Test statistic, r_s, and the standardized test statistic, Z_{SR} are calculated as follows (Sneyers 1990).

$$r_S = 1 - \frac{6\left[\sum_{i=1}^{n}(R(x_i) - i)^2\right]}{(n^3 - n)} \quad (10)$$

$$Z_{SR} = r_S\sqrt{\frac{n-2}{1-r_{S^2}}} \quad (11)$$

Where $R(X_i)$ is the rank of the i^{th} observation X_i in the time series, and is the length of the time series. Positive values of Z_{SR} indicate an increasing trend, while negative Z_{SR} indicates decreasing trends in the time series. For example, at the   significance level, the null hypothesis is rejected if $|Z|>1.96$. A higher magnitude of Z value indicates that the trend is more statistically significant.

The Mann-Kendall and Spearman's Rho tests are non-parametric tests to be applied for the detection of trends because the tests do not require the data to fit any particular probability distribution.

RESULTS AND DISCUSSION

SPI is a probability of rainfall at a location computed from rainfall records at any number of timescales from 1 to 48 months or longer. The time scales 3M (three-month) and 6M (six-month) are applied in the estimation since the mentioned scales are agreed to be the right options to address basic drought and the resulting impact on agriculture in a region (WMO and GWP 2016). Figures 2-4 show the estimated SPIs for the stations: Rajshahi, Ishwardi, and Bogura, respectively. Results show that Rajshahi region has suffered from drought in the years 1992 and 2010. The indices in most of the months in 1992 have obtained a value as less than -1.0 [Fig. 2(a)] indicating that the year 1992 experienced moderate to severe drought. The value of indices has even gone below -2.0 in the year 2010 as shown in Fig. 2(b), which indicates that the area suffered from extreme drought. Similarly, Ishwardi region experienced moderate to severe drought in the years 1992, 1994, and 2012, and extreme drought in the year 2010 (Fig. 3). It is also notable that the estimated indices for the month of January with 6M

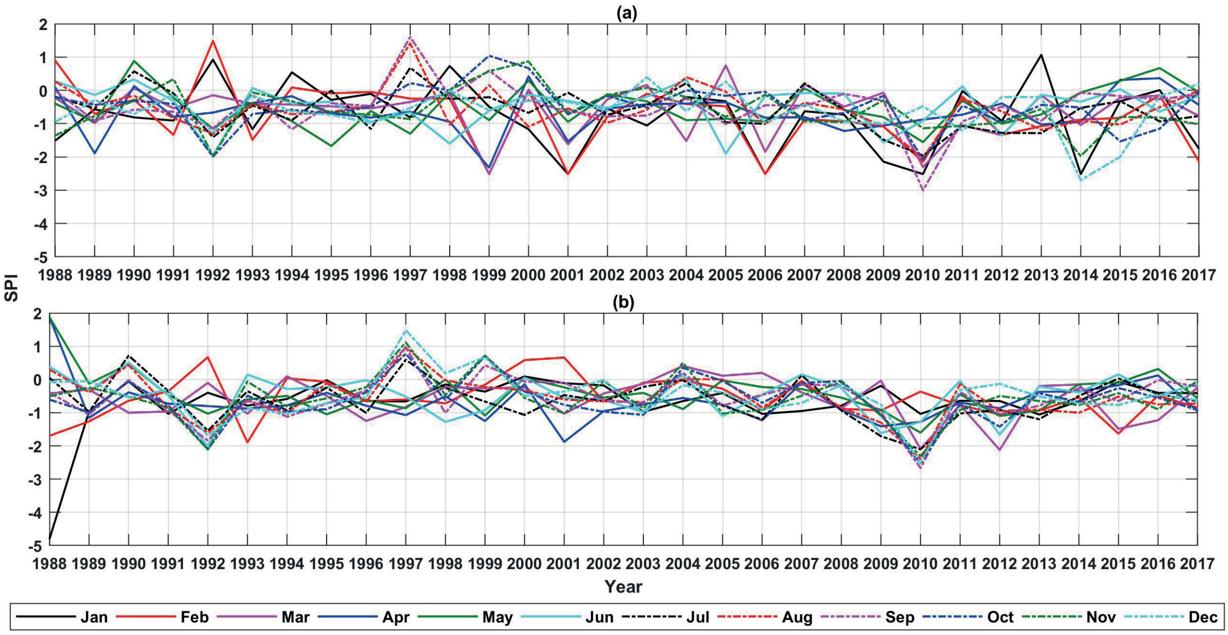

Fig. 2. Estimated monthly SPIs for the duration from 1988 to 2017 at Rajshahi, using 3M time-scale (a), and 6M time-scale (b)

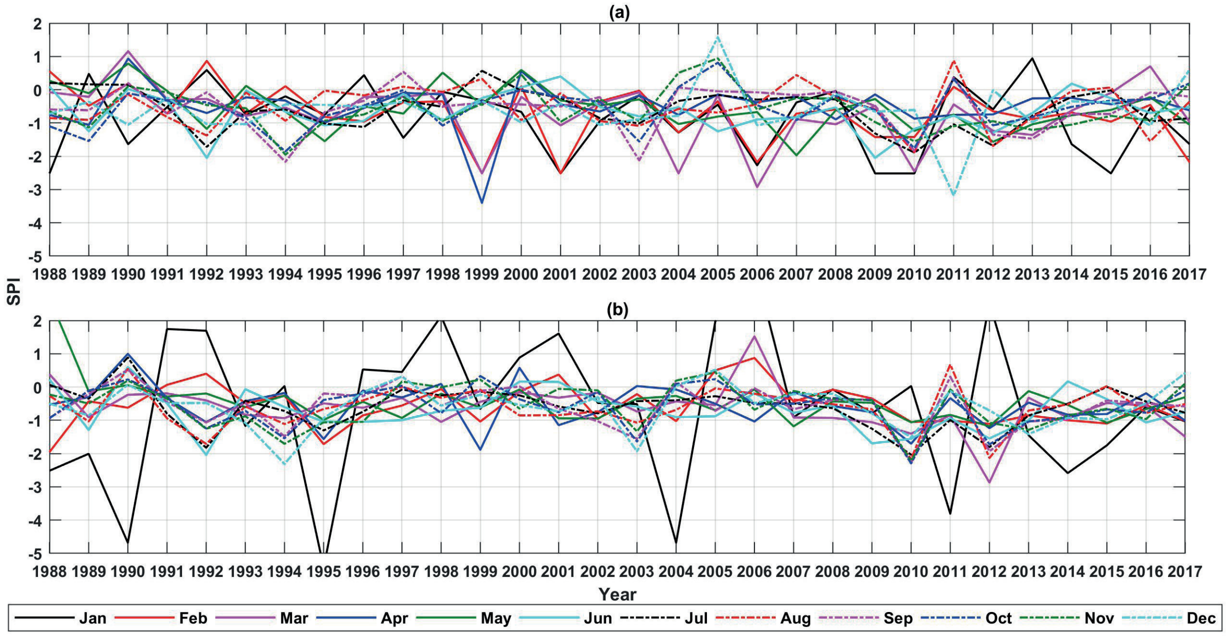

Fig. 3. Estimated monthly SPIs for the duration from 1988 to 2017 at Ishwardi, using 3M time-scale (a), and 6M time-scale (b)

time scales were found to be overestimated, and hence were not considered in later analyses to assess drought in this work. In contrast, most of the estimated SPIs in Bogura are found greater or close to -1.0 as shown in Fig. 4. However, the years 2006 and 2012 experienced moderate to severe drought.

According to the investigation made by the Center for Environmental and Geographic Information Services (CEGIS) (2013) based on rainfall data for the duration 1982–2008, Rajshahi experienced severe drought in the years 1995 and 1996. In contrast, this study finds that the years 1995 and 1996 experienced mild drought, or mostly enjoyed normal condition. Drought severity in the year 1992 for Rajshahi region is found well aligned with the findings of Miyan (2015), Adnan (1993) and Hossain (1990). Besides, this study resembles the findings of Nury and Hasan (2016), where the authors found extremely dry events in the years 1992, 1999, and 2010 in Rajshahi.

This study has estimated the trends using Mann-Kendall and Spearman's Rho tests as shown in Tables 2-4 over the estimated SPIs as shown in Figures 2-4. The months July and August in Rajshahi; March, May, and July in Ishwardi; and July to November in Bogura are showing strong negative trends (Tables 2-4). The months June, July, and August are the rainy or monsoon season all over Bangladesh (Banglapedia 2014), while March to May and September to November are pre- and post-monsoon seasons (Syed and Amin, 2016). Trend analyses show that the months June to November have strong negative trends in the estimated indices. Whereas, the months July and August or the monsoon season are approximated to be common in all three stations having stronger negative trends. In addition, this work has also included the month of June as one of the monsoon months to estimate the shortage of water during the whole monsoon season to be explained in a later section. The yearly maximum and minimum indices along with linear trends are shown in Figures 5-6. In the yearly maximum in both 3M and 6M analyses, linear trends are found to be negative for the whole study area with a significant slope of -0.03 in 6M analyses. On the other hand, in the yearly minimum in 3M analyses, the whole study is showing a negative trend with a slope of -0.02, while 6M analyses are also showing a negative trend, except the case of Rajshahi station which has shown a tiny positive trend. Results are indicating that Rajshahi division is likely to suffer more in the coming years than those of the past from drought.

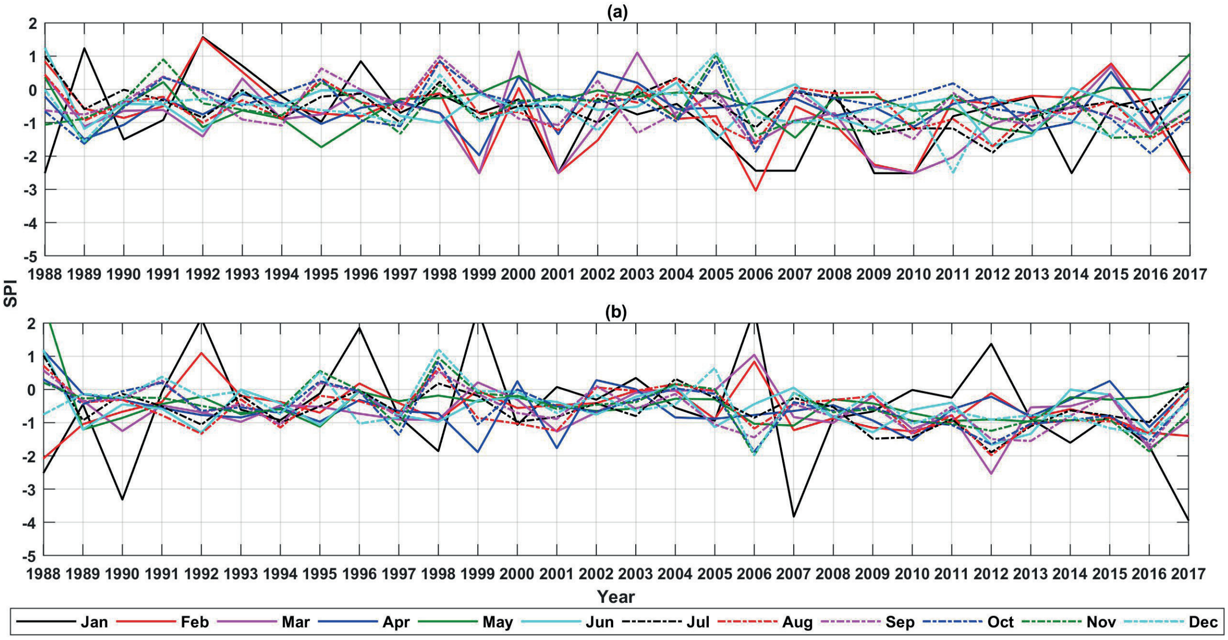

Fig. 4. Estimated monthly SPIs from 1988 to 2017 at Bogura, using 3M time-scale (a), and 6M time-scale (b)

Table 2. Trend estimations using Mann-Kendall and Spearman's Rho tests in SPIs estimated for Rajshahi station

Month	Using 3M Time Scale SPI			Using 6M Time Scale SPI			Remarks
	MK test	SR test	Trend	MK test	SR test	Trend	
January	-0.0	0.1	-/+	1.6	1.7	+	
February	-1.3	-1.3	-	0.0	0.0	+	
March	-0.4	-0.5	-	0.1	-0.0	+/-	
April	-0.2	-0.2	-	0.2	0.2	+	
May	1.3	1.3	+	0.6	0.8	+	
June	-0.1	-0.2	-	-0.7	-0.6	-	Both -
July	-2.1	-2.3	-	-1.1	-1.2	-	Both - and stronger
August	-1.0	-1.0	-	-1.9	-1.9	-	Both - and stronger
September	0.5	0.5	+	0.4	0.5	+	
October	-1.0	-0.9	-	-0.1	-0.1	-	Both -
November	-1.9	-1.7	-	-0.7	-0.7	-	Both -
December	0.0	0.0	+	-0.8	-0.9	-	

Table 3. Trend estimations using Mann-Kendall and Spearman's Rho tests in SPIs estimated for Ishwardi station

Month	Using 3M Time Scale SPI			Using 6M Time Scale SPI			Remarks
	MK test	SR test	Trend	MK test	SR test	Trend	
January	-0.9	-0.7	-	-0.3	-0.2	-	Both -
February	-1.6	-1.6	-	-0.7	-0.8	-	Both -
March	-1.5	-1.6	-	-1.2	-1.2	-	Both - and stronger
April	0.1	0.2	+	-0.9	-0.9	-	
May	-2.4	-2.8	-	-1.5	-1.5	-	Both - and stronger
June	-0.5	-0.5	-	-0.9	-1.0	-	Both -
July	-1.2	-1.4	-	-1.6	-1.5	-	Both - and stronger
August	0.1	0.1	+	0.4	0.3	+	
September	0.2	0.1	+	-1.0	-1.1	-	
October	1.2	1.3	+	-0.7	-0.8	-	
November	-0.8	-0.9	-	-0.6	-0.5	-	Both -
December	0.4	0.5	+	0.0	-0.1	-	

Table 4. Trend estimations using Mann-Kendall and Spearman's Rho tests in SPIs estimated for Bogura station

Month	Using 3M Time Scale SPI			Using 6M Time Scale SPI			Remarks
	MK test	SR test	Trend	MK test	SR test	Trend	
January	-1.6	-1.3	-	-0.9	-0.8	-	Both -
February	-0.4	-0.5	-	-1.6	-1.4	-	Both -
March	-0.5	-0.5	-	-0.0	-0.0	-	Both -
April	0.4	0.4	+	-0.2	-0.0	-	
May	0.9	0.9	+	0.8	1.0	+	
June	-0.8	-0.7	-	-0.3	-0.3	-	Both -
July	-1.8	-1.8	-	-1.7	-1.7	-	Both - and stronger
August	-1.5	-1.6	-	-1.5	-1.5	-	Both - and stronger
September	-1.8	-2.0	-	-2.7	-2.8	-	Both - and stronger
October	-1.1	-1.0	-	-2.7	-3.2	-	Both - and stronger
November	-1.5	-1.7	-	-3.0	-3.7	-	Both - and stronger
December	-0.7	-0.5	-	-2.3	-2.6	-	Both -

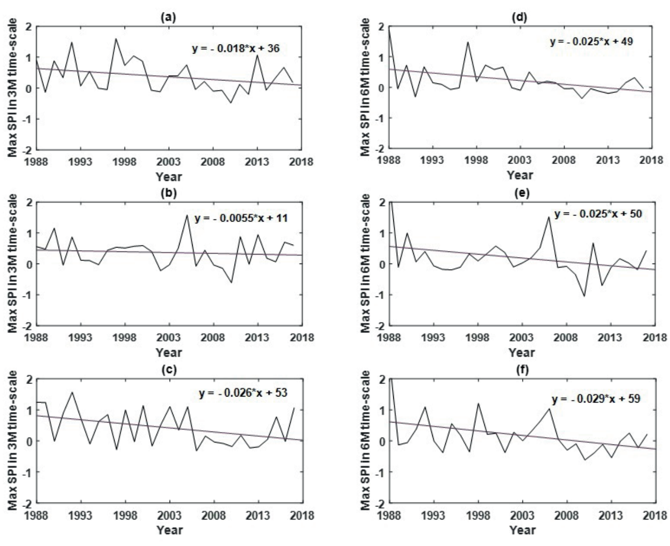

Fig. 5. Yearly maximum index for the duration from 1988 to 2017, in 3M time-scale analyses Rajshahi (a), Ishwardi (b), and Bogura (c); in 6M time-scale analyses Rajshahi (d), Ishwardi (e), and Bogura (f)

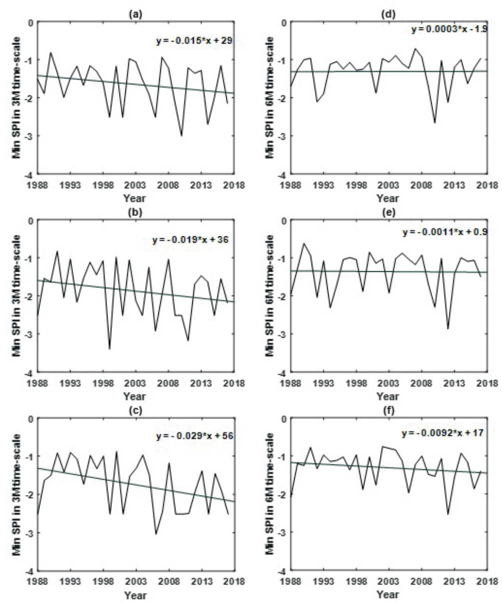

Fig. 6. Yearly minimum index from 1988 to 2017, in 3M time-scale analyses Rajshahi (a), Ishwardi (b), and Bogura (c); in 6M time-scale analyses Rajshahi (d), Ishwardi (e), and Bogura (f)

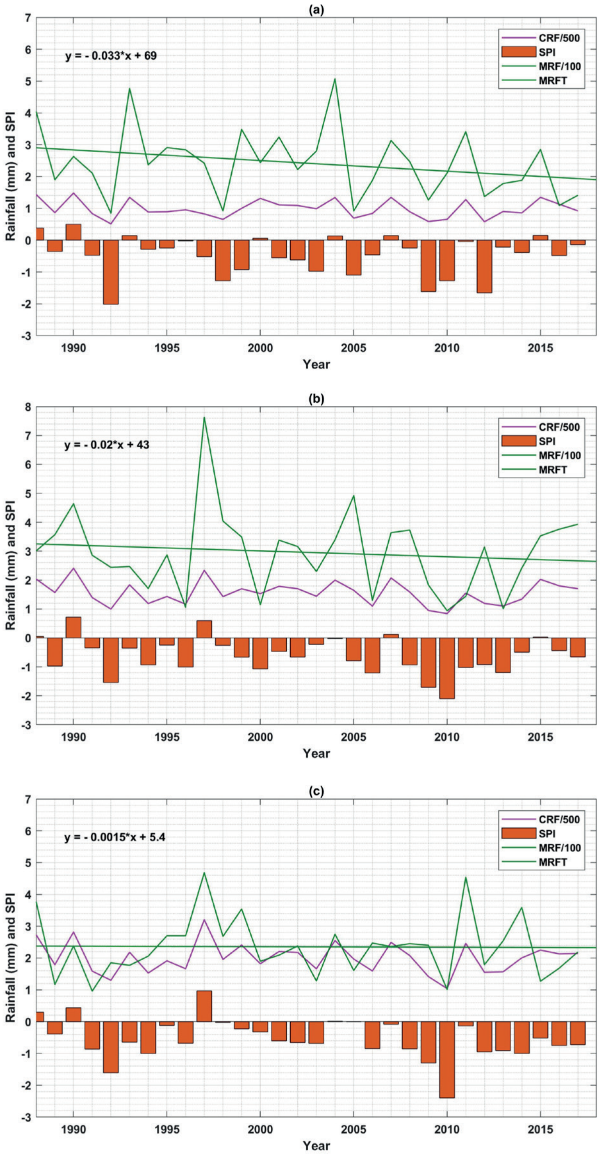

Fig. 7. Monthly rainfall (MRF), cumulative rainfall (CRF), and SPIs with the 6M time-scale along with monthly rainfall trend (MRFT) for the months June (a), July (b), and August (c) at Rajshahi

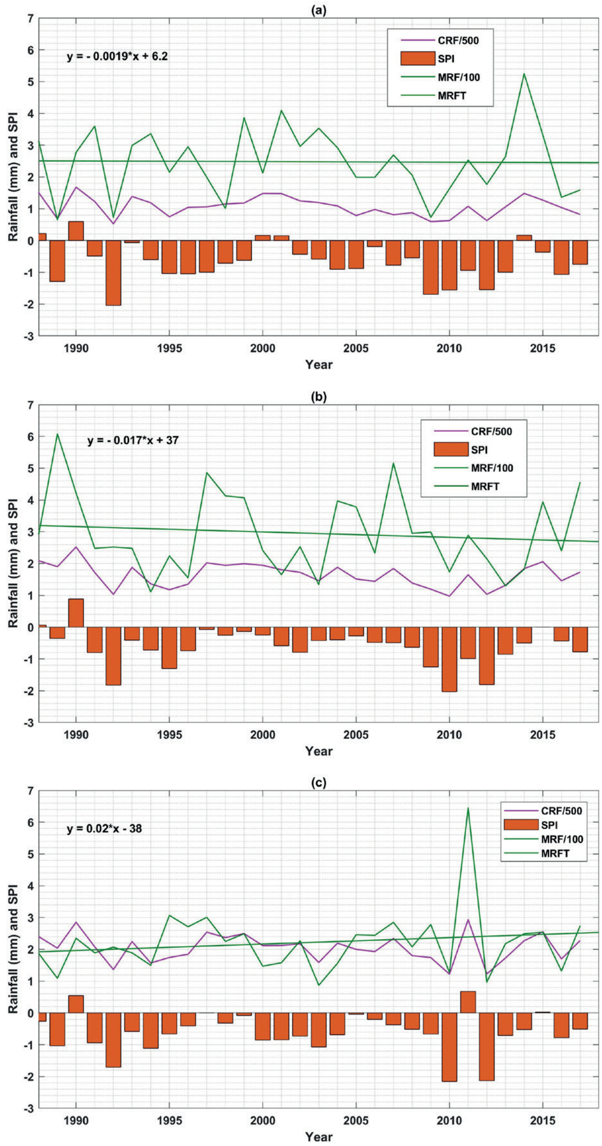

Fig. 8. Monthly rainfall (MRF), cumulative rainfall (CRF), and SPIs with the 6M time-scale along with monthly rainfall trend (MRFT) for the months June (a), July (b), and August (c) at Ishwardi

MK and SR tests (Tables 2-4), along with maximum indices (Figure 5) have attributed that the months June, July, and August are showing stronger negative trends. With a little slope yearly minimum indices (Figure 6) also show the negative trends. As the months June, July, and August belong to the monsoon season and are showing stronger negative trends in the estimated drought indices, the following section is appended to show detailed rainfall along with estimated SPIs for the monsoon season. Monthly rainfall, cumulative rainfall through which the indices are estimated, and indices estimated using a 6M time scale are shown in Fig. 6-8 for the rainfall recorded at Rajshahi, Ishwardi, and Bogura for the months June, July, and August. Here, the 6M time scale is applied since the scale is suggested for investigating agricultural impacts from drought.

Monthly rainfall in the monsoon season in Rajshahi region shows negative trends with the slopes -0.03, -0.02, and -0.002 for June, July, and August, respectively (Figure 7). The month of August shows that the difference between monthly rainfall and cumulative rainfall is minimum, and this minimum difference indicates that the months June and July are experiencing less rain than that of the month August.

Similarly, the monthly rainfall in the monsoon season in Ishwardi shows negative trends with the slopes -0.002 and -0.02 for June and July, respectively (Figure 8). The month of August shows a positive trend with a slope of 0.02. Estimations once again indicate that the months June and July lack rainwater than that of the month August.

Monthly rainfall in the monsoon season in Bogura shows a stronger negative trend with the slopes -0.05 and -0.07 for June and July, respectively (Figure 9). The month of August showing positive trends with the slope of 0.02 indicates a similar pattern that the months June and July lack rainwater compared to that during the month of August. However, the positively trended rainfall in August in all regions do not show better indices (Fig. 2-4), since many of the slopes are found to be close to -1.0 or less.

The above findings interpret that during the monsoon season the whole study area lacks rainwater, whereas rainwater is the most important agent for keeping better agricultural production. If the amount of rainwater becomes scarce, the area is likely to face a shortage of agricultural productivity. Initially, groundwater may be used for agriculture to replenish the productivity gap, but the overall climate of the region would deteriorate. An overall water deficiency in percentage is estimated

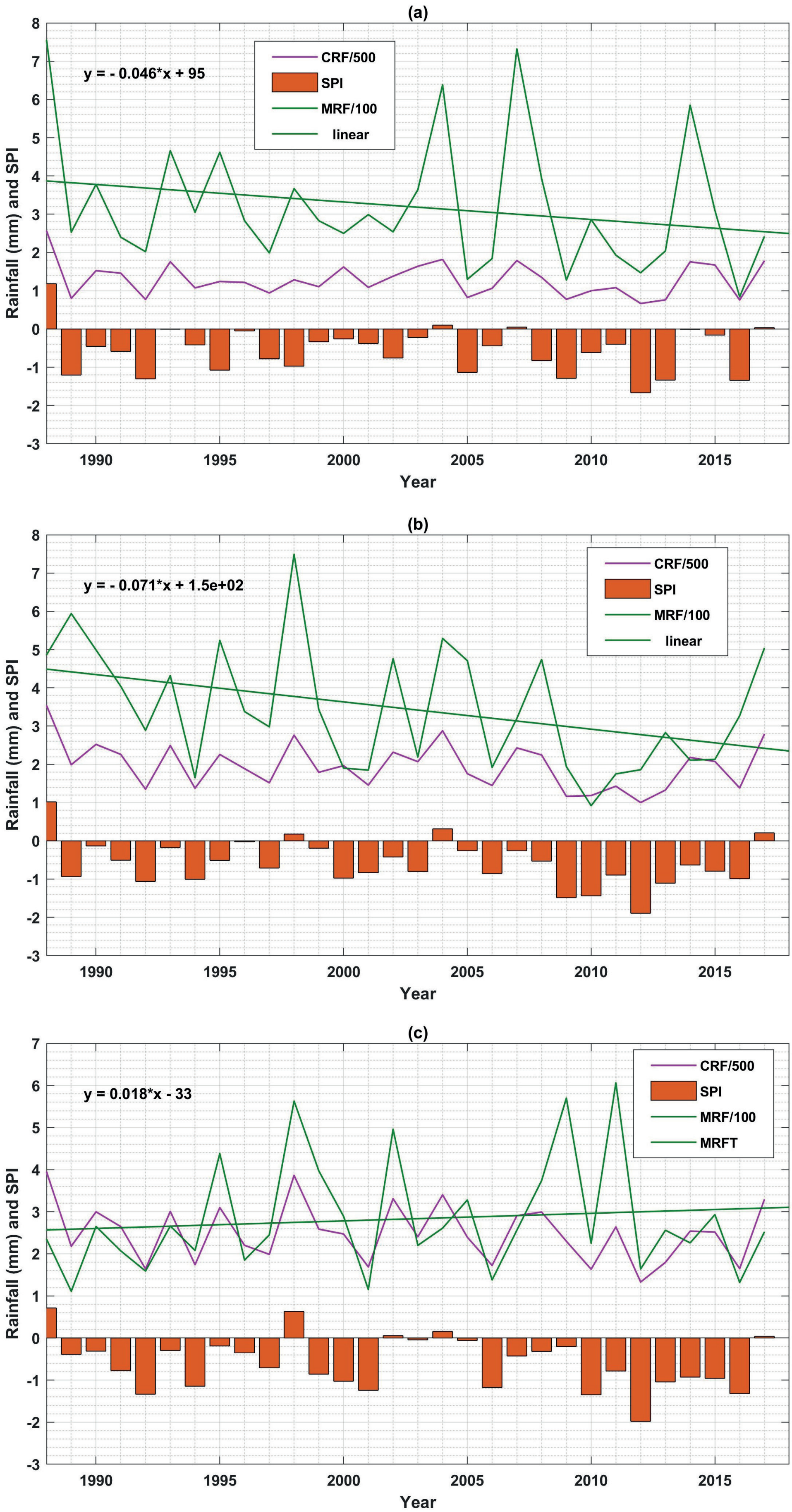

Fig. 9. Monthly rainfall (MRF), cumulative rainfall (CRF), and SPIs with the 6M time-scale along with monthly rainfall trend (MRFT) for the months June (a), July (b), and August (c) at Bogura

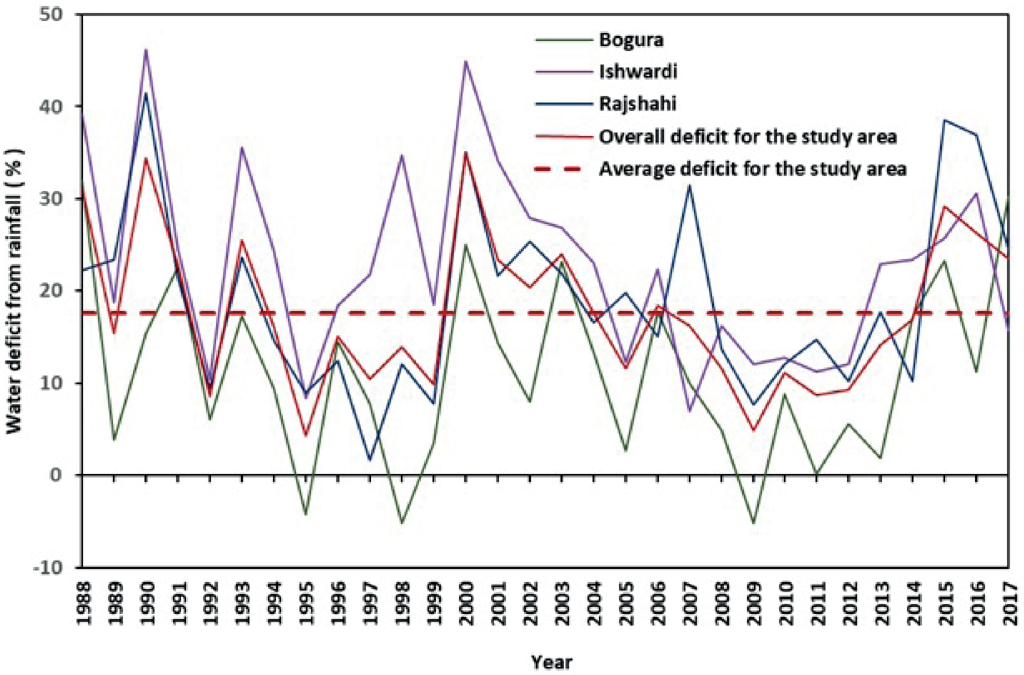

Fig. 10. Overall water deficit from rainfall in monsoon for the months June, July, and August in the study area

using rainfall data during monsoon. This is done from the differences of converted monthly rainfall and cumulative rainfall to a unique scale for Rajshahi division (Figure 10). Results show that Bogura experiences the least water deficit in the region, while Ishwardi experiences the most. Overall water deficit ranges from 4% to 35% in different years, and the average water deficit is found to be 18% for the whole study area. Hence, Rajshahi division has to increase the supply of water from alternative sources for agriculture to maintain the current level of production.

CONCLUSIONS

Rajshahi division, part of northwestern Bangladesh, is highlighted as one of the most drought-prone areas in southeast Asia. This research has reinvestigated the recent drought status of Rajshahi division with the estimation of SPI using rainfall data from 1988 to 2017 and has found discrepancies in past drought years. This work has identified that the years 1992, 1994, 2006, 2012 have experienced moderate to severe drought, while the year 2010 has suffered from extreme drought. Drought trends have figured out a shortage of water in the study area using the estimated SPIs. Most of the estimated yearly maximum and minimum indices have attributed negative trends with a diverse slope from -0.001 to -0.029 except Rajshahi having a very small positive trend with a slope of 0.0003 in minimum indices with 6M analysis. Mann-Kendall and Spearman's Rho tests have identified strong negative trends for the monsoon season, i.e. the months of June, July, and August. Findings have interpreted that the study area is experiencing a roughly 18% of shortage in rainwater during the monsoon season. It has been observed that the cumulative monthly rainfall is always higher than the monthly rainfall. As a result, most of the estimated indices have been found below zero. Water from rainfall replenishes water bodies on the surface and recharges groundwater, and shortage of water obstructs sustainability and overall irrigation. The estimation of rainwater deficit would therefore help to identify the water requirement to replenish water sources in the study area to continue irrigation for smooth agriculture. This research may be replicated and/or extended to other regions to assess the trend in rainfall.

REFERENCES

Abramowitz M. and Stegun I.A., (1965). Handbook of mathematical functions Dover Publications. New York, 361.

Adhikary S.K., Das S.K., Saha G.C. & Chaki T. (2013). Groundwater drought assessment for Barind irrigation project in Northwestern Bangladesh. In MODSIM2013, 20th International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, December 2013, 2917-2923. Modelling and Simulation Society of Australia and New Zealand.

Adnan S. (1993). Living without floods: Lessons from the drought of 1992. Research and Advisory Services, Dhaka.

Ahammed S.J., Homsi R., Khan N., Shahid S., Shiru M.S., Mohsenipour M. and Yuzir A. (2020). Assessment of changing pattern of crop water stress in Bangladesh. Environment, Development and Sustainability, 22: 4619-4637, DOI: 10.1007/s10668-019-00400-w.

Alamgir M., Khan N., Shahid S., Yaseen Z.M., Dewan A., Hassan Q. and Rasheed B. (2020). Evaluating severity–area–frequency (SAF) of seasonal droughts in Bangladesh under climate change scenarios. Stochastic Environmental Research and Risk Assessment, 34: 447-464, DOI: 10.1007/s00477-020-01768-2.

Alam M.M., Siwar C., Talib B., Mokhtar M., Toriman M. (2012). Climate Change Adaptation Policy in Malaysia: Issues for Agricultural Sector (2012). African Journal of Agricultural Research, 7(9), 1368-1373, Available at SSRN: https://ssrn.com/abstract=2941970.

Alauddin M. and Sarker M.A.R. (2014). Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation. Ecological Economics, 106: 204-213, DOI: 10.1016/j.ecolecon.2014.07.025.

Banglapedia (2014). National Encyclopedia of Bangladesh. http://en.banglapedia.org/index.php?title=Season retrieved on: 06 Feb 2020.

Bari M.F. and Anwar A.H.M.F. (2000). Effects on irrigated agriculture on groundwater quality in Northwestern Bangladesh. Proceeding of integrated water resources management for sustainable development, 1: 19-21.

Centre for Environmental and Geographic Information Services (CEGIS). (2013). Vulnerability to Climate Induced Drought Scenario and Impacts (Study Report), Comprehensive Disaster Management Programme (CDMP II), Ministry of Disaster Management and Relief, GoB.

Edossa D.C., Woyessa Y.E. & Welderufael W.A. (2014). Analysis of Droughts in the Central Region of South Africa and Their Association with SST Anomalies. International Journal of Atmospheric Sciences, 2014(5), 1-8, 508953, DOI: 10.1155/2014/508953.

Edwards D.C. and McKee T.B. (1997). Characteristics of 20th Century drought in the United States at multiple time scales. Atmospheric Science Paper No. 634. Climatology Report No. 97-2.

Hayes M.J., Svoboda M.D., Wiihite D.A. & Vanyarkho O.V. (1999). Monitoring the 1996 drought using the standardized precipitation index. Bulletin of the American meteorological society, 80(3), 429-438, DOI: 10.1175/1520-0477(1999)080<0429:MTDUTS>2.0.CO;2.

Heim Jr R.R. (2002). A review of twentieth-century drought indices used in the United States. Bulletin of the American Meteorological Society, 83(8), 1149-1166, DOI: 10.1175/1520-0477-83.8.1149.

Helsel D.R. and Hirsch R.M. (2002). Statistical methods in water resources (Vol. 323). Reston, VA: US Geological Survey.

Hoque M.A.A., Pradhan B. & Ahmed N. (2020). Assessing drought vulnerability using geospatial techniques in northwestern part of Bangladesh. Science of The Total Environment, 705, 135957, DOI: 10.1016/j.scitotenv.2019.135957.

Hossain M. (1990). Natural calamities, instability in production and food policy in Bangladesh. The Bangladesh Development Studies, 18(1), 33-54.

Islam M.R., Jahan C.S., Rahaman M.F. & Mazumder Q.H. (2020). Governance status in water management institutions in Barind Tract, Northwest Bangladesh: an assessment based on stakeholder's perception. Sustainable Water Resources Management, 6(2), 1-14, DOI: 10.1007/s40899-020-00371-1.

McKee T.B., Doesken N.J. & Kleist J. (1993, January). The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, 17(22), 179-183.

Miyan M.A. (2015). Droughts in Asian least developed countries: vulnerability and sustainability. Weather and Climate Extremes, 7, 8-23, DOI: 10.1016/j.wace.2014.06.003.

Nury A.H., Hasan K., Mohammed Erfan K. & Chandra Dey D. (2016). Analysis of spatially and temporally varying precipitation in Bangladesh. Asian Journal of Water, Environment and Pollution, 13(3), 15-27, DOI: 10.3233/AJW-160023.

Quiring S.M. & Papakryiakou T.N. (2003). An evaluation of agricultural drought indices for the Canadian prairies. Agricultural and forest meteorology, 118(1-2), 49-62, DOI: 10.1016/S0168-1923(03)00072-8.

Rahaman K.M., Ahmed F.R.S. & Islam M.N. (2016). Modeling on climate induced drought of north-western region, Bangladesh. Modeling Earth Systems and Environment, 2(1), 45, DOI: 10.1007/s40808-016-0089-7.

Rahman M.S. & Islam A.R.M.T. (2019). Are precipitation concentration and intensity changing in Bangladesh overtimes? Analysis of the possible causes of changes in precipitation systems. Science of The Total Environment, 690, 370-387, DOI: 10.1016/j.scitotenv.2019.06.529.

Rahman S.M., Rahman S.M., Ali M.S., Mamun M.A. and Uddin M.N. (2020). Estimation of seasonal boundaries using temperature data: a case of northwest part of Bangladesh. Mathematics of Climate and Weather Forecasting, 6(1), 50-62, DOI: 10.1515/mcwf-2020-0102.

Shahid S. & Behrawan H. (2008). Drought risk assessment in the western part of Bangladesh. Natural hazards, 46(3), 391-413, DOI: 10.1007/s11069-007-9191-5.

Shahid S. & Hazarika M.K. (2010). Groundwater drought in the northwestern districts of Bangladesh. Water resources management, 24(10), 1989-2006, DOI: 10.1007/s11269-009-9534-y.

Shahid S. (2011). Trends in extreme rainfall events of Bangladesh. Theoretical and applied climatology, 104(3-4), 489-499, DOI: 10.1007/s00704-010-0363-y.

Sneyers R. (1990). On the statistical analysis of series of observations. WMO Technical Note (143). World Meteorological Organization, Geneva.

Syed M. and Al Amin M. (2016). Geospatial modeling for investigating spatial pattern and change trend of temperature and rainfall. Climate, 4(2), 21, DOI: 10.3390/cli4020021.

Uddin M.J., Hu J., Islam A.R.M.T., Eibek K.U. & Nasrin Z.M. (2020). A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. Arabian Journal of Geosciences, 13, 1-10, DOI: 10.1007/s12517-020-05302-0.

Wilhite D.A. and Glantz M.H. (1985). Understanding: the drought phenomenon: the role of definitions. Water international, 10(3), 111-120, DOI: 10.1080/02508068508686328.

World Bank (2013). World development indicators 2013. Washington D.C.

World Meteorological Organization (WMO) and Global Water Partnership (GWP) (2016). Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva, 52.

Yenigun K., Gumus V. and Bulut H. (2008). Trends in streamflow of the Euphrates basin, Turkey. In Proceeding of the Institution of Civil Engineers-Water Management, Thomas Telford Ltd, 161(4), 189-198.

Yue S., Pilon P. and Cavadias G. (2002). Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. Journal of hydrology, 259(1-4): 254-271, DOI: 10.1016/S0022-1694(01)00594-7.