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Changing Pattern of Droughts during Cropping Seasons of Bangladesh

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Abstract There has been a growing concern on temporal variations on drought characteristics due to climate change. This study compares meteorological drought characteristics for two different periods to quantify the temporal changes in seasonal droughts of 18 weather stations of the country. Fifty-five years rainfall and temperature data are divided into two different thirty-year periods, 1961–1990 and 1985–2014 and standardized precipitation evapotranspiration index (SPEI) for those periods are calculated to assess the changes. Four seasons in this study are selected as two major crop growing seasons namely, Rabi (November to April) and Kharif (May to October) and two critical periods for crop growth in term of water supply namely critical Rabi (March–April) and critical Kharif (May). Results show that moderate, extreme, and severe Rabi droughts has increased in 11, 9, and 4 stations out of 18 stations, respectively, and Kharif severe and extreme droughts has increased in 8 and 9 stations, respectively, In addition, the frequency analysis shows that the return periods have decreased during 1985–2014 at the stations where it was high during 1961–1990 and vice versa. This has made the spatial distribution of return periods of droughts more uniform over the country for most of the seasons. Increased return period of droughts in highly drought prone north and northwest Bangladesh has caused decrease in average frequency of droughts. Consequently, this result corresponds that Bangladesh experiences fewer droughts in recent years. Trend analysis of rainfall and temperature data reveals that significant increase of mean temperature and no significant change in rainfall in almost all months have increased the frequency of droughts in the regions where droughts were less frequent.

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1 Introduction

Rises in temperature due to global warming has affected evapotranspiration and atmospheric water storage, and thereby changed precipitation patterns all over the world (Middelkoop et al. 2001; Wang et al. 2016). Number of studies reported increasing trend in drought frequency and intensity in recent decades due to the changes in precipitation pattern (Dai 2011; Ahmed et al. 2016). Dai (2011) reported that the percentage of global dry areas increased by about 1.74% per decade during 1950–2008 with major increases over Africa, East Asia and South Asia. Bangladesh is also experiencing a clear shift in climate variables (Siddik and Rahman 2014; Rahman and Lateh 2017; Bari et al. 2016; Rahman and Lateh 2016; Shahid et al. 2016). It has been reported that changes in rainfall pattern has caused increased extreme weather events (Shahid 2011; Nowreen et al. 2015; Dastagir 2015) and hydrological disasters (Karim and Mimura 2008; Islam et al. 2010; Dasgupta et al. 2014; Dasgupta et al. 2015; Xenarios et al. 2016) in the country.

Government report show that droughts in Bangladesh occur on average twice in a decade (CCCB 2009). Agricultural losses from drought are more severe than from floods in Bangladesh (World Bank Bangladesh 1998). Droughts in 1973 led to famine in 1974, droughts in 1978–1979 reduced crop production by 2 million tons and droughts of 1994–1995 led to a decrease in rice and wheat production of 3.59 million ton (Rahman and Biswas 1995). Recently Xenarios et al. (2016) reported that the flood-prone and saline affected regions in Bangladesh are less vulnerable to climate change compared to drought prone areas.

Number studies reported changes in drought pattern in neighboring countries of Bangladesh including India and China due to global climate change (Mishra and Liu 2014; Chen and Sun 2015; Wang et al. 2017). Increased frequency of droughts in Bangladesh in recent years is also reported by Miyan (2015). On contrary government report (CCCB 2009) of crop damages due to natural hazards suggests that impact of drought has reduced in recent years. It is often remarked that this is due to reduction of drought risk after implementation of mitigation measures like extensive use of groundwater. However, no study has been conducted so far to assess how the recent changes in climate has altered drought severity in Bangladesh.

Thus, the major objective of this study is to assess the changes in drought characteristics of Bangladesh using meteorological drought index. Standardized precipitation index (McKee et al. 1993) is most widely used due to its capability to assess drought severity, frequency and duration solely from precipitation data. However, evapotranspiration plays an important role in defining drought severity (Hu and Willson 2000; Tsakiris and Vangelis 2005; Vicente-Serrano et al. 2010), particularly in tropical region. Therefore, standardized precipitation evapotranspiration index (SPEI), which combines the effect of rainfall and temperature to quantify the condition of droughts (Vicente-Serrano et al. 2010) is used in this study.

Crops in Bangladesh are mainly grown during two seasons namely, Kharif (May–November) and Rabi (December–April). The moisture supply from rainfall is enough to support rainfed crops during Kharif. On the other hand, Rabi season is characterized by dry sunny weather and the crop in this season is grown under irrigation. Rice is the major crop in Bangladesh and about 55% of rice (Boro rice) is grown during Rabi season under irrigation scheme and the rest are grown (mainly Aman rice) during Kharif. Water deficit during the flowering period of Boro rice (March–April) is very critical for rice yield and therefore, drought during this period causes fatal damage to crop production. Similarly, late arrival of monsoon can cause damage to rain-fed crop and therefore, insufficient rainfall in May is very critical of Aman rice. In this study, droughts during two cropping seasons namely, Rabi and Kharif as well as two critical periods of rice namely, flowering period of Boro rice (March–April) or critical Rabi (CR) and beginning of monsoon (May) or critical Kharif (CK) are separately studied. Therefore, droughts during these two periods, termed as Rabi critical and Kharif critical in this study, were also considered.

Impacts of climate change on characteristics of droughts during crop growing seasons are assessed in this study. Droughts are destructive when they coincide with crop growing season, particularly with the critical period of crop growth (Alamgir et al. 2015; Ahmed et al. 2016). Therefore, the methodology used in this study can provide better assessment of the changes in droughts having significant impacts in agriculture and economy of Bangladesh.

2 Materials and Methods

2.1 Study Area and Data

Bangladesh experiences a tropical humid climate characterized by wide seasonal variations in rainfall, moderately warm temperatures and high humidity. The average annual rainfall of the country varies from 1472 mm in the northwest to 4032 mm in the northeast (Fig. 1). Almost 80% of total annual rainfall occurs during Kharif season. The average temperature ranges from 7.2 °C to 12.8 °C during winter and 23.9 °C to 31.1 °C during summer (Shahid 2010).

Monthly rainfall and average temperature data recorded at 18 stations distributed over Bangladesh (Fig. 1) for period 1961–2014 are collected from Bangladesh Meteorological Department for this study.

2.2 Procedure

Procedure followed to quantify the temporal changes in seasonal droughts is outlined below:

1. Observed data are divided into two separate 30 years period namely, 1961–1990 (P1) and 1985–2014 (P2) and SPEIs for cropping seasons are computed, individually.
2. Return periods of droughts during different seasons are analyzed for P1 and P2 to show the differences of droughts.
3. Trends in monthly rainfall and temperature for the time period 1961–2014 are assessed and results are analyzed to understand the possible causes of the changes in drought pattern.

Details of the methods used for estimation of droughts and trend analysis are given below.

2.3 Standardized Precipitation Evapotranspiration Indices

SPEI calculates the status of droughts based on the difference between precipitation and potential evapotranspiration (PET). The SPEI values are not sensitive to PET estimation method (Stagge et al. 2014). Therefore, any method based on availability of data can be

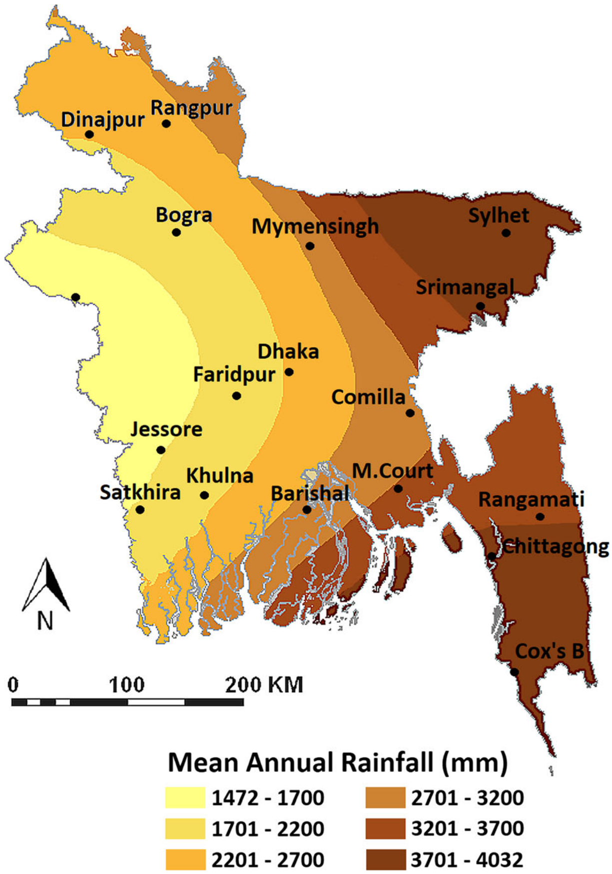

Fig. 1 Spatial distribution of rainfall in Bangladesh and location of rain gauges

chosen to calculate PET. In this study, Thornthwaite method (Thornthwaite 1948) was used to calculate PET,

$$\mathrm{PET} = 16\mathrm{N_m}\left(\frac{10\mathrm{T_m}}{\mathrm{I}}\right)^{\mathrm{a}} \tag{1}$$

where N_m is the correction factor defined based on the latitude of the area and the month of the year; T_m is the monthly average of daily mean temperature (°C); I is a heat index, which is calculated for the whole year; and a is a coefficient which can be calculated from I. Details of the calculation of PET using Thornthwaite method can be found in Vicente-Serrano et al. (2010).

The accumulated water profit or loss series can be constructed using the following formula:

$$\mathrm{D_n^k} = \sum_{i=1}^{k-1}(\mathrm{P_{n-1}} - \mathrm{PET_{n-1}}), \quad \mathrm{n} \geq \mathrm{k} \tag{2}$$

where P is precipitation and k is the time scale (month), n is the calculation frequency, and D is the difference between P and PET for the month i.

Parameter *D* can have negative values and therefore, three-parameter distributions are needed to fit the distribution of *D*. Previous studies suggest that the log-logistic distribution fit best to *D* values compared with other three-parameter distributions (Yang et al. 2016). Therefore, in the present study the probability distribution function of *D* is estimated using a three-parameter log-logistic distribution,

$$F(D) = \left[1 + \left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{3}$$

where α, β, and γ are scale, shape, and origin parameter, respectively.

The SPEI can be obtained as the standardized values of F(D). Drought can be categorized based on SPEI values as follows: moderate ($-1.5 < \text{SPEI} \leq -1.0$), severe ($-2.0 < \text{SPEI} \leq -1.5$), and extreme ($\text{SPEI} \leq -2.0$) drought.

2.4 Estimation of Return Period of Seasonal Droughts

Annual maximum series (AMS) of SPEI is used to estimate the return period of seasonal SPEI values using frequency analysis. The AMS is the most severe drought event in each year (the greatest drought magnitude), provided that it exceeds a given threshold (Sung and Chung 2014). Because the drought frequency analysis uses the non-zero values, a correction should be conducted using non-exceedance probability (F′), according to the following expression:

$$F^{l} = q + (1-q)F \tag{4}$$

where F is the non-exceedance probability value obtained by using frequency analysis on the non-zero values, and q is the probability of zero values, which can be calculated as the ratio of the number of time intervals without drought occurrences to the total number of time intervals in the recording period (Santos et al. 2011; Ahmed et al. 2016). In this study, the SPEI values of different seasons are fitted with Normal, Lognormal, Weibull, Gamma and Extreme Value-I distributions. Kolmogorov-Smirnov (KS) test is conducted to estimate the goodness of fit to a particular distribution. The KS test statistics show that the null hypothesis of sample distribution similar to Lognormal distribution cannot be rejected for any seasonal SPEI series. Therefore, Lognormal distribution is used in the study for the estimation of distribution parameters of seasonal droughts.

2.5 Trend Analysis by Mann-Kendall test

MK test is a non-parametric trend test which uses ordered time series to analyze trend. It estimates the normalized test statistic *Z* to estimate significance of trend. In the present study, confidence level of 95% is taken as thresholds to classify the significance of positive and negative trends. At the 95% significance level, the null hypothesis of no trend is rejected if $|Z|>1.96$. Details of Mann-Kendall test can be found in Sneyers (1990).

3 Results

3.1 Trends in SPEI

To assess the changes in droughts, SPEI time series was divided into two periods, P1(1961–1990) and P2(1985–2014). World Meteorological Organization (WMO) recommended thirty-year period for climatic trend analysis. As the total period of available data is limited to 55 years, an overlap of five years is used to assess the trend. Trends in droughts for P1 and P2 are analyzed separately to show the temporal changes. Obtained Z-values for P1 and P2 of 18 stations for all the 4 seasons are shown in Fig. 2. It shows a clear increasing trend in SPEI values during P2 and decreasing trend during P2 for all seasons in most of the stations.

Increases in Rabi SPEI values at 95% level confidence are observed at 7 out of 18 stations for P1. The SPEI values at all those 7 stations are found to decrease at 95% level of confidence for P2. Similar trends are observed for SPEI values in other seasons. The SPEI values for Kharif are fond to decrease at 5 stations during P2. Significant decrease in SPEI is observed at 8 stations for CR and at 3 stations for CK during P2. This indicates that dryness in Bangladesh has increased in all the four seasons under study. This also indicates that droughts in recent years (1985–2014) happen more frequently than in the past period (1961–1990).

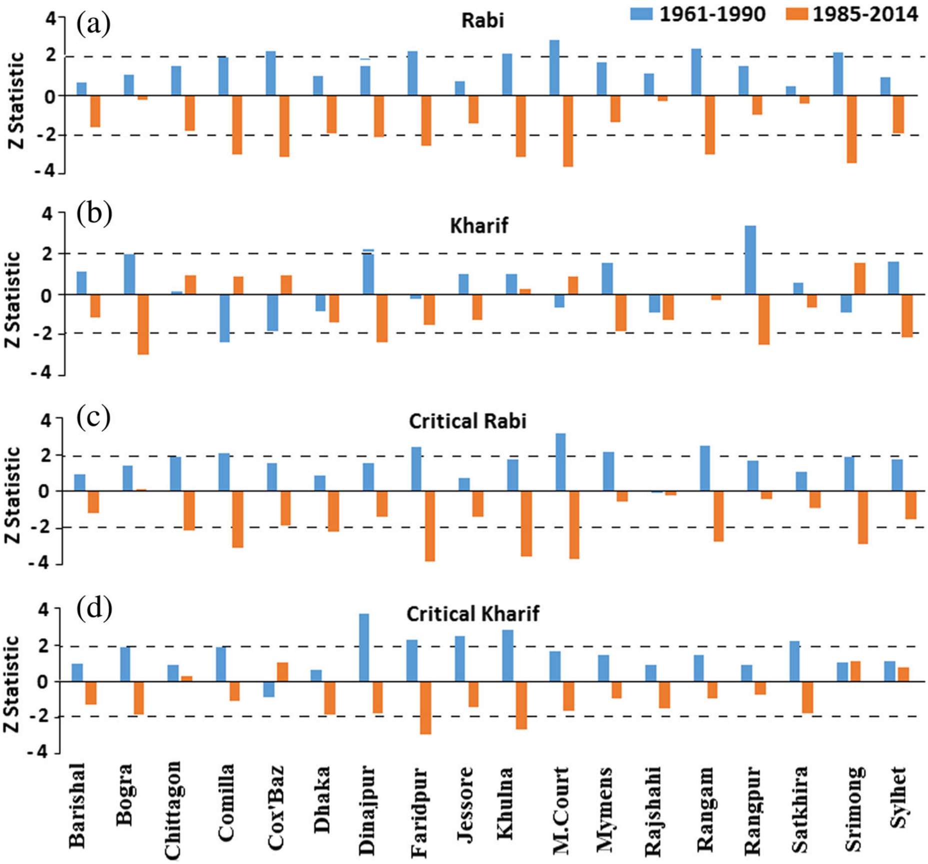

Fig. 2 Z-statistics of SPEI trend over two periods: 1961–1990 (blue bar) and 1985–2014 (red bar) during different cropping seasons: **a** Kharif; **b** Rabi; **c** KC; **d** RC. The dashed horizontal line at Z = 1.96 represents the critical value of Z at 95% level of confidence

3.2 Changes in Drought Events

Numbers of drought events with various severities for P1 and P2 are compared to assess the change in different categories of droughts. Numbers of moderate, severe and extreme Rabi and Kharif droughts for P1 and P2 are shown in Fig. 3a and b, respectively. The upper graph shows the number of droughts with various severities during P1, and the lower graph shows the number of droughts for the same severities during P2. The figure shows that number of moderate Rabi droughts has increased at 11 stations, severe droughts at 9 stations and extreme droughts at 4 out of 18 stations. Extreme Rabi drought occurred only in 1 station during P1,

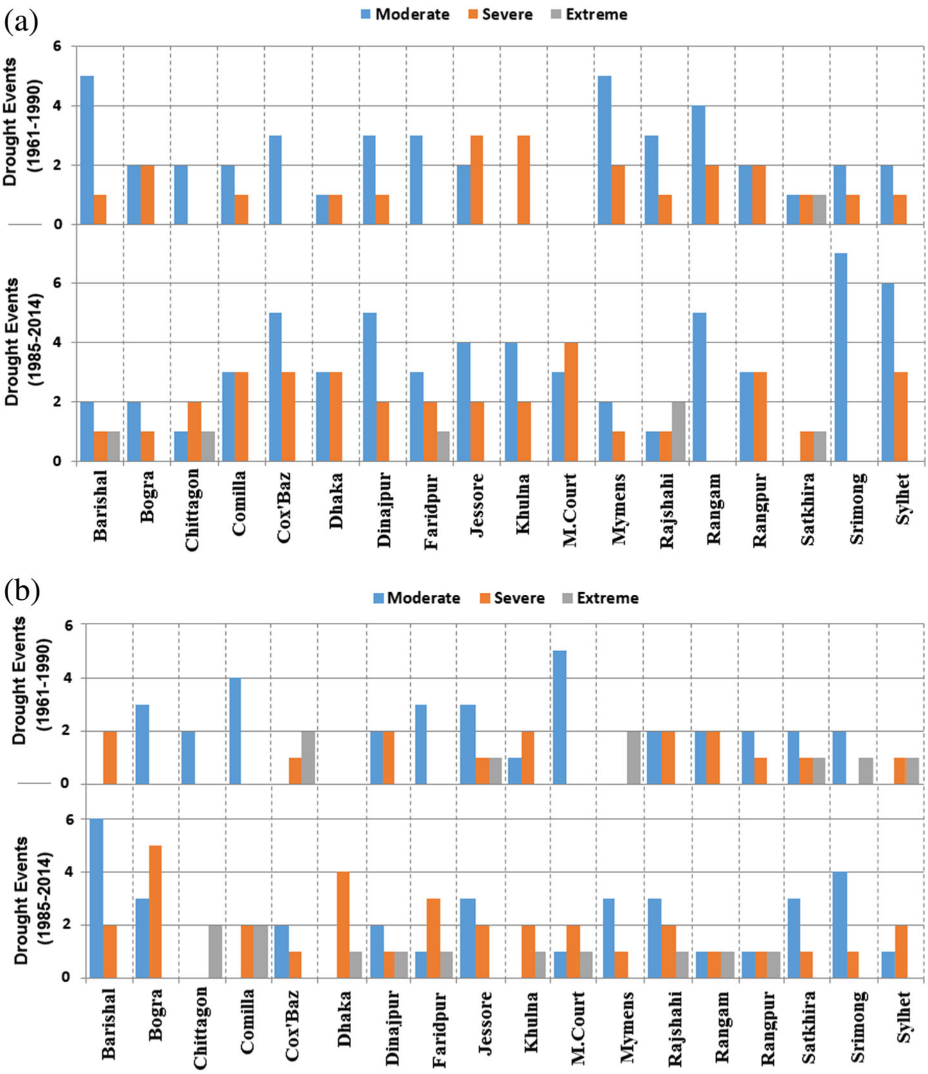

Fig. 3 Number of drought events with various severities during **a** Rabi; and **b** Kharif seasons over two periods, 1961–1990 and 1985–2014

but at 5 stations during P2. At Rajshahi (northwest Bangladesh), it occurred twice during P2. This indicates increases in Rabi drought events.

Decrease in moderate droughts and increase in severe and extreme droughts during Kharif season is observed at most of the stations in Bangladesh (Fig. 3b). A distinct change in extreme drought pattern is also observed. The extreme droughts during P2 are not observed at the stations where they were experienced during P1. On the other hand, some of the stations not experienced any extreme Kharif droughts for P1, are found to experience one or two extreme

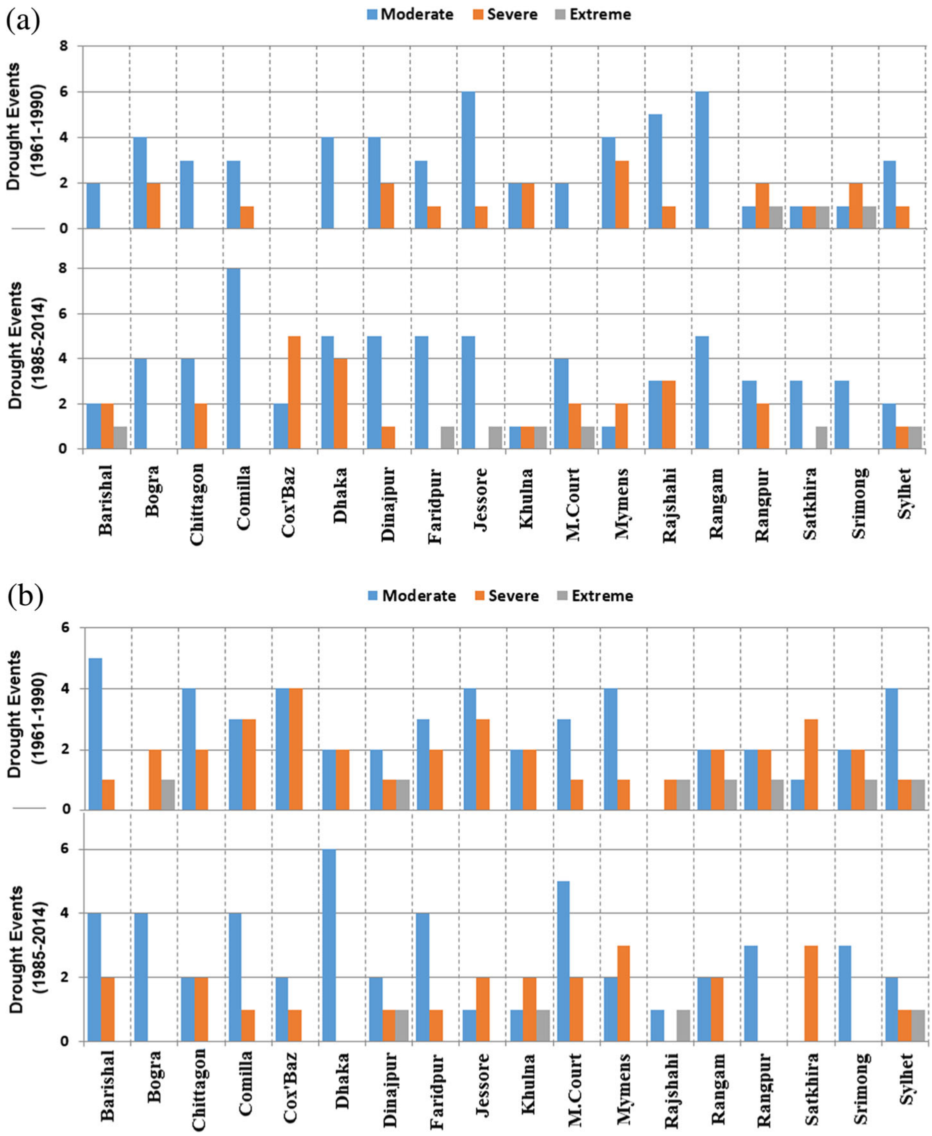

Fig. 4 Number of drought events with various severities during (a) CR; and (b) CK seasons over two periods, 1961–1990 and 1985–2014

Kharif droughts for P2. This indicates not only the increase in drought events, but also the changes in spatial pattern of droughts due to climate change.

Numbers of droughts occurred in CR and CK for P1 and P2 are shown in Figs. 4a and b, respectively. All categories of droughts are found to increase in most of the stations during these two seasons. However, droughts, particularly severe and extreme droughts during both the seasons are found to decrease at the stations located in the north and northwest Bangladesh, which are historically more prone to droughts.

3.3 Changes in Return Period of Droughts

Return periods of different categories of droughts for all the four seasons are computed to assess the changes in drought frequency between periods P1 and P2. Besides, drought maps for different seasons are also prepared to show the changes in spatial pattern in return period of seasonal droughts (not shown here). Figure 5 shows the range of return periods (in year) of

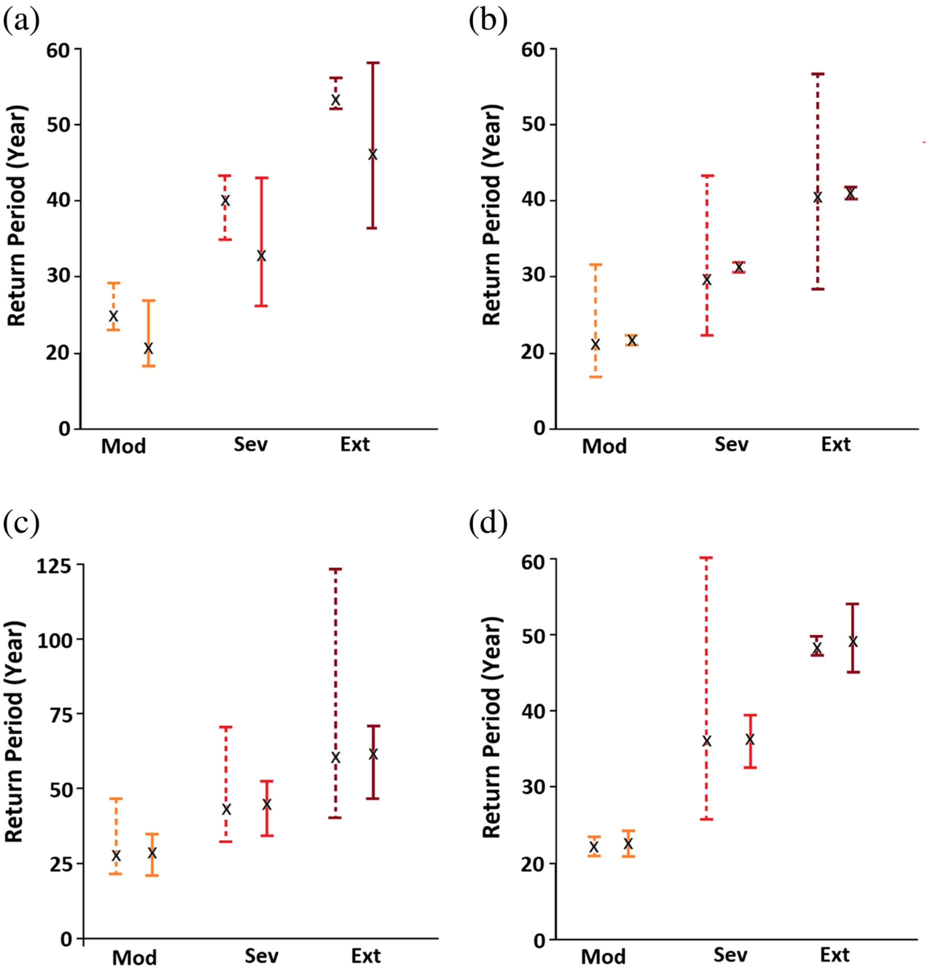

Fig. 5 Changes in the return period of different categories of droughts between periods P1 and P2 for **a** Rabi; **b** Kharif; **c** CR; and **d** CK

different categories of droughts for P1 and P2. The country wise averages of drought return periods are also shown in figure using cross (×) symbol. Figure 5 shows that the country used to experience moderate Rabi drought with an average return period below 29 years during P1. It was less frequent in southeastern region (29 years) and more in northwest part (23 year). The frequency of moderate Rabi drought increased in all over the country during P2. It became more frequent in southwest part (return period near to 18 year) in recent years. Similar changes are also observed for severe and extreme Rabi droughts. The range of return periods of severe and extreme Rabi droughts over Bangladesh were 35–43 and 52–56 years, respectively during P1, which changed to 26–43 and 36–58 years, respectively in P2. This indicates that both the severe and extreme Rabi droughts have become more frequent.

Ranges of return periods of moderate, severe and extreme Kharif droughts were 13–32, 22–45 and 28–57 years during P1 (Fig. 5b). It changed to 21–22, 30–31 and 41–42 years in recent years (P2). This indicates that all categories of Kharif drought have become uniformly distributed over the country. However, the average return period of moderate, severe and extreme Kharif droughts which were 21, 28 and 39 years for P1 increased to 22, 31 and 41 years for P2. This indicates that average frequency of Kharif droughts has decreased over the whole country.

Figure 5c shows less changes in the return period of different categories of droughts during CR. The return period of all categories of droughts has increased in the region where those were less and decreased in the regions where those were high. Therefore, the ranges of return period of CR droughts over Bangladesh have reduced. For example, ranges of return period of moderate, severe and extreme droughts during CR were 21–46, 32–70 and 40–123 years, respectively during P1, which reduced to 22–35, 34–52 and 46–70 years, respectively during P2. The average values of the return periods of different severities of droughts indicate that the frequency of CR droughts have decreased in recent years.

Figure 5d shows no change in the lower range and a slight increase in the upper range of the return periods of moderate drought during CK season. This means no change in the return period of moderate droughts in the drought prone areas and decrease in the frequency of moderate droughts in less drought prone area for CK. On the other hand, the range in the return period of severe drought changed from 24 to 59 years for P1 to 32–38 years for P2. This means that the frequency of severe droughts has decreased in high drought prone area and increased in less drought prone areas. A complete different pattern in extreme droughts is observed for two periods. Frequency of CK extreme droughts are found to increase in high drought prone areas and decrease in less drought prone areas.

Overall, frequency of all categories of droughts in most of the seasons has increased in the regions which are historically considered as less prone to droughts and increase in the regions, particularly in the north and northwest Bangladesh where droughts were more frequent. Changes in return periods of droughts have made spatial distribution of droughts more uniform in most of the seasons under study. However, due to increase in the return period of droughts in north Bangladesh in all the seasons except Rabi, the country experiences less frequency of droughts in recent years.

3.4 Trends in Rainfall and Temperature

Trends in rainfall and mean temperature during different months for the period 1961–2014 are analyzed to understand the causes of changing pattern of droughts in

Table 1 Trends in mean monthly temperature/rainfall at different stations of Bangladesh. The positive/negative sign represents increase/decrease at 95% level of confidence

	Station	Winter		Pre-monsoon			Monsoon				Post-monsoon		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South	Barishal				+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	
	M.Court	+/−		+/•	+/•	+/•	+/+	+/•	+/−	+/•	+/•	+/•	+/+
South west	Jessore				+/•	+/+	+/•	+/+	+/•	+/+	+/•	+/•	
	Khulna						+/•	+/•	+/•				•/−
	Satkhira					•/+	+/•	+/•	+/•				
North west	Bogra				−/•	+/•	+/•	+/−	+/•	+/•	+/•	+/•	
	Rajshahi	−/•				+/•	+/•	+/−	+/•	+/•		−/•	−/+
North	Rangpur				•/+	+/•	+/•	+/•	+/•	+/+		+/+	
	Dinajpur	−/•				+/•	+/+	+/•	+/•	+/•		•/+	−/−
Central	Mymens				•/+	+/•	+/•	+/•	+/•	+/•	+/•		
	Dhaka		+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•
	Faridpur				+/+	+/•	+/•	+/•	+/•	+/•			+/•
North east	Srimongal	•/−				•/+	+/•	+/•	+/•	+/•		+/•	+/•
	Sylhet	+/−	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•	+/•
South east	Chittagon			+/•	+/•	+/+	+/•	+/•	+/•	+/•	+/•		
	Comilla	+/•	+/•				+/•	+/−	+/−			•/+	
	Cox'Baz	+/•	+/•	+/•	+/•	+/+	+/•	+/•	+/•	+/+	+/•	+/•	+/•
	Rangamati	−/•	−/•	−/•			+/•	+/•	+/•		+/•	+/•	+/•

Bangladesh. Trends in monthly average of daily mean temperature and monthly total rainfall at 18 stations are given in Table 1. The positive sign (+) in the table indicates increase, the negative sign (−) indicates decrease, and the symbol dot (.) indicates no change in temperature or rainfall. The first sign in each cell of the table shows the change in temperature and the second sign shows the change in rainfall. The table shows significant increase in temperature at most of the stations in all the months. Particularly, it is found to increase at all stations during most of the Kharif months. Significant increase in temperatures is found more prominent at the stations located in the eastern part of the country. On the other hand, temperature at stations located in western part of Bangladesh is found to increase only in monsoon and decrease in winter.

Significant changes in rainfall are found very few compared to temperature. It is found to increase at highest number of station in May. Changes in rainfall in other months are found significant only at few stations. Overall, significant changes are found more at the stations located in the western part of Bangladesh compared to eastern part.

Increase in temperature in most parts of Bangladesh and almost no change in rainfall are the cause of decrease of the return of period of droughts in most of the stations in all the seasons. Overall, temperature in western part, particularly northwest part of Bangladesh has increased less compared to other parts. Rainfall in some months has increase at some of the stations located in western part of Bangladesh. The changes in temperature and rainfall pattern have caused a shift in spatial pattern in droughts. The droughts which were more frequent and severe in the northwest part of Bangladesh have found to occur with similar or less frequency in recent years. On the other hand, eastern, particularly southeastern part which was less prone to droughts is found to experience more frequent droughts in almost all seasons.

4 Discussion

Bangladesh has a tropical monsoon climate characterized by wide seasonal variations in rainfall. Therefore, seasonal droughts occur due to deficit of rainfall in a particular season. This study reveals a change in spatial pattern in drought frequency in Bangladesh. The frequency of droughts in drought prone regions like northwest and northern Bangladesh has reduced. On the other hand, the regions which were usually considered less prone to droughts are found to have more frequent droughts. However, the frequency of droughts in those areas is still less compared to droughts which were usually faced in northwest Bangladesh in the past. This has made the spatial distribution of the frequency of occurrence of drought in Bangladesh more homogeneous. Overall, country wise average of return period of seasonal droughts with various severities has increase or in other words, the frequency of drought has been reduced. This is mainly due to increase in the return period of droughts in high drought prone areas.

This can also be justified from the trends in crop damage reports of Bangladesh. Reported droughts and there impacts in recent years showed that number of crop damaging droughts has decreased in Bangladesh in recent years (CCCB 2009). No significant drought occurred after the last reported worst droughts in 1994–1996. Planning Commission, Bangladesh (2009) also reported that out of 11 major droughts occurred in Bangladesh after independence in 1971, four occurred in 70s, three in 80s, three in 90, and only one in 2000–2009. This indicates a decrease in droughts in Bangladesh.

In SPEI time series, a number of meteorological droughts are noticed after 1996 in some stations. However, those meteorological droughts are not reported as those droughts did not affected crop production in the region. This indicates that though meteorological droughts exist there as before, it has no impact on agriculture due to the changes in spatial pattern of droughts. These droughts in recent years have occurred in the regions where crop cultivation during that season is less.

Changes in drought pattern has been reported in recent studies in neighboring countries of Bangladesh (Pal and At-Tabbaa 2011; Mishra and Liu 2014; Wang et al. 2014; Chen and Sun 2015; Ge et al. 2016; Wang et al. 2017). Pal and At-Tabbaa (2011) reported an increasing tendency in moderate droughts over India including the northeast part of India bordering Bangladesh for the period 1871–2005. An increase in moderate droughts by 66% and severe droughts by 79% in northeast India for the period 1951–2010 have also been reported by Mishra and Liu (2014). Present study found increase in all categories of droughts in most of the seasons in the eastern regions of Bangladesh bordering northeast of India. This study also collaborates with the findings of Ge et al. (2016) that the severity of droughts is increasing in the areas of India where rice is the major crop. Similar changes in drought pattern in China have been reported in recent years. Wang et al. (2014) found significant increase in dry conditions in Central China for the period 1961–2012 in terms of both SPI and SPEI. Chen and Sun (2015) reported that droughts have become more frequent and severe across China since the late 1990s. Wang et al. (2017) found northwest China became significantly wetter and central China became more arid over the period 1961–2009 due to changes in climate.

The present study suggests that the droughts during cropping seasons of Bangladesh are changing with the changes of climate. Overall, there is a decrease in average drought frequency in major crop growing seasons. Trend analysis of rainfall and temperature data reveals that significant increase of mean temperature in almost all the months and no significant change in rainfall in any of the months are the cause of increasing frequency of droughts in the regions where droughts were less frequent.

5 Conclusion

The drought patterns during cropping seasons have changed in Bangladesh in recent years due to the changes in spatial and temporal pattern of rainfall and temperature. This study reveals that frequency of droughts has increased in the regions which are historically considered as less prone to droughts and increase in the region, particularly the north and northwest Bangladesh where droughts were more frequent. Changes in return periods of droughts have made spatial distribution of droughts more uniform in all the crop growing seasons under study. Increase in the return period of droughts in north and northwest Bangladesh in most of the seasons has made droughts less frequent in Bangladesh in recent years. Analysis of reported crop damage by droughts in recent years collaborates the finding. The study indicates that changes in spatial pattern in rainfall and temperature have changed the spatial and temporal pattern of droughts in Bangladesh. In future, global climate model projected rainfall and temperature data can be used to understand the possible future changes in drought pattern. Furthermore, the changes in hydrological and socio-economic droughts should be studied in order to assess the impacts of droughts on agricultural production and population.

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