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FUTURE CHANGES OF METEOROLOGICAL DROUGHT OVER BANGLADESH USING HIGH RESOLUTION CLIMATE SCENARIOS

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ABSTRACT: Drought has a significant impact over the socioeconomic condition of Bangladesh as it has an agriculture based economy. The current situation of climate change related to agriculture's impact, impact on food security and national policy in these regards need especial scholarly attention in Bangladesh. To assess the meteorological drought (by considering rainfall only), Standardized Precipitation Index (SPI) is used to diagnose drought which uses historic records of monthly rainfall data over Bangladesh. Droughts are categories as extreme (SPI < -2.0), severe (-2.0 < SPI < -1.5) and moderate (-1.5 < SPI < -1.0) droughts and frequencies of these drought events are compared with two time slices, namely, 1971-1990 and 1991-2010 of each 20 years of length. Historical analysis has suggested that extreme droughts are decreased whether severe and moderate droughts are increased during past two decades especially in the north western part of the country. Future drought conditions are also analyzed using 25km high resolution downscaled and projected climate data generated from the regional climate model known as PRECIS. The SRES A1B emission scenarios boundary data have used to run the simulations for a continuous period of 1971-2100. SPI values are also determined with these simulated time series data and validated with existing observed data from 1971 to 2010. It has found that model can capture observe climatology quite well. Considering seasonal (using 3 months SPI) drought events, all three types of droughts will be decreased in future years where there will be a comparative higher frequency of drought at mid 21st Century.

Keywords: *Climate change; Drought Index; PRECIS; Standard Precipitation Index (SPI); Regional Climate Model (RCM).*

1. Introduction

1.1. Background

An extended period of dry weather with insufficient rainfall along with the deficiency in groundwater or surface water is characterized as drought. It is one of the major natural hazards of Bangladesh throughout the history. Drought events have severe impact on country's agricultural economy in past years. Between 1960 and 1991, 19 drought events occurred in Bangladesh. Past droughts have typically affected about 47 percent area of the country and 53 percent of the population (NAP, 2005). After the liberation of Bangladesh in 1971, one of the severest droughts in country's history was 1973 drought. That drought caused a serious famine during 1974 in the northern parts of Bangladesh. Subsequent year, another drought hit over the country causing about 53% of the population to suffer. During

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1978 to 1979 period, severe drought cause wide spread damage to the crops. It reduced rice production by about 2 million tons and one of the severest in recent time. Droughts in 1981 and 1982 damaged crop production of the country. After couple of years, another severe drought happened in 1989 due to drying up of top soil moisture and reductions of river flow. Three consecutive droughts occured from 1994 to 1996 which caused severe damage to crops in the north western part of Bangladesh, especially, to the rice and jute productions. It was one of the longest drought events in recent time (Banglapedia, 2013).

To facilitate future plan and policy in agricultural sector of Bangladesh, it is essential to determine the previous state of drought with accurate indicator. Due to global warming, change of the frequency of drought events was observed all over the world (IPCC, 2007). So, there is an obvious need to understand the changing frequency of drought over Bangladesh and to find out future probabilities of drought events using climate change projections.

Assessing drought is a challenging tasks despite many methods of drought assessment exists. One of the widerly used meteorological drought assessment techniques is Standard Precipitation Index (SPI) method. Many studies have carried out using SPI index to calculate meteorological droughts all over the world (Biabanaki et al., 2012; Zhang et al. 2009; Oliveria Junior et al., 2012; Türkeş and Tatli, 2009). But only a few studies were conducted to predict droughts over Bangladesh. Dash et al. (2011) have characterized meteorological droughts over Bangladesh using SPI index and compared with climate model, RegCM. They concluded that SPI is one of the effective tools to capture previous historical droughts over Bangladesh. However, no analysis has been made to observe the climate change impact on historical frequency of drought events over the country.

On the other hand, future analysis is also essential to determine future state of drought which is a key feature of agricultural practice. In this regards, numerical climate models are one of the best tools available to acquire future climatic information over Bangladesh. Global circulation models are used to predict future climate change in coarser scales typical of 250km. However, often information is in much finer scale which can be obtained dynamically downscaling through regional climate models (RCM). PRECIS (Providing Regional Climate for Impact Studies) is a regional climate model, developed by the Hadley Centre of the UK Meteorological Office, used in the study to project future climate over Bangladesh. PRECIS is simulated for 130 years time period to downscale Hadley Center Coupled Model (HadCM3), a Global Circulation Model produced of Met Office Hadley Center, UK. Simulation has made from 1971 to 2100 with high resolution 25×25 km grid to project accurate, robust climate change information. SRES A1B scenario has simulated and analyzed in future periods. No study has conducted so far using such high resolution climate information to find the future changes of the frequency of droughts over Bangladesh.

This study is carried out to observe the effect of climate change on the frequency of meteorological droughts using SPI index as an indicator. Analysis has also made using data from high resolution climate information generated from PRECIS simulations. SPI index has been calculated for 130 years from 1971 to 2100 over the whole country. Results of baseline periods (1971-2000) are compared with three future time slices (e.g. 2020s, 2050s and 2080s) to assess the future changes of droughts.

1.2. Standard Precipitation Index (SPI)

The Standard Precipitation Index (SPI) is a very useful tools to predict meteorological droughts over a region. As a probability index of rainfall, it shows negative value for a drought condition and positive value for a wet condition. It was designed to enhance the detection of onset and monitoring of drought (McKee et al., 1995). A key feature of the SPI method is the flexibility to measure drought at different time scales. Because droughts vary greatly in duration, it is important to detect and monitor them at a variety of time scales. Short term (1-month) drought has importance to detect the regional historical climatology. Medium term drought like three to six months drought is essential to agriculture as it can be provide an indication of deficiency of soil moisture. Long-term drought like nine to twelve months drought can have impacts on groundwater or surface water supplies. Mathematically, SPI is calculated based on the following equation (Eqn. 1).

$$SPI = \frac{(Xi - Xm)}{\sigma} \quad (1)$$

where, Xi is monthly rainfall record of the station; Xm is rainfall mean; and σ is the standard deviation. The value of SPI can be classified as Table 1 to characterize different magnitude of droughts. SPI value ranging from 0.99 to -0.99 is considered as normal condition of any station. Values that are exceeded 2 or -2 are considered as the extreme wet or dry condition for a specific time interval. Values ranging from -1 to -1.5 and from -1.5 to -2 are characterized as moderate and severe dry conditions, respectively. When SPI values of time series data are continuously negative and crossing -1 or less value it represents the start of a drought. SPI values continues negative until it again become greater than -1 or more value which represents the end of a drought. The total time duration between start and end of drought can be considered as the drought duration.

Table 1: Classifications of droughts based on SPI values.

Range	Drought conditions
SPI ≤ -2	Extremely dry
-2 < SPI ≤ -1.5	Severely dry
-1.5 < SPI ≤ -1	Moderately dry
-1 < SPI ≤ 1	Near normal
1 < SPI ≤ 1.5	Moderately wet
1.5 < SPI ≤ 2	Severely wet
SPI ≥ 2	Extremely wet

1.3. Regional Climate Model, PRECIS

PRECIS (Providing Regional Climate for Impact Studies) developed by the Hadley Centre of the UK Meteorological Office is used in this study. PRECIS was developed to generate high-resolution climate change information for as many regions of the world as possible. RCMs are full climate models and physically based. The PRECIS RCM is based on the atmospheric component of the HadCM3 climate model (Gordon et al., 2000) developed by Hadley Centre, UK. In this study, the domain of PRECIS model for the South Asia with a horizontal resolution of 25×25 km has been set up to determine climate change impact over Bangladesh. This domain allows full development of internal mesoscale circulation and regional forcing at the regional level. The SRES A1B scenario of IPCC was used to derive the lateral boundary conditions of the simulation using three dimensional ocean-atmospheric coupled model (HadCM3Q) to generate diagnostic variables over the Indian sub-continent which includes Bangladesh.

2. Methodology

This study is carried out using data of a total of 34 rainfall stations from Bangladesh Meteorological Department (BMD) located all over Bangladesh. After quality control, six stations are removed from the analysis as they have missing value greater than 20% and failed in the homogeneity test. Two so called time slices of 1971 to1990 and 1991 to 2010 are used in this study to assess the mean change of the frequency of droughts over this region. Five specific time durations of 1-month, 3-month, 6-month, 9-month and 12-month can be considered to provide idea of existing drought conditions. But for some time durations, SPI values provide wrong information about droughts in some parts of country, especially for regions experiencing annual rainfall more than 3500mm. It has found that 3-months seasonal SPI and 12-month yearly SPI values provide reasonable results than other duration. Spatial analyses are also made to see the change of mean state of -droughts in different severity levels. The 3-month and 12-month SPI values are also detected using rainfall data generated from regional climate model, PRECIS. Performance of the regional climate model is validated by comparing with observed BMD data. PRECIS results has been validated for different hydrological zones of Bangladesh according to National Water Management Plan (NWMP, 2009). Finally, climate projections are presented for the three future time slices, namely 2020s from 2011 to 2040, 2050s from 2041 to 2070 and 2080s from 2071 to 2100. Seasonal and annual SPI values are calculated using projected rainfall data from regional climate models.

3. Results and Discussion

3.1 Historical Drought in context of climate change

From the historical records, it has found that agricultural droughts are more prominent in the north western parts of Bangladesh. Meteorological droughts are a representation of the deficiency of rainfall over a particular area from mean state of climate. As a country having monsoon climate, some parts of Bangladesh experiencing annual rainfall over 3500mm. After analyzing different duration of SPI indices, it has been found that 3-month SPI indices are most representative of droughts over Bangladesh. Moreover, seasonal SPI or 3-month SPI is also useful to understand the soil moisture condition of an area. Considering 3-month SPI, frequency of extreme droughts has found increased in the north western part of Bangladesh. Historical evidence also states that this part of the country has experienced more number of extreme droughts in recent years. Figure 1 shows spatial distributions of the number of extreme drought events for two past time slices based on observed rainfall data from BMD. On the other hand, occurrence of extreme seasonal drought decreased drastically in the eastern part of the country. Frequency of severe seasonal droughts has increased all over the country especially, in the north western and north central zone as shown in Figure 2. Frequency of the moderate seasonal droughts also has become more frequent than extreme and severe. Higher in number of moderate drought events are observed in Rajshahi, Pabna, Shirajgonj and Nator district as shown in Figure 3. These districts are more vulnerable to droughts and directly affect food security of the nation. From the time series analysis it has found that all types of drought events are increasing in the north western region of the country.

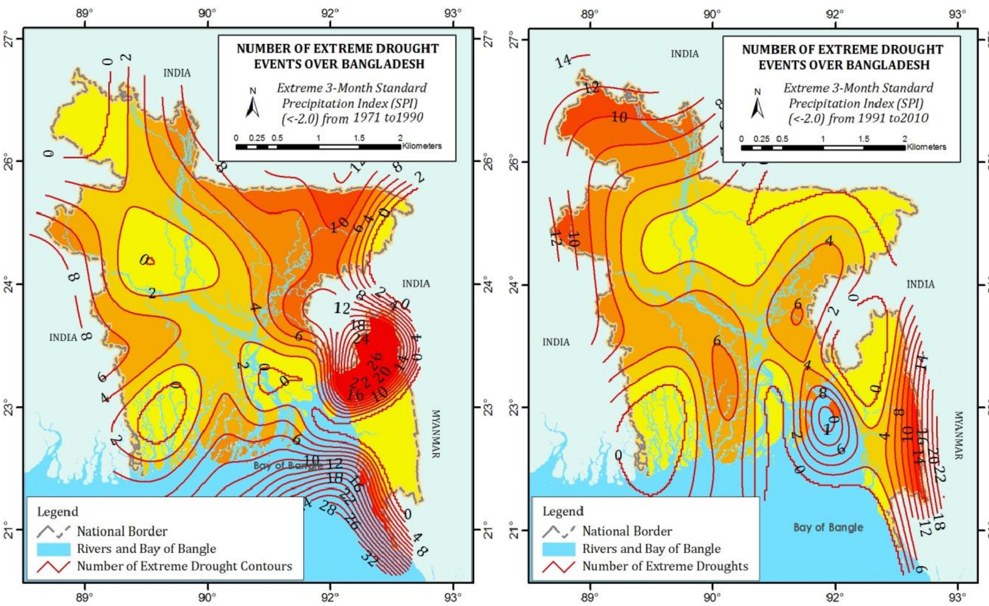

Figure 1: Number of extreme droughts based on 3-month SPI over Bangladesh during 1971-1990 (left) and 1991-2010 (right)

3.2 Validations of climate model

SPI values calculated from PRECIS projected rainfall are compared with the observed SPI values calculated from BMD data. Results are compared and presented for different hydrological zones of Bangladesh as categorized by the NWMP (2009). As only a few of extreme drought events are occurred in the past, model was not able to provide enough indication of its occurrence. However, model was successfully able to provide information about the severe and moderate droughts. Table 2 presents moderate and severe droughts occurred in the past based on observed and model results. It can found that climate model shows only 20% overestimation of the frequency of severe droughts over the country. In places like the south western zone, frequency of meteorological droughts are well captured by the model. But, some places like the north western regions where agricultural droughts are more prominent, model overestimates the frequency of droughts is about 40%. Moderate droughts are well captured by the model than severe droughts. Model overestimates only 9.6% than observed. In the north western part of the country, model shows only 6% deviation from the observed SPI value indicating higher accuracy in capturing moderate droughts. Hence, it can be suggested that region models like PRECIS can capture smaller magnitude of droughts more accurately than higher magnitude of droughts. Analysis also suggests that model overestimate about 60% of drought frequency over the Eastern Hill Track region. Most of the RCMs are less efficient in capturing monsoon circulation over hilly terrain or terrain with rapid change of elevation. Moreover, GCM could not able to capture magnitude of monsoon circulation properly and accurately due to computational and grid size limitations. However, some studies also suggest that rainfall pattern over Indian region is well captured with PRECIS climate model. RCM results should be used over the region with proper bias correction.

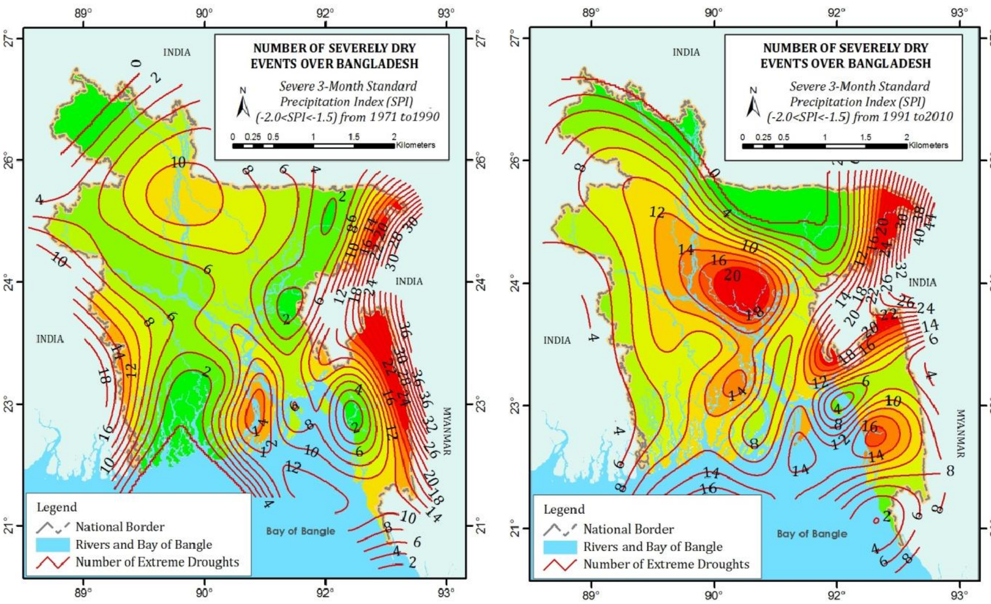

Figure 2: Number of severe droughts based on 3-month SPI over Bangladesh during 1971-1990 (left) and 1991-2010 (right)

Table 2: Comparison between observe and model simulated SPI values.

Hydrological Zone	Severe			Moderate		
	Observe	Model	Percentage	Observe	Model	Percentage
Eastern Hill track (EH)	15.8	25.4	60.8	33.6	42.4	26.2
North Central Zone(NC)	20.0	21.3	6.7	42.7	47.0	10.2
North Eastern Zone (NE)	18.0	24.0	33.3	44.5	54.5	22.5
North Western Zone (NW)	14.4	20.2	40.3	46.6	43.8	-6.0
River And Estuary (RH)	15.0	22.5	50.0	28.0	34.0	21.4
South Central Zone (SC)	18.8	16.4	-12.8	41.4	46.4	12.1
South Eastern Zone (SE)	19.5	19.5	0.0	39.0	41.8	7.1
South Western Zone (SW)	17.3	18.7	7.7	45.3	46.0	1.5
Bangladesh	17.27	20.72	20.0	40.44	44.34	9.6

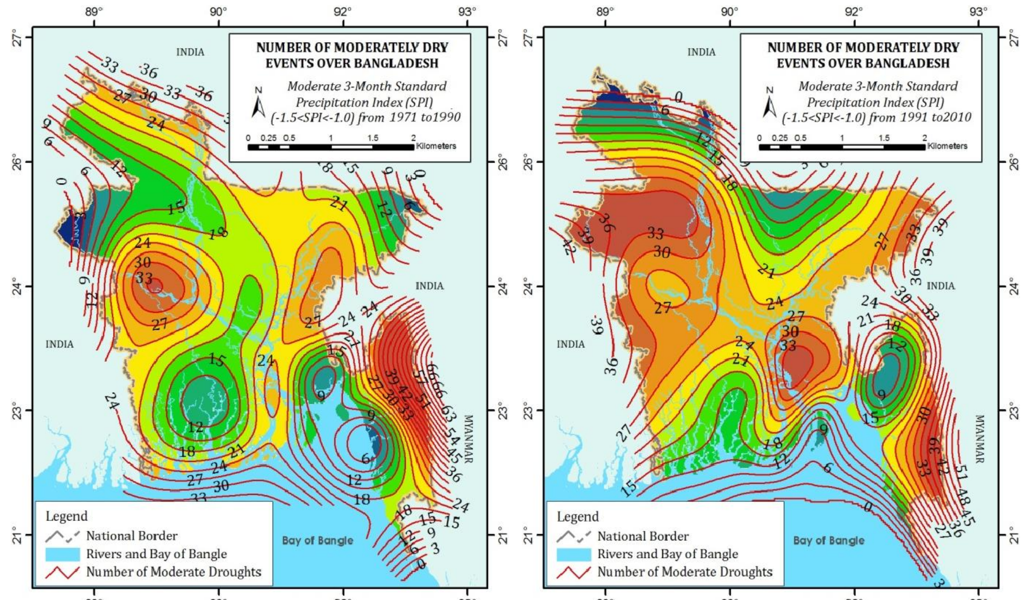

Figure 3: Number of moderate droughts based on 3-month SPI over Bangladesh during 1971-1990 (left) and 1991-2010 (right)

3.3 Future projection of droughts

SPI values are also calculated for future periods using rainfall projections simulated by PRECIS. It has found that almost meteorological droughts will be decreased in many parts of the country. However, a few drought prone areas, especially in the north western parts of the country will experience increasing number of drought events. During the middle of the 21st century, extreme droughts will be less frequent than present days (base line period of the model simulation) but more frequent than 2020s period. There will be rise and fall of overall drought frequencies during the 21st century, where during the 2050s, more frequent number of drought events will observed than other two slices, namely 2020s and 2080s. Frequency of severe droughts will vary more than other two types of droughts in the future. Changes of three types of drought events (Extreme, sever moderate droughts) over Bangladesh that will occurred in the three future time slices are shown in Figure 4.

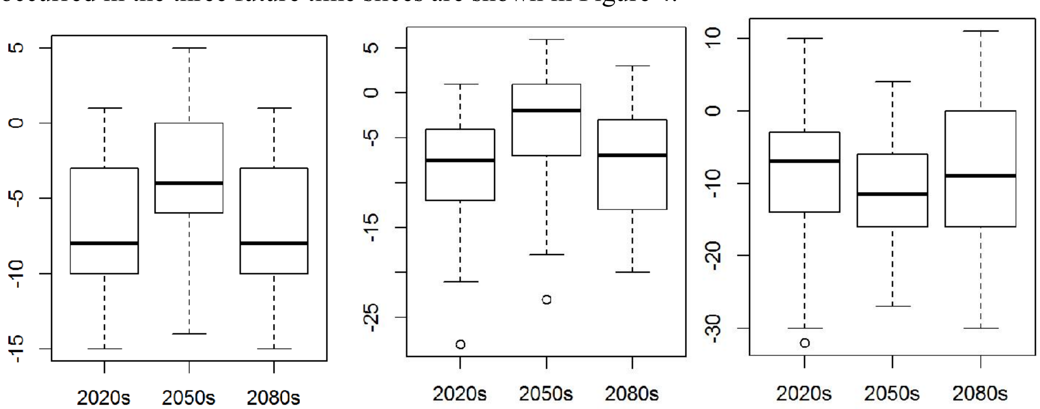

Figure 4: Changes of the frequency of extreme, severe and moderate drought events (from left to right) during 2020s (2011 to 2040), 2050s (2041 to 2070) and 2080s (2071 to 2100) time slices from the baseline (1971 to 2010) period.

4. Conclusion

This study made an attempt to assess the present droughts and possible changes of the frequency of droughts in future considering climate change. It has been found that 3-month seasonal SPI are better capture meteorological droughts over Bangladesh. The frequency of extreme drought events (SPI value less than -2) have decreased during the periods 1991-2010 comparing to the period 1971 to 1990. On the other hand, frequency of severe and moderate drought events have increased in the last two decades. Droughts are found more frequent in the north western parts of the country. Future projections using regional climate model suggested that droughts will be increased in all three time period of 2020s, 2050s and 2080s in the north western parts of the country. However, all the other parts will experience a decrease of the frequency of droughts.

According to IPCC 4th assessment report, some of the projections of GCM showed increasing precipitation in future over some part of eastern India and Bangladesh. Enhance monsoon precipitation would led towards decrease of droughts. It is also noted that, this study is carried out with only one members of A1B SRES future climate projections. Studies can be done considering all other ensembles of A1B scenario as well as considering other extreme scenarios e.g. SRES A2 or B2 which will eventually capture the wider range of uncertainties of climate. Future studies can also able to combined both meteorological and agricultural droughts using remote sensing techniques.

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6. Abbreviations and Acronyms

BARC	Bangladesh Agriculture Research Council
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering and Technology
GCM	Global Circulation Model
IPCC	Intergovernmental Panel on Climate Change
PRECIS	Providing Regional Climate for Impact Studies
RCM	Regional Climate Model
SPI	Standard Precipitation Index
SRES	Special Report on Emissions Scenarios

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