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Drought Analysis of Rajshahi of Bangladesh Using CORDEX data by Palmer Method

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Drought, frequently occurred natural calamity is an impendence to the agro based economy like Bangladesh. Rajshahi is one of the most drought prone districts in Bangladesh. In this study Palmer method has been applied to determine drought features of Rajshahi using both observed meteorological data and MIROC5 GCM (Global Climate Model) data from CORDEX for the control period of 1965-2005.CORDEX data is evaluated comparing with observed data for the period 1965-2005 and it is seen that PDSI (Palmer Drought Severity Index) of CORDEX data can successfully capture the historic drought events like 1975,1979, 1981-82, 1984, 1992, 1994-95.Whileevaluating CORDEX data, it shows some bias and by RMSE (Root Mean Square Error) comparison bias was mitigated. PDSI from CORDEX data reveals October rather than November or December as the onset of drought and May as the termination month of drought events. PDSI has found an effective index to quantify drought. Other GCMs are suggested for comprehensive studies and further drought prediction can also be done using GCMs future data of different RCP(Representative Concentration Pathways) values.

Keywords: PDSI, CORDEX, Rajshahi station, MIROC5 GCM, 1965-2005.

Field of Research: Climatology.

1. Introduction

Tropical monsoon climatic region like Bangladesh (Koppen Climate Classification) has to face severe climatic variability and drought is one of them. The central theme in the definitions of a drought is the concept of water deficit for a prolong period in accordance with demand. (Donald and Wilhite (1985)) categorized four types of drought, 1) Meteorological Drought, 2) Hydrological Drought, 3) Agricultural Drought, 4) Socio-economical Drought. This classification has been made on focusing the area of damage the most. The PDSI is the most widely used index of meteorological drought specially used in the United States (Richard and Heim (2002)). PDSI can also be used in Bangladesh to quantify drought and have a satisfactory result.
The main objectives of this study are:

- To evaluate the precipitation and temperature data of MIROC5 GCMs (Global Climate Model) obtain from CORDEX by comparing with respective observed data of Rajshahi station for 1964-2005.
- To determine drought spells, its frequency and severity by Palmer Method for Rajshahi station using observed data and CORDEX historic data for 1965-2005.

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- To compare the drought features from CORDEX and observed data based on Palmer method for the base period (1965-2005).

Organizations of the Paper:

First section of the paper contains introduction, 2ndsection focuses on literature review and 3rdsection elaborates the methodology. Results and discussions are in section 4, conclusion is in section 5 and section 6 contains references.

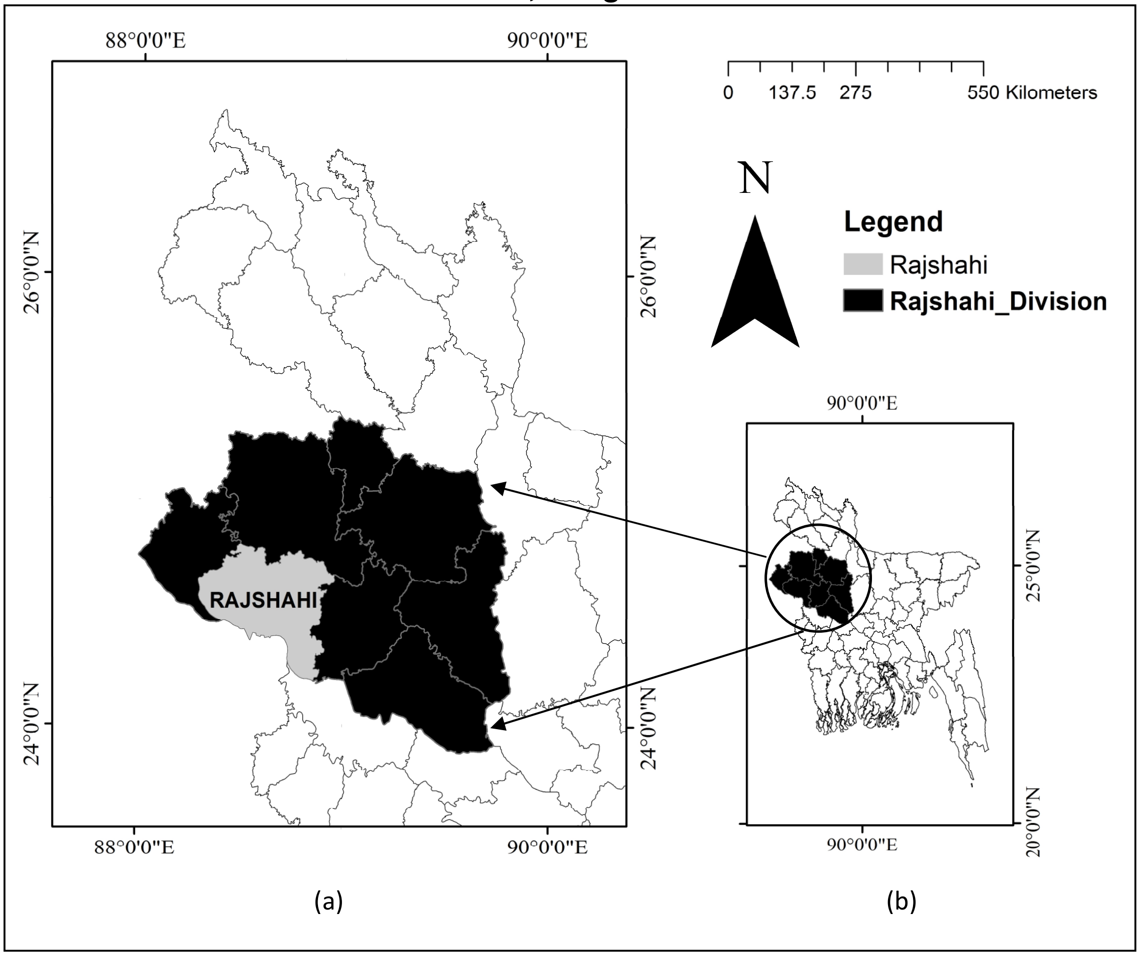
1.1 Background

Very strong droughts hit the country in 1961, 1975, 1981, 1982, 1984, 1989, 1994, and 2000. These droughts have naturally affected about 53% of the population and 47% of the country (WARPO, 2005).For this reason drought analysis is an important issue to research. Data required for this research is not always available. CORDEX is a project provides open source of data that can be easily collected and so the suitability and accuracy of CORDEX to quantify drought in Bangladesh is needed to be measured. If the CORDEX data can capture the historic drought events then its predicted data of GCM (Global Climate Model) can be used to predict future drought. Future drought prediction can be very much beneficial to the policy makers, farmers and resources planners. Moreover, various indices are there to quantify drought features among them PDSI and scPDSI are mostly used indices in United States and a short range of use of PDSI in Bangladesh also seen. So the evaluation of PDSI for Bangladesh is also needed to be measured.

1.2 Study Area

The northwest region is the most drought prone area of Bangladesh and Rajshahi division is one of the drought affected area of the northwest region of Bangladesh. It has coordinates of 24.7106° N, 88.9414° E. Rajshahi division consists of eight districts namely Bogra, Chapainawabganj, Joypurhat, Naogaon, Natore, Pabna, Rajshahi and Sirajganj. In this study climate data of Rajshahi climate station isused. A large portion of Rajshahi division lies on Barind Track, locally named as Barandravumi. Here precipitation is comparatively less than any other part of the country. The average rainfall is about 1,971 mm during monsoon and average temperature is about 35° to 25℃ where at the coolest month temperature becomes 12° to 15℃.Lalpur of Rajshahi has the record of the warmest temperature of about 45℃ (Banglapedia, 2014).

Figure 1: Location Map of (a) Districts of Rajshahi Division, (b) Rajshahi Division, Bangladesh



2. Literature Review

There are different method to assess drought among them Palmer Method (1965), Method of Herbst et al (1966) and Method of Mckee et al (1993) are the most common and worldwide used methods. In 1965, Palmer developed Palmer Drought Severity Index (PDSI) for quantifying the severity of meteorological drought. PDSI value represents current condition and recent past conditions as well because the calculation of climatic coefficients to assess PDSI is nothing but a continuous function of time for a long period of time (Palmer, 1965).The value of PDSI ranges from -0.5 to +0.5 refers to as normal condition and value above +4.0 and below -4.0 indicates extreme wet and extreme drought respectively.

Herbst et al (1966) developed a method to quantify drought using monthly rainfall data where both the duration and intensity of drought can be determined as well as their months of onset and termination. In 1997 a modification of Herbst et al. technique is suggested by Datta using fortnightly rainfall data of NW region of Bangladesh. McKee et al (1993) developed the Standardized Precipitation Index (SPI) to quantify the precipitation deficit for multiple time scales, reflecting the impact of precipitation deficiency on the availability of various water supplies. Datta (2005) assessed the drought using PDSI of selected districts of Bangladesh using data from

BWDB, BMD and SRDI over the time period of 1972 to 2002. Author compared the result of PDSI with other indices SPEI and SPI and found a realistic result.

Gizaw and Gan (2016) analyzed impact of climate change and El Niño episodes on droughts in Saharan Africa (SSAF). The authors used some GCMs climate data and also predicted drought for the years till 2100.Most of the studies in Bangladesh have been carried out using SPI, SPEI, CMI and in narrow range of PDSI indices. In this study drought has been quantifying by PDSI using MIROC5 GCMs data.

3. Methodology

There is various methods to quantify droughts like SPEI, SPI, CMI, VCI, SMI, RDI, PDSI etc. and among them Palmer Method (1965) has been used here. PDSI is embedded on moisture departure between actual precipitation and the precipitation predicted to occur for the average conditions of the climate, which is obtained by performing a monthly water balance and the calibration of local monthly coefficients for the various terms of the soil water balance. Before calculation of PDSI data is needed to prepare by performing some procedures. The following procedures are done chronologically to carry out the study.

3.1 Data Collection

In the very beginning of the study necessary data from various sources were collected. Two types of data one is observed and another is Climate model data has to be collected.

3.1.1 Observed Data Collection

Table1:Observe Data and Sources

Station Name	**Type of data**	**Source of Data**
Rajshahi	Daily Rainfall	Bangladesh Meteorological Department (BMD)
	Mean Daily Temperature	Bangladesh Meteorological Department (BMD)
	Available Soil Moisture	Soil Research Development Institute (SRDI)

Available soil moisture capacity in in/ft unit was collected from the study station and next available soil water capacity was converted to cm unit for the most concerned crop paddy of root zone depth about 90 cm.

3.1.2 Global Climate Model Data

Global Climate Model data were collected from CORDEX (The Coordinated Regional Climate Downscaling Experiment) for the historic period of 1964-2005. For temperature data monthly near surface air temperature is collected. Near-Surface means at a height between 1.5 to 10.0 m. In this study MIROC5 (Model for Interdisciplinary Research On Climate) GCM and SMHI-RCA4 as Regional Climate Model (RCM) of resolution 50km X 50km has been used. MIROC5 (The Model for

Interdisciplinary Research on Climate) is a new version of the atmosphere–ocean general circulation model cooperatively produced by the Japanese research community, University of Tokyo.

3.2 Bias Correction

By comparing the GCM precipitation and temperature data with the observed climate data it was seen that there was some error or bias to be mitigated. Among various methods of bias correction "The Regression Analysis " had been done in this study as bias correction. Bias mitigation had been checked by comparing Root Mean Square Error (RMSE) before and after the correction and each station showed successful RMSE reduction by regression analysis of CORDEX and observed data for control period.

$$\boldsymbol{RMSE} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}}(\boldsymbol{X}-\boldsymbol{Y})^{\mathbf{2}}}$$

Figure 2: Regression Analysis of CORDEX and Observed Data for Control Period, for Rajshahi Station(1964-2005)

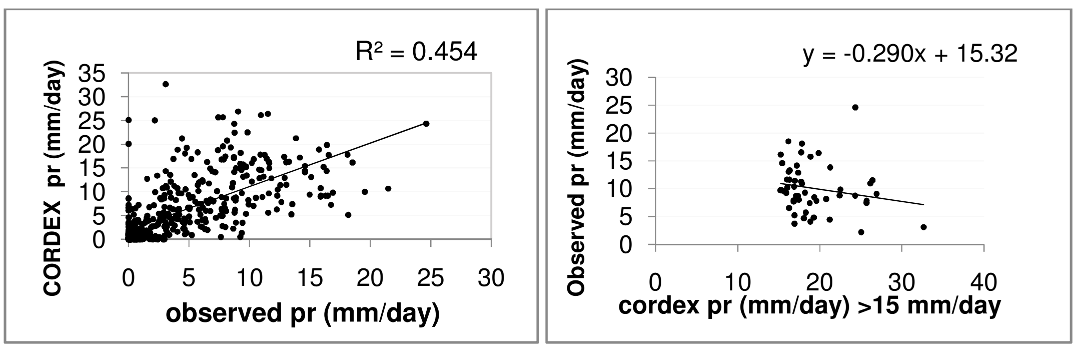
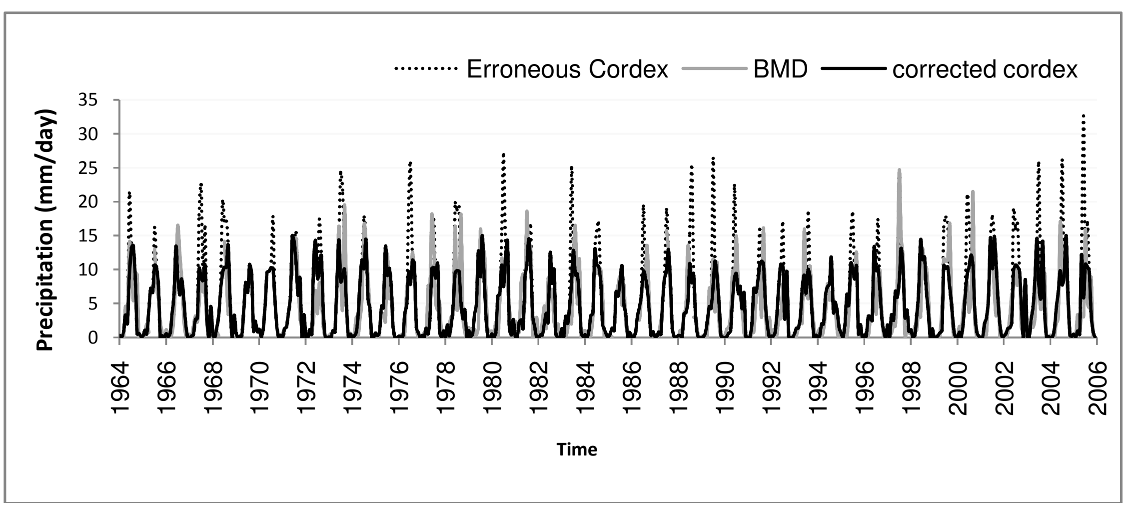


Figure 3: Result of Bias Correction, CORDEX and Observed Precipitation for Rajshahi Station (1964-2005)



In the same manner CORDEX temperature data were corrected by regression analysis. In Rajshahi station for precipitation 29.56% error was reduced where for temperature 14.28% error was mitigated.

3.3 Palmer Method

Palmer (1965) developed a soil moisture algorithm (a model), which uses precipitation, temperature data and local available water content based on the supply-demand concept of the water balance equation, taking into account more than only the precipitation deficit at specific locations. For this regard Palmer developed an index named Palmer Drought Severity Index to quantify drought and its severity.

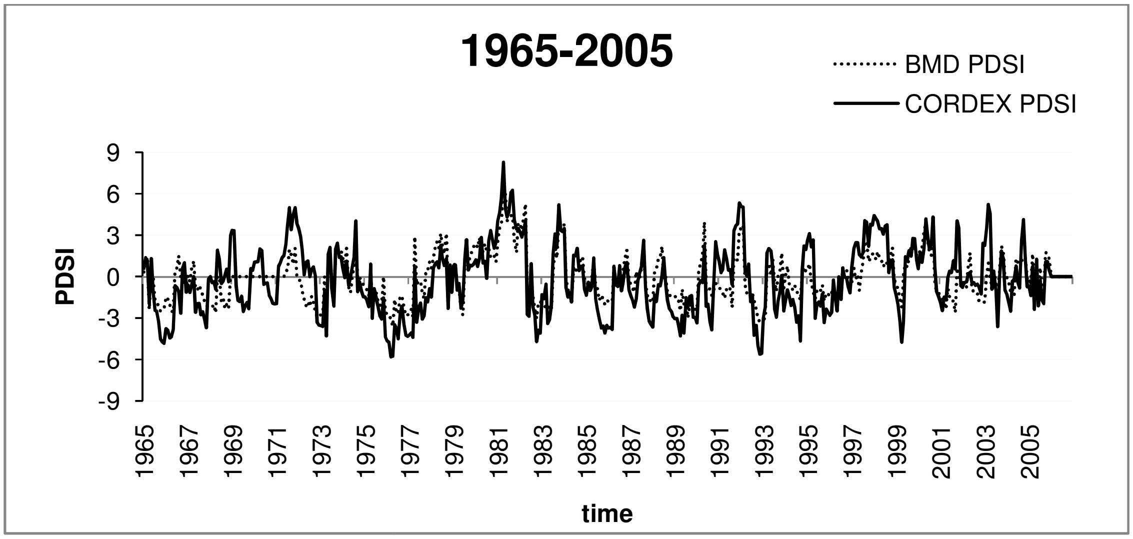
While calculating the moisture departure within the PDSI algorithm, the potential evapotranspiration (PE) estimated either by the Thornthwaite (PE_th) or Penman–Monteith (PE_pm) method has been shown to give marginally different PDSI values in the twentieth century (Schrier et al 2006; Dai 2011a). In this study Thornthwaite Method was used to estimate PDSI though Dai (2011a) has shown that using PE_th could over-estimate the impact of global warming, resulting in much lower PDSI than using PE_pm. Thornthwaite method was used due to its simple application and can easily calibrated for the desired regions.

Table2: Palmer Classifications

PDSI Value	Weather Condition
+4.0 or more	Extremely wet
+3.0 to +3.99	Very wet
+2.0 to +2.99	Moderately wet
+1.0 to +1.99	Slightly wet
+0.5 to +0.99	Incipient wet spell
+0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderately drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

4. Result and Discussion

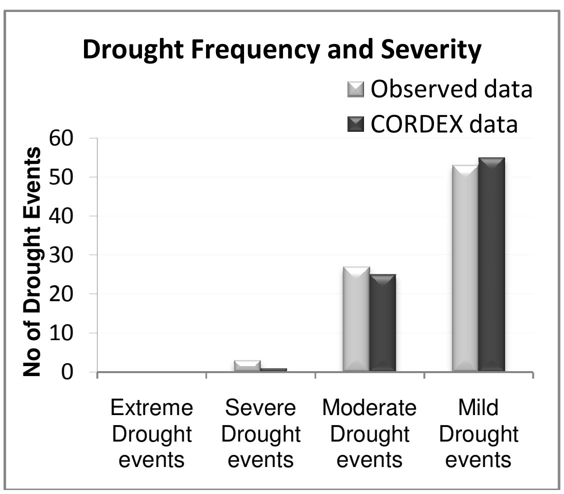
Figure4: Comparison between Observed and CORDEX Calculated PDSI

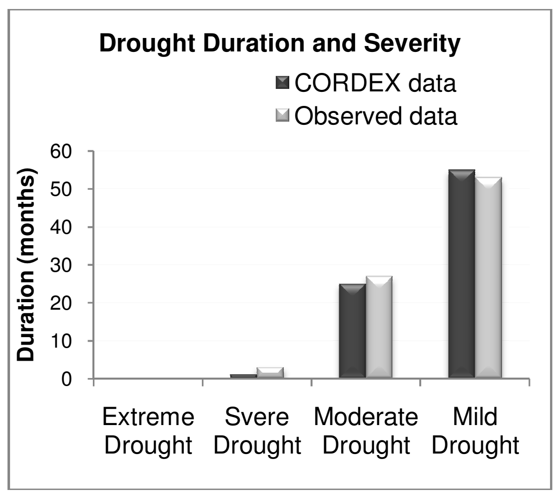


PDSI from CORDEX is nearly resemble to PDSI from observed data. In 1975 PDSI calculated from observed data shown dry to moderate drought where as PDSI from CORDEX shows it mild drought.Though severity may vary but PDSI from CORDEX captured the historical drought periods.

Figure 5: Comparison of Drought Features Calculated from CORDEX and Observed data

(a) **(b)**





Drought events calculated from CORDEX data indicates that there was total 43 drought events covering 81 months where as from observed data it was 44 drought event which coved83months of 1965-2005. Though the drought frequencies and duration of that droughts are very much resembles but from the historic drought analysis it has been seen that Rajshahi faced very severe droughts in 1974, 1982 and in 2000. But from the table it has been seen that from both CORDEX and observed data show no extreme drought rather very few severe drought events. It has been said that around 53% population was affected due to drought in 1974 but the result shows no extreme drought events. From that it can be concluded that though CORDEX data successfully capture the drought events but it fails to identify the accurate severity of drought.

Table3: Drought Events and Durations

Drought Severity	**Observed data**		**CORDEX data**	
	drought events	duration (months)	drought events	duration (months)
Extreme Drought events	0	0	0	0
Severe Drought events	3	3	1	1
Moderate Drought events	27	27	25	25
Mild Drought events	53	53	55	55
Total Drought events	43	83	44	81

Drought features from CORDEX is resemble to drought features from observed data. But in some cases it fails to evaluate the severity that may be due to Palmer method. In this study during the calculation of moisture anomaly index(Z), moisture departure(*d*) is multiplied by a constant 17.67 (K) which basically differs slightly from place to place. To avoid this error in Wells et al (2004) proposed a self-calibrating PDSI algorithm (scPDSI) designed to automatically calibrate the PDSI parameters from historical climate data at the location of interest, and so it is applicable for any region in the world. The scPDSI has been shown to provide more univocal PDSI values between regions of different climates (Schrier et al2006; Dai 2011). If scPDSI was calculated rather than PDSI, drought severity may also be identified successfully.

The frequency analysis of the onset and termination of drought it has been seen that October shows more frequent onset of drought where as May is the month of termination of drought. From the historical drought frequency analysis, the onset and termination of drought shows the same.

5. Conclusion

After completion of the study it can be concluded that Palmer method can successfully identify the drought event and more accuracy can be achieved by considering and mitigating its limitations but it slows more severity then the actual occurrence in some cases and sometimes fails to evaluate drought due to regional climatic variability. This method successfully identify historical drought events like 1975, 1979, 1981-82, 1984, 1992, 1994-95.Though PDSI calculation by using CORDEX data evaluates drought events but not able to capture the severity accurately. CORDEX data can be effectively used in Bangladesh but need some calibration like bias correction. It has been identified the month of October rather than November or December as the beginning of drought spells and successfully identified the month of May as the ending month of drought spell. It is suggested that other GCMs with more finer resolution can be used in drought analysis and further prediction can also be done. Moreover scPDSI can be used for further precise analysis as it works in account with climatic variability for regional variance.

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