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Analyzing Wetness and Dryness Severity in Bangladesh: Using Standardized Precipitation Index (SPI) in GIS Environment

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Abstract
Daily precipitation data of 33 stations were analyzed to know the Standardized Precipitation Index (SPI). Both spatial and temporal SPI were analyzed. Inverse Distance Weighting (IDW) technique was used to map the spatial SPI with a decadal change. From 1983 to 2013, four maps showed the decadal changes of SPI over Bangladesh. 1993 was a dry year in the regarding time period. Station based trends were analyzed for Dhaka, Srimongol, Khulna, Cox's bazaar and Rangpur as preventative for five regions in Bangladesh. Dryness is increasing over Northern and Central regions whereas wetness is increasing over Southwestern, Northern and eastern region in Bangladesh.

Key words: Dryness, GIS, Standardized Precipitation Index, Spatial analysis, Wetness

Introduction

Drought can be defined as a natural but temporary imbalance of water availability, consisting of persistent lower-than-average precipitation of uncertain frequency, duration and severity, of unpredictable or extremely hard to predict occurrences, resulting in diminished water resources availability and reduced carrying capacity of the ecosystems (Pereira *et al.*, 2009). Drought is a major natural hazard faced by communities directly dependent on rainfall for drinking water, crop production, and rearing of animals. In Bangladesh drought is defined as the period when moisture content of soil's less than the required amount for satisfactory crop-growth during the normal crop-growing season. Droughts are common in the northwestern districts of Bangladesh. Drought has become a recurrent natural phenomenon of northwestern Bangladesh (i.e., Barind Tract) in recent decades. Barind Tract covers most parts of the greater Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, Joypurhat and Naogaon districts of Rajshahi division. Rainfall is comparatively less in Barind Tract than the other parts of the country. The average rainfall is about 1,971 mm which mainly occurs during the monsoon. Rainfall varies aerially as wells as yearly. For instance, rainfall recorded in 1981 was about 1,738 mm but in 1992 it was 798 mm. The distribution of rainfall is rather variable from one place to another. Thus this region has already been known a drought prone area of the country. Drought mostly affects Bangladesh in pre-monsoon and post-monsoon periods. From 1949 to 1979 drought conditions had never affected the entire country. The percentage of drought affected areas were 31.63% in 1951, 46.54% in 1957, 37.47% in 1958, 22.39% in 1961, 18.42% in 1966, 42.48% in 1972 and 42.04% in 1979. Various drought indices have been developed with the objective of showing that a drought is in progress or has occurred, as well as to identify the intensity, duration, severity, magnitude and spatial variability of droughts (Mishra and Singh, 2010). Most relevant indices include the Palmer Drought Severity Index, PDSI (Palmer, 1965) and the Standardized Precipitation Index, SPI (McKee et al., 1993, 1995), which are considered herein together with a modification of the PDSI for Mediterranean conditions, the MedPDSI (Pereira et al., 2007). Among these indices, SPI has been widely used in recent years because of its computational simplicity and reliable interpretation. For representing dryness, a simple measure is better than using complex hydrological indices (Oladipio, 1985). SPI is a simple and more effective method for studying drought climatology (Lloyd-Hughes and Saunders, 2002). The SPI is a normalized index for calculating the deviation from the precipitation normal, allowing identification and characterization of droughts at different time scales. Shorter time scales like 3 months seem to be adequate for the identification of agricultural droughts, while longer time scales, e.g. 12 months, better describe hydrological and water resources droughts (Mishra and Singh, 2010; Paulo and Pereira, 2006). Pai et al. (2010) evaluated district-wise drought climatology in India using SPI. Bordi et al. (2001) computed SPI with time series rainfall data from 1948 to 1981 and analyzed regional drought patterns in the Mediterranean. Rodriguez-Pubela et al. (1998) analyzed annual precipitation observations through empirical orthogonal functions and derived four regional precipitation regimes. Sirdas and Sen (2003) used a kriging technique to generate spatial maps of rainfall, and SPI to characterize drought intensity and magnitude in Trakya region, Turkey. Vicente-Serrano et al. (2004) analyzed drought patterns in Spain using SPI and observed significant increase in the area under drought from mid to northern areas. The spatial patterns of drought were found to be very complex in the rest of the areas.

The main objective of this current study is to generate spatial maps of SPI to characterize drought intensity and magnitude of different regions in Bangladesh using Inverse Distance Weighting (IDW) techniques.

Materials and Methods

Study area

Bangladesh extends from 20°34'N to 26°38'N latitude and from 88°01'E to 92°41'E longitude. Except the hilly southeast, most of the country is a low-lying plainland. Bangladesh is located in the tropical monsoon region and its climate is characterized by high temperature, heavy rainfall, often excessive humidity, and fairly marked seasonal variations. From the climatic point of view, three distinct seasons can be recognized in Bangladesh - the cool dry season from November through February, the pre-monsoon hot season from March through May, and the rainy monsoon season which lasts from June through October. The rainfall in Bangladesh varies, depending upon season and location. The average annual rainfall in Bangladesh varies from 1,500 mm in the west-central part to over 3,000 mm in the northeast and southeast. In Surma Valley and neighboring hills, the rainfall is very high. At Sylhet the rainfall average is 4,180 mm near the foot of the abrupt Meghalaya Plateau at Sunamganj it is 5,330 mm and at Lalakhal 6,400 mm, the highest in Bangladesh. Rainfall in the pre-monsoon hot season (March-May) accounts for 10-25% of the total annual rainfall. The rain in this period is caused by convective storms (thunderstorms) or Norwester's (locally called Kalbaishakhi). Average rainfall of this season varies from 200 mm in the west-central part of the country to 800 mm in the northeast. Enhanced rainfall in the northeast is caused by the additional effect of the orographic uplifting provided by the Meghalaya plateau.

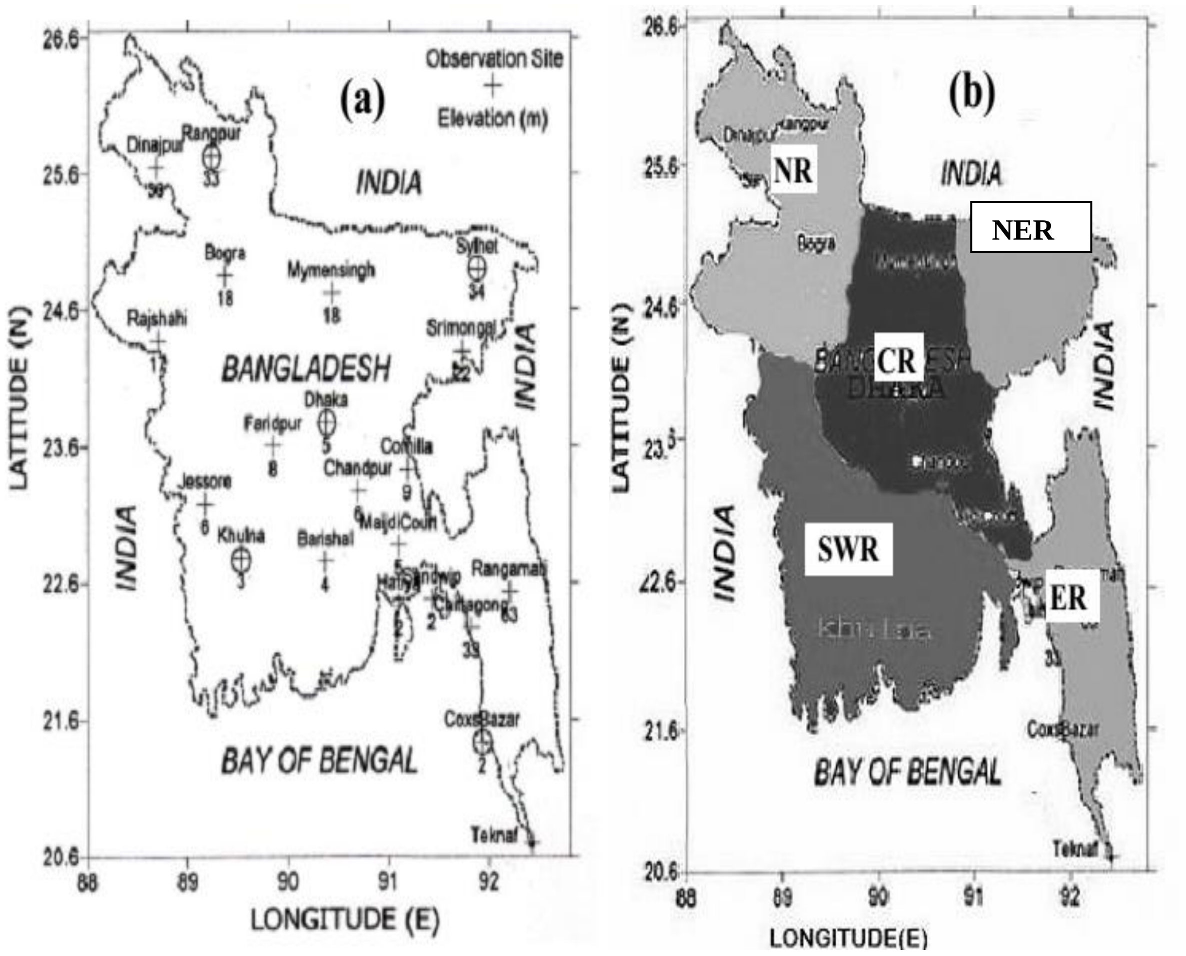

Fig.1. Left map indicate samples of BMD stations and right map shows major regions

Total 33 stations data were analyzed for spatial distribution of SPI magnitude all over the country and five stations 3, 6, 9 and 12 month SPI analyzed for five distinct regions. The listed BMD stations data were assessed;

Table 1. List of stations assessed

Station name	Latitude (^{0})	Longitude(^{0})	Station name	Latitude(^{0})	Longitude(^{0})
Dinajpur	25.65000	88.68333	Feni	23.03333	91.41667
Rangpur	**25.73333**	**89.23333**	M.court	22.86667	91.10000
Rajshahi	24.36667	88.70000	Hatiya	22.43333	91.10000
Bogra	24.85000	89.36667	Sitakunda	23.58333	91.70000
Mymensingh	24.71667	90.43333	Sandwip	22.48333	91.43333
Sylhet	**24.90000**	**91.88333**	Kutubdia	21.81667	91.85000
Srimangal	24.30000	91.73333	**Cox's Bazar**	**21.43333**	**91.93333**
Ishurdi	24.13333	89.05000	Teknaf	20.86667	92.30000
Dhaka	**23.76667**	**90.38333**	Rangamati	22.53333	92.20000
Comilla	23.43333	91.18333	Patuakhali	22.33333	90.33333
Chandpur	23.26667	90.70000	Khepupara	21.98333	90.23333
Faridpur	23.60000	89.85000	Saydpur	25.78333	88.88333
Madaripur	23.16667	90.18333	Tangail	24.25000	89.91667
Khulna	**22.78333**	**89.53333**	Mongla	22.33333	89.60000
Satkhira	22.71667	89.08333	Chuadanga	23.65000	88.86667
Barisal	22.75000	90.33333	Ambagan(Ctg)	22.35000	91.81667
Bhola	22.68333	90.65000			

(Bolded five stations data were analyzed for regional analysis)

Standardized precipitation index

The SPI (McKee and others, 1993, 1995) is a powerful, flexible index that is simple to calculate. In fact, precipitation is the only required input parameter. In addition, it is effective in analyzing wet periods/cycles as it is in analyzing dry periods/cycles. Ideally, one need at least 20-30 years of monthly values, with 50-60 years (or more) being optimal and preferred (Guttman, 1994). The program can be run with missing data, but it will affect the confidence of the results, depending on the distribution of the missing data in relation to the length of the record. McKee *et al.* (1993) used the classification system shown in the SPI value table below (Table 1) to define drought intensities resulting from the SPI. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, thus, wet periods can also be monitored using the SPI. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude".

Table 2. SPI values

2.0 +	Extremely wet
1.5 to 1.99	Very wet
1 to 1.49	Moderately wet
-.99 to .99	Near normal
-1 to -1.49	Moderately wet
-1.5 to -1.99	Severely dry
-2.0 and less	Extremely dry

Soil moisture conditions respond to precipitation anomalies on a relatively short timescale. Groundwater, stream flow and reservoir storage reflect the longer-term precipitation anomalies. So, for example, one may want to look at a 1 or 2 month SPI for meteorological drought, anywhere from 1 month to 6 month SPI for agricultural drought, and something like 6-month up to 24 month SPI or more for hydrological drought analyses and applications.

Results and Discussion

A decadal spatial change of three months SPI map from 1983 to 2013 presented in Figure 1. These three months represents pre-monsoon period of Bangladesh. Arc-GIS spatial analyst tool IDW was used to mapping the spatial distribution of SPI. The figure represent that the dry area in Bangladesh is increasing day by day and the northern part specially becomes drier than southern part of Bangladesh.

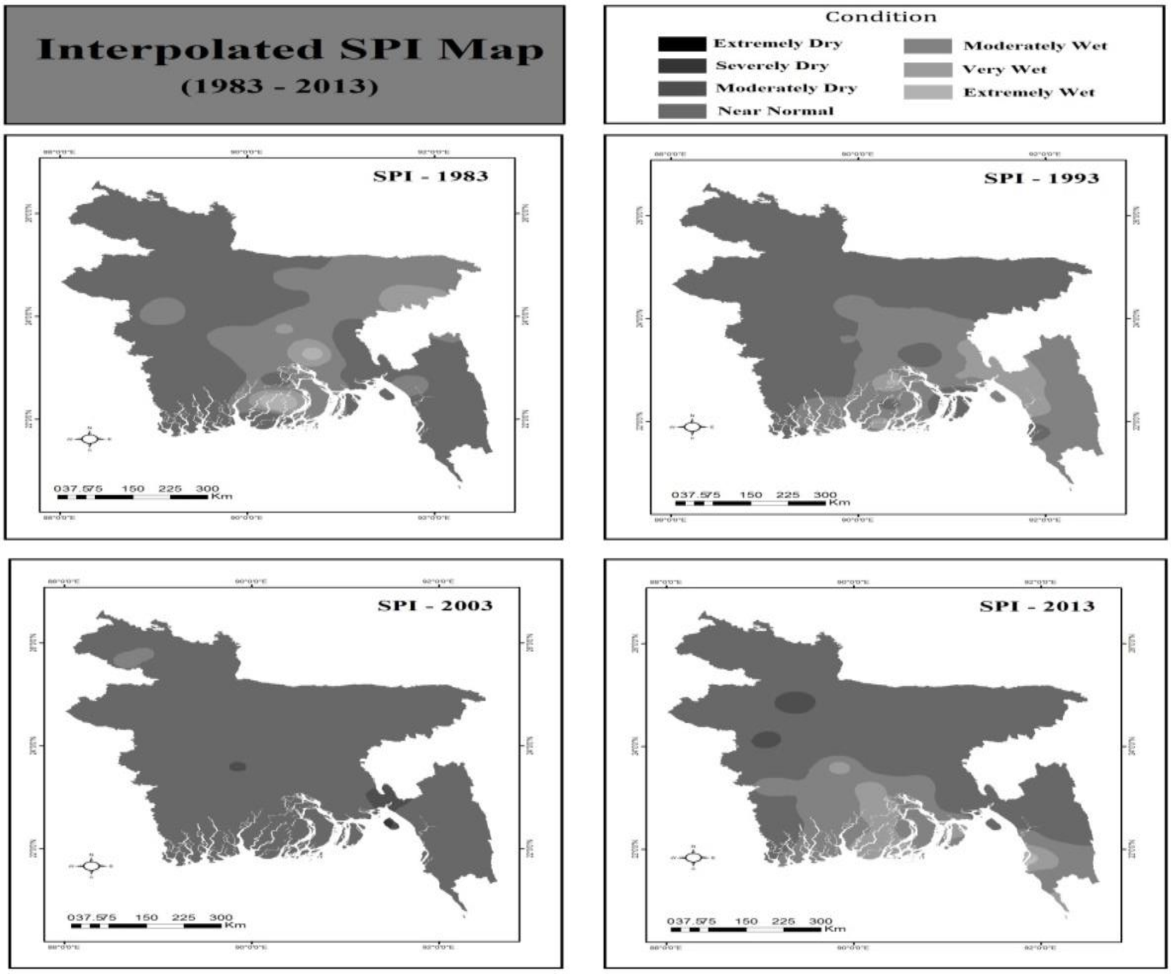

Fig. 2. Pre-monsoon SPI over Bangladesh

Pre-monsoon SPI showed an increasing trend over the country. 2003 is a prominent year of dryness. Moreover, over the decades the area under pre-monsoon dryness is increasing. Especially the northeastern region represents increase of dryness. There is a shift of rainfall in the Southern region from its east to west in pre-monsoon season. The dryness is increasing in the northwestern region from 1983 to 2013.

Table 3. Regional wetness and dryness trend

Region	3 Month SPI	6 Month SPI	9 Month SPI	12 Month SPI
NR (based on Rangpur)	Dryness increasing	Dryness increasing	Dryness increasing	Dryness increasing
SWR (based on Khulna)	Wetness increasing	Wetness increasing	Wetness increasing	Wetness increasing
CR (based on Dhaka)	Dryness increasing	Dryness increasing	Dryness increasing	Dryness increasing
NER (based on Srimongal)	Wetness increasing	Wetness increasing	Wetness increasing	Wetness increasing
ER (based on Cox's bazaar)	Wetness increasing	Wetness increasing	Wetness increasing	Wetness increasing

In northern region (NR) dryness in increasing for all 3, 6, 9 and 12 month SPI.Wetness in increasing at southwestern region (SWR). In central region (CR) dryness is increasing and for both north eastern region (NER) and eastern region (ER) wetness in increasing.

Conclusions

Dryness and wetness shows a spatial variability over Bangladesh. The Northern part of Bangladesh already shows a dryness symptom like soil moisture reduces and ground water table loss. On the other hand the coastal region from eastern part to northwestern part enjoys wetness increasing phenomenon. The increasing dryness in northern region will cause a surface water scarcity and push community to migrate to other region and will face a huge ecological loss in that region. Meteorological, agricultural and hydrological draughts are prolonged to northern part of Bangladesh. The coastal region will face a water related hazards like unusual flood and make trouble in their daily life style and cause a huge loss in agriculture and fisheries.

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