Environmental concern: assessment of meteorological drought

Mohammad Nurul Azam*

King Saud University,
Riyadh, 11451, Kingdom of Saudi Arabia
and
Daffodil International University,
102 Mirpur Rd.,
Dhaka 1207, Bangladesh
Email: mazamd@gmail.com
Email: mazamd@daffodilvarsity.edu.bd
*Corresponding author

Md. Anisur Rahman and SM. Mostafa Kamal

Department of Mathematics,
Islamic University,
Kushtia-7003, Bangladesh
Email: anismathiu@yahoo.com
Email: kamaliubd@yahoo.com

Mahbuba Yeasmin

EKRA Institute,
Melbourne, Victoria 3166, Australia
Email: yeasmin.mahbuba@gmail.com

Abstract: The drought is a lengthy period of unusually low precipitation, leading to a scarcity of water. The Standardized Precipitation Index (SPI) communicates the genuine precipitation as a standardised departure from precipitation probability distribution function. In this study, the daily data for the period 1975–2014 from five precipitation stations surrounding the study area are taken from the Bangladesh Meteorological Department and used as a part of the investigations. We assessed the severity and spatial pattern of the meteorological dry spell are investigated in the North-Western region of Bangladesh using multi-temporal SPI. The greatest SPI value is found –2.27 for six-month timescale, –2.17 for 12 month timescale and –1.85 for three months timescale individually in the year 2010 of Rajshahi station. Mild and moderate drought happen at all stations in the different year of the study area. Severe and extreme drought is mostly found in Rajshahi and Ishurdi locales in the years 1982, 1992, 1994, 1997, 2006, 2000, 2010 and 2012. It is expected that the findings of the study will support drought observing and the outcomes will demonstrate lesser precipitation in the future over the North-West region of Bangladesh.

Keywords: precipitation; climatology; drought; SPI; Bangladesh.

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Biographical notes: Mohammad Nurul Azam is a Professor of Statistics and Econometrics at Daffodil International University, Dhaka, Bangladesh and Consultant Statistician at King Saud University, Riyadh, Saudi Arabia. His research areas include statistics, applied statistics, econometrics, model selection, changepoint problem, forecasting, time series analysis, linear model, biostatistics, environment, climate, power, energy, Monte Carlo simulation method, optimisation, simulated annealing, grid search, and information criteria.

Md. Anisur Rahman is an Assistant Professor at the Department of Mathematics, Islamic University, Kushtia, Bangladesh. He is a PhD scholar in this department. He is engaged in meteorology and environmental issues related to Bangladesh and other countries.

SM. Mostafa Kamal is a Professor at the Department of Mathematics, Islamic University, Kushtia, Bangladesh. He is engaged in research relating to public health, HIV/AIDS, gender, meteorology and environmental issues related to Bangladesh and other countries.

Mahbuba Yeasmin is teaching at Deakin University and a Senior Research Fellow at EKRA Institute, Melbourne, Victoria, Australia. Her research is in multiple maxima and minima, optimisation, data analysis, environment, mathematical and applied statistics.

1 Introduction

Drought as an environmental occurrence is an indispensable part of climatic variability. Droughts are the after-effect of intense water deficiency bringing in serious and, once in a while, disastrous financial and social results. Out of all the regular catastrophes common in the region, drought influences a greater number of individuals and bigger zones than any other. It is, by and large, thought to be happening when the monsoon (a seasonal change in the direction of the dominant wind) fails or are lacking or insufficient. Usually in the monsoon season there is adequate downpour. Disappointment of enough downpour in the monsoon may bring about harvest disappointment, insufficiency of drinking water and impacting the monetary state of the rural and urban people. The drought is a recurring phenomenon in the North-Western region of Bangladesh. In spite of the fact that the drought has attracted less scientific attraction than flood or typhoon, researchers found that the effect of the drought can be more defenseless than flood and cyclone (Shahid and Behrawan, 2008; Shahid, 2008). Food security is a vital issue in Bangladesh. Since the drought is firmly related to food security; subsequently, study on drought perils, particularly drought observing, are fundamental for executing moderation to diminish drought impact in Bangladesh. In Bangladesh, researchers have been exploring drought impact on agriculture, food production, economy, and society (Shahid and Behrawan, 2008; Mazid, et al., 2005). Precipitation is one of the major climatic components for crop production. All crops have genuine stages when it needs water for their development and improvement. In the last 50 years, Bangladesh has endured around 20 drought conditions. In the midst of the drought of 1981 and 1982, the production of the monsoon crops was influenced as it were. The drought condition in the North-Western Bangladesh in the late decades had prompted a deficiency of rice production of 3.5 million tons in the 1990s. Northwestern areas of Bangladesh are especially vulnerable to droughts. An extreme drought can bring about more than 40% harm to aus paddy (a major cereal crop sown during the month March–April and harvested in July–-August) production. Every year, during the Kharif (crops are cultivated and harvested during the rainy season, between April and October) season, drought makes noteworthy harm on the t. aman (transplanted aman usually grown during July to October) crop in around 2.32 million ha. In the Rabi season (from October–March), 1.2 million ha of cropland is confronted by dry seasons at different extents (Anik et al., 2012). Apart from loss to agriculture, droughts have critical impact ashore debasement, the livestock populace, occupation, and wellbeing. Somewhere around 1960 and 1991, droughts happened in Bangladesh 19 times. Exceptionally extreme droughts hit the nation in 1951, 1961, 1975, 1979, 1981, 1982, 1984, 1989, 1994, 1995 and 2000. Past dry seasons have regularly influenced around 47% of the nation and 53% of the populace (FAO, 2007).

In Bangladesh, the significant common dangers are likewise in accordance with worldwide patterns. In the setting of a worldwide temperature alteration, a large portion of the climate models extends a lessening in precipitation in the dry season and an increase during monsoon in South Asia (Christensen et al., 2007). This will bring about a remorseless mix of more amazing floods and droughts in the region. Because of the land use changes inside of the nation and in neighbouring nations, Bangladesh has as of now demonstrated an expanded recurrence of droughts as of late (Shahid and Behrawan, 2008). The worry among researchers has developed on changes of precipitation and continuous event of dry seasons in Bangladesh. In this way, it is important to distinguish various types of the drought (e.g. meteorological, agricultural and so on.) for taking legitimate administration arrangement. In addition, drought is an exceptionally abused word in light of the fact that there is no generally acknowledged meaning of drought. Several authors defined drought on the basis of meteorological, agricultural, hydrological and socio economic impact and also tries to linking up the various types of drought. The meteorological drought is straightforwardly identified with the climate parameter precipitation, yet agricultural drought is the outcome of meteorological drought (Darcup et al., 1980; Ramsey et al., 2006; Wilhite and Glanz, 1985). Drought indices are one of the essential devices to monitor and to evaluate drought since they streamline complex interrelationships between numerous atmosphere parameters. There is extensive literature on the evaluation of drought different indices, models, and water parity recreations (Palmer, 1965; Stahl and Demuth, 1999). Precipitation has been utilised to add to an assortment of lists since it is a key variable to consider meteorological drought. Among the meteorological indices, the Standardized Precipitation Index (SPI) is all the more regularly utilised. The SPI has certain focal points over others, for example, utilisation of precipitation data alone furthermore its variable time scale, which permits it to portray drought conditions imperative for orchestrating of meteorological, hydrological and agrarian applications (McKee et al., 1993). A few studies utilised SPI for constant observing and investigation of the drought. SPI was utilised by Edossa et al. (2010) on the temporal and spatial analysis of the meteorological drought and hydrological drought in light of theory of runs. Drought severity and its characteristic in Thessaly Region, Greece, were examined utilising SPI and the study showed that moderate and severe drought is common in Thessaly Region (Loukas and Vasiliades, 2004). SPI was applied to screen the power and spatial augmentation of drought at various time scales in South Africa (Rouault and Richard, 2003).

Contemporary indices for describing a draught, for example, Palmer Hydrological Drought Index (PHDI) or Surface Water Supply Index (SWSI) are, by and large, information-requesting and computationally-concentrated. Actually, for meteorological draught, exceptionally straightforward and successful records, for example, the SPI have been proposed and widely tried. Much toward effortlessness, the Reconnaissance Drought Index (RDI) has been proposed as of late fusing separated from total precipitation the combined evapotranspiration (Daniel, 2015; Moreira et al., 2015; Cornel et al., 2015; Asadi et al., 2015; Nguyen et al., 2015; Sorin et al., 2014; Chunlan et al., 2014; Zhuo et al., 2014; Merlin and Mkankam, 2014). So we use a simple and useful index SPI for draughts assessment in this paper. In this paper, an endeavour has been utilised to analyse spatial patterns of meteorological drought utilising SPI which can look at the characteristic of a drought and can give a sign of drought at different levels.

2 Data and methods

Bangladesh Meteorological Department (BMD) gathers regular precipitation data through 35 climate stations situated all over Bangladesh. Among them, there are five climate stations located in the North-Western region of Bangladesh. Considering long haul accessibility of daily precipitation data and their suitability for destinations of five stations, in particular, Ishurdi, Rajshahi, Bogra, Rangpur and Dinajpur, have been chosen for this study. The study period is January 1975 to December 2014. It is to be noted that there were some missing data. The missing precipitation qualities are processed by expectation maximisation (EM) technique (McLachlan and Krishnan, 1997). The data have been compiled, tabulated and analysed by MS Excel and SPSS v22 (SPSS Inc., Chicago, IL, USA). The monthly precipitation data were utilised as a part of putting in the computation of SPI. The SPI is computed by fitting a proper probability density function (PDF) to the frequency distribution of precipitation summed over the timescale of interest (generally 3, 6, 12, and 24 months). The SPI is computed by dividing the contrast between the standardised seasonal precipitation and its long-term seasonal mean by the standard deviation. Along these lines

$$SPI = \frac{R_{ij} - R_{im}}{\sigma}$$

where, R_{ij} is the seasonal precipitation at the i^{th} rain gauge station and j^{th} observation, R_{im} the long term seasonal mean and σ is its standard deviation. Seven classes of the SPI appeared in Table 1 and is utilised as a part of this study. The way that precipitation is not normally distributed is overcome by applying a transformation (i.e., Gamma function) to the distribution. Table 2 reveals normality test for SPI for different locations.

Table 1 Drought criteria as per SPI

SPI values	*Drought criteria as per SPI*
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
–0.99 to 0.99	Near normal
–1.0 to –1.49	Moderately dry
–1.5 to –1.99	Severely dry
–2 and less	Extremely dry

The calculation of SPI requires long term precipitation data. It is found by Thom (1966) that the gamma distribution function fit to the precipitation time series. The long term record is fitted to a probability distribution, which is then changed into a normal distribution, so that the mean SPI for the area and desired period is zero (Edwards and McKee, 1997). The precipitation series was fitted to the gamma distribution. It is characterised by its frequency or PDF. The gamma PDF is given as follows. The alpha and beta parameters of the gamma PDF are estimated for each station.

$$g(x) = \frac{x^{\alpha-1} e^{-\frac{x}{\beta}}}{\beta^{\alpha}\Gamma(\alpha)} \text{ for } x > 0$$

where,

x = rainfall amount

α = shape parameter $= \frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right) A = \ln\left(\bar{x}\right) - \frac{\sum \ln(x)}{n}$

n = number of rainfall observations

β = scale parameter $\frac{\bar{x}}{a}$

This allows the precipitation distribution at the stations to be effectively represented by a mathematical cumulative probability function given by,

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1} e^{\frac{x}{\beta}} dx$$

Since the gamma function is undefined for $x = 0$ and a precipitation distribution may contain zeros, the cumulative probability becomes: $H(x) = q + (1 - q)\, G(x)$ where q is the probability of a zero. The cumulative probability $H(x)$ is then transformed to the standard normal distribution to yield the SPI (Stahl and Demuth, 1999). The gamma distribution function is fitted to the data for estimating the parameters α and β. The gamma cumulative distribution function (CDF) is computed at each value of x by integrating PDF with respect to x and inserting the estimated values of α and β. The CDF is then transformed into the standard normal distribution to find SPI.

Table 2 Normality test for SPI for different locations

Location	*SPI*	*Test/P-value*	*Shapiro-Wilk*	*Skewness-kurtosis*
Ishurdi	3 months	Test	0.823	47.484
		P-value	0.000	0.000
	6 months	Test	0.912	17.661
		P-value	0.004	0.000
	12 months	Test	0.928	10.918
		P-value	0.014	0.004
Rajshahi	3 months	Test	0.959	3.407
		P-value	0.154	0.182
	6 months	Test	0.982	0.319
		P-value	0.745	0.853
	12 months	Test	0.955	3.237
		P-value	0.112	0.198
Bogra	3 months	Test	0.958	2.195
		P-value	0.144	0.334
	6 months	Test	0.984	0.902
		P-value	0.844	0.637
	12 months	Test	0.966	1.899
		P-value	0.275	0.387
Rangpur	3 months	Test	0.935	8.848
		P-value	0.024	0.012
	6 months	Test	0.941	12.287
		P-value	0.037	0.002
	12 months	Test	0.934	5.168
		P-value	0.021	0.075
Dinajpur	3 months	Test	0.946	9.319
		P-value	0.057	0.009
	6 months	Test	0.975	0.106
		P-value	0.511	0.948
	12 months	Test	0.946	4.059
		P-value	0.056	0.131

3 Results and discussion

The results of the present study on the assessment of meteorological drought in the North-West area of Bangladesh have been analysed and discussed. Time series datasets are used for this study. The SPI values for 3, 6 and 12 months over the North-Western area of Bangladesh in during the 40 years (1975–2014) are shown in Figure 1, Figure 2 and Figure 3.

Figure 1 Variation of SPI for three months of June to August (1975–2014) (see online version for colours)

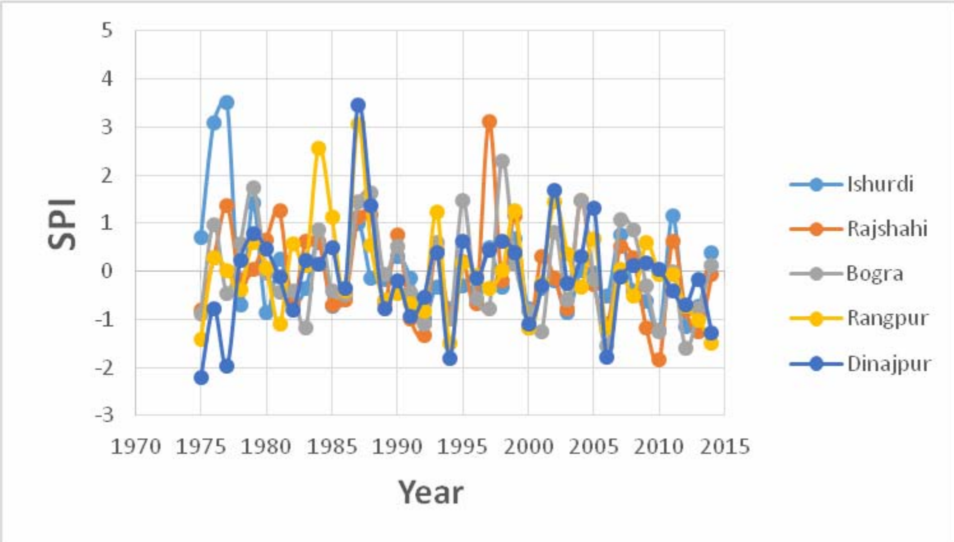


Figure 2 Variation of SPI for six months of May to October (1975–2014) (see online version for colours)

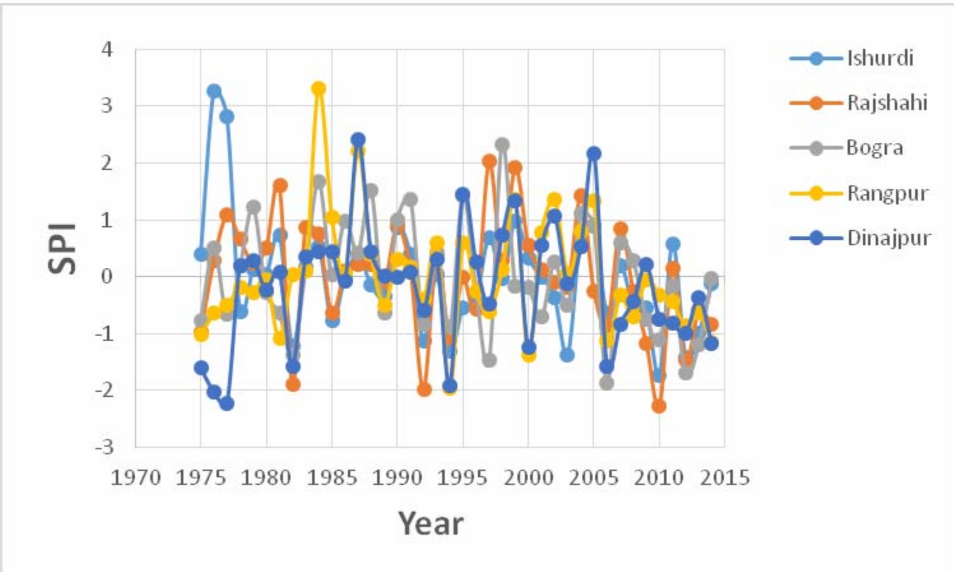
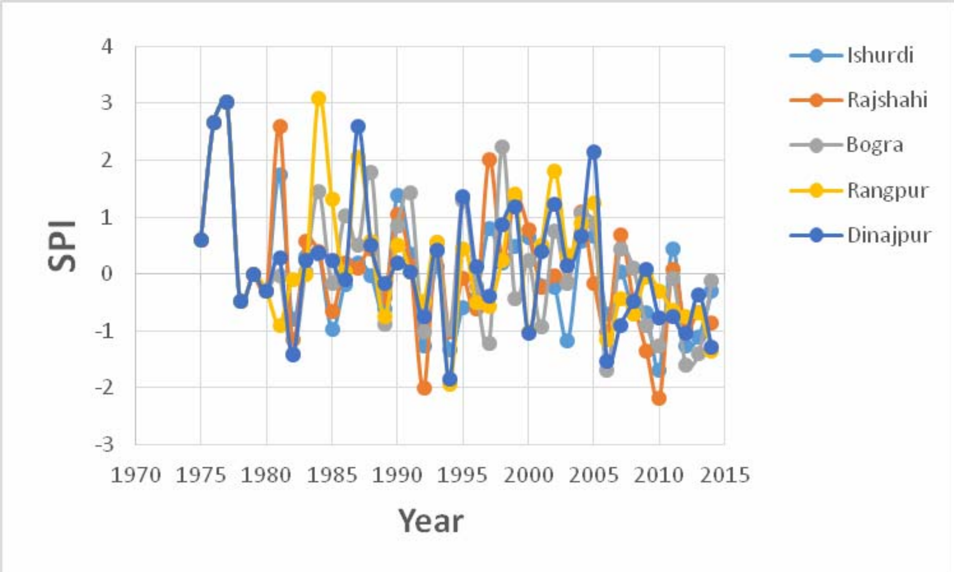


Figure 3 Variation of SPI for 12 months of January to December (1975–2014) (see online version for colours)



The study delivered the severity of drought at 3, 6 and 12 months' time ventures, in the five rain gauge stations. The results of the study demonstrate that in Rajshahi station, the most extreme SPI value were found at –2.27 for 6-month timescale,–2.17 for 12-month timescale and –1.85 for 3-month timescale respectively in the year 2010. Then again, around the same time for Ishurdi station, the SPI qualities were observed to be –1.22, –1.74, –1.70 for 3, 6, 12-month timescales respectively. For station Bogra, the SPI was –1.60 in the year 2012 for 3-month timescale and for 6, 12-month timescale the SPI qualities were –1.87 and –1.70 respectively in the year 2006. In the year 1994 we observed that that for Rangpur station, the maximum SPI quality was –1.96 for 6-month timescale yet for 3 and 12-month timescale the SPI qualities were –1.49 and –1.94 respectively. It was likewise revealed that around the same year for Dinajpur station, the SPI qualities were –1.80, –1.91 and –1.85 for 3, 6 and 12-month timescale respectively. Drought had been analysed, the moderate drought was seen in the year of 1975, 1981, 1982, 1985, 1991, 1992, 1994, 1997, 2000, 2003, 2006, 2009, 2010, 2012, 2013, 2014 and extreme Drought was distinguished in the year of 1982, 1992, 1994, 1997, 2006, 2000, 2010 and 2012.

As shown in our findings, almost all SPI non-normal distributions occur during the wintertime season. Further studies should better look into the grounds for this non-normality, which appears to be connected to the high chance of zero rainfall values during the dry time of year. In this horizon, following Wu et al. (2007), it is worth mentioning that computations are based on both negative and positive SPI values. Above discussion indicates that application of SPI for one-month time step may lead to erroneous assessment of drought situation. Further, it can be concluded from above discussion that the SPI has captured the real essence of drought situation of study area.

The comparative analysis of various indices indicated that the drought period with single or two instances of above normal rainfall during this period. This period has been affirmed with the documented records of Statistical Handbook. It is observed from the analytic thinking that during the period of drought identified, the region suffered with huge crop loss. On the other hand, the wet periods identified using SPI did not help much in terminating the drought. It revealed that SPI seems to be more suitable in the timely detection of long term as well as short term rainfall deficiency as compared to other indices. It is understood from the investigation that the mild drought ranges in the various year. On these lines, the North-West part of the study area is unprotected for a hard drought, yet less inclined for severe droughts.

4 Conclusions

This paper managed to make an appraisal of the meteorological drought for five rain gauge stations of the North-Western part in Bangladesh for the period 1975–2014 to evaluate the drought cataloguing according to SPI for this period. The most extreme SPI values for Rajshahi station discovered are –2.27 and –2.17 for 6 and 12-month timescale respectively in the year 2010. Though, the SPI values for Ishurdi, Bogra, Rangpur, and Dinajpur are mostly the same in the years 1994 and 2014. It is seen from this study that the moderate and severe drought happens in each station. It is expected that the findings of the study will strengthen drought checking and the outcomes show lesser precipitation in the future over the North-West region of Bangladesh.

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