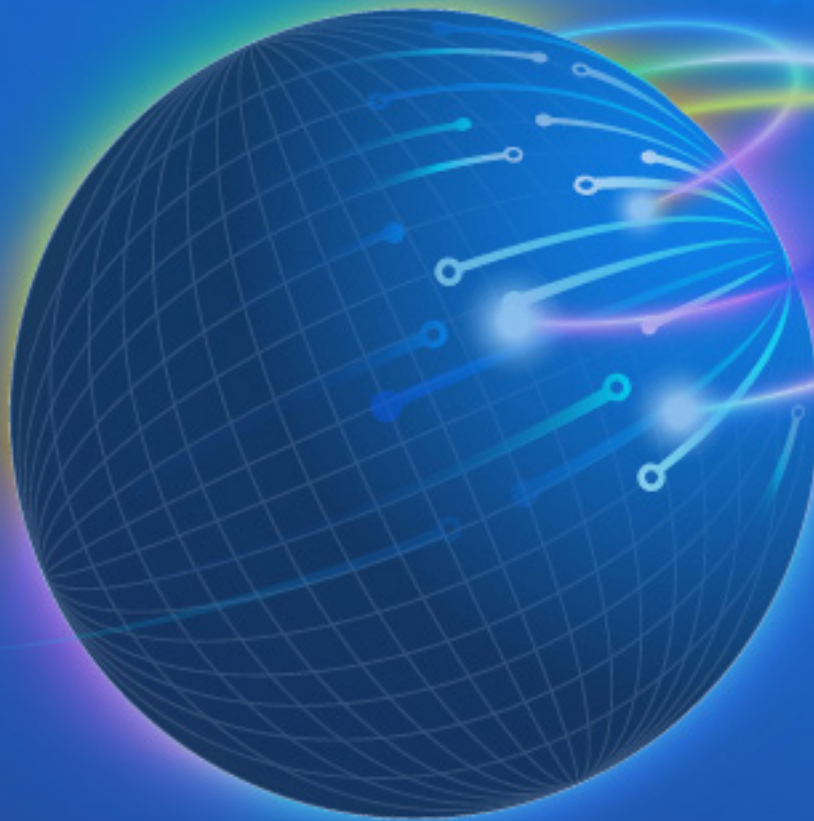




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## Spatial and Temporal Distribution of Meteorological Drought Using GIS in Bangladesh

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### ABSTRACT

The meteorological definition of drought is a prolonged condition of subnormal precipitation that results in significantly reduced soil moisture and an impaired water supply to crops and to the world's population. Standardized drought indices, such as the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) are commonly used to monitor drought. Aggregating SPI and SPEI analysis were done to explore temporal and spatial patterns of drought in different geomorphic regions of Bangladesh. The study considered 42 years (1980–2022) of monthly precipitation and temperature data from 35 meteorological stations for drought intensity, severity, occurrence pattern, as well as a geographic information systems (GIS) platform to draw a map of the drought-prone areas. Results showed that droughts took place every 2-3 years in different areas of the country. More severe droughts were experienced in North Centre and East relative to South West, South East, South Centre and North West, implying a graduating susceptibility to water stress from central zones towards the east. There is also a declining trend of drought in the hilly eastern zone and an opposite trend from southern to northern zones, with high magnitude observed largely over northwestern parts. The spatial-temporal patterns suggest that in some regions, no short- or medium-term droughts (3- and 6-month SPI) were recorded, but long-term drought (12-month SPI), whereas the opposite was true for other areas. From January to May, a positive relationship between increased mean temperature and precipitation was identified, followed by the intensification of monsoon from June to August and subsequent decreases until December. In conclusion, the research contributes to the drought evaluation process, enabling hazard control and development of agricultural disaster mitigation policies in Bangladesh.

### INTRODUCTION

Droughts are defined as prolonged periods of low precipitation compared to the anticipated average. It poses significant challenges in many regions worldwide, including South and Southeast Asia, Sub-Saharan Africa, and North Africa (Adapa & Venkatreddy, 2024). Droughts are becoming more frequent and severe due to severe climate change, over-exploitation of water resources, and weather variability (Krishna Prabhakar, 2022). The concerning trend is expected to continue and pose threats to various sectors, including agriculture, health, and the economy (Salvador *et al.*, 2023). Bangladesh, a South Asian country where flooding often captures more attention due to its recurring nature and severity, droughts are an equally important natural hazard that affects agriculture, water availability, and socio-economic stability (Ahmad *et al.*, 2022; Islam, 2020). Drought is a multi-faceted natural hazard with slow onset but catastrophic environmental, social and economic impacts. In contrast to suddenly occurring disasters, drought occurs over time with prolonged periods of reduced rainfall, increased evapotranspiration and regional climatic anomalies (Ahady *et al.*, 2025). It is that dynamical drought when rainfall deficits persist over the long term and catchment, river flow and agricultural stresses are what first appear in response to increasingly difficult conditions (Pourzand & Noy, 2022). With

increasing climate variability on a global scale, there is a growing frequency and severity of droughts that strongly affects both food security, water supply for humans and socio-economic stability (Runde *et al.*, 2022). Therefore, exploring the spatiotemporal variability of drought patterns has become a major research focus, especially in regions with climate vulnerability (Chen *et al.*, 2025). Bangladesh, situated in the South Asian monsoon zone has a subtropical monsoon climate characterized by intense seasonal fluctuations in temperature, rainfall and humidity (Khan *et al.*, 2019). While the nation is internationally renowned for its vulnerability to flooding and cyclones, drought is another major natural hazard that has received less attention. Recurrent rainfall deficits, untimely onset of monsoon, and prolonged dry spells in the northwestern, northern, and central subzones have an adverse impact on agricultural production, groundwater recharge, and rural livelihoods (M. M. Rahman *et al.*, 2020). Rapid population increase, increasing irrigation needs and changes in land-use enhance drought vulnerability over the entire country. With such a dependence on rained agriculture and monsoon-driven hydrology, it is important to understand the spatial and temporal distribution of drought in order to improve national resilience (Opu *et al.*, 2023).

Recently, more and more studies of drought have made use of modern indices with robust statistical property

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(e.g., SPI and SPEI) to describe droughts over multiple time scale. SPI is based on precipitation anomalies -while the latter accounts for temperature-induced evapotranspiration, and permits a more thorough evaluation in warming climate (S. Rahman *et al.*, 2025). When linked with Geographic Information Systems (GIS), these indices permit detailed spatial mapping of drought severity, frequency and coverage, which can be used to inform water resources management, agricultural planning and disaster risk reduction. Although SPI–SPEI was widely applied at a global scale, the use of both SPI–SPEI and GIS-based spatial analysis together is still not common in Bangladesh, especially for long-term data from varied geomorphic localities (Opu *et al.*, 2025). The meteorological drought in Bangladesh is primarily caused due to insufficient rainfall during the monsoon season (Mondol *et al.*, 2021). However, it is seen that the degree to which it occurs varies across different regions in the country (Sadiq *et al.*, 2023). The northwestern regions of Bangladesh, including districts like Rajshahi, Bogura, and Dinajpur, are particularly prone to high vulnerability to droughts, primarily due to high rainfall variability and high groundwater extraction (Sadiq *et al.*, 2023; Salvador *et al.*, 2023). Most recently, it has been observed that the central region of Bangladesh is becoming vulnerable to droughts, which will severely impact agriculture and water resources (Kamruzzaman *et al.*, 2022). Furthermore, scholarly studies have found that the southwestern region of Bangladesh is experiencing frequent drought spells due to the variability of rainfall (Kamruzzaman *et al.*, 2019). So, it is evident that changes in rainfall intensity patterns and temperature increases are influencing drought events throughout Bangladesh. Therefore, it is now an urgent issue to understand drought’s spatial and temporal dynamics. The common approach to assessing meteorological droughts is by using Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) (Ariyanto *et al.*, 2020; Mostafazadeh & Zabihi, 2016). Both of the indices are widely used for their simplicity and effectiveness (M. R. Rahman & Lateh, 2016). The SPI uses precipitation data, and measures deviations in precipitation over a specific period (Ariyanto *et al.*, 2020; Mostafazadeh & Zabihi, 2016). While, SPEI incorporates both precipitation and potential evapotranspiration (PET) to measure anomalies in climate and water balance (Ariyanto *et al.*, 2020; Mostafazadeh & Zabihi, 2016). Although there are several studies on drought events in Bangladesh. However, most of the studies have focused on small or local regions or relied on a single drought index (A. T. M. S. Rahman *et al.*, 2017; M. R. Rahman & Lateh, 2016; Sultana *et al.*, 2021; Towfiqul Islam *et al.*, 2023). Thus a gap in the literature persists. To fill the gap in scholarly findings on drought events in Bangladesh, this research aims to analyze drought conditions on a national scale (Bangladesh) considering from year of 1980 to 2022.

The study’s primary objectives are mainly three-fold. Firstly, it will calculate SPI and SPEI values across 35 meteorological stations in Bangladesh over a period of 42 years (1980 to 2022) to assess the frequency, severity, and temporal variation of meteorological drought. Secondly, spatial distribution maps of drought in Bangladesh will be generated to identify higher-risk drought-prone regions. Finally, insights will be provided for improving drought preparedness, water resource management, and agricultural practices. The research questions are:

- What are the regional meteorological drought patterns in Bangladesh during 1980–2022?
- How does drought temporal variation changes over monthly, seasonal and annual using SPI and SPEI?
- Which areas in Bangladesh are most susceptible to short, medium and long-term drought?
- What are the effects of temperature and precipitation on drought impacts and occurrence over the study area?
- How effective is the GIS-based spatial analysis to delineate drought prone areas and contribute to drought monitoring and management in Bangladesh?

To solve these questions, we specified the following research objectives:

1. To map the spatial character of meteorological drought over Bangladesh for the period, 1980–20220 using SPI and SPEI indices.
2. To assess the drought’s temporal variation in monthly, seasonal and yearly time scales.
3. To find short, medium and long-term drought-prone areas according to different multi-time scale SPI and SPEI values.
4. To investigate how multi-decadal temperature and precipitation trends may affect drought severity and frequency.
5. To use native GIS spatial operations techniques for mapping of drought hotspots and helping to achieve better strategies for monitoring and management of drought in Bangladesh.

## MATERIALS AND METHODS

The methodology employed in this study was to assess drought using SPI, SPEI, and GIS mapping. The methodology is presented in the flow chart (Figure 1):

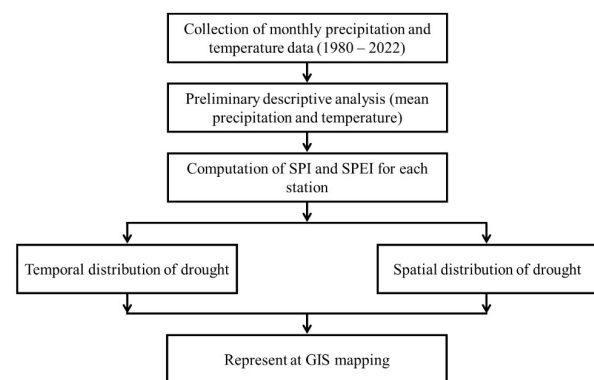


Figure 1: Flow Chart of Research Methodology

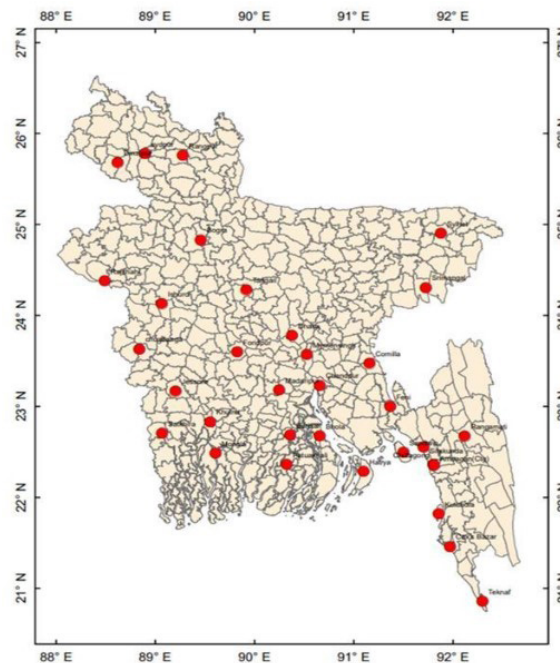
### Study Area

The present study includes several drought prone regions of Bangladesh with difference in geography and climate and each having unique characteristic of drought. The South Eastern Zone (Chittagong Hill Tracts and Cox's Bazar) is characterized by high mountain terrain and comparatively high rainfall, while the erosion-free North Eastern Zone (Sylhet and Mymensingh) comprises green panoramas with vast wetlands. The Northern Zone (Rangpur and Dinajpur) is an agro-flat land, whereas the Northwestern Zone (Rajshahi and Bogura) consistently confronts water scarcity and agricultural sustainability. The Western and South Western Zones (Sundarbans, Barisal and Patuakhali) are subject to pressures from climate resilience along the coastline; water management or subsidence, salinity intrusions. The South-Central Zone is becoming more challenged by rapid urban growth and water contamination. A variety of geomorphologic and climate conditions lead to the necessity of investigating drought variations in multiple regions. Bangladesh's climate is heavily influenced by the monsoon system, which, in turn, results in three principal seasons of rainfall: a dry winter (November–February) that accounts for less than 4% of annual rainfall; an intense pre-monsoon hot season (March–May) with 10–

25% of total precipitation dependent on thunderstorms and orographic uplift near the northeast; and a dominant monsoon season (June–October), accounting for 70–85% of yearly precipitation, with regional extremes (M. M. Rahman *et al.*, 2020). Temperature patterns also exhibit a strong seasonal gradient, with minimum and maximum winter temperatures in between 15–20°C and 25–29°C respectively; increasing during pre-monsoon to reach 20–25°C and 30–35°C respectively; before moderating during monsoon to peak at a range of 25–27°C (minimum) and 30–33°C (maximum); then post-monsoon to fluctuate within the ranges of minimum temperature 20–25°C and maximum temperature 28–32°C. These features cumulatively contribute towards the nature as well as spatial distribution of meteorological drought events across Bangladesh.

### Data Collection

The dataset used in this study is monthly precipitation and temperature data collected from 35 meteorological stations across Bangladesh. The data were obtained from the Bangladesh Meteorological Department (BMD), which maintains a network of meteorological stations that provide reliable data on weather patterns (Figure 2). The period of analysis covers 42 years (1980–2022).



**Figure 2:** The Locations of BMD Weather Stations

### Determination of Meteorological Drought Using SPI

The SPI is calculated using the following formula:

$$SPI = \frac{x_i - x_m}{\sigma}$$

Where,  $x_i$  is the observed monthly rainfall at the station,  $x_m$  is the mean monthly rainfall for the historical period and  $\sigma$  is the standard deviation of the precipitation over the same period.

Monthly rainfall data from 1980 to 2022 for 35 rainfall

stations are used as input for the SPI program. In the present case, precipitation was scaled up by a factor of 100 for use in decimal form, but when inputting into the model scaling up should yield a rounded set of whole numbers (e.g., no larger than two significant digits after placing a power to their side). It requires a limited amount of monthly precipitation observations, and the program generates an error message if data are available only from one year (so that there are not

enough monthly values to use in calculations). In order to consider drought condition in various lengths, the SPI for 3 (short-term), 6 (mid-term) and 12 months long-time scales was calculated, representing short-, mid-, and long-term cumulative curves of water deficit that are crucial to achieve an adequate assessment of drought conditions. The steps to calculate SPI across timescales are as follows: For each month  $j$ , the SPI is calculated using the P-PET difference. This difference is defined as:

$$D(i,j)=P-PET$$

Where P is the precipitation, and PET is the potential evapotranspiration.

$$\text{If } j < k; X_{i,j}^k = \sum_{l=13-k-j}^{12} D_{i-1,l} + \sum_{l=1}^j D_{i,l}; \text{ If } j \geq k; X_{i,j}^k = \sum_{l=j-k+1}^j D_{i,l}$$

SPI Database: A database has been created to store SPI results spanning from 1980 to 2022 (Table 1).

**Table 1:** Drought Severity Classification (Modified)

Category	Description	SPI
D0	No drought	-0.50 and above
D1	Abnormally dry	-0.51 to -0.70
D2	Moderate drought	-0.71 to -1.10
D3	Severe drought	-1.11 to -1.50
D4	Extreme drought	-1.51 to -1.99
D5	Exceptional drought	-2 or less

**Determination of Meteorological Drought Using SPEI**

The Standardized Precipitation Evapotranspiration Index (SPEI) is utilized in the evaluation of meteorological drought by taking into account the impacts of both precipitation deficits and evapotranspiration, thus presenting a more holistic picture of climatic water balance. For this purpose, the SPI was calculated at short (1-month and 3-month), medium (6-month and 12 -month) and long (24- month and 36-month) time scales to assess drought of different periods. SPEI computation substitutes the precipitation-only term with the difference of P-PET, reflecting both the effect of lack of rain and atmospheric water request. The steps in the computation are passing through a period of interest (normally 30 years) which represents “normal” climate, and then computing mean and standard deviation of precipitation and evapotranspiration on the reference period. The anomaly series of precipitation minus PET are then fitted to a gamma distribution for the removal of skewness and kurtosis in climatic data. Lastly, CDF values are normalized by subtracting the mean and dividing by standard deviation to obtain standardized drought index values for evaluating SPEI over multiple regions at multiple timescales.

To determine the SPEI value, the water balance discrepancy is normalized using a log-logistic probability distribution, represented by the following probability density function:

$$f(x) = \frac{\beta}{\alpha} \left(\frac{x-\gamma}{\alpha}\right) \left[1 + \frac{\beta}{\alpha} \left(\frac{x-\gamma}{\alpha}\right)\right]^{-2}$$

Where:

$\alpha$ ,  $\beta$  and  $\gamma$  are the scale, shape, and origin parameters, respectively

The cumulative distribution function (CDF) is then represented as:

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

Calculated the SPEI as follows:

$$SPEI = w \cdot \frac{c_0 + c_1w + c_2w^2}{1 + d_1w + d_2w^2 + d_3w^3}$$

$$\text{When } P \leq 0.5, W = \sqrt{-2 \ln(p)}, \text{ and}$$

$$\text{When } P > 0.5, W = \sqrt{-2 \ln(p)}, C_0 = 2.5155, C_1 = 0.8028, C_2 = 0.0203,$$

$$d_1 = 1.4327, d_2 = 0.1892, d_3 = 0.0013.$$

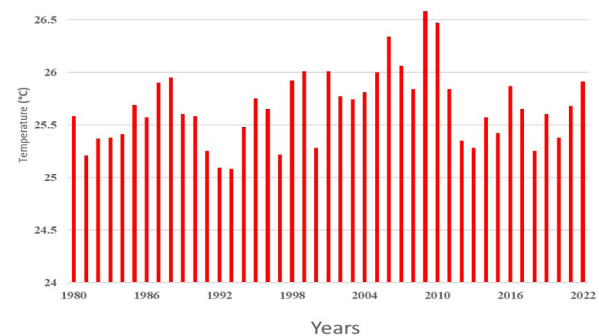
**GIS-Based Spatial Mapping**

The GIS-based tools were used to develop spatial distributions of drought, by integrating the station-based drought indices into a geospatial framework. SPI and SPEI values computed for each meteorological station were first imported to ArcGIS for spatial analysis. The Inverse Distance Weighting (IDW) interpolation method was further used to predict the drought status for those regions between stations assuming that locations near a station share similar drought characteristics. Based on these interpolated values, maps of drought severity were mapped to illustrate the spatial extent and intensity (severity) of drought within the study area, which facilitated clear identification obtain a more precise view on drought-prone areas and regional variability.

**RESULTS AND DISCUSSION**

**Temporal Variation of Annual Mean Temperature**

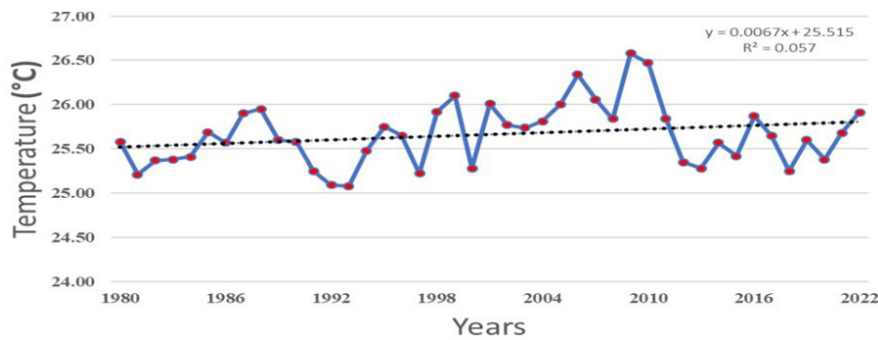
The temporal variation of the annual average temperature in Bangladesh reflects a broader global trend of climate change. In recent decades, Bangladesh has experienced a warming climate characterized by an increase in annual average temperatures (Khan *et al.*, 2019). The distinct seasons in Bangladesh, including a hot and humid summer, a monsoon season with heavy rainfall, and a cooler winter, are all influenced by changes in temperature. Rising temperatures can impact agriculture, affecting crop yields and the timing of planting and harvesting. Thus, monitoring and understanding the temporal variation of temperature in Bangladesh is crucial for adapting to the



**Figure 3:** Temporal Variation of Overall Annual Mean Temperature

changing climate and implementing strategies to mitigate its impacts on ecosystems and communities (Figure 3). The data analysis reveals an acceleration in the rate of temperature change, particularly over the last three decades.

This acceleration is substantiated by the observed plots, with a noteworthy correlation coefficient denoted by  $r = 0.057$ . This finding showed the heightened pace of temperature variations in the more recent 30-year (Figure 4).

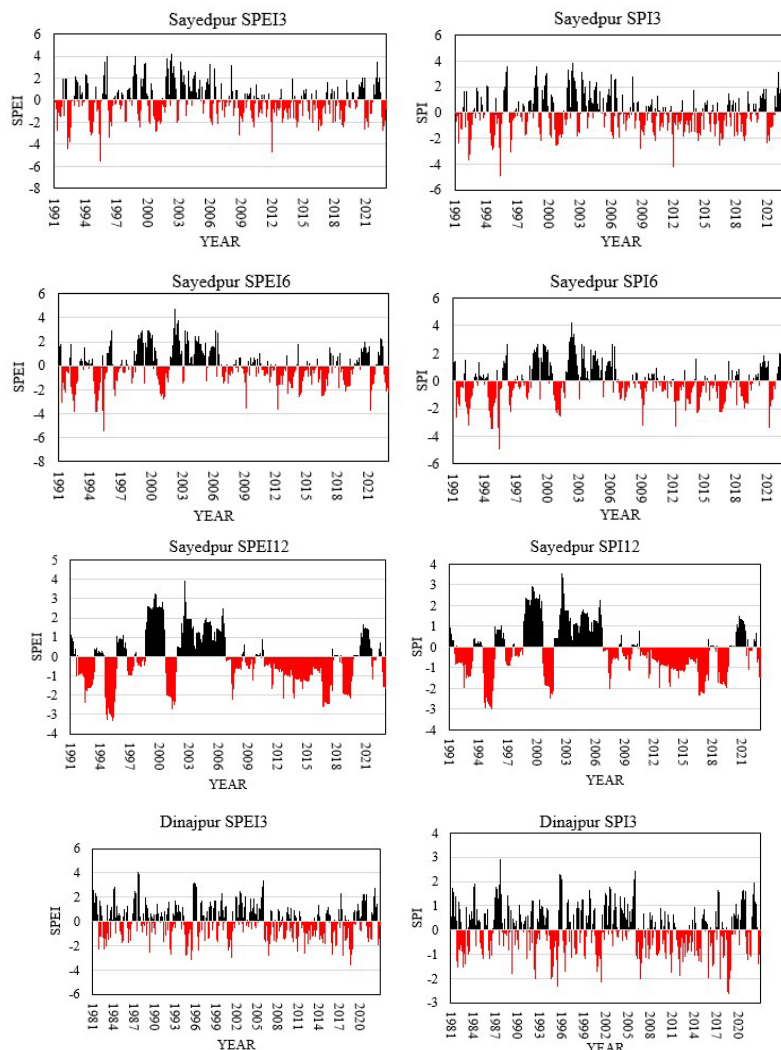


**Figure 4:** Trend of the Annual Mean Temperature

### Temporal Variation of Drought

Drought risk has been assessed using SPI and SPEI in various regions of Bangladesh. The monthly SPI and SPEI values were computed for a total of 35 weather stations, covering the period from 1980 to 2022 at three unique time scales (3, 6, and 12 months). SPI and SPEI values were subsequently averaged across three timescales to define drought conditions in Bangladesh (Islam *et al.*,

2021). Wet or dry transitions become more apparent as the timescale shortens, while the sensitivity of the SPI and SPEI measurements varies significantly. This refers to drought conditions analyzed over both space and time. It suggests an examination of how drought evolves and varies across different geographical locations over a specified time period. The extreme drought plots are presented here (Figure 5).



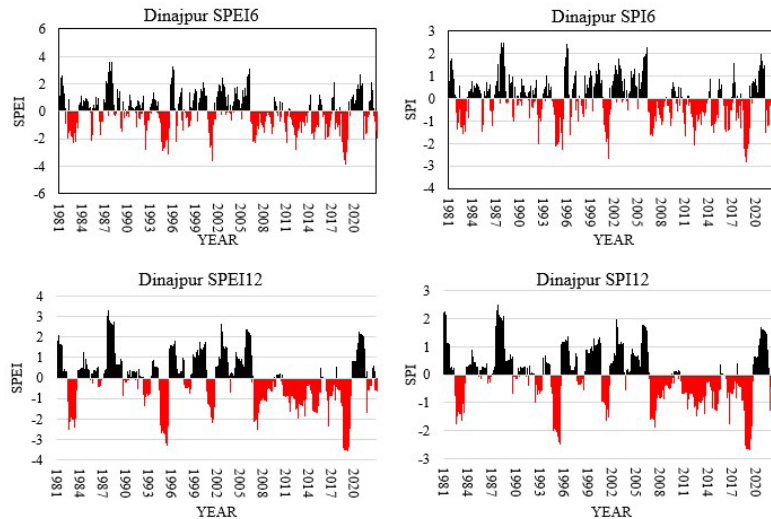


Figure 5: The Time Series Plots of the Drought Indices for Extreme Drought Area

**Moderate Drought Frequency**

For moderate drought, negative SPEI values would typically fall within a specific range, indicating a moderate level of dryness (Sarkar & Islam, 2024). The specific SPEI values for moderate drought can vary, but they often fall in the range of approximately -0.71 to -1.1. This means

that the observed precipitation during the given period is below average, and the conditions are indicative of a moderate drought. A moderate drought risk area (Barishal, Cox’s Bazar, Ranagamati, Khulna, Chuadanga, Chandpur, Dhaka, Tangail, Madaripur, Mymensingh and Satkhira) is a region where a higher frequency value is seen (Table 2).

Table 2: Moderate Drought Frequency Using SPEI at Different Time Scales (1980-2022)

Climatic zone	Station	SPEI 3			SPEI 6			SPEI 12		
		MD	SD	ED	MD	SD	ED	MD	SD	ED
South Eastern Zone	Barishal	55	38	21	52	37	22	56	37	19
	Bhola	48	37	23	46	35	21	47	34	18
	Chattogram	39	35	21	43	29	22	34	15	3
	Cox'sbazar	51	25	12	49	16	15	48	15	8
	Hatiya	41	22	22	27	13	9	19	14	11
	Khepupara	41	36	17	45	30	21	41	28	22
	Kutubdia	45	24	14	35	15	13	39	17	11
	M.Court	49	38	13	37	28	17	39	26	13
	Patuakhali	40	37	22	41	26	24	34	27	20
	Rangamati	53	37	16	56	36	20	73	35	19
	Sitakunda	47	38	5	36	28	11	31	22	5
Teknaf	49	14	17	35	10	20	9	10	10	
Sandwip	49	31	15	48	26	16	42	26	8	
South Western Zone	Khulna	55	39	15	49	35	21	41	35	29
	Mongla	29	33	18	45	18	18	39	23	6
	Satkhira	51	39	17	54	28	13	59	36	23
	Chuadanga	52	38	21	55	28	17	59	26	18
Central and South Central Zone	Chandpur	53	36	14	57	28	22	73	37	14
	Cumilla	47	37	24	46	29	22	38	34	21
	Feni	39	39	21	28	19		33	22	12
	Dhaka	50	39	15	49	34	26	50	34	29
	Tangail	50	32	22	48	41	19	42	24	9
	Madaripur	60	17	3	59	13	4	60	19	3
	Mymensingh	56	37	19	54	37	22	50	37	25

MD = Moderate Drought; ED= Extreme Drought; SD= Severe

### Severe Drought Frequency

A severe drought, as evaluated through the SPEI values, occurs when the computed index reveals a prolonged and notable shortfall in precipitation compared to the historical average (Raja & Gopikrishnan, 2022). Within the SPEI scale, which standardizes both precipitation and potential evapotranspiration data, negative values

indicate conditions drier than the long-term average. In the context of severe droughts, the SPEI values typically descend significantly below an established threshold, ranging from -1.11 to -1.5. A severe drought risk area (Rangpur, Rajshahi, Ishwardi, Jeshore, and Bogura) is a region where there is a high likelihood of experiencing severe drought conditions (Table 3).

**Table 3:** Severe Drought Frequency Using SPEI at Different Time Scales (1980-2022)

Climatic zone	Station	SPEI 3			SPEI 6			SPEI 12		
		MD	SD	ED	MD	SD	ED	MD	SD	ED
The northern part of the northern region	Rangpur	49	40	20	43	43	22	40	39	20
Northwestern region	Bogura	43	48	29	43	41	29	56	38	26
	Ishwardi	52	48	27	51	41	28	38	41	28
Western Zone	Rajshahi	60	43	26	61	42	22	48	43	25
South Western	Jashore	46	43	18	56	40	21	66	42	18

MD = Moderate Drougt; ED= Extreme Drougt; SD= Severe Drougt

### Extreme Drought Frequency

For extreme droughts, the SPEI values plunge well below an established threshold, often reaching levels ranging from -1.51 to -2. This indicates an extreme departure from expected climatic conditions, signaling an unprecedented

and protracted scarcity of water resources. An extreme drought risk area (Dinajpur and Sayedpur) is a region where there is a very high likelihood of experiencing extreme drought conditions (Table 4).

**Table 4:** Extreme Drought Frequency Using SPEI at Different Time Scales (1980-2022)

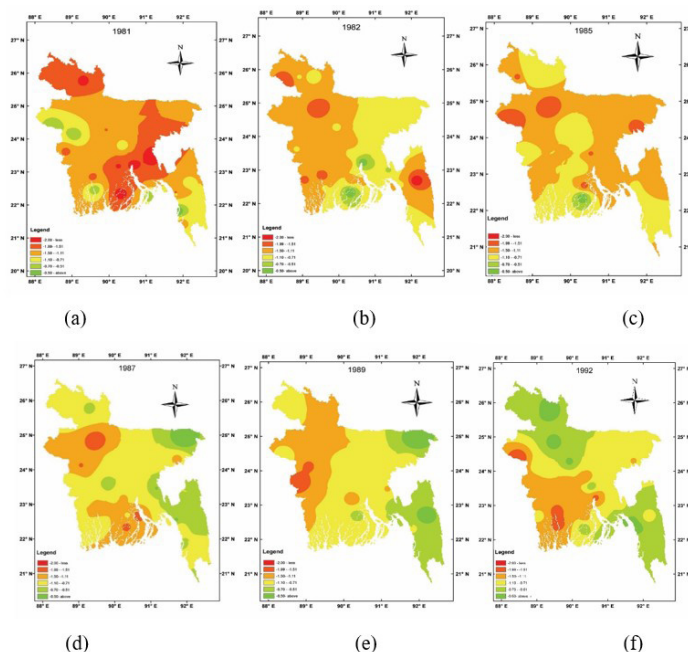
Climatic zone	Station	SPEI 3			SPEI 6			SPEI 12		
		MD	SD	ED	MD	SD	ED	MD	SD	ED
Northwestern region	Sayedpur	42	45	36	47	27	34	49	26	31
	Dinajpur	59	52	39	51	35	33	54	28	35

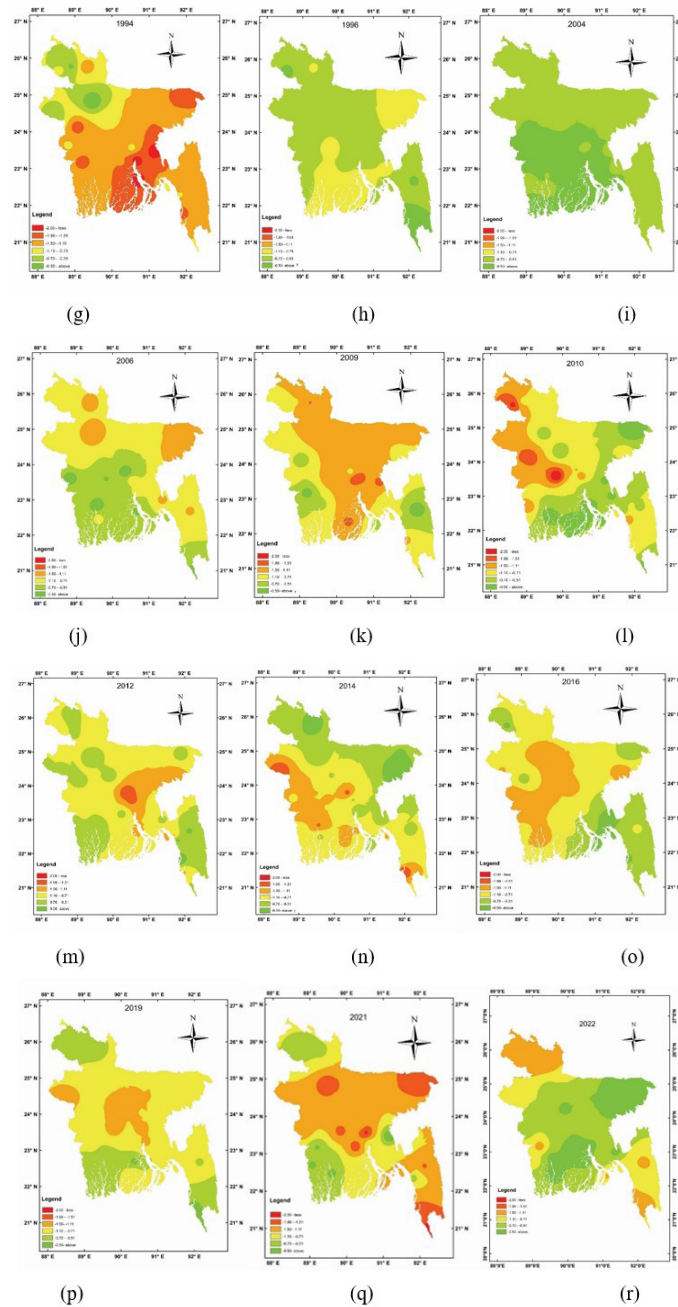
MD = Moderate Drougt; ED= Extreme Drougt; SD= Severe Drougt

### Special Drought

As depicted in Figure 5, the areas affected by drought, characterized by higher intensity, were primarily

concentrated in the northeast and southern coastal regions of Bangladesh during the 1980s. During the 1990s, regions across the country, except for the coastal





**Figure 6:** Bangladesh Drought Map of Different Years

areas, experienced widespread drought intensity values below  $-0.71$ , with the northwest being notably dominant in this regard. In the 2000s, drought intensity weakened, with indices values generally rising from  $-0.71$  across most regions. Notably, from 2010 to 2022, there was a shift in the territory experiencing drought with higher intensity, transitioning from the southern coastal regions to the western part of the country. The 3-month SPI values obtained from 35 meteorological stations distributed over Bangladesh from 1980 to 2022 were used during this study. The main objective was to map meteorological hotspots by analyzing the frequency of drought occurrence. According to GIS-derived surface area data, the results show that between 1980 and 2022, the frequency of droughts surpassing moderate levels

ranged from 4% to 5% at each of the 35 meteorological stations in Bangladesh. A GIS map illustrates the spatial-temporal distribution of drought years across various regions in Bangladesh (Figure 6).

### Map of Drought Prone Area

The geographical distribution of drought in Bangladesh exhibits distinct patterns, with certain regions facing more frequent occurrences than others. The study area map represent depicting drought-prone areas in both the northern and southwestern regions of Bangladesh reveals critical geographical insights. In the northern region, characterized by areas such as Rangpur and Dinajpur, the map indicates zones with heightened vulnerability to drought conditions. Similarly, in the southwestern region,

encompassing districts like Khulna and Satkhira, the map highlights areas susceptible to drought occurrences. The GIS map has a profound impact on the distribution of drought. Additionally, north and southwest areas characterized by lower rainfall and maximum temperatures further exacerbate drought conditions by intensifying evaporation rates. Specific drought hotspots are identified in the northwest, especially in regions such as Rajshahi,

Rangpur, and Dinajpur more face extreme drought. Also, southwestern regions Khulna, Satkhira, and Jeshore were more severe drought areas. The understanding of the geographic distribution of drought is crucial for tailoring region-specific mitigation and adaptation strategies to address the varying degrees of water stress faced by different parts of Bangladesh (Figure 7).

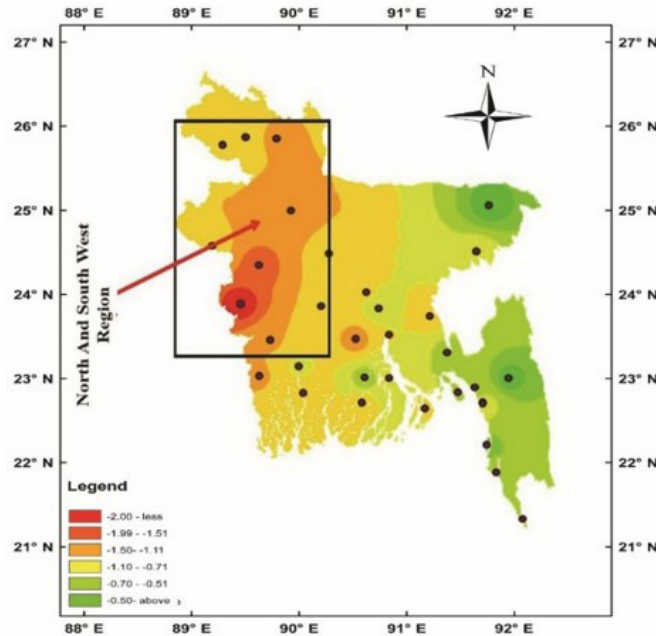


Figure 7: Drought Prone Area Map

**Variation of Drought with Different Duration**

Throughout the study period, Bangladesh encountered varying drought conditions, including short-term drought (three-month SPI), medium short-term drought (six-month drought), and frequent long-term drought (twelve-month drought) conditions. GIS was used to calculate the spatial variation of drought during different period's visualization of average short-term, medium short-term, and long-term SPI values across all regions. The calculation involved

averaging all SPI data across three-month, six-month, and twelve-month categories, which were then visualized on GIS maps. Spatial variability in drought patterns was evident across Bangladesh during the study period. Some regions experienced no drought in the short term (three-month SPI) and medium short-term intervals (six-month SPI), yet faced drought in the long term (twelve-month SPI). Conversely, other areas encountered drought in the short-term or medium short-term periods while remaining

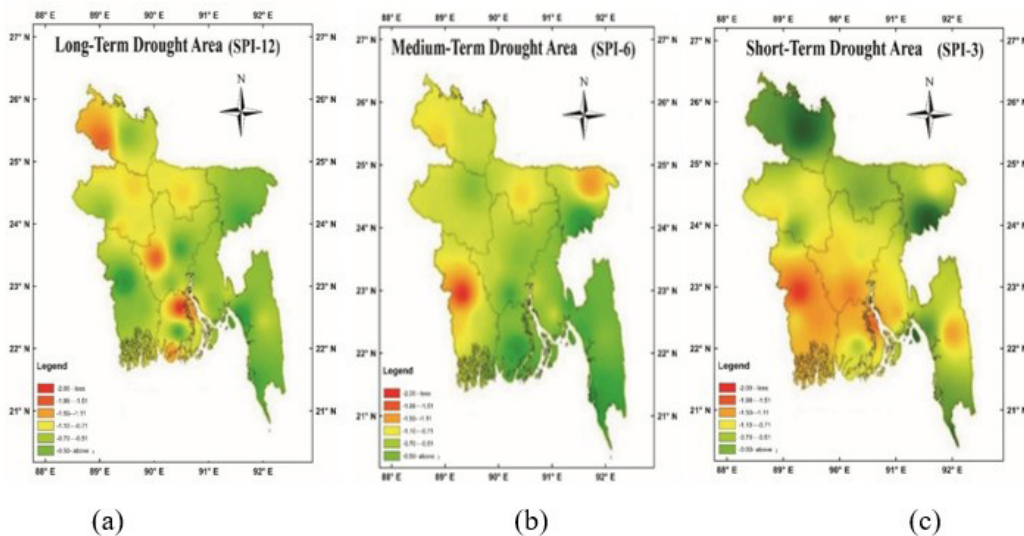


Figure 8: Bangladesh Drought Map of Different Years

free from drought in the long term.

These occurrences also manifested independently within the SPI intervals. The findings underscored the dynamic nature of drought conditions across different regions of Bangladesh (Figure 7). Specifically, the northern and southeastern parts of the country consistently faced drought, as indicated by the prevalence of red color denoting high drought, while the green color signified the absence of drought (Figure 8).

### Relation between Rainfall and Temperature

Establishing a direct correlation between rainfall and temperature parameters is challenging due to the complexity of their interactions within the Earth's climate system. While temperature influences the amount

of moisture in the atmosphere through processes such as evaporation and condensation, the relationship between temperature and rainfall is not always linear or predictable. Factors such as atmospheric circulation patterns, topography, and regional climate dynamics can significantly modulate the relationship between temperature and rainfall.

### Mean Temperature and Precipitation

Observed from BMD data source which provides a detailed overview of surface air temperature and precipitation level fluctuations throughout the month. The monthly climate data reveals the fluctuation in surface air temperatures and precipitation levels throughout the year as showed in Figure 9 and Figure 10.

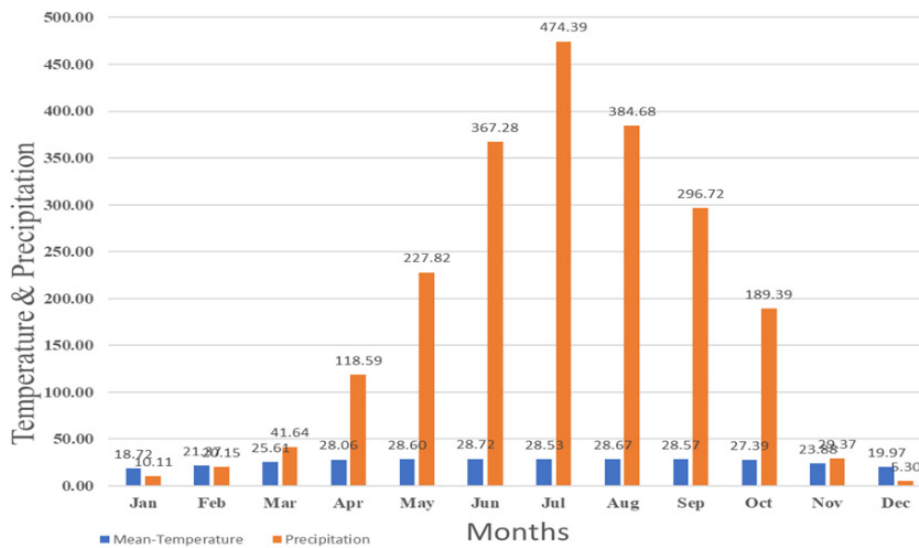


Figure 9: Monthly Mean Precipitation and Temperature

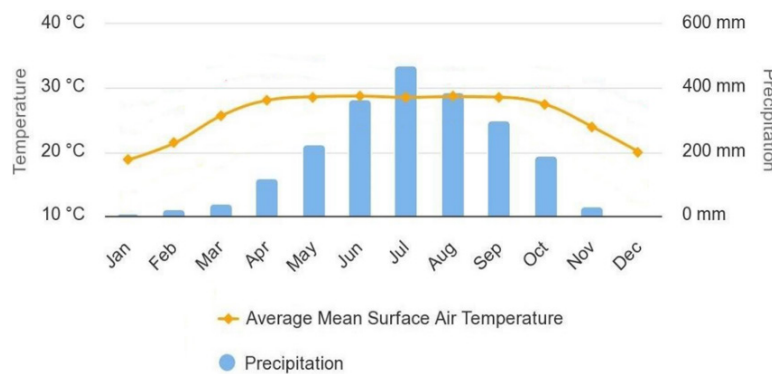


Figure 10: Monthly Climatology of Mean Temperature and Precipitation

### Rainfall Deviation Map

To create a rainfall deviation map comparing 42 years of rainfall data with the past decade and identify areas of decline rainfall, we first calculate the standard deviation of rainfall values for both periods. The standard deviation helps quantify the variability of rainfall around the mean value. By comparing the standard deviations of the two datasets, we can identify regions where rainfall deviates significantly from the long-term average during the last decade. Once we have

the standard deviation values, we can plot them on a map using a color scale to represent the magnitude of deviation. Areas with negative deviations indicate a decrease in rainfall in comparison to the long-term average, while positive deviations represent an increase. The map will visually highlight regions where rainfall has notably decreased over the past 10 years relative to the 42-year average. These areas may be subject to changes in climate patterns, land use, or other factors affecting precipitation (Figure 11).

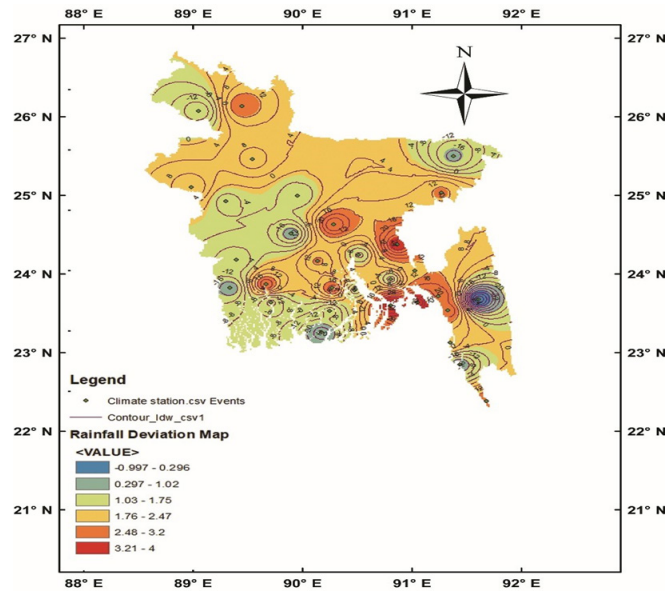


Figure 11: Rainfall Deviation Map with Contour

### Temperature Deviation Map

A Temperature Deviation Map visually represents the temperature differences between two periods. It

typically compares long-term historical data with recent observations. This study temperature deviation map is presented in Figure 12.

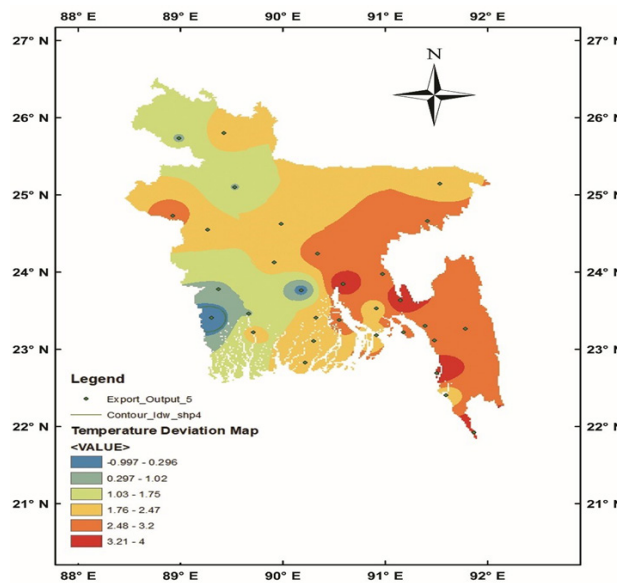


Figure 12: Temperature Deviation Map with Contour

### Practical Applications of Research Findings

Meteorological drought, a significant concern in Bangladesh, has become a focal point for practical applications of research findings. The significance of research findings lies in their practical applicability and their ability to enhance outcomes when effectively implemented.

### In the Agricultural Domain

On 17 August 2017, the International Centre for Integrated Mountain Development (ICIMOD), the Bangladesh Agricultural Research Council (BARC), and the International Maize and Wheat Improvement Centre (CIMMYT) jointly organized a day-long consultation and

user engagement workshop. The workshop focused on the collaborative development of agricultural drought monitoring services in Bangladesh. The workshop was conducted as part of the USAID-funded SERVIR-Hindu Kush Himalaya initiative and the Climate Services for Resilient Development partnership in South Asia. By analyzing historical data, meteorological patterns, and environmental indicators, BARC can offer detailed assessments, categorizing the nature and severity of droughts in specific areas. So, these research findings will be of great value to them.

### Bangladesh Meteorological Department

The BMD highlighted that groundwater accessibility

is becoming an increasing concern due to the ongoing drought. The government has implemented restrictions on deep well extraction, allowing it only for drinking water to conserve vital groundwater resources. They can emphasize that access to drought monitoring and early warning information could play a key role in developing climate services that assist farmers in adapting to these challenges. This research underscores the importance of integrating drought monitoring and early warning systems into climate services to aid farmers in adapting to these adversities.

### The Ministry of Water Resources

The Ministry of Water Resources is the apex body of the Government of the People's Republic of Bangladesh for developing and managing the country's entire water resources (Alamgir *et al.*, 2025). It develops policies, plans, strategies, guidelines, instructions, acts, rules, and regulations related to the management and development of water resources and the regulation and oversight of the institutions under its authority. It designs and executes development projects focused on flood control and drainage (FCD), flood control, drainage, and irrigation (FCDI), riverbank erosion control, delta development, and land reclamation. These efforts include constructing barrages, regulators, sluices, canals, cross-dams, embankments, and sea-dykes along riverbanks and coastal areas. The Ministry, through its executing agency, the Bangladesh Water Development Board (BWDB), carries out the implementation of FCD/FCDI and other development projects. Sustain shallow groundwater aquifers by regulating water extraction in identified scarcity zones, ensuring transparency and public awareness. Develop tailored drought monitoring and contingency plans for regions facing recurrent seasonal water shortages. Empower local governments or relevant authorities to allocate water in scarcity zones during severe droughts, monitor water levels, and enforce regulations. Grant water rights to private and community organizations, ensuring secure, defensible, and enforceable access to both ground and surface water. Ensure minimum streamflow are maintained to preserve the conveyance capacity of water channels.

### Department of Disaster Management

This research likely outlines methodologies for developing early warning systems tailored to drought events. Using historical drought patterns and predictive modeling techniques, the department can issue timely warnings to vulnerable communities, allowing them to prepare and respond effectively. They can provide recommendations on how the department can collaborate with local communities to gather real-time information on drought impacts and facilitate community-led resilience-building initiatives. Findings from this research can inform evidence-based policy recommendations to support the development of comprehensive drought management policies and strategies. These recommendations can guide

the department in integrating drought resilience into broader disaster risk reduction frameworks.

### Comparison of Findings with Existing Literature

Monthly precipitation data spanning 36 years from 1980 to 2015, collected from 27 meteorological stations in Bangladesh (Kamruzzaman *et al.*, 2019). Their findings revealed that the western and central regions of the country were more susceptible to drought, with the southwestern region being particularly prone to extreme droughts. Furthermore, the central region exhibited a higher likelihood of severe droughts. Additionally, the central region was identified as being more susceptible to extra-long-term droughts, while coastal areas in the southwestern, central, and northwestern regions were more vulnerable to prolonged and long-term droughts. We largely agree with his findings. Specifically this study's findings was drought hotspots in the northwest, particularly in regions such as Rajshahi, Rangpur and Dinajpur more faced extreme drought. Also south west region Khulna, Satkhira and Jashore were more severe drought area. The findings reveals that Dhaka and Tangail also exhibited signs of drought, with indications of moderate drought conditions in these areas.

The main focus of this study was to investigate the trends in spatiotemporal drought intensity across seven distinct climatic zones in spanning the period 1979 to 2019 (M. N. Rahman *et al.*, 2021). The study's results highlight a consistent decline in SPEI across all climatic zones, with the exception of the south-eastern zone, where SPEI values exceed specific thresholds: greater than 0.65, 0.7, 0.12, and -0.01 for SPEI 06, 09, 12 and 24, respectively. The northern region exhibits the highest negative SPEI values, particularly emphasizing a pronounced decrease in SPEI values also underscore more significant drought conditions. SPEI 09 and SPEI 12 indicate a higher level of drought severity. Specifically, regions including Barisal -3.75, Rangpur -3.65, Dinajpur -3.00, Rajshahi -4.35, Bogura -4.50, Ishurdi -3.45, Faridpur -4.30, and Madaripur -2.10 was identified as being situated within extreme drought-prone climatic zones. The main finding was drought trend line establish in seven region. This research findings was the North Western region also experiences severe drought, with stations like Bogura SPEI 3, SPEI 6 and SPEI 12 (48, 41 and 38) and Ishwardi SPEI 3, SPEI 6 and SPEI 12 (48, 41 and 41) exhibiting. Likewise, in the Western Zone, Rajshahi faces severe drought conditions, as indicated by SPEI frequency values of (43, 42, and 43) for 3 months, 6 months, and 12 months, respectively. The South Western region, represented by Jashore, is also affected by severe drought, with SPEI frequency values of (43, 40, and 42) for the respective time scales.

Rabby & Adhikary (2024) conducted research at two specific climate stations, Bogura and Ishurdi, situated in the northwest region of Bangladesh (1975-2019). Their main objective was to determine the extent of severe drought occurrence in two stations and calculate the duration and intensity of the drought. Their most severe

drought frequency was forty-two in Bogura and thirty-eight in Ishwardi up to thirty-five years. The findings of this study are the North Western region also experiences a severe drought, with stations like Bogura and Ishwardi.

### Findings

- Droughts were frequent in Bangladesh, occurring at a rate of about two to three per year and producing an also regular return period.
- Based on SPI and SPEI, more severity of drought was observed in North Centre and North East compare to other parts of the country.
- Central Bangladesh became more vulnerable to drought, while the distribution of droughts further shifted from the southwest to eastwards.
- The eastern hilly regions of the basin showed a decline in drought severity over time.
- The drought occurred in an upward transpiring trend toward the northwest region from the south.
- In some areas drought conditions were prolonged (12-month SPI) with no short- or medium-term drought observed.
- Some areas experienced brief or average-length droughts but were still able to escape long-term drought in shorter studies.
- The monthly climate data showed a positive correlation between temperature and precipitation from January to May.
- The monsoon months (June to August) showed a synchronous increase in temperature and precipitation with temperature decreasing for September to December.
- The integrated SPI–SPEI–GIS approach adequately delineated drought hot spots and furnished credible spatial depiction of drought factors in Bangladesh.

### RECOMMENDATIONS

- Formulate drought management plans at regional level, especially taking place in the North Centre, North East and Northwestern regions where intensity of drought is most pronounced.
- Enhance early warning systems through integrated SPI–SPEI–GIS monitoring for timely alert levels of short-, middle- and long-term drought risk.
- Introduce drought-resistant crop varieties in areas which are repeatedly affected by long-term drought.
- Improve water resource planning through the promotion of centralized/north Bangladesh-well as rainwater harvesting and groundwater recharge activities.
- Introduce soil moisture conservation practices and efficient irrigation systems in drought affected farm areas.
- You should promote climate-smart LULCCP to deal with the increasing drought vulnerability migration from southwest toward east of the country.
- Attach importance to sustainable management in the watersheds and afforestation work of areas with rising drought trend from south to north.
- Enhance climate monitoring system through

modernizing weather stations and setting up in hilly and far areas.

- Incorporate seasonal temperature and rainfall variability in agricultural calendars for ideal cropping, minimizing risks due to climate.
- Promote policy-based interventions at the national level for durable drought response, such as investment in sustainable infrastructure and climate-resilient projects to minimize drought impact and community-led drought preparedness programs.

### CONCLUSION

In this study, a comprehensive assessment of drought using SPI and SPEI in Bangladesh is conducted, focusing on both spatial and temporal dimensions. At all-time scales, the SPI and SPEI designate the North West (NW) and South West (SW) regions as prone to drought. This observation implies a growing risk to drought in the central part of Bangladesh. Bogura, Sayedpur, Dinajpur, Ishwardi, and Rajshahi are identified as exceptional drought areas, consistently reporting high negative (SPEI) frequency values across different time scales. Dinajpur and Sayedpur are particularly affected by the extreme drought zone. Rangpur, Rajshahi, Ishwardi, Jashore, and Bogura fall into the severe drought category, indicating a high likelihood of drought conditions. Additionally, Barishal, Cox's Bazar, Rangamati, Khulna, Chuadanga, Chandpur, Dhaka, Tangail, Madaripur, Mymensingh, and Satkhira are recognized as moderate drought-risk areas. The GIS mapping highlighted the most notable area drought conditions in 1981, 1892, 1989, 1994, 1995, 2006, 2009, 2012, 2014, 2016, 2019, 2021, and 2022. The findings indicate a gradual decrease in drought intensity in Bangladesh's eastern hilly region over time. No strong relationship was revealed between precipitation and temperature. SPI and SPEI values from the existing 35 stations may not be adequate to portray the comprehensive drought condition across all of Bangladesh. Therefore, it is advisable to incorporate data from the maximum possible number of stations to accurately identify meteorological drought conditions. The examination of drought from a socio-economic perspective has been lacking. While identifying areas at risk of drought is essential, the relevance of risk assessment can be significantly enhanced by incorporating socio-economic data. This entails assessing not only the geographical areas susceptible to drought but also delving into the impact on both human and livestock populations. Therefore, it is strongly recommended to integrate socio-economic data into the analysis, providing a more comprehensive understanding of the factors that contribute to vulnerability in the context of drought. Upon obtaining the conclusive risk map delineating regions with heightened drought risk, it is advisable to conduct an in-depth examination of these areas. This study should encompass factors such as soil composition, water availability, temperature conditions, rainfall patterns, types of crops cultivated, and the economic significance of the region.

### Authors' Contribution

Md. Sabuj Ahammed contributed to write introduction, define aims and objectives, did the data analysis and results of this paper. He also did the final revision of this paper. Rokshana Pervin wrote the abstract, methods and materials part of this research. Mohammad Nazim Uddin did the literature review very carefully and also wrote the finding and recommendations.

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