

Emerging Asymmetry in Drought Timescales under High-Emission Scenarios

Md Rayhan

rayhan.nkr11@gmail.com

Bangladesh University of Engineering and Technology

Research Article

Keywords: RCP8.5, Future Drought Projection, Terms of Drought, CORDEX

Posted Date: September 8th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10943071/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Emerging Asymmetry in Drought Timescales under High-Emission Scenarios

Md Rayhan ^{1,*}

¹Water Resources Engineering, Bangladesh University of Engineering

*Correspondence: rayhan.nkr11@gmail.com;

Abstract

Drought is a major climate hazard in Bangladesh, threatening agriculture, water resources and livelihoods in a highly vulnerable region. Understanding how drought patterns may change under future climate conditions is essential for effective adaptation planning. This study analyzes drought characteristics and projected trends across Bangladesh using the Standardized Precipitation Index (SPI) at multiple timescales (SPI3, SPI6, SPI12, SPI24, and SPI48). Future projections are derived from the MIROC5 climate model under the RCP8.5 scenarios for the 2020s, 2060s, and 2080s, and are validated against observed rainfall data from the Bangladesh Meteorological Department (2005–2023). Results reveal a dual drought regime. Short-term droughts (3–6 months) are projected to remain frequent and severe nationwide, with the southwest districts such as Satkhira, Khulna, Mongla, and Jessore facing the highest risk due to existing seasonal water stress. In contrast, long-term droughts (12–48 months) show a declining trend from the 2060s onward, particularly in northern and central districts such as Rajshahi, Rangpur, Bogra, Dinajpur, and Ishurdi, where SPI values shift toward wetter conditions. Overall, future drought risk in Bangladesh is expected to be dominated by recurring short-term events rather than persistent multi-year droughts.

Keywords: RCP8.5; Future Drought Projection; Terms of Drought; CORDEX

1. Introduction

Climate change is one of the most significant environmental issues of the 21st century (Kabir et al., 2023). It is causing long-term changes in temperature and rainfall patterns and messing up the global water cycle. Rising temperatures speed up evaporation, dry out the soil, and put more stress on surface water and groundwater systems, which makes the risk of drought even higher (Priyan, 2021). Drought, which is a long time without enough water because of not enough rain, is one of the most dangerous natural disasters in the world. Bangladesh is one of the countries that is most likely to be affected by climate change. Drought makes it hard to keep up agricultural productivity, water availability, and overall socioeconomic stability (Qtaishat et al., 2022). Bangladesh is the fifth most vulnerable country to climate change, according to the Global Climate Risk Index (Kreft et al., 2014). This vulnerability is clear from its history of droughts, severe droughts in 1995, 1973, 1978, 1979, 1981, 1982, 1992, 1994, 1995, 2000, 2006, and 2009, caused major problems for crop yields (Al Mamun et al., 2024). For example, the 1995 drought cut Aman rice production by 377,000 tons (Adnan, S., 1993; Mirza, M.Q. and Paul, 1992).

Bangladesh's drought risks are also affected by its geography and climate. There are eight different climate zones in the country: North East, North Central, North West, South East, South Central, South West, Eastern Hill, and River and Estuary (Pour et al., 2018). The amount of rain that falls in these areas changes a lot, with the west usually being drier than the east (Shahid, 2012). Cropping systems depend a lot on seasonal rain, and the two main agricultural seasons, Rabi and Kharif, are both at risk of rain changes (Gupta et al., 2023). Droughts before the monsoon hurt Rabi and pre-Kharif crops like wheat, pulses, and potatoes. Droughts after the monsoon hurt Kharif crops like Aman rice, which needs a lot of water during its

reproductive stage. It has been estimated that Bangladesh will experience drought once every 2.5 years (Adnan, S., 1993), which shows how common and long-lasting it is.

Drought is a complicated event that can be divided into meteorological, hydrological, agricultural, and socioeconomic types. Meteorological drought is when there is less rain than usual over a long period of time (Gibbs, W.J., 1975). Hydrological drought is when there is less surface and groundwater (H., AJ, 2004). Agricultural drought happens when the soil doesn't have enough moisture for crops to grow. This can be caused by temperature, how much water evaporates, and the type of soil. When there isn't enough water, it can lead to unmet human and economic needs, which is called socioeconomic drought (Liu et al., 2020; Mishra & Singh, 2010). To keep an eye on and study these multi-faceted drought conditions, we need strong tools. Drought indices are some of the most commonly used ones.

There have been more than 80 drought indices created over the years (S. Niemeyer, 2008). The Standardized Precipitation Index (SPI) is one of the most popular because it is easy to use and only looks at precipitation (McKee et al., 1993a). SPI can be calculated for different periods of time, so it can be used to measure both short-term agricultural droughts and longer hydrological droughts. Previous research has established SPI's efficacy in various contexts, including the United States (Hayes et al., 1999), Greece (Karavitis et al., 2011), India (Kumar et al., 2009), and Bangladesh (Chowdhury & Jahan, 2018). On the other hand, the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010) and the Palmer Drought Severity Index (PDSI) (Palmer, W.C, 1995) include temperature and evapotranspiration, but they usually need more complicated datasets and assumptions. Even though these indices give us useful information about how droughts work in a changing climate, SPI is still a simple and effective way to measure droughts in a certain area (Burke & Brown, 2008; Guttman, 1999).

Choosing the right climate models is just as important for predicting future droughts. Earlier research has evaluated various models to replicate historical droughts in Bangladesh (Chowdhury & Jahan, 2018). The MIROC model has demonstrated a high degree of reliability in replicating observed drought conditions (Rayhan & Afroz, 2024). Based on this evidence, the current study uses MIROC as the best model for predicting drought in Bangladesh and the high-emission pathway RCP8.5 to look at extreme future conditions. This scenario enables the examination of the upper limit of drought risks in the context of sustained elevated greenhouse gas emissions.

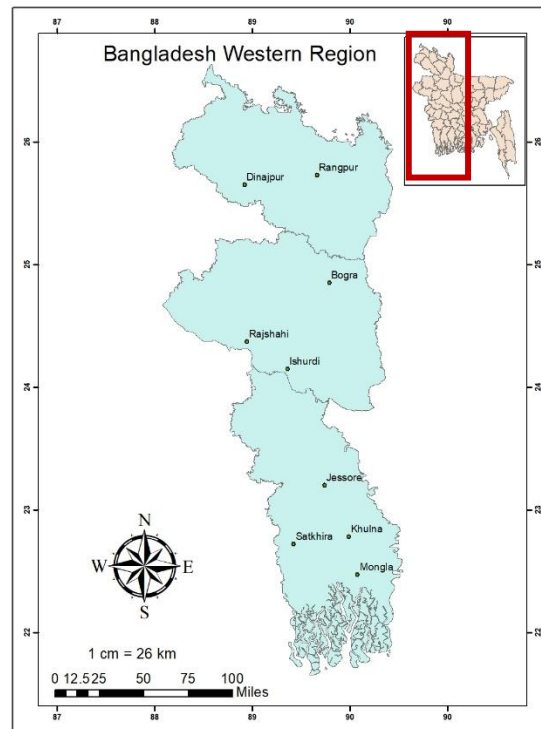
Numerous prior studies have analyzed historical droughts or assessed overall precipitation variations; however, limited research has focused on prospective drought scenarios in Bangladesh, particularly distinguishing between short-term and long-term droughts. This viewpoint is essential as the effects of drought vary significantly across timescales: short-term droughts (3–6 months) can severely impact agriculture by diminishing seasonal water availability, whereas long-term droughts (12–48 months) can compromise hydrological stability, groundwater recharge, and livelihood resilience. Nevertheless, no exhaustive study has explicitly illustrated the potential evolution of these two drought types in the context of climate change. This study fills that gap by giving a thorough forecast of drought characteristics in Bangladesh, breaking them down into short- and long-term trends and checking the model's results against data from 2005 to 2023.

2. Materials and Methods

Bangladesh's climate is greatly affected by where it is located and what the land is like. The country is located between 20°34'N and 26°38'N latitude and 88°01'E and 92°41'E longitude. The Assam Hills are to the east, the Meghalaya Plateau is to the north, and the Himalayas are farther to the north. The climate is subtropical monsoon, which means it has heavy rain in the summer, high humidity, and high temperatures (Mirza, M.Q. and Paul, 1992). The amount of

rain that falls each year varies a lot from one part of the country to another. For example, it falls about 1,500 mm in the northwest and more than 4,000 mm in the northeast (Pour et al., 2018).

Bangladesh has eight different climate zones: North East (NE), North Central (NC), North West (NW), South East (SE), South Central (SC), South West (SW), Eastern Hill (EH), and River and Estuary (RE). The current study concentrates on the Northwest (NW) and Southwest (SW) regions. Dinajpur, Rangpur, Bogra, Rajshahi, and Ishurdi are the stations chosen for the northwest. Jessore, Satkhira, Khulna, and Mongla are the stations in the southwest, **Figure 1** and **Table 1**. These stations show how different drought-prone areas in Bangladesh can be.



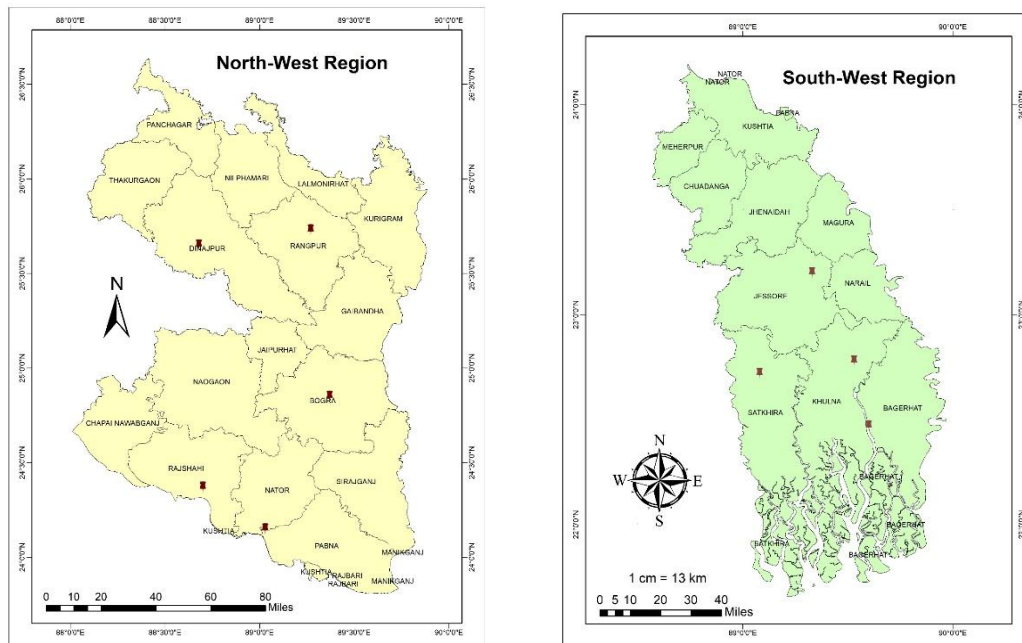


Figure 1: illustrates the location of the study area, highlighting the selected BMD stations in the northwest and southwest regions.

Table 1: Geographic coordinates of selected BMD stations

Climatic Zone	Stations	Longitude °E	Latitude °N	Station ID
North-West	Dinajpur	88.68	25.65	10120
	Rangpur	89.27	25.73	10208
	Bogra	89.37	24.85	10408
	Rajshahi	88.70	24.37	10320
	Ishurdi	89.03	24.15	10910
South-West	Jessore	89.33	23.2	11407
	Satkhira	89.08	22.72	11610
	Khulna	89.53	22.78	11604
	Mongla	89.6	22.47	41958

2.1. Materials and Method

2.1.1 Climate Data

This study used both observed and climate model data to analyze drought conditions in Bangladesh. Observed monthly rainfall data for the period 2005–2023 were collected from the Bangladesh Meteorological Department (BMD) (<https://www.bmd.gov.bd/>). To assess future drought scenarios, we used CORDEX regional climate projections based on the MIROC5 model (<https://esgf-node.llnl.gov/projects/esgf-llnl/>). MIROC5 (Model for Interdisciplinary

Research on Climate) is an Atmosphere-Ocean General Circulation Model (AOGCM) developed by the Japanese research community, and has been shown to reproduce rainfall and drought conditions in Bangladesh with higher reliability compared to other models. For this reason, MIROC5 was selected as the most suitable model for Bangladesh drought projection (Rayhan & Afroz, 2024).

The climate model data were extracted under the RCP8.5 scenario, which represents the high-emission pathway of the IPCC Representative Concentration Pathways (Di Nunno & Granata, 2023; Endris et al., 2013; Gleckler et al., 2008; Kis & Pongrácz, 2023; Molina et al., 2020). RCP8.5 assumes a radiative forcing of 8.5 W/m² by 2100 and serves as a worst-case scenario to evaluate drought risks under extreme conditions. Using this pathway allows for a robust assessment of potential future drought severity and frequency.

2.1.2 Drought Index

To characterize droughts across different timescales, we applied the Standardized Precipitation Index (SPI). SPI was calculated at five durations: SPI3 and SPI6 for short-term droughts (seasonal and half-year), and SPI12, SPI24, and SPI48 for long-term droughts (annual to multi-year). This distinction is critical for Bangladesh, as short droughts can severely impact seasonal crops and water supply, while long droughts influence groundwater recharge and regional water security.

SPI values were computed by standardizing the difference between observed precipitation and its long-term mean, divided by the standard deviation. Following (McKee et al., 1993b), drought categories were assigned based on SPI thresholds (mild, moderate, severe, extreme) shown in **Table 2**.

Table 2: Drought Category

SPI	SPI Category
≥ 2	Extreme Wet
1.50-1.99	Severe Wet
1.00-1.49	Moderate Wet
0-0.99	Mildly Wet
<0 to -0.99	Normal/ Mild Drought
-1.00 to -1.49	Moderate Drought
-1.50 to -1.99	Severe Drought
-2.00 to less	Extreme Drought

2.1.3 Analytical framework

The analysis Methodology flowchart is illustrated in **Figure 2**.

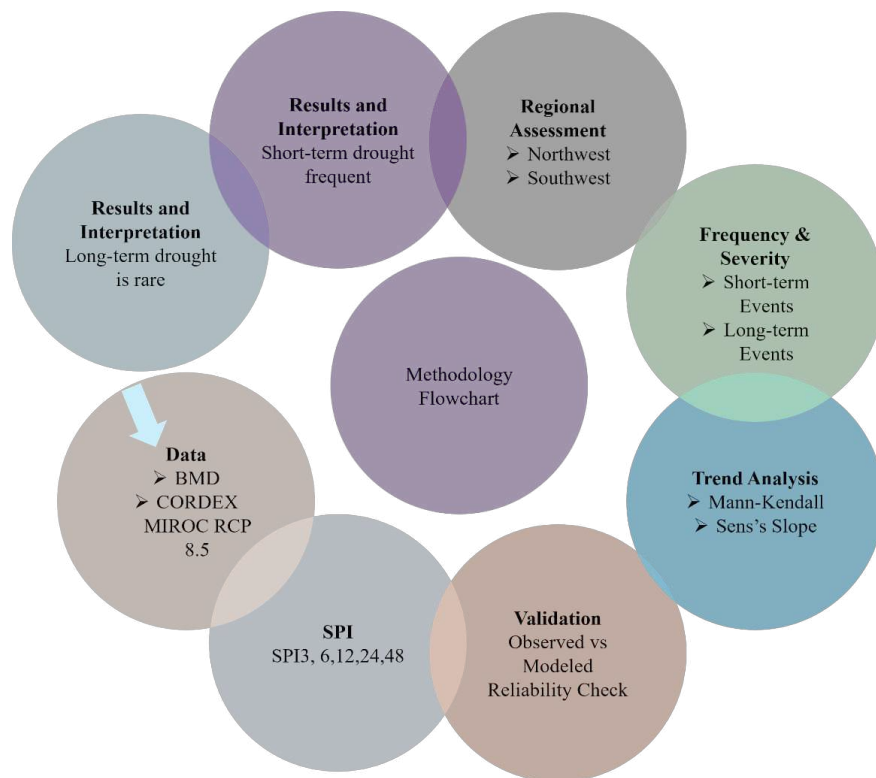


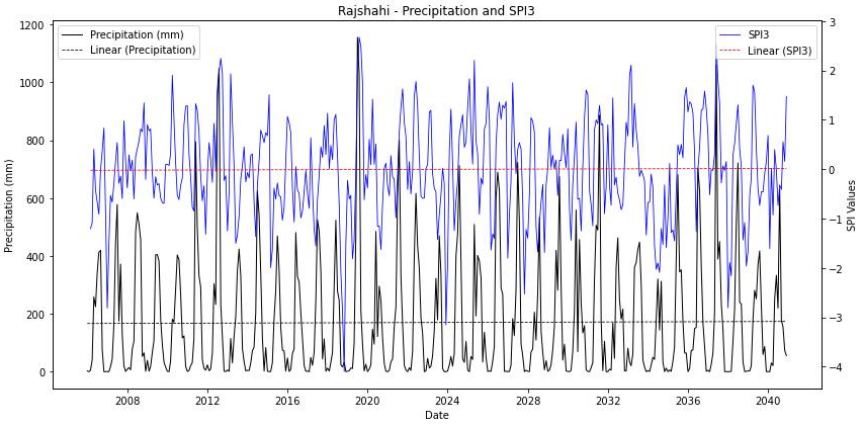
Figure 2: Methodology Flowchart

3. Results

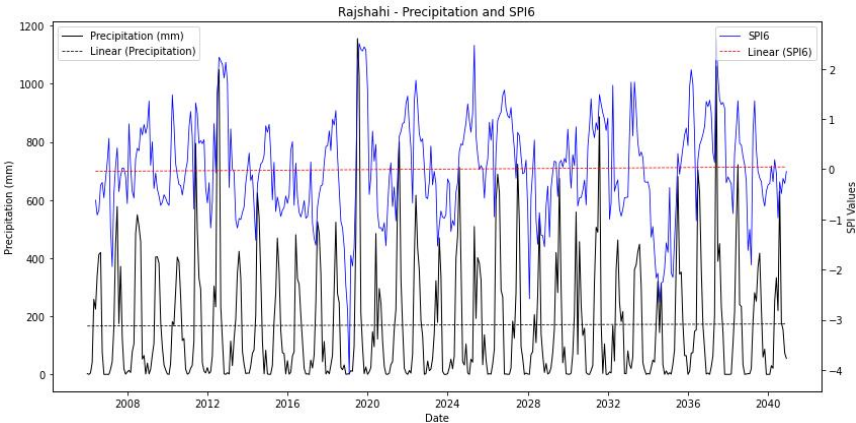
3.1. Graphical Analysis

Figure 3-5 and **Appendix A (Figure A. 01- 03)** in **supplementary file** show a scenario analysis of precipitation and Standardized Precipitation Index (SPI) values. Drought behavior will be very different in Bangladesh in the 2020s, 2060s, and 2080s.

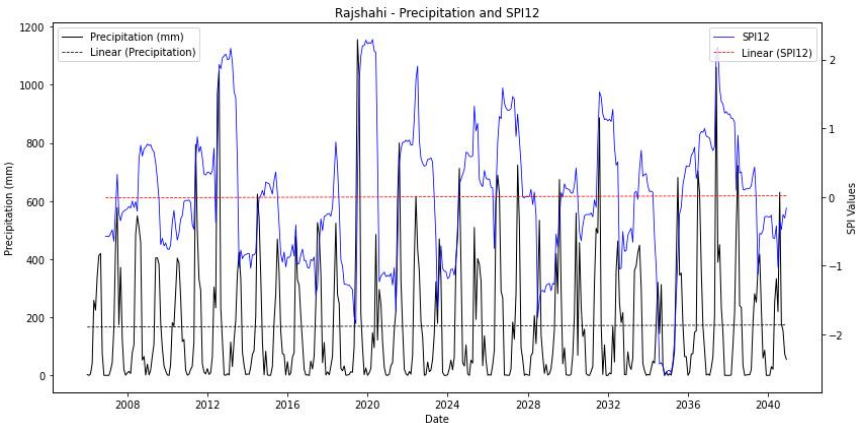
146



147



148



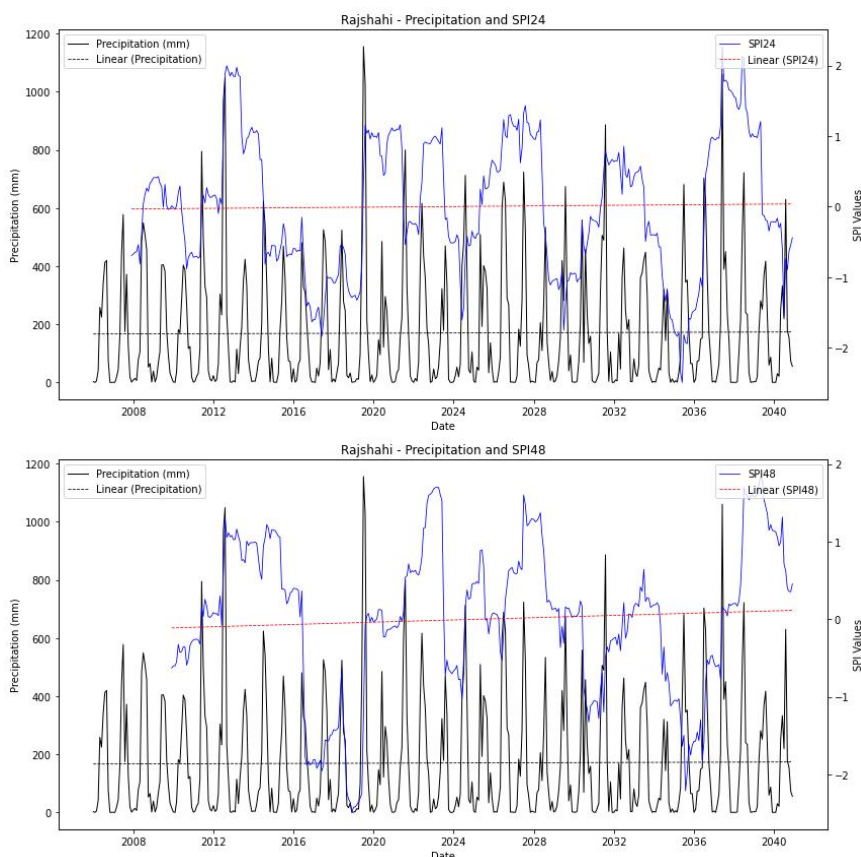
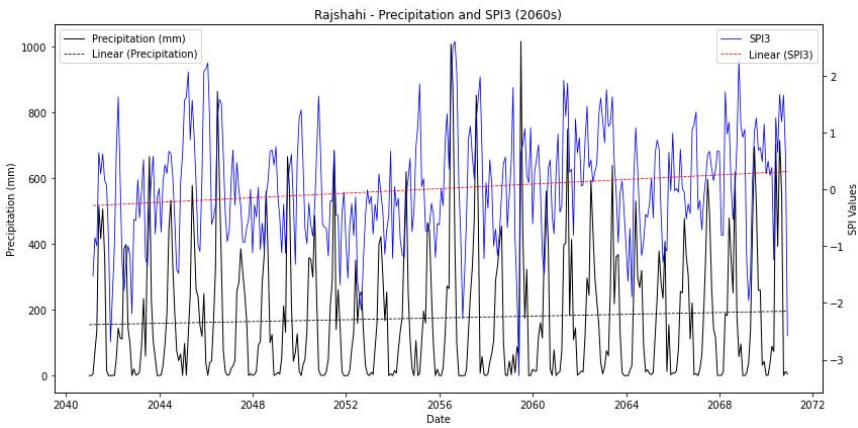


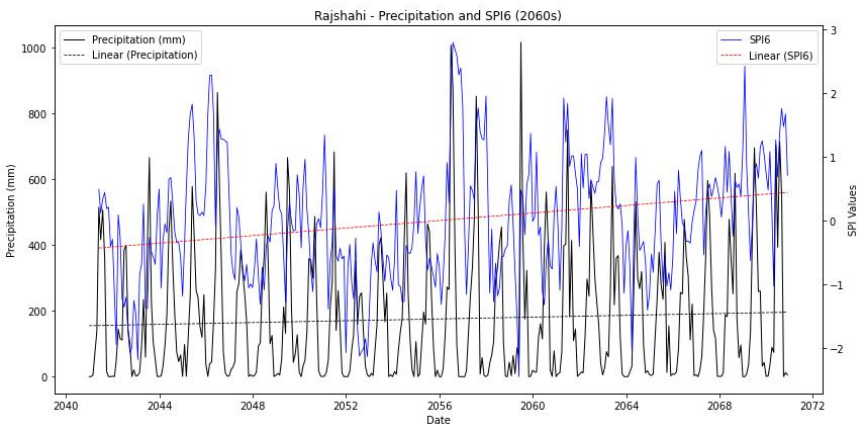
Figure 3: Precipitation and SPI (SPI3–SPI48) trends for Rajshahi under different climate scenarios: 2020s (2006–2040)

Drought patterns in the 2020s (2006–2040) in **Figure 3** and **Figure S1 in the supplementary file** are mostly short-term changes. The SPI3 and SPI6 indices often drop below zero, and several stations, like Rajshahi, Bogra, Khulna, and Satkhira, have recorded drought severity below -3. This means that short, severe droughts are common, even though they only last a few months. Dinajpur and Rangpur, on the other hand, get more than 1000 mm of rain a year, so they have milder short-term droughts and are less affected than the southwest. Droughts happen less often on longer timescales like SPI12, SPI24, and SPI48, but when they do happen, they last for more than one season, which makes their effects worse. During this time, the trendlines are mixed. Dinajpur and Rangpur show small improvements toward wetter conditions, but Satkhira, Khulna, and Mongla show signs of drying out. So, the 2020s are a time when short-term droughts happen a lot and are often very bad, while long-term droughts are still different from one region to the next.

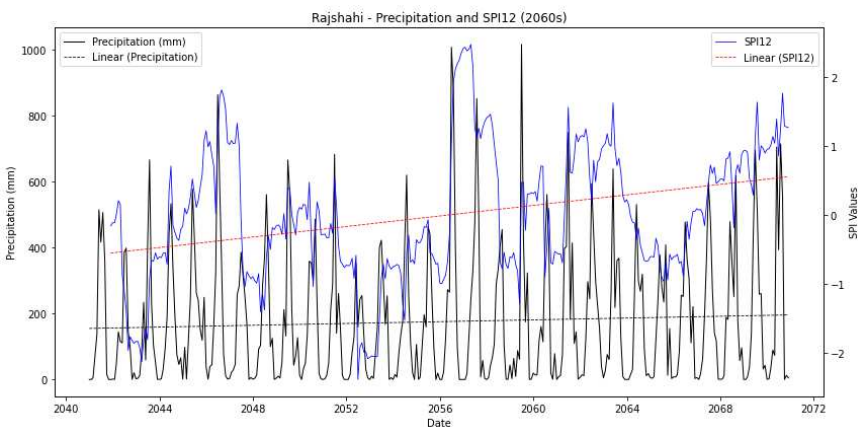
165



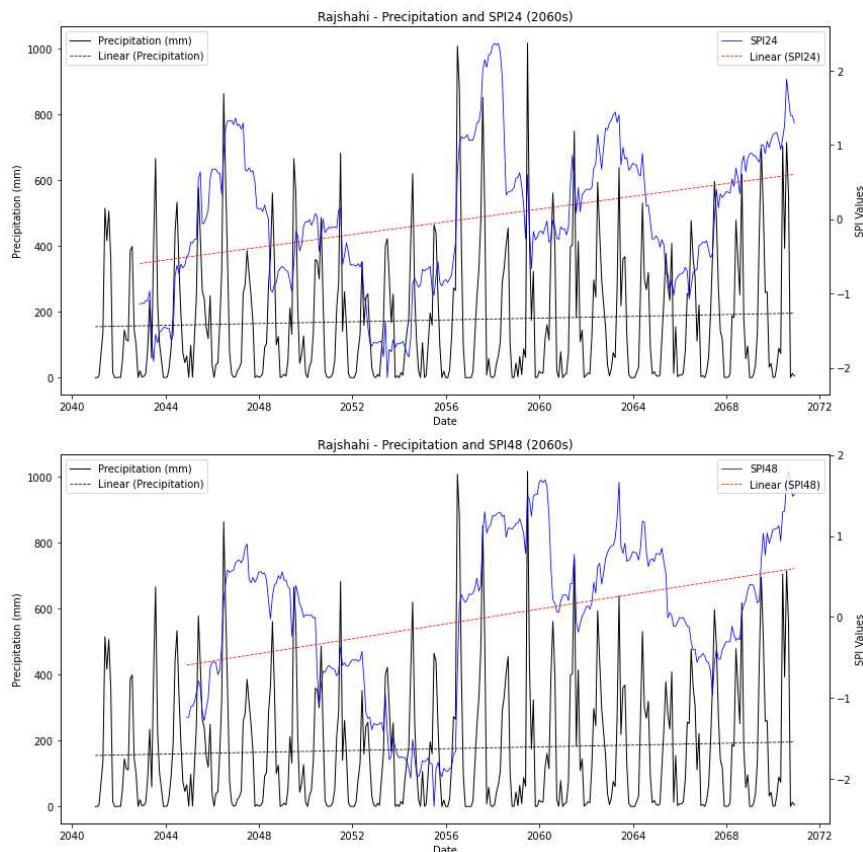
166



167



168



169

170

171

Figure 4: Precipitation and SPI (SPI3–SPI48) trends for Rajshahi under different climate scenarios: 2060s (2041–2070).

172

173

174

175

176

177

178

179

180

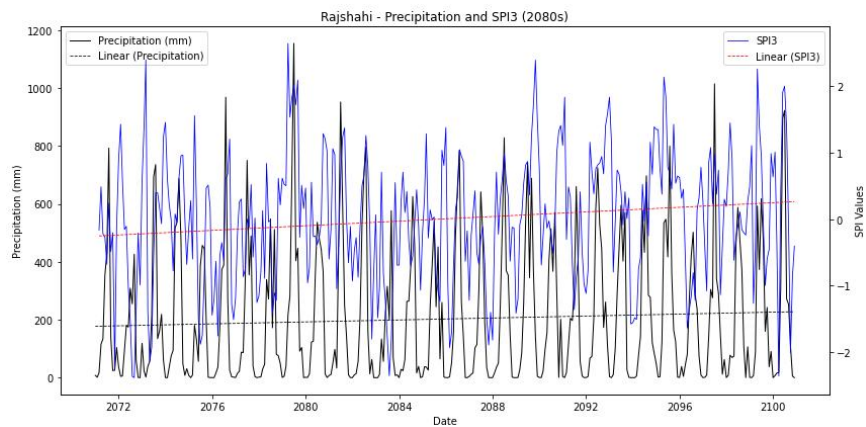
181

182

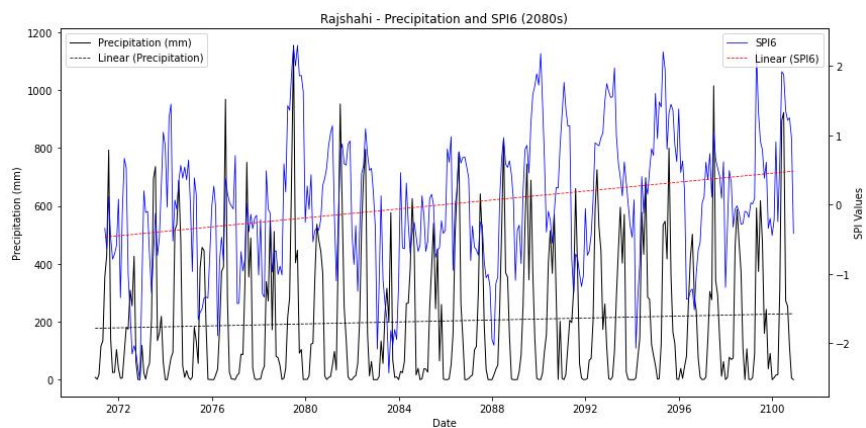
183

The occurrences start to change in the 2060s (2041–2070) shown in **Figure 4** and **Figure S2 in the supplementary file**. The SPI3 short-term drought indicator stays almost flat, which means that seasonal droughts keep happening regularly and don't change much from the past decades. But the longer indices, like SPI6, SPI12, SPI24, and SPI48, start to show steady positive slopes at most stations. This showed that droughts that last for more than one season and more than one year are becoming less common, which is a relief from the long-term lack of water. SPI24 and SPI48 are going up in Rajshahi, Bogra, Ishurdi, Rangpur, and even some southwestern districts like Khulna and Mongla. This means that long-term drought conditions are getting better. In Dinajpur, however, SPI48 is going down, which could mean that long-term water availability is getting worse in that area, even though things are getting better in other areas. The 2060s seem to be a decade of change. While short droughts are still common and disruptive, the overall risk of long, multi-year droughts starts to go down a lot.

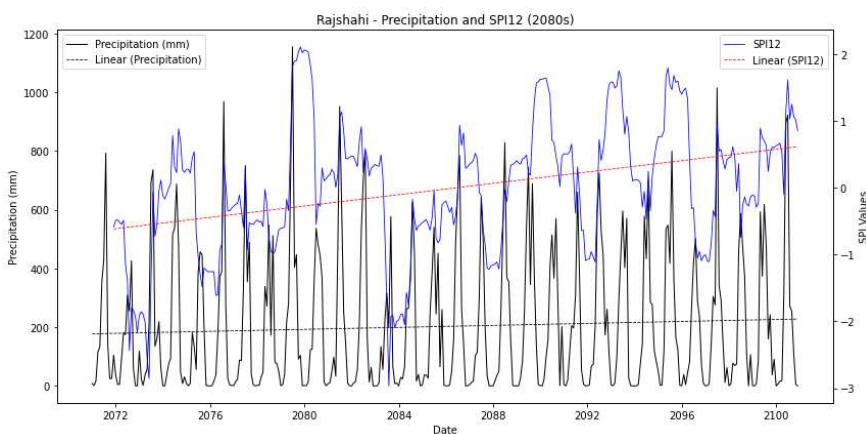
184



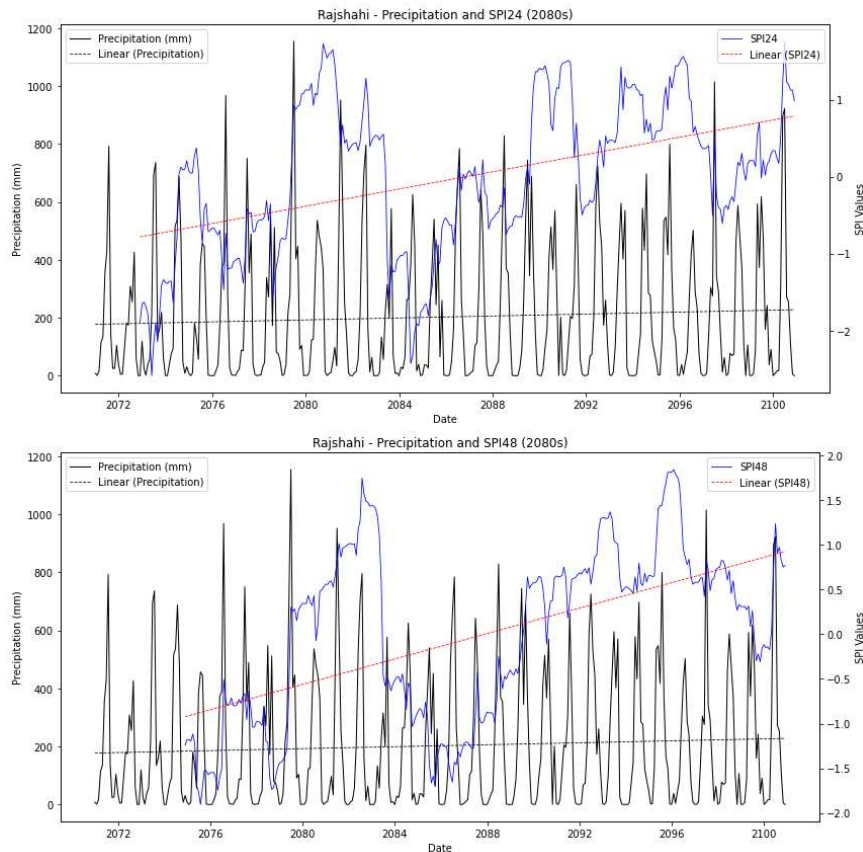
185



186



187



188

189

190

Figure 5: Precipitation and SPI (SPI3–SPI48) trends for Rajshahi under different climate scenarios: 2080s (2071–2100).

191

192

193

194

195

196

197

198

199

200

201

202

203

204

205

206

207

208

209

The 2080s (2071–2100) in **Figure 5** and **Figure S3** in the **supplementary file** show the most noticeable change. At this point, the long-term SPI indices (SPI12, SPI24, SPI48) are all going up quickly and steadily across the country. This means that long periods of drought are becoming less common. Northern and central districts, such as Dinajpur, Bogra, Ishurdi, Rajshahi, Rangpur, and Jessore, show especially steep increases. This shows that the weather is getting wetter and water is more stable. Even in the southwest, where drought conditions were more severe in the past, long-term droughts are less common now. However, these areas are still more likely to experience short seasonal droughts. It's important to note that the SPI3 values at most stations are still the same, which shows that short-term droughts are still happening even though long-term conditions are getting better. This persistence shows that the country's biggest drought problem by the end of the century won't be dry spells that last for years, but rather seasonal drought shocks that happen often.

When we look at all of these results together, they show a dual drought regime. Short-term droughts are the most common type of drought in the early part of the century. Long-term droughts are still a problem, especially in the southwest. Long-term droughts start to get better by the middle of the century, but short-term droughts stay the same. By the end of the century, long-term droughts are mostly gone from most of Bangladesh, but short-term droughts are still a common and widespread part of the climate system.

210

3.2. Statistical Analysis

211

212

Table 3: Statistical trend parameters of SPI values for Rajshahi under the 2020s, 2060s, and 2080s scenarios.

District	SPI	Trend	Mann-Kendall p-value	Sen's Slope	Spearman R	Spearman p-value
Rajshahi	2020s					
	SPI3	Increasing	0.622	0	0.023	0.633
	SPI6	Increasing	0.306	0	0.057	0.249
	SPI12	Increasing	0.402	0	0.066	0.181
	SPI24	Increasing	0.504	0	0.041	0.413
	SPI48	Increasing	0.285	0	0.054	0.298
	2060s					
	SPI3	Increasing	0	0.002	0.205	0
	SPI6	Increasing	0	0.003	0.285	0
	SPI12	Increasing	0	0.003	0.33	0
	SPI24	Increasing	0	0.004	0.362	0
	SPI48	Increasing	0	0.003	0.355	0
	2080s					
	SPI3	Increasing	0.003	0.002	0.154	0.003
	SPI6	Increasing	0	0.003	0.284	0
	SPI12	Increasing	0	0.004	0.38	0
	SPI24	Increasing	0	0.005	0.471	0
	SPI48	Increasing	0	0.006	0.54	0

The statistical trend analysis from all study stations shows that drought behavior will change over time and space in future climate scenarios, as shown in **Table 3** and **Table. S1 in the supplementary file**. Most districts have weak trends that aren't statistically significant in the 2020s. For example, Rajshahi shows slightly rising trends across all SPI timescales, but the numbers are too small to be useful. In Dinajpur and Ishurdi, SPI3 and SPI6 show small positive slopes that aren't statistically significant, which is a similar weak or flat response. In contrast, some southwestern stations, like Satkhira, Khulna, and Mongla, show trends that are going down in the early period, especially at shorter and medium timescales (SPI6–SPI24). This means that the coastal belt will still be more likely to have short-term droughts in the near future, while the northern areas will have more stable weather.

A clearer change happens as we move into the 2060s. Almost all stations start to show big upward trends over medium and long periods of time. Rajshahi, Jessore, Bogra, Ishurdi, and Rangpur all show steady positive trends from SPI6 to SPI48, which means that the weather is getting wetter. Dinajpur is also going up, but the SPI48 index shows a negative trend, which means that water availability over a long period of time could still face problems in some areas. The coastal stations that were drying out at first, like Satkhira, Khulna, and Mongla, start to show positive and significant trends in the 2060s, especially for SPI12, SPI24, and SPI48. This means that even though short droughts may continue, the chance of long-term drought in these areas will slowly go down by the middle of the century.

The trends get stronger and more common by the 2080s. At almost all timescales, all stations, even those in the southwest, show big positive slopes. The improvement is most noticeable at longer indices (SPI24 and SPI48), which show sharp upward slopes in Rajshahi, Bogra, Dinajpur, Rangpur, and Ishurdi. This confirms that prolonged multi-year droughts are becoming less common. Even in Khulna, Satkhira, and Mongla, where short droughts are still common, the longer timescales are becoming wetter. This means that multi-season droughts will be less of a problem in the future.

When we look at all the results together, they show a common pattern across Bangladesh: short-term droughts (SPI3 and SPI6) will happen a lot throughout the century, especially in the coastal belt. Long-term droughts (SPI12–SPI48), on the other hand, will happen less often and be less severe, especially after 2060. The northern and northwestern districts (Dinajpur, Rangpur, Rajshahi, Bogra, and Ishurdi) are expected to see bigger improvements because there will be more rain and water available. In the meantime, the southwestern districts (Khulna, Satkhira, Mongla, and to some extent Jessore) are still at high risk for seasonal drought, even though their long-term drought conditions get better later in the century.

3.3. Drought properties Analysis

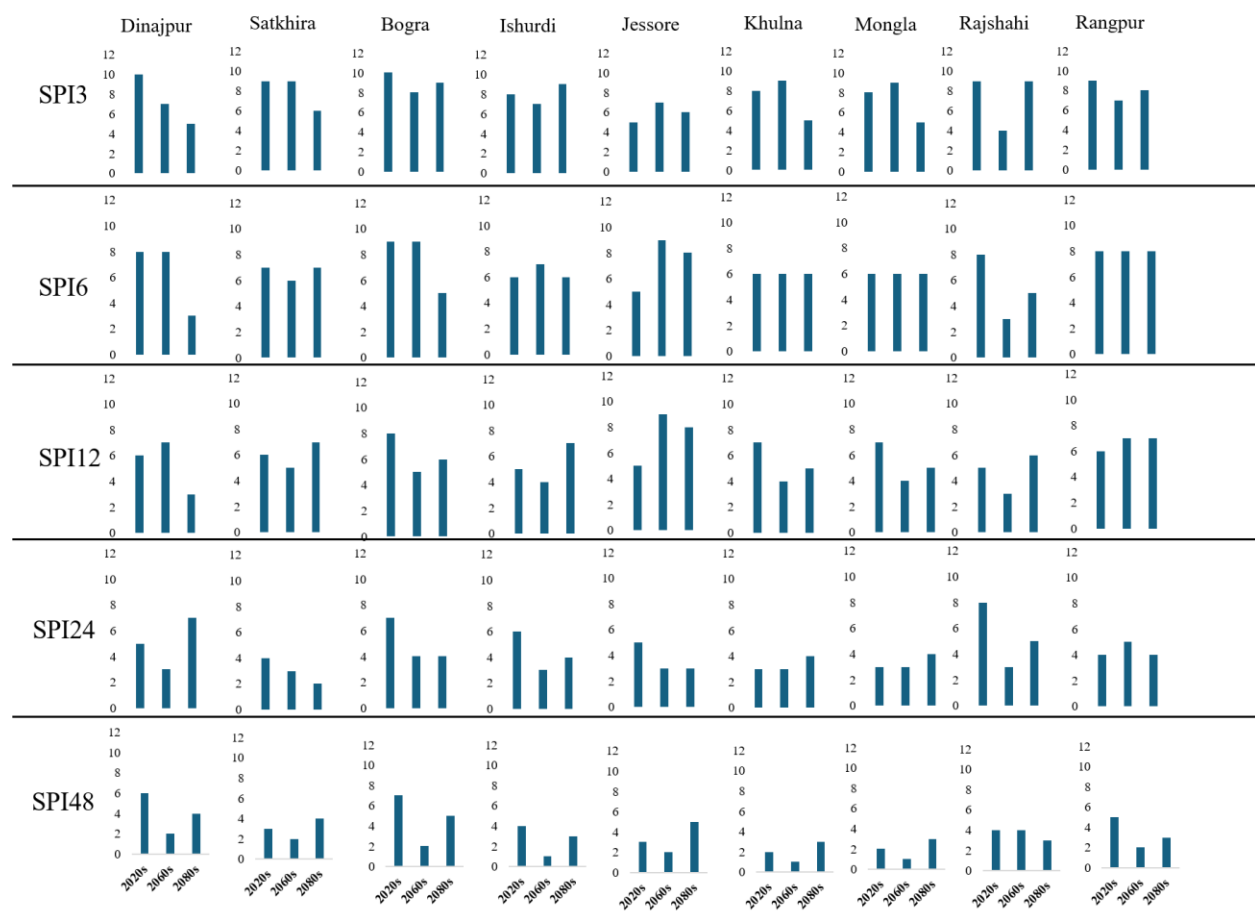


Figure 6: Frequency of drought events across stations in Bangladesh at different SPI timescales (SPI3, SPI6, SPI12, SPI24, SPI48) under the 2020s, 2060s, and 2080s scenarios.

The bar chart in **Figure 6** shows the number of drought events across different timescales (SPI3, SPI6, SPI12, SPI24, and SPI48) for all regions in future periods (2020s, 2060s, and 2080s) time scale.

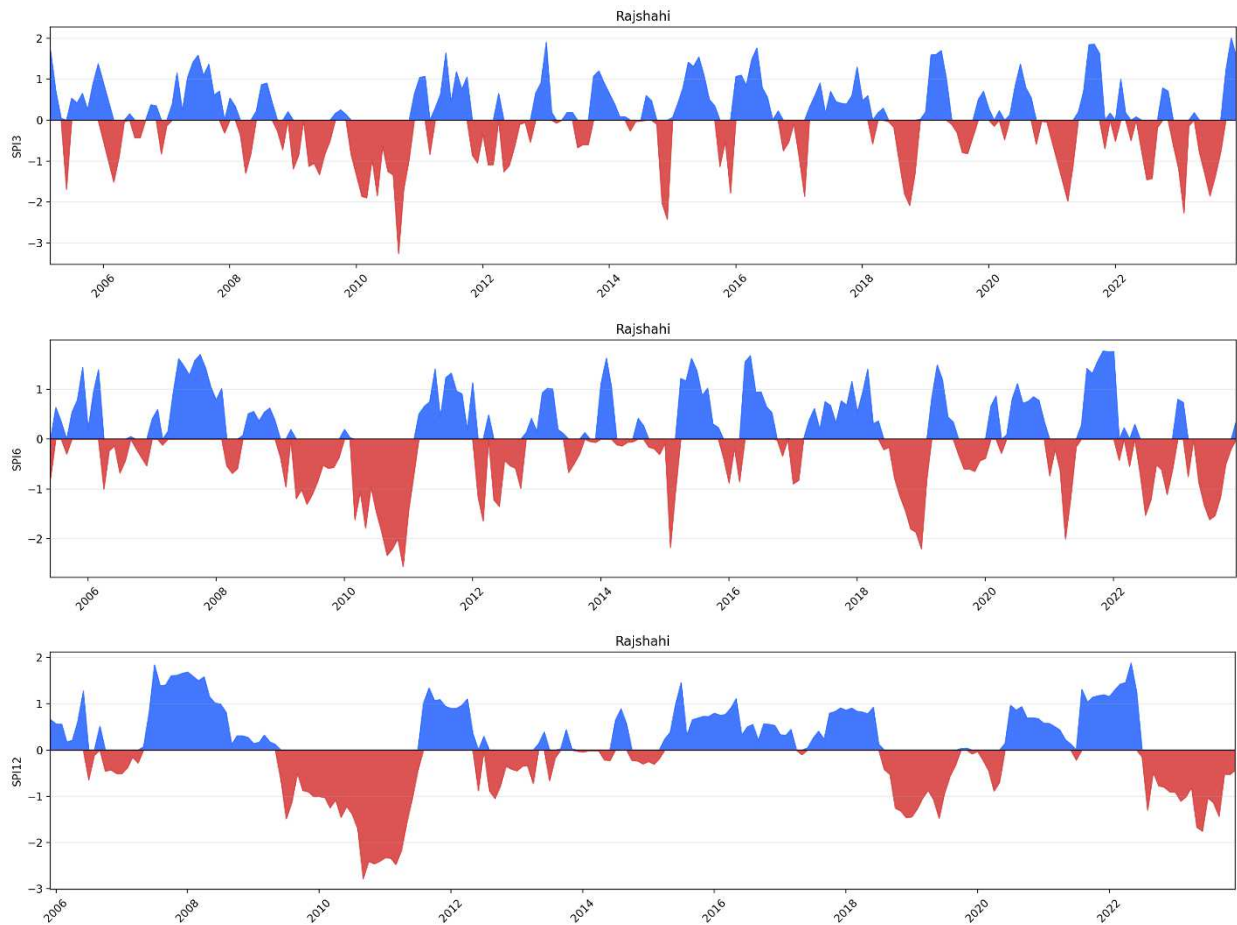
When we look at the top row (SPI3), we can see that the number of short droughts is always high in every region. This means that 3-month droughts will remain the most frequent type of drought in Bangladesh, no matter which decade we look at. Regions such as Satkhira, Khulna, and Rajshahi show especially high counts, which means that these places will continue to suffer frequent seasonal dry spells. Even in wetter regions like Dinajpur and Rangpur, the number of short droughts does not disappear.

Moving to the second row (SPI6), we see a similar pattern. Six-month droughts are also quite common, though usually a bit fewer in number compared to SPI3. Still, they remain an

important feature of future droughts, showing that seasonal water shortages will continue to challenge agriculture and water resources in many parts of the country. In contrast, when we look at the longer timescales (SPI12, SPI24, SPI48) in the lower rows, the bars get much shorter. This tells us that long-term droughts are becoming less frequent in the future. For example, at SPI12 and SPI24, most regions show a gradual drop in drought numbers from the 2020s to the 2080s. By the time we reach SPI48, almost all regions show very few drought events, especially in the later decades. This means that multi-year droughts are expected to decline significantly, and Bangladesh will face fewer prolonged dry periods in the future.

3.4. Validation

3.1.1. observed SPI Variability from BMD Stations (2005- 2023)



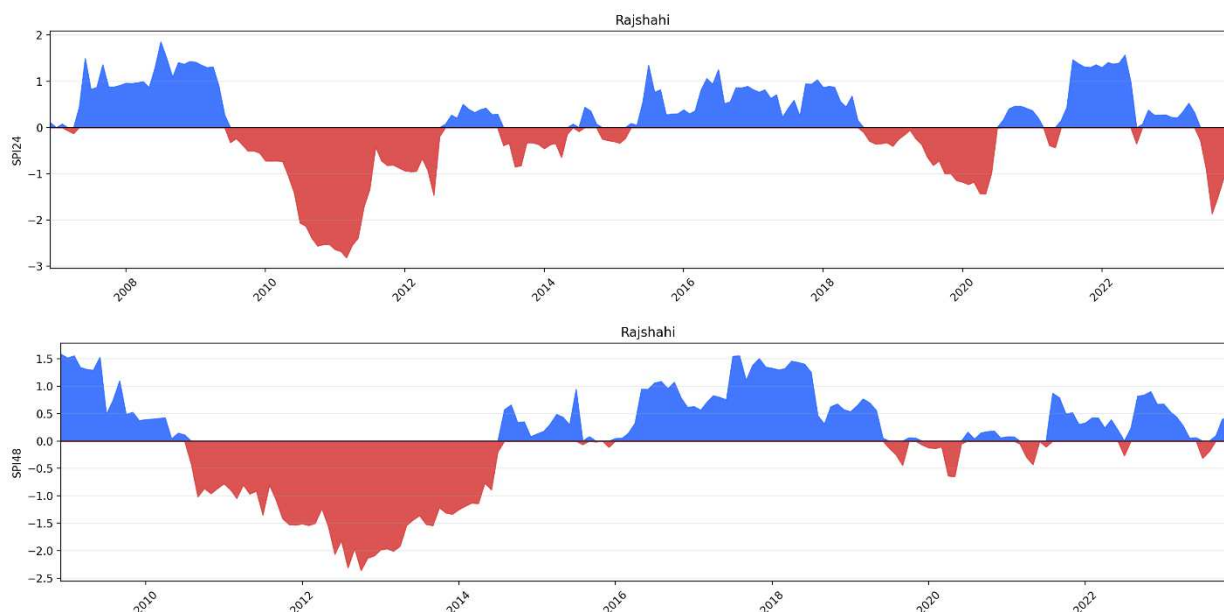


Figure 7: Standardized Precipitation Index (SPI3–SPI48) variability for Rajshahi BMD stations in Bangladesh during 2005–2023.

The Standardized Precipitation Index (SPI) was used to look at the drought variability in Bangladesh from 2005 to 2023. The SPI was used at five different timescales: SPI3, SPI6, SPI12, SPI24, and SPI48. **Figure 7** and **Figure S4 in the supplementary file** shows how the SPI changes over time for a few representative stations. It shows how the wet (blue) and dry (red) periods change. The short-term indices (SPI3 and SPI6) show that seasonal droughts are common at all stations because they often go above and below zero. These short droughts happen over and over again, and some of them are so bad that they fall into the severe and extreme categories ($SPI \leq -2$). This shows how much they affect farming and the supply of water.

The longer timescales (SPI12, SPI24, SPI48) show fewer changes, but they do show more drought episodes that last longer. The number of long-term droughts is lower, but they tend to last longer, as seen in Rajshahi, Bogra, and Jessore. This difference between short and long droughts is in line with earlier research that showed Bangladesh is more vulnerable to seasonal drought shocks, while multi-year droughts are still rare and limited to certain areas.

3.1.1. Drought Properties analysis for BMD Stations

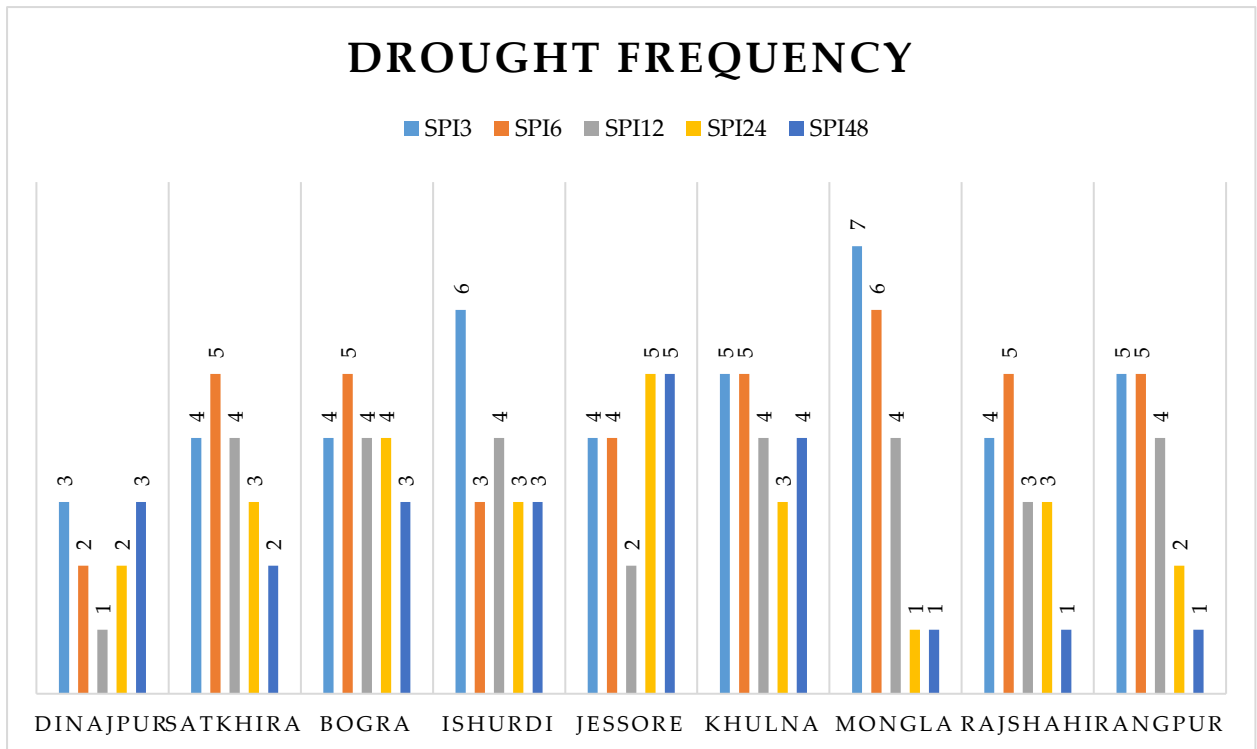


Figure 8: Observed drought frequency (2005–2023) across stations in Bangladesh at different SPI timescales (SPI3, SPI6, SPI12, SPI24, SPI48).

The drought frequency depicted in **Figure 8**, derived from Bangladesh Meteorological Department (BMD) data spanning 2005 to 2023, reveals distinct patterns across various timescales and regions. The shorter indices (SPI3 and SPI6) show that most stations have the most drought events, which shows that short-term droughts are the most common type in Bangladesh. For instance, Mongla has the most droughts at the 3-month (7 events) and 6-month (6 events) scales. Ishurdi comes in second with 6 events at the SPI3 scale. Rajshahi and Rangpur also have five events at SPI6, which shows that seasonal water stress is still a problem in these areas.

The longer timescales (SPI12, SPI24, SPI48), on the other hand, show fewer drought events. These numbers are between 2 and 4 for most stations, which shows that multi-year droughts are less common during the time period studied. Jessore is different because SPI24 and SPI48 each recorded 5 drought events. This means that this station is more likely to have long dry spells than other stations.

The data also shows a difference between regions. The southwestern stations (Mongla, Khulna, Satkhira, Jessore) usually have more droughts, especially for SPI3 and SPI6. This is because they are more likely to get seasonal rainfall and extreme weather. Northern stations (Dinajpur, Rangpur, Bogra), on the other hand, tend to record fewer droughts overall, especially over longer periods of time. This suggests that water availability is more stable in these areas.

The observed record confirms the RCP8.5-based findings, short-term droughts are common and widespread throughout Bangladesh, whereas long-term droughts are less frequent but can still impact specific areas, such as Jessore.

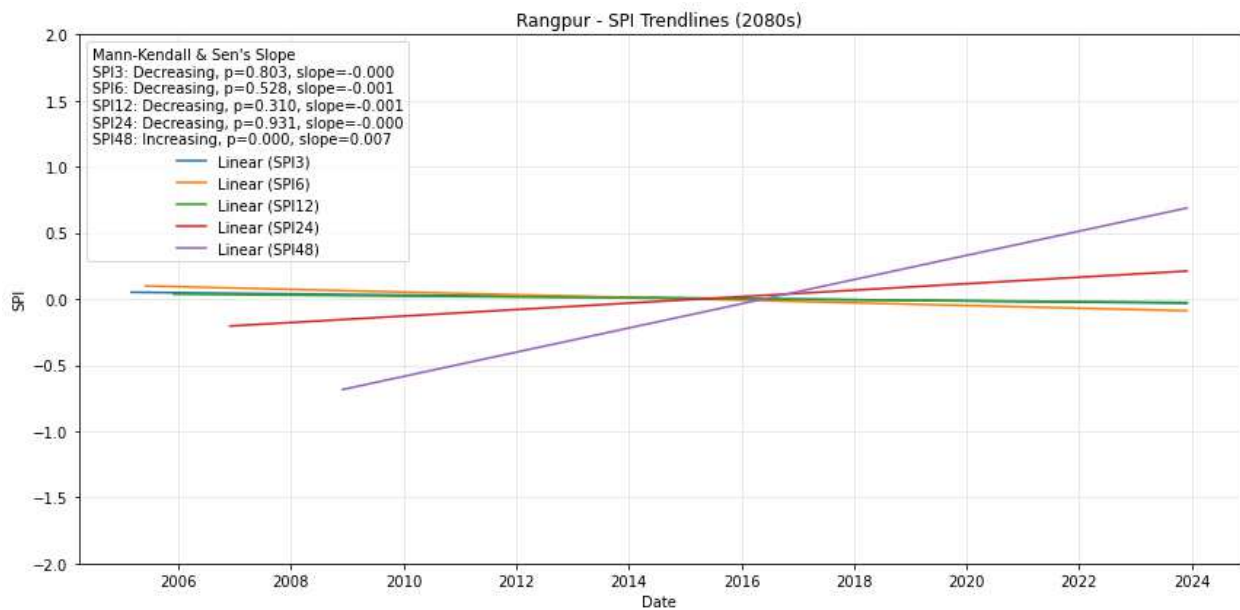


Figure 9: Observed SPI trendlines (2005–2023) for Rajshahi at different timescales (SPI3, SPI6, SPI12, SPI24, SPI48).

From 2005 to 2023, the SPI trendlines show a mixed picture across Bangladesh in **Figure 9** and **Figure S5 in the supplementary file**, with clear differences between the northern districts and the southwestern coastal belt.

The SPI trends in the southwestern stations like Jessore, Khulna, and Satkhira mostly show a downward trend over a range of time scales. For Jessore, almost all of the indices (SPI12, SPI24, and SPI48) show significant negative slopes. This shows that this area has had longer and worse dry spells in the past few years. In the same way, Khulna and Satkhira both show decreasing trends for most timescales, especially at SPI12 and SPI24. This means that these areas have had more medium- to long-term droughts. These results show that the coastal belt is still one of the driest places in Bangladesh, with short seasonal droughts and longer dry spells happening at the same time.

Mongla, on the other hand, illustrated a very different view. All of the indices, but especially the longer ones (SPI24 and SPI48), show strong positive slopes. This means that this station has been getting wetter in recent years. This difference from nearby Khulna and Satkhira could be due to localized changes in rainfall or certain coastal climate factors.

The trends are mostly neutral to positive over longer periods of time in the northwestern and central districts, like Rajshahi, Rangpur, Bogra, Dinajpur, and Ishurdi. For example, SPI3 and SPI6 show slightly negative or flat slopes in Rajshahi and Rangpur, but SPI48 shows a clear positive trend. Bogra, Dinajpur, and Ishurdi all show steady upward movement at SPI12–SPI48, which suggests that long-term water conditions are getting better slowly. This means that even though these areas still have short-term droughts, the chance of longer, multi-year droughts has gone down in the past few years.

Overall, the trends we saw show that short-term droughts (SPI3 and SPI6) are still common and widespread, especially in the southwest. Long-term droughts (SPI12–SPI48), on the other hand, are less common in the northern and central regions but still cause problems in Jessore, Khulna, and Satkhira.

The observed data validates the RCP8.5 scenario analysis. The RCPs said that short-term droughts would continue to be the norm in Bangladesh, but long-term droughts would drop a lot by the 2060s and 2080s. The BMD observations from 2005 to 2023 show the same pattern: short droughts are common everywhere, but longer droughts are becoming less common in the

northern districts. The coastal southwest, on the other hand, is still experiencing long-term drought stress.

4. Discussion

The study of drought characteristics over various timescales and prospective climate scenarios underscores significant spatial and temporal variations in Bangladesh. The RCP8.5-based scenario analysis results for the 2020s, 2060s, and 2080s show a clear pattern: short-term droughts happen a lot, but long-term droughts happen less and less. This aligns with the statistical assessment across stations and is strengthened by the observed BMD data for 2005–2023.

The trends are still weak or inconsistent in the 2020s. Most stations have SPI3 lines that are almost flat, which means that short-term droughts are still happening without much change. Some areas in the southwest, like Satkhira, Khulna, and Mongla, are even drying out over medium to long periods of time. This shows that the southwest is especially at risk of seasonal and long-term droughts in the near future. Northern stations like Dinajpur and Rangpur, on the other hand, are protected by higher rainfall and have fewer events.

A clear change happens all over the country by the 2060s. Most stations show big positive changes in SPI6, SPI12, SPI24, and SPI48, which means that droughts that last for more than one season or year will happen less often. SPI24 and SPI48 show strong positive slopes in Rajshahi, Bogra, Ishurdi, and Rangpur, which means that long-term water stability is getting better. But Dinajpur is different at the longest timescale, where SPI48 goes down. This suggests that there may be localized risks in northern Bangladesh, even though the overall trend is toward wetter weather. It's important to note that SPI3 is still mostly flat across regions. This means that short droughts will still be a common problem even in wetter times.

The 2080s confirm these findings, as long-term indices (SPI12–SPI48) show strong upward trends at almost all stations. This means that Bangladesh will probably have a lot fewer long-lasting droughts by the end of the century. But SPI3 still shows that short-term droughts happen a lot, especially in the southwest. Stations like Satkhira and Khulna are still at higher risk of seasonal water stress, while Dinajpur, Rajshahi, Bogra, and Rangpur are better off with wetter weather and long-term stability.

The validation using observed BMD data from 2005 to 2023 backs up these predictions. The drought frequency analysis shows that SPI3 and SPI6 cover most of the droughts that have happened in the last few decades. This is especially true in Mongla, Jessore, and Khulna, where short droughts are more common. Longer timescales like SPI24 and SPI48 show fewer events at most stations, which backs up the idea that multi-year droughts are less common in real life as well. Trendline analyses of the observed data further demonstrate regional disparities. Jessore, Khulna, and Satkhira display substantial decreases in SPI across various timescales, confirming their susceptibility, whereas Bogra, Dinajpur, and Ishurdi exhibit positive trends at SPI24 and SPI48, aligning with RCP forecasts of diminishing long-term drought risk. Mongla is an outlier because it has a positive increase across all indices. This could be because of rain patterns that are different from those in nearby districts.

The results show that Bangladesh is at risk of two different types of drought. Short, frequent droughts are still the most common type of weather in all areas. They are still a threat to farming and water supply. On the other hand, long, severe droughts are likely to become much less common in the next few decades, especially in the northern and central parts of the country. This duality shows that future drought management needs to take both of these things into account, getting communities ready for short-term drought shocks that happen often, and also realizing that long-term water availability may get better in some areas.

5. Conclusions

The study indicates that future drought risk in Bangladesh will be influenced by two opposing trends. Short-term droughts lasting three to six months will continue to be frequent across the country. The southwestern districts of Satkhira, Khulna, Mongla, and Jessore will be impacted the most severely. Even though it rains more in other parts of the world, these seasonal dry spells are likely to keep affecting farming and the water supply. On the other hand, long-term droughts that last one to four years are expected to go down a lot, especially in the 2060s and 2080s. The biggest changes will happen in the northern and central districts, like Rajshahi, Rangpur, Bogra, Dinajpur, and Ishurdi.

The validation with observed data (2005–2023) confirms this pattern. Recent records already show that short droughts happen more often than long ones, and there are clear regional differences, with the southwest being more prone to drought than the north.

In general, these results show that Bangladesh's future risk of drought will be more from short-term events that happen often than from long-term droughts that last for years. Adaptation strategies should prioritize resilience against seasonal drought shocks in vulnerable regions, while also taking advantage of the gradual improvement in long-term water availability in the north. Policymakers, planners, and communities should focus on systems for managing water, monitoring droughts, and tools for giving early warnings about these changing risks.

References

- Adnan, S. (1993). Institutional Aspects of Flood Protection Programmes: November 1991-October 1992: Living without floods: Lessons from the drought of 1992 (No. 7). Research & Advisory Services.
- Al Mamun, Md. A., Sarker, M. R., Sarkar, M. A. R., Roy, S. K., Nihad, S. A. I., McKenzie, A. M., Hossain, Md. I., & Kabir, Md. S. (2024). Identification of influential weather parameters and seasonal drought prediction in Bangladesh using machine learning algorithm. *Scientific Reports*, 14(1), 566. <https://doi.org/10.1038/s41598-023-51111-2>
- Burke, E. J., & Brown, S. J. (2008). Evaluating Uncertainties in the Projection of Future Drought. *Journal of Hydrometeorology*, 9(2), 292–299. <https://doi.org/10.1175/2007JHM929.1>
- Chowdhury, S., & Jahan, N. (2018). Drought Analysis of Rajshahi of Bangladesh Using CORDEX data by Palmer Method.
- Di Nunno, F., & Granata, F. (2023). Future trends of reference evapotranspiration in Sicily based on CORDEX data and Machine Learning algorithms. *Agricultural Water Management*, 280, 108232. <https://doi.org/10.1016/j.agwat.2023.108232>
- Endris, H. S., Omondi, P., Jain, S., Lennard, C., Hewitson, B., Chang'a, L., Awange, J. L., Dosio, A., Ketiem, P., Nikulin, G., Panitz, H.-J., Büchner, M., Stordal, F., & Tazalika, L. (2013). Assessment of the Performance of CORDEX Regional Climate Models in Simulating East African Rainfall. *Journal of Climate*, 26(21), 8453–8475. <https://doi.org/10.1175/JCLI-D-12-00708.1>
- Gibbs, W.J. (1975). Drought-its definition, delineation and effects. Drought. Lectures presented at the twenty-sixth session of the WMO Executive Committee., pp.1-39.
- Gleckler, P. J., Taylor, K. E., & Doutriaux, C. (2008). Performance metrics for climate models. *Journal of Geophysical Research*, 113(D6), D06104. <https://doi.org/10.1029/2007JD008972>
- Gupta, R., Sarkar, M. J., Islam, Md. S., Uddin, Md. R., Riza, I. J., Monira, S., Zaman, F., Hasan, A. K., Islam, A. K. M. M., Hashem, A., Avila-Quezada, G. D., Parray, J. A., Abd_Allah, E. F., & Sarker, U. K. (2023). Introducing New Cropping Pattern to

- Increase Cropping Intensity in Hill Tract Area in Bangladesh. *Sustainability*, 15(14), 11471. <https://doi.org/10.3390/su151411471>
- Guttman, N. B. (1999). ACCEPTING THE STANDARDIZED PRECIPITATION INDEX: A CALCULATION ALGORITHM¹. *JAWRA Journal of the American Water Resources Association*, 35(2), 311–322. <https://doi.org/10.1111/j.1752-1688.1999.tb03592.x>
- H., AJ, allaksen, L. M. and van Lanen. (2004). *Hydrological Drought: Process and Estimation Methods for Streamflow and Groundwater Developments in Water Science*.
- Hayes, M. J., Svoboda, M. D., Wilhite, D. A., & Vanyarkho, O. V. (1999). Monitoring the 1996 Drought Using the Standardized Precipitation Index. *Bulletin of the American Meteorological Society*, 80(3), 429–438. [https://doi.org/10.1175/1520-0477\(1999\)080%3C0429:MTDUTS%3E2.0.CO;2](https://doi.org/10.1175/1520-0477(1999)080%3C0429:MTDUTS%3E2.0.CO;2)
- Kabir, M., Habiba, U. E., Khan, W., Shah, A., Rahim, S., Rios-Escalante, P. R. D. L., Farooqi, Z.-U.-R., Ali, L., & Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. *Journal of King Saud University - Science*, 35(5), 102693. <https://doi.org/10.1016/j.jksus.2023.102693>
- Karavitis, C. A., Alexandris, S., Tsesmelis, D. E., & Athanasopoulos, G. (2011). Application of the Standardized Precipitation Index (SPI) in Greece. *Water*, 3(3), 787–805. <https://doi.org/10.3390/w3030787>
- Kis, A., & Pongrácz, R. (2023). Analyzing the influences of the selection of the RCP scenario and the reference period on the evaluation results of EURO-CORDEX simulations for Hungary. *International Journal of Climatology*, joc.8184. <https://doi.org/10.1002/joc.8184>
- Kreft, S., Junghans, L., Eckstein, D., & Hagen, U. (2014). Global climate risk index ... 2015. Who suffers most from extreme weather events? Weather-related loss events in 2013 and 1994 to 2013 / S. Kreft .. Germanwatch e.V.
- Kumar, M. N., Murthy, C. S., Sesha Sai, M. V. R., & Roy, P. S. (2009). On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. *Meteorological Applications*, 16(3), 381–389. <https://doi.org/10.1002/met.136>
- Liu, S., Shi, H., & Sivakumar, B. (2020). Socioeconomic Drought Under Growing Population and Changing Climate: A New Index Considering the Resilience of a Regional Water Resources System. *Journal of Geophysical Research: Atmospheres*, 125(15). <https://doi.org/10.1029/2020JD033005>
- McKee, T. B., Doesken, N. J., & Kleist, J. (1993a). THE RELATIONSHIP OF DROUGHT FREQUENCY AND DURATION TO TIME SCALES. 6.
- McKee, T. B., Doesken, N. J., & Kleist, J. (1993b). THE RELATIONSHIP OF DROUGHT FREQUENCY AND DURATION TO TIME SCALES.
- Mirza, M.Q. and Paul. (1992). *Natural disaster and environment in Bangladesh*. Centre for Environmental Studies and Research, Dhaka.
- Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 391(1–2), 202–216. <https://doi.org/10.1016/j.jhydrol.2010.07.012>
- Molina, M. O., Sánchez, E., & Gutiérrez, C. (2020). Future heat waves over the Mediterranean from an Euro-CORDEX regional climate model ensemble. *Scientific Reports*, 10(1), 8801. <https://doi.org/10.1038/s41598-020-65663-0>
- Palmer, W.C. (1995). *Meteorologic Drought*. US Department of Commerce, Weather Bureau, Research Paper No. 45, p. 58.
- Pour, S. H., Shahid, S., Chung, E.-S., & Wang, X.-J. (2018). Model output statistics downscaling using support vector machine for the projection of spatial and temporal changes in rainfall of Bangladesh. *Atmospheric Research*, 213, 149–162. <https://doi.org/10.1016/j.atmosres.2018.06.006>

- Priyan, K. (2021). Issues and Challenges of Groundwater and Surface Water Management in Semi-Arid Regions. In: Pande, C.B., Moharir, K.N. (eds) Groundwater Resources Development and Planning in the Semi-Arid Region.
- Qtaishat, T., El-Habbab, M. S., Bumblauskas, D. P., & Tabieh, M. (2022). The impact of drought on food security and sustainability in Jordan. *GeoJournal*, 88(2), 1389–1400. <https://doi.org/10.1007/s10708-022-10702-8>
- Rayhan, Md., & Afroz, R. (2024). Evaluating climate models to analyze drought conditions in the western region of Bangladesh. *Progress in Disaster Science*, 23, 100356. <https://doi.org/10.1016/j.pdisas.2024.100356>
- S. Niemeier. (2008). New Drought Indices.
- Shahid, S. (2012). RAINFALL VARIABILITY AND CHANGES IN BANGLADESH DURING THE LAST FIFTY YEARS. 24.
- Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index. *Journal of Climate*, 23(7), 1696–1718. <https://doi.org/10.1175/2009JCLI2909.1>

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryDocument.docx](#)