DROUGHT PROJECTION OF THE RAJSHAHI REGION USING SPI INDEX AND CORDEX CLIMATE MODEL DATA ACROSS DIFFERENT TIME SCALE

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ABSTRACT

Climate system change, currently, is a global challenge. Additionally, climate change defines the weather patterns changes. Due to the weather changes, it has an impact on the overall environment. This has led to natural disasters such as floods, excessive rainfall, and excessive deficit of water. The water deficit compared to the demand or requirement creates a drought condition. Bangladesh is not safe from such a situation, especially in the North-West region where it has been historically drought-prone. To address this, the study on the Rajshahi region has analyzed the future scenarios of drought events under RCP 8.5 w/m^2 emission rate using the MIROC climate model's CORDEX data. The Standard Precipitation Index (SPI) is utilized to assess short (SPI3) and long-term (SPI12) drought projections, revealing that drought frequencies will decrease in the far future. Notably, the study results show that short-term drought events occur more frequently than long-term drought events in the near, mid, and far future. This study provides valuable insights into the future trends of drought projection so that the public and policymakers can make good decisions for the region susceptible to drought impacts.

Keywords: *Drought, Statistical Analysis, RCP Scenario, Climate Model, Drought Index*

1. INTRODUCTION

Climate changes affect the development and underdevelopment of countries. The climate cycle depends on lots of variables for which the worst situation happens such as increasing temperature, higher or lower rainfall intensity, unexpected floods, etc (Chowdhury et al., 2022). Another such natural calamity is Drought. Drought is a natural hazard, and the scale of effects depends on climatic variables. That's why different definitions are used for different research fields. Gumbel defined 'Drought as the smallest annual value of daily demanding flow' (Gumbel, 1963). A conceptual definition related to farming is, 'Drought is a prolonged period of deficient precipitation resulting in extensive damage to crops, and a consequential loss of yield' (National Drought Mitigation Center). Palmer described a drought as a significant deviation from the normal hydrologic conditions of an area (Palmer, W.C, 1995).

Among the countries, Bangladesh is not safe from climate change. Climate change effects on socio-economic properties, and livelihoods of Bangladesh. Bangladesh ranked 5th in the Global Climate Risk Index, a ranking of 170 countries for most vulnerable to climate change (Dastagir, 2015). The average temperature increased by 0.103°C per decade throughout the last four (Pour et al., 2018). Bangladesh seems to experience an increase in temperature of about 1.5°C (Shahid, 2012). For that, there will be rainfall variation and due to uncontrolled extraction of groundwater, in the future, there will be a demand for water for irrigation and other than supply. That will enhance the probability of drought conditions that already have been affected by severe drought in the historical period (Dash et al., 2012; Mondol et al., 2021; Shahid, 2008; Uddin et al., 2020). In 1951, 1961, 1975, 1979, 1981, 1982, 1984, 1989, and 1995 Bangladesh faced severe drought. In 1995 drought occurred during the late Kharif period and caused a net reduction of 377,000 tons of Aman production (Mirza, M.Q. and Paul, 1992). That's why drought analysis is necessary for Bangladesh regions. Mostly the north-west regions of Bangladesh are badly affected by severe drought (Murad.; Shahid & Behrawan, 2008).

For monitoring of drought events the tools generally used is called drought indices (S. Niemeyer). For example, NDVI, ADI, PDSI, SPEI, SPI, etc. are commonly used indices (Akbar et al., 2012; Albert J. Peters et.al, 2002; Karnieli et al., 2010; Murad.; Shahid, 2008; Stagge et al., 2015; Willium, 1984). Rajshahi region is the region that is analyzed for future prediction so that can predict the future drought conditions of different time scales using Standard Precipitation Index. In another word, in this study, Standardized Precipitation Index (SPI) is used to predict the short-term and long-term drought scenarios of the drought-prone region of Rajshahi region under the RCP 8.5W/M^2 for Near, Mid and Far future.

2. METHODOLOGY

The following steps are used in this study for analyzing the output in Figure 1

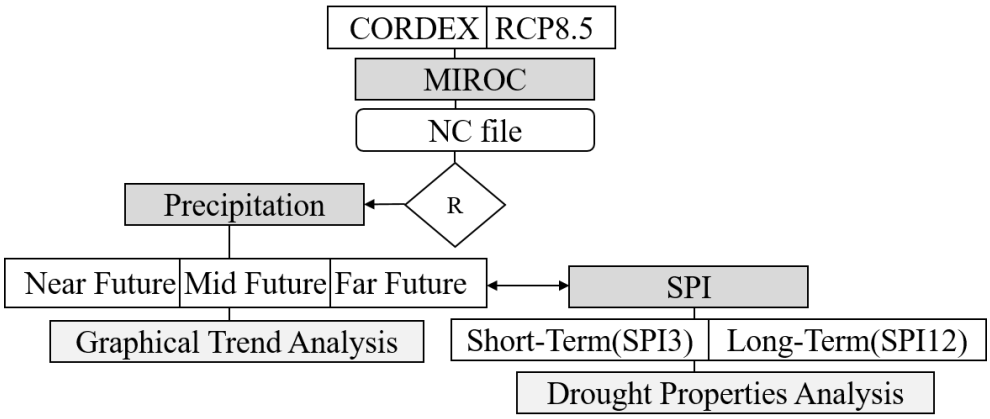

Figure 1: The Methodology flowchart for the Study

2.1 Study Area

Bangladesh's mostly drought-prone areas are North-west regions where rainfall intensity is less than expected. Thus this study is mainly focused on the Rajshahi region from the north-west regions, which is shown in Figure 2.

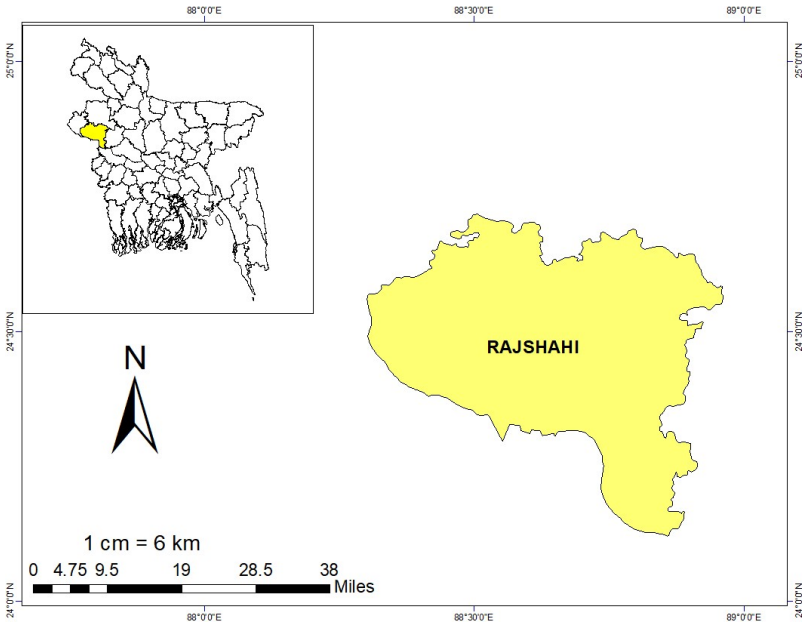

Figure 2 : The study Area

2.2 Standard Precipitation Index (SPI)

The SPI index was first enveloped by Mckee (McKee et al., 1993). This index is the widely useable index for drought analysis because of its simplicity and required single parameter. Also, the index has great approximation capacity in drought frequency, and duration analysis (Guttman, 1999; Ji & Peters, 2003; Lorenzo et al., 2024). That's why the SPI method is used for Rajshahi district drought analysis. SPI index values can be determined using different month averages. It can be from one month to 24 months (Feng et al., 2020; Paulo & Pereira, 2007). A gamma distribution function is fitted to the precipitation histogram to calculate SPI (Hsin-Fu Yeh & Chia-Fu Chang, 2019). The next step is to convert the cumulative density function (CDF) of the gamma distribution to the CDF of the standard normal distribution. Dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation given Z values. The drought classification are shown in Table 1.

Table 1: 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

2.3 Data Use

2.3.1 CORDEX Data

The climate information at a regional scale by downscaling over several continental regions of the world is done by the CORDEX program (see, https://cordex.org/). Based on several RCM emissions rates, different institutions, and research groups work on providing climate outputs. The output contains multivariable time series at different spatial and time resolutions over several climate scenarios (McGinnis & Mearns, 2021; Spinoni et al., 2020; Suman & Maity, 2020).

Table 2: Details of the CORDEX Data

Station	Data Used	Data Source
Rajshahi	Precipitation	https://esgf-node.llnl.gov/projects/esgf-llnl/

2.3.2 Representation Concentration Pathway (RCP)

RCP means Representative Concentration Pathway which is basically Carbon dioxide or greenhouse gas concentration. RCP 8.5 watts per meter square means that at an average of 8.5 watts per square meter throughout the globe, concentrated carbon delivers global warming (Buras & Menzel, 2019; Park et al., 2015; Payne & Magnusdottir, 2015; Riahi et al., 2011). Under RCP8.5, precipitation data are extracted from 2006 to 2100 which is divided into three time spans for this study in Table 3.

Table 3: Time Span

Time Span	Representation
2006-2040	Near Future
2041-2070	Mid Future
2071-2100	Far Future

2.4 Short-Term and Long-Term Drought

A deficit of water than the demand for water is primarily called drought. Drought can be a long time to short. In some regions there may be a monthly deficit of water, have seasonal deficit of water, and somewhere, a yearly deficit of water. This study mainly discusses the consecutive three-month deficit of water and the twelve-month deficit of water. Three monthly deficit is called a short-term drought and twelve monthly deficit of water is called a long-term deficit of water. In another word, The monthly precipitation time series and the running sum of 3 (short-term drought), and 12 (Long-term Drought) months are modeled using gamma distributions.

3. RESULTS

3.1 Graphical Analysis

3.2 Short-Term Drought (SPI3)

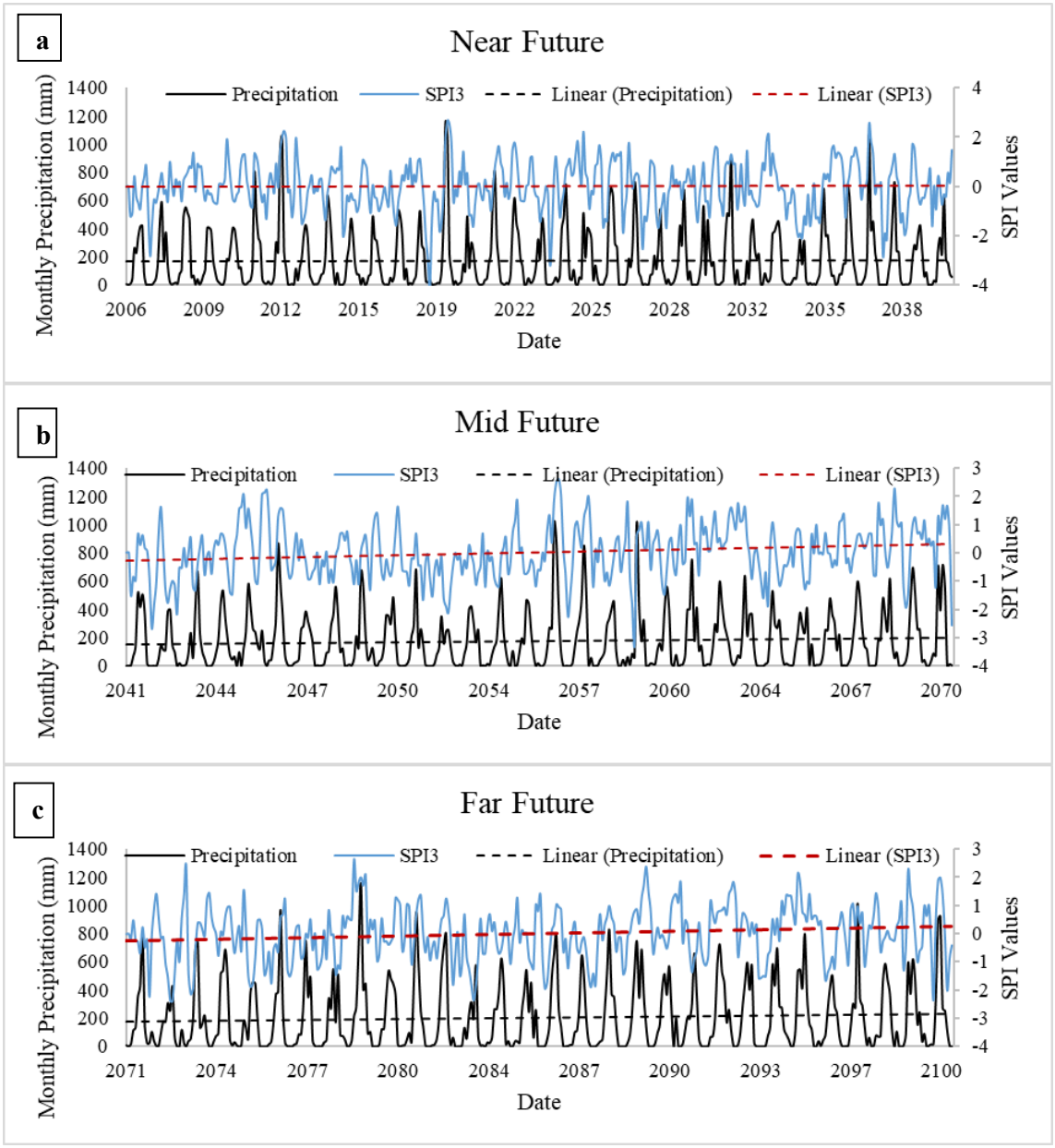

Figure 3: Precipitation and SPI3 Plot with trendline

Time series plots for Near, Mid, and far future are illustrated for short-term drought or SPI3 in Figure 3. Here, the SPI3 values sinusoidal curve pattern follows the precipitation hydrograph curve lines. When the precipitation values move to peak through the rising limb, the SPI3 values also increase. Alternative situations also happen, SPI3 values fall to negative when the falling lamb approaches to negative values. For instance, in the near future 2019, with high precipitation peak values the SPI3 values define the wetted character. For three future segments, the average trendline of precipitation has a positive slope. Compared with the near future to far future, the precipitation values best-fit line is a stepper that demonstrates the tendency to increase precipitation rate is high in far future than mid future and mid future rate is high than near future.

Short-term drought best-fit lines of SPI3 values Figure 3, near future have less stepper slope than mid-future. Also, the mid-future has less steeper slope than the far future. Near future the SPI3 values

severity intensity decreases from 2006 to 2040. The decreasing rate is higher in Far future from 2071 to 2100.

3.3 Long-Term Drought (SPI12)

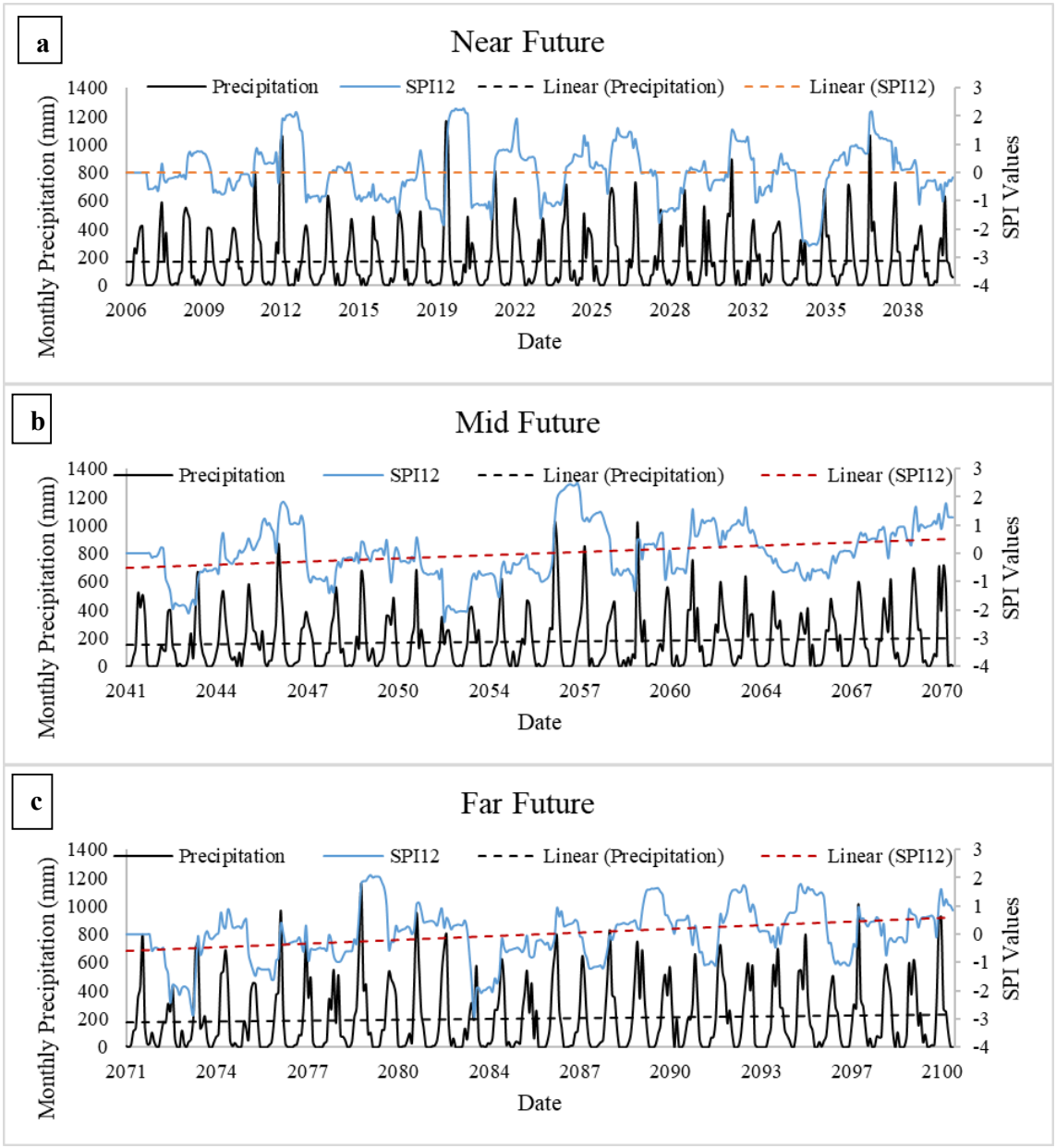

Figure 4: Precipitation and SPI12 Plot with trendline

Time series plots for Near, Mid, and far future are illustrated for long-term drought or SPI12 in Figure 4. Precipitation event changes are similar to the explanation in section 3.2.

In the far future, the best-fit line has a steeper slope than in the near and mid-future. This indicates that the severity of long-term drought occurrences will be at a minimum between 2071 and 2100.

However, the severity level will not change significantly from 2005 to 2040. In the mid-future, the values for drought severity are expected to decrease.

3.4 Graphical Comparison between short and long-term drought

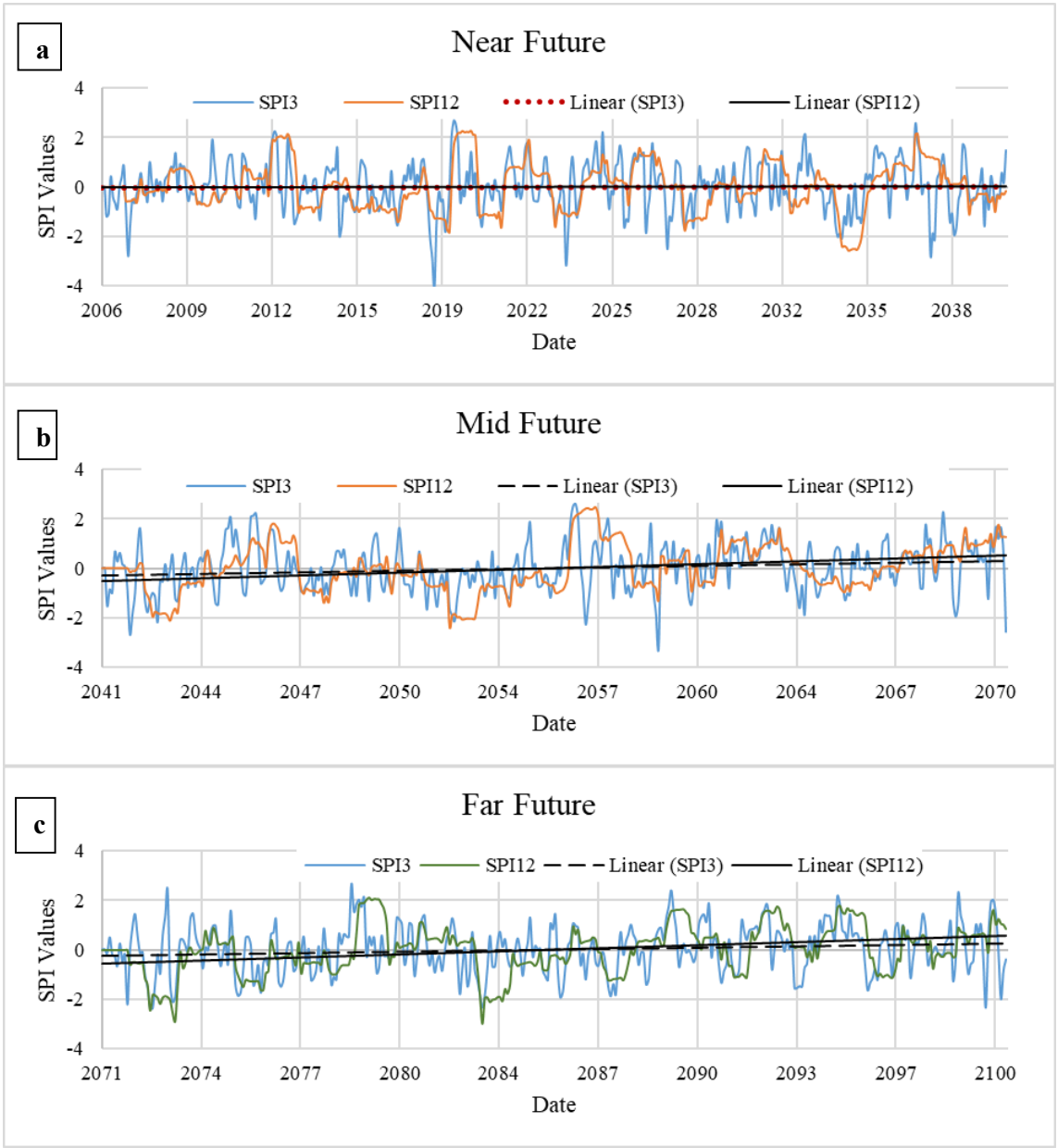

Figure 5: SPI3 and SP12 time series with trend line (a) NF (b) MF (c) FF

The Standard Precipitation Index is used to characterize drought conditions. These index values are calculated using R coding for short-term over three months and long-term over twelve-month drought conditions in Rajshahi. After that, the values with corresponding time make a series for three time spans which are plotted in Figure 5. Here, the near future time series graph, 2006 to 2040, is illustrated for both SPI3 and SPI12. From that illustration, the SPI values of short-term drought are more severe than long-term drought. For instance, in 2018-2019 the drought severity is higher than long-term drought. That means that the short-term drought severity probability is higher in the near

future compared with the long-term. That point is also true for the remaining two-time span that is discernible in Figure 5(b, c).

The trend line positive slope defines values of y-axis increase with x-axis data. Here, Figure 5 (a) indicates two trend lines of SPI3 and SPI12. Both trend line, follows the same trend without any noticeable difference, in the near future both SPI3 and SPI12 have the same trend to increase from the dry period to the wet period although have severities difference. As the values are positively increasing in both cases, makes a comment that in the near future, the drought occurrence frequency may be decreased.

Figure 5 (b), mid future trend line, also has positive trending like Figure 5 (a) trend line, but with a higher slope trend defines that the drought occurrences are minor in mid future than near future. Also, the SPI12 values trend line slope is higher than the SPI3, which means, in the far future the SPI12 or long-term drought events frequency will be less than the SPI3 or short-term drought.

Figure 5 (c), has a similar point of view like the mid-future. But the slope of SPI12 is higher than the SPI3 which indicates that in the far future, the short-term drought will be greater than the long-term drought although both time-scale droughts will decrease from the near future to the far future.

3.5 Drought Property

Table 2: Frequency of short and long-term drought.

	SPI3	SPI12	SPI3	SPI12	SPI3	SPI12
Properties	**Extreme Drought**		**Severe Drought**		**Moderate Drought**	
Near Future	4	1	4	3	1	1
Mid Future	1	2	2	0	1	1
Far Future	3	2	5	1	1	3

Table 2 shows the frequency of drought occurrences from the near future to the far future for both cases of SPI3 and SPI12. In the case of SPI3 and SPI12, the overall drought events will decrease from the near to far future support Figure 5.

The comparison between short and long-term drought can be noticed from the table also. Here, in the long-term drought cases, the extreme drought events are less than the short-term drought. That is also highlighted in severe and moderate drought. That again helps to comment that in the future the short-term drought events will be higher than long-term drought although in the case of both time scales drought trend line illustrates a positive slope from 2006 to 2100.

4. DISCUSSION

The main objective of this study was to predict the future short and long-term drought conditions of Rajshahi district for the RCP 8.5 emission rate with gridded data. The precipitation time series from near future to far future over three segments illustrates the values are increasing. This indicates that precipitation intensity in the distant future will be higher than the current circumstances, as indicated in Table 3.

Table 3: Precipitation Positive trend Equation

Precipitation	Regression Line Equation
Near Future	y=0.0006x+ 144.98
Mid Future	y=0.0037x-37.916
Far Future	y=0046x-110.46

Hence, the increase in precipitation values indicates a decrease in drought conditions. The drought conditions from near future to far future, within three segments, regression lines again illustrate the values are increasing. For both cases, short and long-term drought conditions it is true that the probability of drought scenarios from the present to the future minimizing. The frequency of drought

for long-term drought, from the near to future also diminishing. But for short-term drought, the drought frequency falls lower or no changes occur.

However, the comparison of short and long-term drought conditions is analyzed by graphical and tabular values. From the graphical analysis and Table 4 , the best bit lines for short-term drought have a lower positive slope than the long-term drought which explains that the short-term will be more frequent than the long-term drought in the future. That can also be seen from the extreme, severe, and moderate drought values where short-term drought frequency values for extreme cases lower value by only one unit but the severe value increases and moderate values do not change. Hence, the fact is concerning because crop base period is around three to four or five months for crops like aus, aman, boro, etc which are the dominant crop variants produced in Rajshahi (Mojid et al., 2020; Rashid et al., 2018), increasing short-term drought conditions may be a threat for crop production and subsequent food security in the district.

Table 4: SPI index values Regression Equations

	Regression Line Equation	
SPI	**Short-Term Drought Condition**	**Long-Term Drought Condition**
Near Future	y = 3E-06x - 0.1360	y = 2E-06x - 0.1019
Mid Future	y = 5E-05x - 3.0725	y = 1E-04x - 5.4380
Far Future	y = 5E-05x - 3.1700	y = 0.0001x - 7.2024

5. CONCLUSION

According to the result, for both short and long-term drought conditions, the frequency of drought events is expected to decrease under the emission rate from the near future (2006–2040) to the far future (2071-2100). Besides that, by comparing, the results show that the probability of short-term droughts is expected to be higher than long-term droughts. Finally, the analysis shows that in the future, if the RCP 8.5 w/m^2 emission scenario happens, future short-term drought in the study region will be more concerning than long-term drought and so this study encourages everyone to focus on mitigating the exaggerating factors that will lead to this scenario.

ACKNOWLEDGEMENTS

I am really thankful to Jumana Akhter, Adjunct Lecturer, Dept. of Civil Engineering, Military Institute of Science and Technology, for her assistance in the construction of the manuscript by giving valuable comments.

REFERENCES

Akbar, N., Ahmad, N., & Ardavan, G. (2012). Comparison of the suitability of standardized precipitation index (SPI) and aggregated drought index (ADI) in Minab Watershed (Hormozgan Province/South of Iran). *African Journal of Agricultural Research*, *7*(44), 5905–5911. https://doi.org/10.5897/AJAR12.1521

Albert J. Peters et.al. (2002). *Drought monitoring with NDVI-based Standardized Vegetation Index*.

Buras, A., & Menzel, A. (2019). Projecting Tree Species Composition Changes of European Forests for 2061–2090 Under RCP 4.5 and RCP 8.5 Scenarios. *Frontiers in Plant Science*, *9*, 1986. https://doi.org/10.3389/fpls.2018.01986

Chowdhury, Md. A., Hasan, Md. K., & Islam, S. L. U. (2022). Climate change adaptation in Bangladesh: Current practices, challenges and the way forward. *The Journal of Climate Change and Health*, *6*, 100108. https://doi.org/10.1016/j.joclim.2021.100108

Dash, B. K., Rafiuddin, M., Khanam, F., & Islam, M. N. (2012). Characteristics of meteorological drought in Bangladesh. *Nat Hazards*.

Dastagir, M. R. (2015). Modeling recent climate change induced extreme events in Bangladesh: A review. *Weather and Climate Extremes*, *7*, 49–60. https://doi.org/10.1016/j.wace.2014.10.003

Feng, K., Su, X., Zhang, G., Javed, T., & Zhang, Z. (2020). Development of a new integrated hydrological drought index (SRGI) and its application in the Heihe River Basin, China. *Theoretical and Applied Climatology*, *141*(1–2), 43–59. https://doi.org/10.1007/s00704-020-03184-6

Gumbel, E. J. (1963). STATISTICAL FORECAST OF DROUGHTS. *International Association of Scientific Hydrology. Bulletin*, *8*(1), 5–23. https://doi.org/10.1080/02626666309493293

Guttman, N. B. (1999). ACCEPTING THE STANDARDIZED PRECIPITATION INDEX: A CALCULATION ALGORITHM [1]. *JAWRA Journal of the American Water Resources Association*, *35*(2), 311–322. https://doi.org/10.1111/j.1752-1688.1999.tb03592.x

Hsin-Fu Yeh & Chia-Fu Chang. (2019). Using Standardized Groundwater Index and Standardized Precipitation Index to Assess Drought Characteristics of the Kaoping River Basin, Taiwan. *Water Resources*, *46*(5), 670–678. https://doi.org/10.1134/S0097807819050105

Ji, L., & Peters, A. J. (2003). Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. *Remote Sensing of Environment*, *87*(1), 85–98. https://doi.org/10.1016/S0034-4257(03)00174-3

Karnieli, A., Agam, N., Pinker, R. T., Anderson, M., Imhoff, M. L., Gutman, G. G., Panov, N., & Goldberg, A. (2010). Use of NDVI and Land Surface Temperature for Drought Assessment: Merits and Limitations. *Journal of Climate*, *23*(3), 618–633. https://doi.org/10.1175/2009JCLI2900.1

Lorenzo, M. N., Pereira, H., Alvarez, I., & Dias, J. M. (2024). Standardized Precipitation Index (SPI) evolution over the Iberian Peninsula during the 21st century. *Atmospheric Research*, *297*, 107132. https://doi.org/10.1016/j.atmosres.2023.107132

McGinnis, S., & Mearns, L. (2021). Building a climate service for North America based on the NA-CORDEX data archive. *Climate Services*, *22*, 100233. https://doi.org/10.1016/j.cliser.2021.100233

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). *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.*

Mojid, M. A., Shibly, F. Y., & Acharjee, T. K. (2020). Trends of Water Requirements of Major Crops and Cropping Patterns in Bogura and Rajshahi Districts of Bangladesh. *Agricultural Science*, *2*(1), p170. https://doi.org/10.30560/as.v2n1p170

Mondol, M. A. H., Zhu, X., Dunkerley, D., & Henley, B. J. (2021). Observed meteorological drought trends in Bangladesh identified with the Effective Drought Index (EDI). *Agricultural Water Management*, *255*, 107001. https://doi.org/10.1016/j.agwat.2021.107001

Murad, H. (n.d.). *DROUGHT ASSESSMENT USING REMOTE SENSING AND GIS IN NORTH-WEST REGION OF BANGLADESH*.

National Drought Mitigation Center. (2022). https://drought.unl.edu/Education/DroughtIn-depth/WhatisDrought.aspx

Palmer, W.C. (1995). *Meteorologic Drought. US Department of Commerce, Weather Bureau, Research Paper No. 45, p. 58.*

Park, C.-K., Byun, H.-R., Deo, R., & Lee, B.-R. (2015). Drought prediction till 2100 under RCP 8.5 climate change scenarios for Korea. *Journal of Hydrology*, *526*, 221–230. https://doi.org/10.1016/j.jhydrol.2014.10.043

Paulo, A. A., & Pereira, L. S. (2007). Prediction of SPI Drought Class Transitions Using Markov Chains. *Water Resources Management*, *21*(10), 1813–1827. https://doi.org/10.1007/s11269-006-9129-9

Payne, A. E., & Magnusdottir, G. (2015). An evaluation of atmospheric rivers over the North Pacific in CMIP5 and their response to warming under RCP 8.5. *Journal of Geophysical Research: Atmospheres*, *120*(21). https://doi.org/10.1002/2015JD023586

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

Rashid, M. H. A., Islam, A., Shirazy, B., & Shahidullah, S. (2018). Cropping Systems and Land Use Pattern in Rajshahi Region. *Bangladesh Rice Journal*, *21*(2), 237–254. https://doi.org/10.3329/brj.v21i2.38209

Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., & Rafaj, P. (2011). RCP 8.5—A scenario of comparatively high greenhouse gas emissions. *Climatic Change*, *109*(1–2), 33–57. https://doi.org/10.1007/s10584-011-0149-y

S. Niemeyer. (2008). *New Drought Indices*.

Shahid, S. (2008). Spatial and temporal characteristics of droughts in the western part of Bangladesh. *Hydrological Processes*, *22*(13), 2235–2247. https://doi.org/10.1002/hyp.6820

Shahid, S. (2012). *RAINFALL VARIABILITY AND CHANGES IN BANGLADESH DURING THE LAST FIFTY YEARS*. 24.

Shahid, S., & Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards*, *46*(3), 391–413. https://doi.org/10.1007/s11069-007-9191-5

Spinoni, J., Barbosa, P., Bucchignani, E., Cassano, J., Cavazos, T., Christensen, J. H., Christensen, O. B., Coppola, E., Evans, J., Geyer, B., Giorgi, F., Hadjinicolaou, P., Jacob, D., Katzfey, J., Koenigk, T., Laprise, R., Lennard, C. J., Kurnaz, M. L., Li, D., … Dosio, A. (2020). Future Global Meteorological Drought Hot Spots: A Study Based on CORDEX Data. *Journal of Climate*, *33*(9), 3635–3661. https://doi.org/10.1175/JCLI-D-19-0084.1

Stagge, J. H., Tallaksen, L. M., Gudmundsson, L., Van Loon, A. F., & Stahl, K. (2015). Candidate Distributions for Climatological Drought Indices (SPI and SPEI). *International Journal of Climatology*, *35*(13), 4027–4040. https://doi.org/10.1002/joc.4267

Suman, M., & Maity, R. (2020). Southward shift of precipitation extremes over south Asia: Evidences from CORDEX data. *Scientific Reports*, *10*(1), 6452. https://doi.org/10.1038/s41598-020-63571-x

Uddin, Md. J., Hu, J., Islam, A. R. Md. T., Eibek, K. U., & Nasrin, Z. M. (2020). A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. *Arabian Journal of Geosciences*, *13*(9), 323. https://doi.org/10.1007/s12517-020-05302-0

Willium. (1984). *The Palmar Drought Severity index: Limitations and Assumptions*.