DROUGHT CHARACTERIZATION AND AGRICULTURAL ADAPTATION IN NORTHWEST BANGLADESH

PhD Dissertation

Researcher
J. M. Adeeb Salman Chowdhury

Institute of Bangladesh Studies
University of Rajshahi
Rajshahi-6205, Bangladesh
January, 2024

DROUGHT CHARACTERIZATION AND AGRICULTURAL ADAPTATION IN NORTHWEST BANGLADESH

A Dissertation Submitted to the Institute of Bangladesh Studies in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

Researcher
J. M. Adeeb Salman Chowdhury
PhD Fellow
Session: 2019-2020
Institute of Bangladesh Studies
University of Rajshahi, Rajshahi

Co-supervisor
Dr. Md. Abdul Khalek
Professor
Department of Statistics
University of Rajshahi
Rajshahi-6205, Bangladesh

Supervisor
Dr. Md. Kamruzzaman
Professor
Institute of Bangladesh Studies
University of Rajshahi
Rajshahi-6205, Bangladesh

Institute of Bangladesh Studies
University of Rajshahi
Rajshahi-6205, Bangladesh
January, 2024

DEDICATION

Dedicated

to

My Late Father

DECLERATION

I hereby affirm that the dissertation entitled "**DROUGHT CHARACTERIZATION AND AGRICULTURAL ADAPTATION IN NORTHWEST BANGLADESH**," submitted to the Institute of Bangladesh Studies at the University of Rajshahi, in accordance with the partial prerequisites for the attainment of the Doctor of Philosophy degree, is an original research work. The present thesis has not been previously submitted, either in its entirety or in any partial form, to any other academic institution for the purpose of obtaining a degree or certification. It does not violate the rights of others and does not contain any libelous or unlawful statements. The information acquired and employed from other sources has been properly cited at the relevant places.

The following two research articles from the dissertation are published in order to fulfil the University's degree requirements.

1. Chowdhury JMAS, Khalek MA and Kamruzzaman M (2023). "Recent Trends of Meteorological Variables and Its Impact on Agriculture in Northwest Bangladesh" In: Das J, Halder S (eds) Advancement of GI-Science and Sustainable Agriculture: A Multi-dimensional Approach. Springer Nature, Switzerland AG.

2. **J. M. Adeeb Salman Chowdhury, Md. Abdul Khalek, Jayanta Das, Md. Kamruzzaman (2024).** "Determinants of Local Farmers' Adaptation Strategies to Drought Vulnerability: Evidence from Northwest Bangladesh. Indian Journal of Spatial Science, special issue, February 2024. ISSN 2249-3921. (Attached Acceptance Letter)

J. M. Adeeb Salman Chowdhury
PhD Fellow
Session: 2019-2020
Institute of Bangladesh Studies
University of Rajshahi, Rajshahi

CERTIFICATE

We are pleased to certify that the dissertation titled "**DROUGHT CHARACTERIZATION AND AGRICULTURAL ADAPTATION IN NORTHWEST BANGLADESH**," submitted by J. M. Adeeb Salman Chowdhury to the Institute of Bangladesh Studies, University of Rajshahi. The research work, is an original and preparing with utmost sincerity under our supervision in fulfilment of the requirements for the Doctor of Philosophy degree.

We recommend and forward the dissertation to the University of Rajshahi through the Institute of Bangladesh Studies for consideration as partial fulfilment of the Doctor of Philosophy degree.

Professor Dr. Md. Kamruzzaman
Supervisor
Institute of Bangladesh Studies
University of Rajshahi, Bangladesh

Professor Dr. Md. Abdul Khalek
Co-Supervisor
Department of Statistics
University of Rajshahi, Bangladesh

ACKNOWLEDGEMENT

I express my gratitude to the administration of Comilla University for granting me study leave, allowing me to focus on my research endeavors, which had a vital role in successful completion of my PhD journey. I would like to thank the distinguished authorities at the University of Rajshahi and the Institute of Bangladesh Studies (IBS) for their important academic support, which enabled me to conduct my research with maximum dedication. I am grateful to the University Grants Commission (UGC) for bestowing upon me the fellowship, which has facilitated the pursuit of my scholarly endeavors.

My deepest appreciation goes to Dr. Md. Kamruzzaman, Professor, Institute of Bangladesh Studies, University of Rajshahi, and Dr. Md. Abdul Khalek, Professor, Department of Statistics, University of Rajshahi, who served as my supervisor and co-supervisor, respectively. Having their assistance and rigorous approval of every detail has been crucial to my ability to complete this challenging task. They were incredibly helpful during the research process, without which this journey would not have been possible. I owe them a great gratitude.

I would like to extend my profound gratitude to the faculty members of the Institute of Bangladesh Studies at the University of Rajshahi. Their unwavering support and excellent guidance have been important in my academic journey, offering me encouragement and insightful feedback at every stage. I express my gratitude to Professor Dr. Mohammad Najimul Hoque, Director of IBS, for his kind support in all matter. I am also thankful to other faculty member-Professor Dr. Swarochish Sarker, Professor Dr. Jakir Hossain and Professor Dr. Md. Mostafa Kamal. I am also indebted to the scholastic course instructors who helped me develop as a researcher.

I want to take the opportunity to thank Professor Dr. Ayub Ali from the Department of Statistics at the University of Rajshahi. He participated in my PhD registration seminar as an expert reviewer. He offered me crucial recommendations and perceptive observations that greatly enhanced the quality of my research.

I am overwhelmed with gratitude for the IBS staff, who are always willing to lend a helping hand. My appreciation for the late Mr. Zahedul Islam, a much-loved associate here at IBS, is beyond description. The man I found so close to me never said "no". It saddens me to consider that I will never have it again. He will make heaven a better place because he is such a wonderful person. However, I am grateful to all of them.

My research has been significantly facilitated by the assistance of fellow students from various academic years at IBS and my colleagues at Comilla University. Specifically, Mr. Md. Abdullah-Al-Mamun has provided me with invaluable guidance and resources, greatly aiding my progress. Additionally, my classmates have offered me sound advice and emotional support. I would like to express my gratitude to the individuals, such as Mr. Mynul Islam, Mr. Md. Abdul Halim, Mr. Main Uddin Ahammed , who have contributed to my work. I am indebted to my esteemed colleagues who have consistently offered their assistance whenever I have needed. I am thankful to have such exceptional companions and colleagues. Specially, I am grateful to Md. Sadekul Islam who helped me to collect data through questionnaire survey in the selected upazilas.

Nobody has been more important to me in the pursuit of this journey than the members of my family. I express my gratitude to my parents specially my mother, whose unwavering affection and direction are a constant source of support in all my endeavors. I am remembering my late father, whose dedication and greatness cannot be measured in a word. Despite many obstacles, most of the times I could not reach my only adorable daughter Afrah Arabee and I feel sorry to my child, because I did not show her affection while I was doing my research. I want to apologize profusely for being absent.

Rajshahi **J. M. Adeeb Salman Chowdhury**
January, 2024

ABSTRACT

Climate change and frequent drought has been detected as a global problem due to extreme climate variability. In recent years, Bangladesh has already shown an increased frequency of droughts, mainly observed in the northwest region. Drought mainly is a slow onset natural disaster that creates threats to agro-ecological properties. The aims of the study are to comprehend the trends of variation in two meteorological variables (Rainfall and Temperature) during the period 1960–2021 as well as analyzing current drought situation, characterization and future prediction of drought in the northwest region. The meteorological data of five stations have been collected from Bangladesh Meteorological Department (BMD), Dhaka. Finally, 375 sample household are selected for investigating farmer's perception, drought impacts and adaptation strategies. Four upazilas (sub-districts or parts of district) are taken randomly (Tanore, Shapahar, Chirirbandar, and Nachole) from the northwest drought prone district for primary data collection through questionnaire survey.

Different types of linear and non-linear trend detection test are applied for identifying variation in the climatic parameters such as linear trend analysis, non-parametric Mann-Kendall (MK), Kendall's tau, Sen's slope estimators, Spearman's rho (SR) test, Autoregressive Integrated Moving Average (ARIMA) model and Seasonal Autoregressive Integrated Moving Average (ARIMA) model (future prediction). Further, sequential Mann-Kendall test is also executed to detect trend variations and abrupt deviations over time in rainfall stations. During the period 1960-2021, Rajshahi station is detected lowest annual average rainfall (1460 mm) but the annual average in the northwest region is 1768 mm. The rate of change assessed by Sen's slope estimator is -5.50 mm/year in the Rajshahi station, which is found highest significant decreasing trend. Cropping seasonal rainfall analysis, only the *Rabi* season (80%) are found most negative trend in all selected stations.

In the northwest region, the annual average temperature is 24.96°C. Among the five stations, Rajshahi station is detected highest maximum annual average temperature (26.57°C) during 1960-2021. The trend analysis test indicates that except Dinajpur station, increasing trends are observed in both the annual and seasonal temperature analysis, apart from that only Bogura and Rangpur stations found positively significant at 5% level of significance. The degree of change has

discovered by the Sen's slope estimates varies from -0.003°C/year to 0.017°C/year. The *Kharif* season is showed a significant positive trend in all recorded stations, while the *Rabi* and pre-*Kharif* seasons are continued both increasing and decreasing trends. The spatial distribution of seasonal rainfall and temperature are identified by Geographical Information System (GIS).

Drought characterization and monitoring using precipitation-based index (SPI), for 1, 3, 6, 9, 12, 24 months at different time scales measure the severity of lack of precipitations of different weather stations of northwest region. Transition probabilities of dry state of SPI values, and probabilistic characterization of different state of selected station using Markov chain analysis. The drought interarrival time and mean drought interarrival are increasing from lower to higher SPI series in all study stations. SPI 12 and SPI 24 are found longer months of drought duration exist high probability that the same state will continues for the next state, like 'severe drought' would follow 'severe drought' and 'extreme drought' would follow 'extreme drought' period respectively.

Survey based, farmers' perceptions about climate change are identical to the meteorological trends in the mentioned period except for Dinajpur station. Study showed, drought is mainly affecting increased cost of production, declining ground water levels, crop failures, scarcity of soil water, lower income and food scarcity etc. The multinomial logistic model (MNL) results are found that age, education, income, family size, farming experience, access to climate, farmer-to-farmer extension, social mobility, and loan subsidies directly influenced adaptative decisions. The most significant adaptation strategies adopted by the farmers are irrigation facilities, agronomic management, drought-tolerant rice varieties, adopting new technologies, and alternative enterprises of land use change. Finally to protect farmers from natural disasters, especially drought, sustainable water management plan, credit support from government and NGO's, less water consuming crops, new crop varieties and re-excavation of traditional ponds must be implemented in the study area.

ABBREVIATIONS

AIC	Akaike Information Criterion
ANN	Artificial Neural Network
ARIMA	Autoregressive Integrated Moving Average
Aus	A rice crop coinciding with late dry and early monsoon season
BBS	Bangladesh Bureau of Statistics
BIC	Bayesian Information Criterion
BMD	Bangladesh Meteorological Department
BMDA	Barind Multipurpose Development Authority
Boro	Dry season rice, grown from December to April
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environment and Geographic Information Services
DAE	Department of Agricultural Extension
DI	Drought Index
DHI	Drought Hazad Index
DVI	Drought Vulnerability Index
ENSO	El Nino Southern Oscillation
FGD	Focal Group Discussion
GDP	Gross Domestic Product
GIS	Geographic Information System
HYV	High Yielding Variety
IPCC	Inter-Governmental Panel on Climate Change
ITA	Innovative Trend Analysis

Kharif	Season typically from July to October
KII	Key Informant Interviews
MK	Mann-Kendall
m-MK	Modified Mann- Kendall
MLR	Multiple linear regression
PCI	Precipitation Concentration Index
P_{bais}	Percent Bias
PDSI	Palmar Drought Severity Index
PET	Potential Evapotranspiration
Pre-*Kharif*	Season typically from March to June
QS	Questionnaire Survey
Rabi	Dry season typically from November to February
RMSE	Root Mean-Square Error
MAE	Mean Absolute Error
SARIMA	Seasonal Autoregressive Integrated Moving Average
SI	Seasonality Index
SLR	Secondary Literature Review
SPI	Standardized Precipitation Index
SGI	Standardized Groundwater Level Index
T.aman	Transplanted *Aman* rice typically from July to October
T.Aus	Transplanted *Aus* rice grown from March to June/July
UNDP	United Nations Development Programme
UNFCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter One

Introduction

1.1 Prelude

Climate change is now recognized as the urgent global problem of the earth. In recent times, the worldwide environment has been characterized by unpredictable weather conditions, which have led to climate variability and change. Despite climate change is a global phenomenon, its effects will not be equally distributed (Shahid & Khairulmaini, 2009; Shaw et al., 2013; Karim et al., 2020). According to research study, underdeveloped countries are more at risk from the effects of climate change than the developed ones (Sem & Moore, 2009). This is mostly due to a poor and constrained capacity to adapt to climate change (Rahman & Lateh, 2017). As a developing nation, Bangladesh is particularly in danger due to high climate inconsistency, extreme temperature, huge population density, extreme poverty, unorganized infrastructure, insufficient money supply, weak educational system, poor health facility (Ahmed, 2004; Kamruzzaman et al., 2018). Almost every year the country experiences disaster of one kind or another, such as tropical cyclones, storm surges, coastal erosion, floods and droughts, causing heavy loss of lives and property of jeopardizing the development activities (Adams et al., 1998). According to the Intergovernmental Panel on Climate Change (IPCC), an increase in global temperature has significantly influenced the distribution of precipitation across different regions of the globe (IPCC, 2018). It is highly observed that global average temperature are increased by 0.85°C between the year 1880 to 2012, and it will increase 0.3 to 4.8 °C by 2100 (Shahid et al., 2012; Karim et al., 2020; Mullick et al., 2019).

According to the 2021 global Climate Risk Index, Bangladesh ranks 7th in the top 10 most affected countries (2000-2019) and the 25th least prepared country in terms of climate change effects (NAP, 2023). This statement indicates that although the country is highly vulnerable to the impacts of climate change, it lacks the necessary measures to mitigate or alleviate climate change effects (MoFA, 2018). Bangladesh is widely recognized as a nation that is highly susceptible to the impacts of climate change and gradual environmental challenges. Though the whole area of

Bangladesh is not highly prone to drought, the North and Northwestern areas are particularly climate stress zone due to geo-climatic and human induced conditions (Uddin et al., 2020b). In this area drought is a regular phenomenon that are not only experienced through high rainfall variability accompanied with high temperature, but also groundwater depletion, re-excavation of river and pond, deforestation, etc. accelerate drought severity (Habiba, 2012; Salam et al., 2020, Uddin et al., 2020b). It is a hazardous phenomenon that experiences drastic implications on socioeconomics, human lives, food insecurity and natural resources degradation around the globe (Rahman et al., 2021; Khan et al., 2021). The International Panel on Climate Change (IPCC) defines drought - "A period of abnormally dry weather long enough to cause a serious hydrological imbalance". It goes to say that "A mega drought is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more" (IPCC, 2012). Drought is characterized into four types meteorological (problematic weather patterns), hydrological (deficit of rainfall), agricultural (water shortfall for agricultural production) and socio-economic (causing starvation, low incomes and social consequences) explanations; that is impacts on people and their activities (Alston & Kent, 2004; Ashraf & Routray, 2015; Rahman et al., 2018; Hosseini et al., 2020).

Drought characterization is a challenging task, however, mitigating its impact can yield significant benefits. This can be achieved through a more proactive, risk-based management approach, the letter increases societal resilience to better cope with drought impact and has become possible thanks to recent scientific and technological advances in drought and water–scarcity management (Moazzam et al., 2022). Agricultural adaptation and coping strategies for climate change and other events like drought have been main concern over the past few decades. In Bangladesh, several agricultural coping strategies have been examined which vary from throughout one region to other, such as shifting planting time, irrigation, rainwater harvesting, and use of drought tolerant varieties (Mardy et al., 2018). Since its independence in 1971, Bangladesh has suffered from nine major droughts (Paul, 1998). Therefore, changes in droughts or dryness in Bangladesh have received considerably less scientific attention than floods and cyclones, although it is common and severe disaster (Rahman et al., 2017). However, loses from drought are likely to be more extreme than floods in Bangladesh.

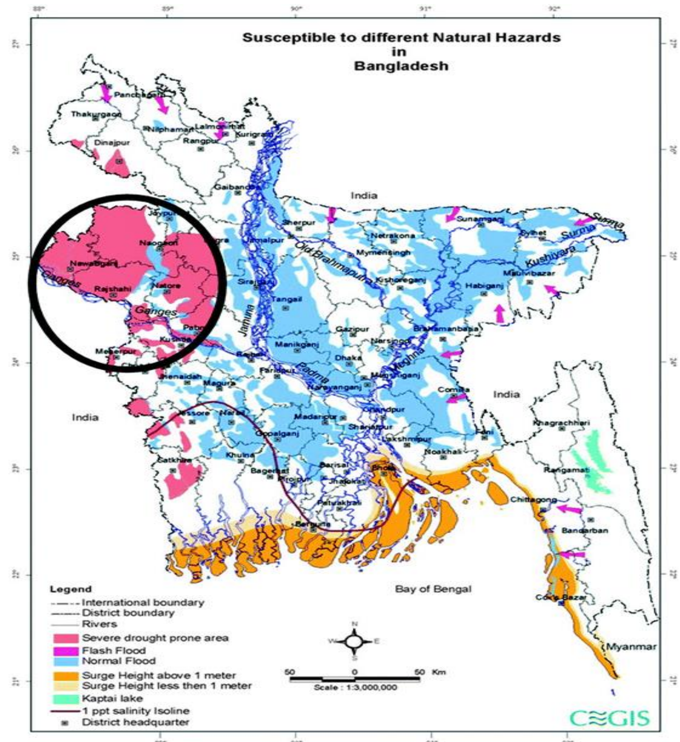


Fig 1.1 Drought-prone area in Bangladesh *Source*: CEGIS (2012)

1.2 Background of The Study

World Health Organization (WHO) explains that approximately 55 million people globally are affected by droughts every year and water scarcity hits 40% of the world's population and around 700 million people are at-risk with the impact of drought by 2030. Bangladesh is an agrarian country that encompasses an area of 147570 km^2 with a population of 165.65 million, which is more than doubled when the first census conducted during 1974 (BBS, 2022a). Although drastic change in development trajectory over the last one and a half decades the country's economic growth has increased more than 7 percent per annum. Additionally, per capita income increased to $2,824 in 2021-2022 from $300 in 1973 (NAP, 2023). Rice production grew from 12 million tons in 1973 to 37 million tons in 2021(MoEFCC, 2022). About 68.49 % of the country's population live in rural areas and these people are highly marginalized and susceptible to climate change and natural disasters (Islam et al., 2019, BBS 2022a). Agriculture is the most common occupation in rural areas where about 51.88% of people are directly engaged in agricultural activities (BBS, 2019b). That's why, agriculture is a vital sector in our country's economy, which contributes 13.82% to country's GDP (BBS, 2019a). However, the economy of Bangladesh and its progress towards sustainable development are under pressure due to changing climate regime and the unique geographical location. The nation suffered approximately $11.3 billion in losses in 2021 as a result of climate related natural disasters which is approximately 2.47 percent of total GDP of fiscal year 2021-2022 (WMO, 2021). Although Bangladesh faces extreme challenge in recent decades due to extreme climate variability, but agriculture plays a crucial role in keeping food and nutrition security for the nation (Alston & Akther, 2016).

In Bangladesh, climate variables like rainfall and temperature influence the agricultural crop production (Kamruzzaman et al., 2018). It is noticed that the average temperature has been increasing sharply over the last three decades and the temperature variations are minimal (0.0067°C per year) during 1961-1990 but after 1991 to 2019 the variations are mounting dramatically (0.03°C per year) (CEGIS, 2022). On the other hand, annual rainfall varies significantly across the different hydrological regions of the country, with lower rainfall ranging from 791-2,241 mm in the dry north-western *Barind* region to high rainfall (2,586-5,944 mm) in the north-eastern region (Roy et al., 2017). It is a recurrent phenomenon in some parts of the country, but the north western region is severely drought prone and water scarcity part because of high rainfall variability (Shahid & Behrawan, 2008) and receiving much lower rainfall compared to the rest of the country, thus this area is relatively dry by dint of high climate variability (Paul, 1998). Shahid et al. (2005) highlighted that meteorological and agricultural drought is a common scenario in the north-west region, which is linked to rainfall pattern and related climatic conditions.

The National Drought Mitigation Center (2006) notes that, Bangladesh has experienced frequent droughts in recent years. During the last 50 years Bangladesh has suffered from 20 drought conditions. Severe droughts took place in 1973, 1978, 1979, 1981, 1982, 1989, 1992, 1994, 1995, 2000, 2006 (Paul, 1998; Habiba et al., 2011). The average occurrence is once in 2.5 years. Usually, Bangladesh undergoes a dry period for 7 months, from November to May, when precipitation level is normally low (Habiba et al., 2011). According to Banglapedia, drought episode begins in our country during the pre-monsoon (March–May) and post-monsoon (October–

November) seasons. In addition, a delay start of the rainy season, insufficient pre-monsoon precipitation, or an early monsoon departure may cause droughts in this part of the world. (Habiba et al., 2012; Shafie et al., 2009). Furthermore, Asian Development Bank states that less rainfall during the dry season could make Bangladesh to more susceptible drought experience due to climate change (ADB, 2005).

Over the years, perceive or anticipated agricultural adaptation practices applied in this region. Such as pond excavation, retention of rainwater in *khari* canals and moisture conservation, deep tube-well irrigation system, supplemental irrigation and minibonds, drought tolerant crop varieties, homestead gardening etc (Habiba et al., 2012; Islam et al., 2019). The IPCC's sixth assessment report (IPCC, 2021) projects a future climate scenario in northwest region is expected to be significantly more extreme and uncertain, despite relentless efforts to adjust drought severity. A total of approximately 3.85 million people in the northwestern Barind area are at risk from the adverse effects of droughts, floods, and extreme heat waves (NAP, 2003). The average losses and damages due to natural disasters were BDT 1.7 billion during 2016–2021, mainly driven by climatic stresses (BBS, 2022). That’s why, the country’s north western region still vulnerable area where drought and groundwater shortage are the biggest challenges for agriculture and food security.

1.3 Statement of The Problem

The Barind Tract, the biggest Pleistocene physiographic unit of the Bengal Basin, which encompasses the country’s northwest region, is considered to be the area most vulnerable to drought (Ahmed, 2012; Shahid & Behrawan, 2008; Hasan & Islam, 2013). This region is relatively drier and receives lower rainfall compared with the rest of the country (Paul, 1998). The distribution of rainfall is not uniform all over Bangladesh. The northwest region of the country receives approximately 1,400 mm of rainfall annually, while the northeast region receives more than 4,400 mm (Shahid et al., 2010). More than 75% of the rainfall in Bangladesh occurs during the monsoon season. It is anticipated that, the climate of Bangladesh will be extreme in nature during next century because of increased emissions of greenhouse gases in the atmosphere. Recently, the climate model of Bangladesh prevails that the region will face extreme temperature, warmer nights, and increased frequency of droughts as a result of rainfall variations (Selvaraju & Bass, 2007). Moreover, complicated geographic nature, groundwater is unavailable in many parts of the region. As a result, the water scarcity creates soil moisture deficiency that affects the agricultural crop production (Rahman et al., 2017a). During the dry season groundwater-based irrigation is practiced for irrigation purpose to produce high yielding rice in South Asia. This region includes India and Bangladesh are ranked as the second and fourth largest rice-producing countries in the world, respectively (Scott & Sharma, 2009; IRRI, 2010). Bangladesh reported declining trends in groundwater level, especially northwest region creates the worst scenario across the country, which designates unsustainable groundwater extraction for irrigation (Jahan et al., 2010; Rahman et al., 2016). Different intensities of drought cause on average annual damages of 2.32 million hectares of cultivable *T.aman* (rice variety) in the *Kharif* [1]season and 1.2 million hectares of *Rabi* crops in the *Rabi* season (Karim et al., 2012, CEGIS, 2012). Even in extreme drought conditions yield reduction ranges from 45 to 60 percent in T. *aman* and from 50 to 70 percent in *Rabi* crops production (Climate Change Cell of Bangladesh, 2009). Evidence from 2006 drought indicated that there was a decrease in *Aman* crop production of roughly 25-30% in the northwestern part of Bangladesh (Rahman et al., 2007). Bangladesh Delta Plan-2100 (BDP) show that, there is a projected negative impact on the aggregate rice production, with an estimated decline of 17% by 2050, which might impede the achievement of food and nutrition security (NAP, 2023).

Between 1980 and 2019, it is projected that about 12 million people had affected by severe drought and triggered economic loses of US$ 21 billion (Uddin et al., 2020). In this context extreme climate variability and ensuring food security are remains a key concern for Bangladesh. Agriculture, the food industry is already under lots of pressure mostly because of increasing food demand, land degradation and water shortage. Changing climate further threatens food security of huge population (Rejmi, 2010). The potential of global climate change makes of this problem a priority for Bangladesh. As a result, it is urgent to investigate the impact of a drought scenario on

[1] Bangladesh has three cropping seasons locally known as Pre-Kharif (mid-March-June), Kharif (July-mid-October), and Rabi (mid-October-mid-March). Among them, Rabi season completely depends on irrigation, where other two are mainly rain-fed agriculture.

regional level. Usually, farmers adopt indigenous agricultural adaptation techniques at the rural level without using a scientific and new technology of farming. Due to destructive nature of drought, the research study is mainly focused on drought characterization and design sustainable drought- resilient adaptation strategies with statistical assessment for crop cultivation. In addition, adaptation research does not consider sustainability issues in designing and implementing adaptation strategies (Alam, 2014). However, characterization of drought and implementation agricultural adaptation methods are not given enough focus in a country like Bangladesh because the disaster make less priority than flood and cyclone. Though, several extensive studies on impact of drought on agriculture, food production, land degradation, economy, and society have been conducted, but very few proposed a suitable adaptation model based on regional climatic conditions for farming in northwest region rather than rest of the country.

1.4. Research Questions

The study entitled "Drought Characterization and Agricultural Adaptation in Northwest Bangladesh" aims to address the fundamental research questions as follows:

1. What factors are responsible for increasing temperature, rainfall and drought hazards in the study area?
2. What types of methods are employed to detect present drought situation in the study region?
3. How future climate change would be affected by the drought?
4. What are the present adaptation strategies taken by the farmers based on their climate change perception and indigenous knowledge?
5. What are the important influential factors for developing adaptation model in northwest region of Bangladesh?
6. What initiatives are taken for future adaptation priorities to combat the impacts of drought?

1.5 Research Objectives

The general objective is to measure the future drought status by using meteorological variables and to develop sustainable adaptation strategies for northwest Bangladesh.

The specific objectives are to:

1) Investigate spatial-temporal variability of rainfall and temperature of different cropping seasons over northwest Bangladesh during the time period 1960-2021;
2) Evaluate changes in drought condition using Standardized Precipitation Index (SPI);
3) Assess and monitor drought characterization by probabilistic approach for different meteorological stations and ;
4) Determine farmers perception, perceive impacts of drought, influential factors on choice of adaptation strategies and efficiency to combat future drought conditions.

1.6 Definition of Key Terms

Drought: Drought is a recurring extreme event over land characterized by below normal precipitation over a period of months to years (Dai, 2011). It is generally defined as a temporary reduction in moisture availability significantly below the normal for a specified period. It is an event of prolonged shortages in the water supply, whether atmospheric-surface water or ground water. Drought occurs over most parts of the world, even in wet and humid regions. It can have a substantial impact on the ecosystem and agriculture of the affected region.

Types of drought: It needs to be distinguished in order to understand its causes and effects. The types of drought to be considered are:

a) Meteorological b) Agricultural c) Seasonal d) Hydrological c) Socioeconomic

The meteorological drought is determined completely based on the level of dryness measured in terms of rainfall deficiency or insufficient rainfall (Keyantash & Dracup, 2004). Meteorological drought arises from prolonged deviations in the current atmospheric circulation patterns, which are often triggered by abnormal tropical sea surface temperatures (SSTs) or other distance factors such as high-pressure anomalies (Giannini, 2003; Hoerling et al., 2006). It occurs when the reduction in rainfall for a specified period (day, month, season or year) is below a specified amount.

The hydrological drought refers to deficiencies in surface and subsurface water supplies based on measurements of steam flow and lake, reservoir and ground water levels (Dai, 2011). When inadequate rainfall extended period of time, this shortage will eventually be reflected in decreasing surface and underground water levels.

According to Hounam (1975), the agricultural drought is caused by deficiencies in soil moisture, rainfall, soil water, above-average evaporation, and other factors that hamper plant growth and crop output. This type of drought happens after meteorological drought but before hydrological drought. Agriculture is usually the first economic sector to be affected by drought.

In addition, the American Meteorological Society (1997) introduced another drought category called socio-economic drought. This category of drought occurs when physical water shortages start to affect the health, well-being and quality of life. The seasonal droughts are related to deficit soil moisture during certain periods within a season. In Bangladesh; three types of droughts are recognized during monsoon season: a) Early-season b) Mid-season c) Terminal-season

Adaptation: Adaptation is the process by which strategies to moderate, cope with or take advantage of the consequences of climate events are enhanced, developed and implemented (Selvaraju & Bass, 2007). The IPCC (2007) also defines adaptation as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or, exploits beneficial opportunities.

Adaptive capacity: Adaptive capacity refers to the capacity of a system to adjust its characteristics or behavior in order to enhance its coping range under current climate variability or future climate condition (Selvaraju & Bass, 2007).

1.7 Significance of the Research

Majority of the people of Bangladesh are dependent on agricultural practices for their livelihood, which is relatively higher in the country's northwestern part. The area mainly consists of 16 administrative districts under Rajshahi and Rangpur Division. On a regular basis, Bangladesh experiences severe nationwide droughts once every five years. However, regional droughts happen regularly and hamper the productions of crops, food security, lives and livelihood of the people. Almost 15% households in Bangladesh had been affected by drought between the year of 2009 and 2014, while one household in every four is affected by drought in Rajshahi Division (BBS, 2015). The direct consequence of drought not only affects the agricultural production and livelihood of the people but also indirectly affects the GDP, local labor market and overall economic growth. In 2006, the country faced severe drought, which caused about 25–30% reduction of *Aman* crop production in the northwest region (Rahman et al., 2007). Additionally, according to Habiba et al. (2011) during the cropping seasons, (namely *Pre-Kharif*, *Kharif*, and *Rabi*) of Bangladesh, approximately 0.4, 0.34, and 0.45 ha agricultural lands are severely affected by drought in every year.

Therefore, to acquire knowledge about the drought's dynamics, intensity, and frequency in the area, it is urgent to raise awareness among the people, so they can cultivate drought-tolerant crops or require minimal water consumption. However, acute water shortage in the northwest region has reached a critical point, pushing a huge number of people to migrate to other parts of the country, which highlights the study area's spatial drought features. Consequently, in order to fully comprehend the state of drought and develop an appropriate management plan for the study region, it is essential to analyze drought features and sustainable farming adaptation techniques. The perception of farmers and their adoption of adaptation techniques are the two key factors in adaptation. Adaptation to catastrophic climatic events has now become a hot topic in Bangladesh, where the consequences are mostly negative. Our vision is to develop an acceptable adaptation model which can be utilized to capture the determinants of drought adaptation.

1.8 Organization of Thesis

The thesis is organized into seven chapters. Chapter one highlights background of the study, statement of the problem, research objectives and significance of the study and overview of the chapter contents. Chapter two reviews literature on theoretical and empirical studies. The theoretical aspect involves a review on drought concepts, climate models and adaptation techniques. The empirical review is carried out the spatiotemporal analysis of climate variables and then draw a complete relationship with drought characterization using SPI, probabilistic models (Morkov Chain). This section further represents farmers perception and sustainable adaptation strategy taken by local farmers to combat future drought. Chapter three deals with materials and methods that includes sources of the data, study area map, missing data estimation and also the estimation procedure. Chapter four presents the spatiotemporal variation of climate variable and forecasting future trends by using MK test, Sen's Slope estimator, Spearman's Rho test, Linear trend analysis, Sequential MK test, ARIMA and SARIMA technique etc. Chapter five includes drought characterization of different station using SPI and Markov chain analysis, alternating renewal process, distribution of drought interarrival time of different SPIs, mean drought interarrival time, two state transition probability matrix of different SPIs, drought frequency. Chapter six describes farmers perception towards climate change in the study region and identify the main effects of drought by rank order. This chapter also explains the determining factors that influence adaptation strategies by using multinomial logistic model and draw a sustainable adaptation policies tec. The final chapter follows conclusions based on discussion related to objectives, policy implication, recommendations and limitations of the study.

Chapter Two

Review of Literature

2.1 Introduction

This chapter provides a critical and systematic review and analysis of the related and relevant literature and theories of climate change and climate variability, spatiotemporal variability of temperature and rainfall analysis, drought characterization and monitoring meteorological drought situation by probabilistic approach, adaptation measure and appropriate adaptation strategies. More so, before designing the study framework, this section provides a comprehensive review of the significant number of relevant research studies both domestically and internationally such as climate modeling; drought related scholarly articles and its implication especially on agricultural sector. Because of our agricultural sectors are very much vulnerable to different types of drought frequency. Modeling and monitoring agricultural drought characteristics and cope with sustainable adaptation strategies is our primary objective in north-west part of Bangladesh.

2.2 Climate Change Concepts

Since the beginning of industrial revolution, there has been a noticeable increase in the global annual temperature, amounting to slightly over than 1 degree Celsius, or about 2 degrees Fahrenheit. From 1880 to 1980, there was an average increase of 0.07 degrees Celsius (equivalent to 0.13 degrees Fahrenheit) per decade. Meanwhile, the rate of increase has more than doubled since 1981. Over the past four decades, a discernible increase in the global annual temperature has been observed, with a rise of 0.18 degrees Celsius, or 0.32 degrees Fahrenheit, per decade (NRDC, 2021). According to sixth assessment report of IPCC (2018), climate scientists argued that, it is crucial to restrict global warming to 1.5 degrees Celsius by the year 2040 in order to prevent future catastrophic consequences of climate change, such as extreme droughts, devastating floods, tropical storms, and other natural disasters that collectively refer to climate change (IPCC, 2018).

The climate history of the Earth has gone through multiple changes due to its natural evolution as well as rapid changes. Climate change is urgent global problem, now a days, its consequence disproportionately affects developing nations in comparison to developed ones. The primary indicators for climate change are temperature, rainfall, and sea level rise (Shaw et al., 2013). During the First World Climate Conference held in 1979, the issue of climate change was emphasized as a pressing global concern that requires collaborative efforts among governments to mitigate potential climate hazards. The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to analyze the magnitude and temporal effects of climate change as well as predict their consequences. The IPCC published its First Assessment Report in 1990, which became a basis for negotiations on a climate change convention under the United Nation General Assembly (UNFCCC, 2006).

The impact of climate change will be across the sectors and across nations. Climate change and fluctuation have both human and non-human consequences around the globe. Increasing temperatures, shifting rainfall patterns, rising sea levels, and an increase in the frequency and severity of extreme weather events are wreaking havoc on ecosystems, agriculture and food security, infrastructure, water resources, and human health (IPCC, 2014a; Hossain et al., 2019).

Climate change is essentially a "development" issue, not merely "environmental" issue for Bangladesh. Bangladesh has been acknowledged by the international community as a nation that is vulnerable to the impacts of climate change (IPCC, 2014b). According to the global circulation model (GCM), it is projected that Bangladesh will face an average temperature rise of 1.0°C by 2030 and 1.4°C by 2050 as a result of climate change. Additionally, there will be a 6.8% increase in monsoon precipitation by 2050 (Selvaraju et al., 2006). In the 2020 edition of the global climate risk index, Bangladesh was found to be the seventh most vulnerable country to climate disasters between 1999 and 2018 (Germanwatch, 2020). The nature of climate change in Bangladesh is a major concern in recent years. Climate change is one of the most susceptible areas in the country to the effects of global warming, eventually losing more than USD 12 billion in the last 40 years (BBS, 2019b). The weather in Bangladesh has been observed to change. In general, the weather patterns are more erratic and volatile than in the past. Total annual rainfall for the country as a whole did not change significantly over the last few decades, although there was a significant increase in some areas most remarkably the west and northwest (Shahid, 2010). The average temperature exhibits an upward trend, particularly in the monsoon season (June-August) with a rate of change 0.07°C per decade and in the early winter (September-November) with a rate of change 0.12°C per decade. According to the IPCC (2007) some regions have experienced negative consequences of higher temperature and unpredictable precipitation patterns, resulting to the dryness of wetlands and the deterioration of ecosystems (Kalmalkar et al., 2012; Al-Mamun & Al-Pavel, 2014).

2.3 Spatial and Temporal Variation of Meteorological Variables

There are so many studies that have been carried out related to climate modeling or spatio-temporal variation of climate variables especially based on rainfall and temperature variability throughout the world:

Tabari & Talaee (2011) examined the patterns of precipitation, both annual and seasonal precipitation trends across 41 stations in Iran from 1966 to 2005. The researcher applied different statistical methods such as the MK test, Sen's Slope, and linear regression to analyze the data. The findings of the study revealed that a declining trend in annual rainfall about 60% of the stations with statistical significance.

Gocic & Trajkovic (2012) involved an analysis of the annual and seasonal trends of seven meteorological variables across twelve weather stations in Serbia, spanning from 1980 to 2010. In their study they described monthly maximum $(T_{\max})$ and minimum $(T_{\min})$ air temperatures, maximum $(RH_{\max})$ and minimum $(RH_{\min})$ relative humidity's, actual vapor pressure (e_a) wind speed (U_2) and precipitation (P). The statistical significance of weather data trends, whether positive or negative, was determined by using Mann-Kendall and Sen's estimator. The upward trend was recognized in both annual and seasonal minimum and maximum air temperature series. The authors reported a notable decrease in relative humidity during the summer and autumn seasons, whereas the vapor pressure had a significant increasing trend in the spring, summer, and autumn periods.

Mondal et al. (2012) carried out a study of precipitation trends in the Orissa river basin, utilizing a 40-year rainfall dataset from 1971 to 2010. The Mann-Kendall (MK) Test and Modified Mann-Kendall Test were employed to examine the monthly variability of rainfall. Additionally, the Sen's Slope Estimator was utilized to determine the trend and slope magnitude. It had been observed that the amount of precipitation was going up in some months and going down in other months, which suggests overall insignificant changes in the area.

Similarly, Zarenistanak et al. (2014) utilized three statistical tests including Pettitt's test, Sequential Mann–Kendall test (SQ-MK test) and Mann–Kendall rank test (MK-test) to detect trend analysis and change point detection of annual and seasonal precipitation and to investigate mean temperature (TM), maximum temperature (T_{Max}) and minimum temperature (T_{Min}) time series for the period 1950–2007. The data obtained from 50 precipitation stations and 39 temperature stations located in southwest Iran. The study revealed that most of the rainfall stations showed insignificant trends in annual and seasonal series while the temperature trends revealed a significant rise during summer and spring seasons.

Tosunoglu & Kisi (2017) analyzed the patterns of hydrologic drought variables, specifically the annual maximum duration (AMD) and annual maximum severity (AMS), through the application of statistical methods such as Mann-Kendall, modified Mann-Kendall, and Şen's innovative trend analysis (ITA) in Coruh River Basin, Turkey. These aforementioned methods were applied to the nine different station in Turkey to observe the critical power plants that had recently been established or presently under construction. The Basic Mann-Kendall test, Modified Mann-Kendall test, and Innovative Trend Analysis methods exhibited statistically significant trends, both positive and negative, at a significance level of 10%. According to the ITA method, it has been suggested that there is a chance of experiencing drought and water stress in future.

Cui et al. (2017) defined the variation characteristics of air temperature and precipitation in the Yangtze River Basin (YRB), China by using a linear regression (LR) analysis, Mann-Kendall (MK) test with Sen's slope estimator and Sen's innovative trend analysis (ITA) during the period of 1960–2015. The findings indicated that there was a noticeable rise in the annual maximum, minimum, and average temperature at varying rates across the entire study region.

Salehi et al. (2019) investigated the spatial and temporal uniformity and change point direction in both seasonal and annual precipitation as well as their variations during the period 1957-2016 in Iran. Eight homogenous regions were used for testing homogeneity *like* the Pettitt-Whitney-Mann, The Standard Normal Homogeneity and Von Neumann test and for trend detection Mann-Kendall and Sequential Mann-Kendall tests were utilized. The results of homogeneity tests indicated that a great deal of seasonal and annual precipitation time series exhibited homogeneity test while only few stations displaying detected change point. There was a noticeable upward trend observed during first 30 years, whereas almost whole country witnessed overall downward trend with higher intensity throughout the whole period. In the late 1990s, rising temperatures decreased precipitation, causing this downward trend.

Sa'adi et al. (2017) conducted a study to examine the spatial pattern of rainfall extremes in Sarawak, Malaysia from 1980 to 2014. The authors utilized the Mann-Kendall (MK) test and modified Mann-Kendall (m-MK) test to investigate trends in annual, seasonal, and monthly rainfall, as well as rainfall extremes through 31 stations. During the research period the trends indicated that there were no significant changes observed in the annual, seasonal, and monthly rainfall, as well as extreme rainfall in the study area.

Das et al. (2019) studied the monotonic trends and change points of winter temperature across six meteorological stations in North Bengal from 1915 to 2016. The result identified that there had been a rise in winter temperatures across all stations located in North Bengal. Notably, the rate of increase was observed to be the most significant at English Bazar. Furthermore, the homogeneity of winter temperatures was disrupted in the year of 1959 for t_{max}, 1988 for t_{min} and 1952 for t_{mean}.

Shahid (2010) discovered recent trends and change of points in the climate of Bangladesh on 17 weather stations by using 50 years (1958-2007) rainfall and temperature data. During the study period, the results showed that average, average maximum and average minimum temperatures increased at a magnitude of change of 0.103, 0.091 and0.097°C per decade, respectively. The spatial distribution of rainfall trends was increased in annual, monsoon and pre-monsoon precipitation within the western region of Bangladesh.

The study conducted by Shahid & Khairulmaini (2009) focused on the investigation of the spatial and temporal variability of rainfall in Bangladesh. The research utilized data from 24 rain gauge stations during 1969 to 2003. The Mann-Kendell test, Sen's Slope method, and GIS were applied to evaluate the presence of moderate inter-annual rainfall variation and high intra-annual rainfall variation. The study found that Bangladesh has experienced insignificant upward trends in annual, monsoon, and pre-monsoon rainfall, while a downward trend has been observed in winter rainfall. These results could potentially serve as an initial indication of the precipitation response towards global warming, however the hypothesis that needs to be further described through the application of climate model projections.

Bari et al. (2016) explained 50 years (1964-2013) of seasonal and annual rainfall trends and their fluctuations over time in northern Bangladesh. By using autocorrelation test, non-parametric Mann-Kendall test and Sen's Slope estimator to examine rainfall trends and magnitude of change. The Sequential Mann-Kendall test was used to identify any temporal variations in the trends over time and to figure out the possible point of change in the rainfall dataset. After early 90's a declining trend in seasonal rainfall was observed in most stations.

Kamruzzaman et al. (2018) aimed to identify trends of climate variables, specially rainfall and temperature, that could impact agricultural development in the western region of Bangladesh at 12 meteorological stations during the period of 1961-2011. The authors discovered the analysis of annual and seasonal rainfall and temperature patterns by implementing different statistical methods such as the Mann-Kendall test, Spearman's rho test, and the modified Mann-Kendall test along with Sen's Slope estimator. The GIS distribution of rainfall showed no significant upward trend in major part of the area. The study revealed a significant rise in the average annual temperature in the northeastern region, while the northwestern region showed insignificant positive trend. Both positive and negative trends were found in the mean temperature during the *Rabi* and *pre-Kharif* seasons, but most of them were not significant. But during *Kharif* season, the temperature climbed significantly at all stations except Barisal.

Islam et al. (2020) explored the spatiotemporal trends in the daily rainfall frequency from 1975 to 2017 utilizing various statistical models based on 23 station data in Bangladesh. Different statistical techniques like Mann-Kendall test, Sen-Slope estimators, Spearman's Rho test, Probability distribution function, the examination of the rainfall patterns over time indicates that there was insignificant downward trend in low and heavy rainfall ranges while insignificant upward trend was observed in medium rainfall ranges over the last five decades.

Das et al. (2021) provided the spatial-temporal analysis of monthly precipitation of 23 meteorological stations in Bangladesh during the period from 1966-2019. The study employed various techniques to analyse rainfall patterns, including the precipitation concentration index (PCI), innovative trend analysis (ITA) and percent bias (P_{bias}) for trend detection. The reliability test was assessed by using the MK or m-MK test, along with Sen's slope estimator (Q) for estimating the magnitude of change. Additionally, discrete wavelet transformation to identify the dominant periodicity of the trend in the annual series. They assumed that the ITA and P_{bias} data demonstrated a more or less consistent trend for all the stations and time scales. Meanwhile, the Z statistic supported the reliability of their assumption.

2.4 Prediction of Climate Variable using ARIMA/SARIMA

A climate model, commonly referred to as a weather forecasting model, is a mathematical depiction of climate variables. The prediction process is extremely complex and involves numerous calculations. The primary expected factors include surface pressure, wind, temperature, humidity, and precipitation. These variables are computed within a specific timeframe to forecast future value. Many researchers have applied different types of climate models in their research studies, including Auto Regressive Integrated Moving Average (ARIMA), seasonal Autoregressive Integrated Moving Average (SARIMA), Auto Regressive Conditional Heteroskedasticity (ARCH), Generalized Auto Regressive Conditional Heteroskedasticity (GARCH), Gaussian mixture, and Markov chain/modified Markov chain/sequential Markov chain analysis, to forecast future climate behavior, specifically rainfall and temperature, on various scales.

The ARIMA model, which is widely used for prediction of time series data, was introduced by Box and Jenkins in 1976. It is regarded as a powerful and extensively used statistical technique. Numerous studies have utilized the Box-Jenkins ARIMA model technique to forecast upcoming trends in rainfall and temperature.

Zakaria et al. (2012) found ARIMA models to analyze weekly rainfall data from four distinct rainfall stations located in the North-West region of Iraq over 21 years record, from 1990 to 2011. The investigation indicated that the model was applied to predict the weekly precipitation data for the forthcoming years (2012-2016).

Aziz et al. (2013) analyzed the precipitation trends, which originated from the meteorological service division from 1974 to 2010, in the Ashanti region of Ghana. They used SARIMA model in the study area to identify the precipitation changes over time with the less variability and others of extreme variability scattered by transitional periods.

Meher & Jha (2013) formulated an ARIMA model to simulate and predict the average rainfall, which was determined using Theissen Weights, at 38 rain-gauge stations in district towns throughout the Mahanadi River Basin in India. They utilized monthly precipitation records from district towns spanning during 1901-2002. The appropriate ARIMA model was taken into consideration to estimate the monthly rainfall data for the following 12 years in each district town in order to help decision makers and policy makers and established priorities on groundwater storage and disaster preparedness.

Rahman et al. (2016) predicted rainfall trends pattern over Bangladesh for the period of 60 years rainfall data 1954 to 2013. Several non-parametric tests were employed, including the sequential Mann-Kendall test and ARIMA modelling, in order to forecast variations in rainfall trends for the purposes of agricultural and water resource development.

2.5 The Concept of Drought Hazards

Drought is the most complicated and least known natural disaster around the world, affecting more people and jeopardize environment than any other natural disaster (Hagman,1984). Drought differs from other natural hazards (e.g., floods, tropical cyclones, and river bank erosion) in several ways. First, it's hard to tell when a drought begins or ends because its effects tend to build up slowly over a long period of time and can last for years after the event is over (Tannehill, 1947).

"We don't really know what the good definition of drought is. We may say truthfully that we scarcely know a drought when we see one. We welcome the first clear day after few days of rain.

Rainless days continue for a time and we are pleased to have a long spell of such fine weather. we are a little worried because it keeps going on. if we wait a few more days, things will get really bad".

Despite the fact that Tannehill's publication dates back to over half a century ago, experts in the field of climatology still encounter difficulties in identifying the onset of droughts. Furthermore, policymakers and scientists engage in ongoing discussions regarding the criteria for terminating an end of drought. Second, the widely accepted definition of drought makes it more difficult to determine whether it happens or not and, if so, how severe it is. In a pragmatic sense, it is essential that definitions of drought exhibit specificity with respect to the region, application, or impact under consideration. This is one explanation for the scores of definitions that have been developed. Wilhite & Glanze (1985) examined more than 150 definitions in their classification study, and there are undoubtably many more. Although most of the definition are numerous but arbitrary in most cases. For example, the importance of achieving a threshold of 75% of average precipitation within a timeframe of three months or more severe. These kinds of problems happen because the people who make the definitions don't understand the idea and don't think about how other scientists or disciplines will use the definition in real-life drought situations. Third, the impacts of drought are non-structural in nature and are dispersed over a wider geographical expanse compared to the damages caused by other types of natural hazards.

Drought is the consequence of a gradual reduction in the amount of precipitation received over a prolonged duration, usually spanning a season or more. The occurrence of drought is closely linked to the temporal aspects of precipitation, such as delays in the onset of the rainy season and the timing of rainfall in relation to crop growing seasons. Additionally, the effectiveness of precipitation, including factors such as rainfall intensity and frequency, can also impact the frequency of drought. Each year of drought possesses distinct climatic features and consequences (Wilhite, 2000).

According to Wilhite (1992), numerous definitions have been formulated by various disciplines due to the wide-ranging impact of drought on several economic and social sectors. Furthermore, drought happens in different parts of globe, across various economic systems and in both developed and developing nations, the methods employed to define are influenced by regional and ideological disparities. The classification of drought definitions can be broadly divided into two categories, namely conceptual and operational, as proposed by Wilhite and Glantz in 1985. Conceptual definitions typically take the form of dictionary entries and draw the parameters of the drought concept. As such, they tend to deliver a general description of the phenomenon. For example, the Encyclopedia of Climate and Weather (Schneider, 2011) defines drought as “an extended period—a season, a year, or several years—of deficient rainfall than the statistical average for a region over many years.” Operational definitions try to figure out the precise features and boundaries that indicate the onset, duration, conclusion, and severity of drought episodes. They can also be used to examine the frequency, severity, and length of droughts throughout a specific historical period.

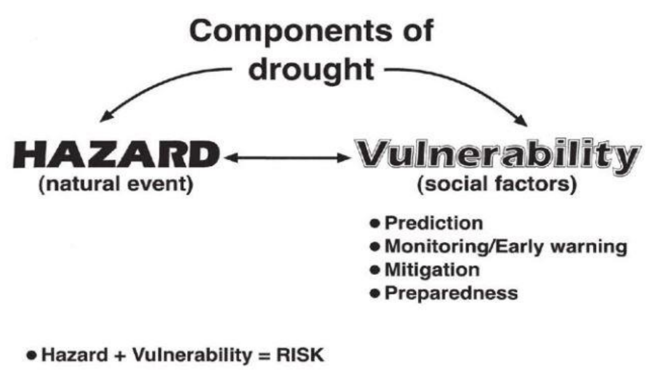


Fig. 2.1 Components of drought (Source: Wilhite, 2000)

2.6 Drought Condition Assessed by Standardized Precipitation Index (SPI)

In recent times, scientific investigations have been focused on the analysis of drought occurrences in different places across the globe (Vicente-Serrano et al., 2014; Golian et al., 2015; Park et al., 2016; Rahman et al., 2017; Yao et al., 2018; Nury & Hasan, 2016; Rahman & Lateh, 2016; Jiao et al., 2019; Jiao et al., 2021). Drought can have a severe consequence on agricultural loss and damage, water deficiency, natural ecosystem and forestry, soil degradation and health impacts (Quiring & Papakryiakou, 2003; Abrams et al., 1998; Nicholson et al., 1998). Throughout the 20th century, numerous indices have been developed to identify and assess drought events. Most drought indices are based on meteorological or hydrological variables. The common indices to evaluate used drought conditions are the Palmer Drought Severity Index (PDSI; Palmer,1965), the Rainfall Anomaly Index (RAI; Van Rooy, 1965), the Crop Moisture Index (CMI; Palmer, 1968), the Surface Water Supply Index (SWSI; Shafer & Dezman, 1982), and the Standardized Precipitation Index (SPI; McKee et al., 1993, 1995). Among these the SPI is widely used for drought monitoring in many countries around the world (Raziei et al., 2009; Zhai, 2009; Manatsa, 2010; Vicente-Serrano, 2006; Vergni & Todisco, 2011; Buttafuoco, & Caloiero, 2014; Zhao et al., 2020; Uddin et al., 2020). In addition, SPI is relatively simple method and less complex than other indices because it is based on precipitation data alone. SPI allows to compare drought conditions in different temporal and spatial contexts (Vicente-Serrano, 2006; Wu et al., 2005). Due to its inherent probabilistic characteristics, SPI is a suitable option for assessing drought risk.

Zin et al. (2012) observed the dry condition in Peninsular Malaysia by utilizing SPI index during 1974 to 2005. The data was collected from 50 rain-gauge stations and the spatial analysis was used to illustrate the percentage of occurrences of moderate and severe drought. Several copula models were used to investigate the relationship between drought duration and drought severity. The best copula model was selected by their corresponding AIC values. The result demonstrated that the Joe copula model is the best-fitted model in most of the stations, followed by the Galambos copula model next.

Buttafuoco et al. (2014) expressed drought condition in a region of southern Italy (Calabria) by using SPI for 129 monthly rainfall series from 1916 to 2006. The study estimated both short-term (3 and 6 months) and long-term (12 and 24 months) SPI values. The objective was to identify the worst possible drought events affected by severe or extreme dry conditions. The findings revealed that the Calabria region has been significantly impacted by multiple severe drought events. The SPI values were found decreasing trend2, which suggests the region much drier to conduct solely for the long-term SPI.

Achour et al. (2020) aimed to study and evaluate drought occurrences by utilizing SPI during the year 1960 to 2010 in Northwestern Algeria. The analysis was covered on monthly precipitation data. The SPI drought index of different time scales indicated that the area under investigation was predominantly affected by severe drought while the eastern part of the country experienced comparatively lower degree of drought severity and duration. Further, ANN also generated for drought forecasting that revealed satisfactory result with the adjusted coefficient of determination R^2_{adj} , the root mean-square error (RMSE), the mean absolute error (MAE) respectively.

Das et al. (2020) used the SPI values of the Luni River Basin in Rajasthan to study the spatial, temporal, and trend behavior of meteorological drought events from 1973 to 2016. The researchers utilized the standardized precipitation index along with the long-term monthly precipitation data from 39 rain gauge stations. The study computed both the long-term (24, 12, and 9 months) and short-term (6, 3, and 1 month) SPI values that were applied to identify the drought episodes and determine the percentage area affected by severe drought conditions. Trend analysis was done by using the nonparametric Mann-Kendall test to determine drought consistency.

In Bangladesh, SPI and SPEI are used in few droughts monitoring research specially in water deficit areas and extreme climate variability (Dash et al., 2012; Alamgir et al., 2015; Nury & Hasan, 2016; Rahman et al., 2017; Das et al., 2020)

Alamgir et al. (2014) conducted a meteorological drought analysis of various cropping seasons by applying SPI to 29 rain gauge stations located throughout the country during a 50-year period (1961–2010). The research findings indicated that the spatial characteristics of droughts exhibited significant variation across different seasons. The northwest region exhibited a higher frequency of pre-monsoon drought, whereas the west and northwest regions were predominantly affected by monsoon drought. Winter droughts dominated in the western region, whereas *Rabi* and *Kharif* droughts occurred more frequently in the northern and northwestern regions of Bangladesh.

Kamruzzaman et al. (2022) investigated the deviations of drought characteristics among diverse physiological categories in Bangladesh and emphasized the changes in drought characteristics over temporal and spatial scales when considering geomorphological scales. The present investigation utilized weather information from 29 stations to calculate SPI and SPEI values over a period of 39 years (1980-2018), based on monthly precipitation and temperature data. The m-MK test and MLR techniques was employed to assess the significance of drought characteristic on various temporal and spatial scales. The study revealed an overall decrease in dryness in the Eastern hill regions, while a rising trend in drought was observed in the rest of the regions in various time scales. The magnitude of the trend ranged from -0.08 decade^{-1} to -0.15 decade^{-1} for the 3-month time scale. It is expected that SPEI will demonstrate superior performance in capturing dry and wet cycles in more complicated areas than SPI. According to MLR model, both longitude and maximum temperature might have an impact on precipitation.

2.7 Markov Chain and SPI Index for Drought Characterization

Markov chain approach are used in order to estimate (a) the probability of various categories of drought severity, (b) the expected time in each class of severity, (c) the recurrence time to a certain class of drought, and (d) the expected time for the SPI to transition from a specific class to another (Isaacson & Madsen, 1985). An experimental evaluation was conducted on a conditional forecasting approach for drought classifications. The non-homogeneous Markov chain model incorporates a dependence of transition probabilities between drought states on the specific month under consideration. Conversely, the homogeneous formulation estimates transition probabilities for the entire series with no distinction between months.

Paulo & Pereira (2007) utilized the Markov chain approach for several locations in Alentejo, southern Portugal with a period of SPI relative 67 years data set. The first attempt to forecast drought class transitions using Markov chains modelling was introduced, discussed and presented by them. Both homogeneous and non-homogeneous Markov models were employed, with the latter offering the benefit of distinguishing between months when computing drought.

Mishra et al. (2007) investigated the drought characteristics by alternative renewal process and run theory, the distribution of drought interval time, mean drought interarrival time, Joint probability density function and the transition probability of drought events. Monthly rainfall data for the years 1965 to 2001 were collected for this study using five rain gauge stations. It was found that different time scales of SPI had a significant effect on the probabilistic characteristic of drought.

Rezaeianzadeh et al. (2016) applied Markov Chain Model and ANN model for drought forecasting in arid and semi-arid regions the Doroodzan watershed within the Fars Province in Iran. This study utilized a Markov chain model to predict drought conditions and forecast values for upcoming months. To predict reservoir inflow and consequent drought conditions ANN model were trained for statistical based input selection procedure. The present study highlights the significance of meticulous data selection or data mining prior to commencing a particular modelling procedure.

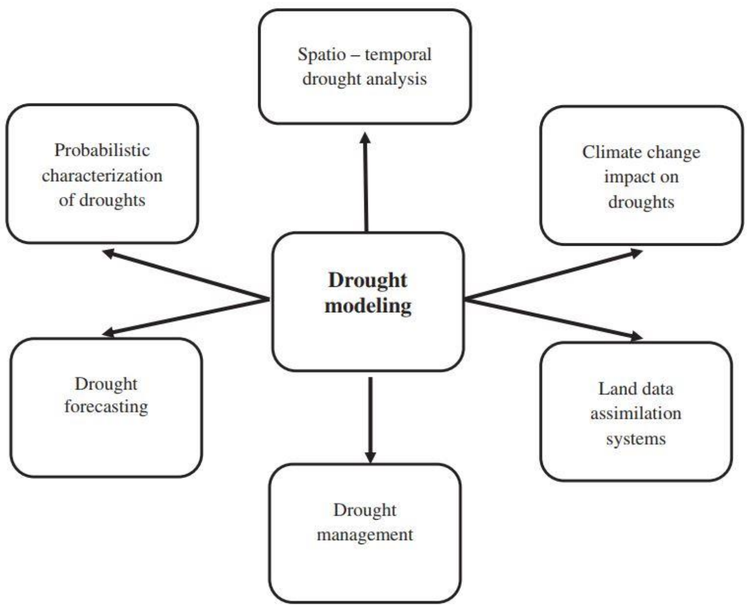


Fig. 2.2 Different components of drought modeling (Source: Misrha & Singh, 2011)

Rahmat et al. (2017) used SPI and non-homogenous Markov chain model for early drought risk management in Victoria, Australia for short time planning. They applied 70 rainfall stations that had long monthly rainfall records from 1856 to 2012. The study developed a methodology for drought prediction in different meteorological stations which had been categorized into six (6) homogenous clusters with similar drought characteristics based on SPI and the related drought characteristics. The non-homogeneous Markov chain model was applied for calculating the probabilities of drought and forecasting up to (3) three months in advance. The drought severity categories, determined through SPI, were developed based on a temporal scale of 12 months.

Overall, the results of the analysis suggested that Markov chains could be able to explain some of the stochastic features of drought.

Yeh & Hsu (2019) used the SPI and SGI along with the first-order Markov chain model and wavelet transform to determine the drought characteristics and propagation, including the steady-state probabilities of drought events and the mean duration for each rainfall and groundwater station in the Southern Taiwan basin. The DI was also employed to examine the impact of rainfall on groundwater drought. The results of the outcome indicated that the probability of experiencing a meteorological drought in the Yanshui River basin located in southern Taiwan was comparatively higher than in other basins. The method used in this study provides a long-term water resource management plan and distribution in the future.

Kamruzzaman et al. (2016) studied the agricultural drought risk situation in the western region of Bangladesh which accounts for 45% area of the country during 1960 to 2011. In their study, Drought Index (DI), Drought Hazad Index (DHI) that had been calculated by Markov chain analysis and also used Drought Vulnerability Index (DVI) for socioeconomic and physical purpose. They analyzed agricultural drought exists at high risk condition in the northern part whereas the southern part was less drought prone. Drought Hazad map was used for decision making in the drought prone area.

Nury & Hasan (2016) studied SPI with the Southern Oscilation Index (SOI) in the drought prone northwest region of Bangladesh. Monthly rainfall for the period of 1983 to 2012 of six weather stations located in the northwest area was used for trend and variability detection. The study employed a 3-month scale of SPI, the non-parametric MK test, Sen's slope estimator, and continuous wavelet transformation in sequential order. A decreasing trend of monthly rainfall was found from the seasonal MK test in Bogura, Ishwardi, Rangpur and Syedpur stations respectively. Sen's Slope estimates also showed decreasing pattern of monthly rainfall. Trends of SPI showed increasing trend of dryness in this region. Dominant periodicity of SPI 3 of different months were discovered in the selected stations.

The study conducted by Uddin et al. (2020) aimed to assess the variability, trends, volatility, and transition patterns of rainfall in the drought-prone region of north-west Bangladesh. The researchers employed various statistical methods to analyze the changes in variability, trends, volatility, and transitions in rainfall. These methods included the non-parametric m-MK test, ITA, GARCH jump model, and Markov chain. The objective of this analysis was to gain insights into the potential persistence of droughts and their predictability. The daily rainfall data for the years 1959 to 2018 were used for this investigation. The results showed an overall decrease of variability in annual and seasonal rainfall, but an increase in mean pre-monsoon rainfall and a decrease in mean monsoon rainfall.

2.8 Climate Change and Agriculture

Agriculture is the largest economic sector of Bangladesh with 62% of its people engaged in agriculture farming to manage their subsistence from agricultural production. Around 87% people of the country live in rural areas, and they rely on agriculture directly and indirectly (BBS, 2022). Agriculture plays an important role in the process of economic development and it has a great contribution to the national GDP. It contributes about 13.82% to the total Gross Domestic Product (GDP) of the country. This sector also accommodates around 46% (in 2018-19) of the labor force (BBS, 2019a). In rural settings, agriculture is the main occupation where about 51.88% of people are directly engaged in agricultural activities (BBS, 2019b). It is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances, weather and climate change are still the key factors in agricultural advance. The research study mainly focusses on present drought situation in North-western parts of Bangladesh that are periodically being affected by droughts in pre-monsoon and post-monsoon seasons and moreover, 41%-50% country area has been experiencing drought every year (Uddin et al., 2014). According to IPCC (2007) prediction, rice production in the country could fall by 8% and wheat by 32% by 2050 due to water stress that could lead to future food shortage (MoEF, 2009). Considering the expected rise in temperature and there exists a high chance of probability that the winter precipitation will decrease further, it is probable that the moisture content of topsoil will experience a significant reduction, resulting in severe moisture stress. Rising temperatures would also result in increased rates of evapotranspiration, thereby causing severe (phenological) drought situations during the winter season. Other variables that contribute to drought include sea surface temperature, deforestation, over exploitation of resources, rising level of CO_2 gas and greenhouse gas etc. (Schubert et al., 2008)

Consequently, a late *Kharif-II* drought in December would adversely affect *Aman* crop at the ripening stage, while an early Rabi drought would more severely affect wheat and *Boro* crops at both germination and vegetative growth stages (Karim et al., 1998). Furthermore, increasing moisture stress in *pre-Kharif* would affect *Aus* production significantly. Increased drought will increase capillary action and salinity builds up in the top soil as well (Karim et al., 1990).

2.9 Agricultural Adaptation Strategies

The term "adaptation" has been used in the climate change community since early 1990s. However, it is worth noting that there is no universally accepted definition of this term within the conservation field. The majority of definitions incorporate climate change adaptation *like* "initiatives and measures designed to reduce the vulnerability of natural and human systems against actual or expected climate change effects." Meanwhile, the concept of 'adaptation' is not yet well understood by the general public in the context of climate change. The term has caused confusion partly due to its multiple usages; the same word refers to the natural process of organisms adapting over time to survive in a new environment, even though the accelerated pace of climate change might exceed the capacity of many organisms to adapt in the traditional sense (Denevan, 1983). The significance of adaptation in the context of climate change can be understood through two distinct dimensions. Firstly, it plays a crucial role in the assessment of impacts and vulnerabilities associated with climate change. Secondly, it is instrumental in the process of developing and evaluating response options to address these challenges (Shaw et al., 2013). There are a number of strategies which are considered as a means to adaptation to climate change in agriculture.

Bradshaw et al. (2004) mentioned a number of adaptation strategies, which includes crop diversification, mixed crop livestock farming systems, using different crop varieties, changing planting and harvesting dates, drought-resistant varieties and high-yield water sensitive crops. Di

Falco et al. (2011) identified a set of strategies (e.g., changing crop varieties, adoption of soil and water conservation strategies) for climate change adaptation in Nile basin area.

Wang et al. (2008) identified the practice of altering crop selection as a viable strategy in their study for adapting to climate change in China. A study conducted in 28 provinces across China involved a sample of 8,405 farmers. The findings of this study indicated that Chinese farmers show a higher propensity to engage in irrigation practices with lower temperatures and reduced levels of precipitation. Farmers in warmer regions selected oil crops, maize, cotton, and wheat as their preferred crops. Additionally, they opted to cultivate vegetables, potatoes, sugar, rice, and soybeans, to a lesser extent. The paper also recognized that future climate scenarios would cause farmers in China to reduce irrigation and shift toward oil crops, wheat, and especially cotton moving away from potatoes, rice, vegetables, and soybeans. Another finding of the paper was that adaptation would likely vary to a great extent from region to region. The implementation of adaptation strategies involved modifying irrigation practices, crop varieties, and livestock species in response to the variations in temperature and precipitation levels.

Derrasa et al. (2009) analyzed the factors that influence the choice of adaptation strategies for climate change based on a cross sectional survey data collected during the 2004/2005 agricultural production year in the Nile river basin of Ethiopia. In the study area, 42% farmers did not take any adaptation but those who could applied adaptation techniques such as soil conservations, use of different crop varieties, planting trees, early and late planting, irrigation reduce the negative impacts of climate change. The Multinomial logit model (MNL) identified that education level, gender, sex, wealth of household head, access to extension, credit support, climate change information, agroecological setting and temperature all influenced farmers adaptation decisions. The main barriers of the adaptation were lack of information, shortage of money, shortage of land and poor irrigation facility in the study area.

Alam (2014) investigated rice farmers' adaptation to water scarcity in drought prone northwestern region of Bangladesh. For this study 546 farming household data were collected by using multistage random sampling technique from 12 randomly selected villages in Rajshahi district. Additionally, focus group discussion, key informant interviews and secondary sources of data were employed to understand the comprehensive view of drought adaptation strategies. The findings of the study indicate that farmers made decisions regarding their adaptation strategies based on various factors, including the socio-economic conditions and farming practices, the institutional framework in which they operated, infrastructural access, and their perceptions of climatic extreme events. The identified factors of determining farmer's adaptation responses to addressing water scarcity was predicted by multinomial logit regression model. The analysis of adaptation using multinomial logit demonstrated that factors such as institutional and infrastructural access, education, tenure status, and awareness of climate variability played a significant role in enhancing farmers' adaptive capacity. The study also found that the current practice of increasing groundwater irrigation couldn't be an ideal solution for sustainable water management resources.

Udmale et al. (2014) conducted an analysis of the perceptions adopted by farmers regarding the impacts of drought on their socio-economic activities and the environment. The study also examined local adaptation strategies at the household level and explored potential government mitigation measures in the drought-prone region of Maharashtra State, India. The results indicated that the most immediate economic effects of the drought were on the output of cereals, horticulture crops, livestock production, job loss, and decreased income of farmers. The study also documented various social consequences, including population migration, health effects and education of children, societal conflicts due to water scarcity, and malnutrition for changing food preferences were also reported. Farmers were observed significant environmental effects during study period, such as increasing average atmospheric temperatures, degradation of pasture-forest areas, water quality deterioration, impacts on aquatic habitats and wildlife, and depletion of groundwater resources, to a considerable degree. Despite the farmers having an adequate awareness of the severity of drought, their level of preference for adopting agricultural practices was insufficient. Finally, the government provided a variety of mitigation measures, but satisfaction was extremely low.

Roy et al. (2020) aimed to assess the comparison between farmers' perception of climate change with meteorological trends, and to investigate the adoption to farm adaptation measures in the hazard porn districts, Kurigram (riverbank erosion-prone) and Nilphamari (drought- prone) located in the northwest region of Bangladesh. A sample size of 252 small householders was surveyed, employing different techniques for collecting primary data. The findings revealed that farmers' perception of climate was consistent with meteorological trends during the previous 30 years (1986-2015), which showed rising temperature parameters and falling rainfall parameters. The farmers residing in the study area exhibited a general inclination towards traditional adaptation strategies; however, their effectiveness in addressing the challenges at hand was found to be suboptimal in both domains. The farmers also reported increased frequency of natural disasters (drought and flood) over the last few years, and they become highly dependent on exploitation groundwater for domestic and agricultural activities, as a result groundwater table will be anticipated to deplete in future.

Ojo & Bayegunhi (2020) discovered to analyze the determinants of adaptation strategies to climate change by applying multivariate probit model (MVP) in a sample of 360 smallholder rice farmers in south-west Nigeria. The study also employed an effective endogenous switching regression model (ESRM) to assess the impact of climate change adaptation strategies on the net income of rice farmers. The findings of the probit model indicated that marital status, off-farm income, locations of farmers, and mean annual precipitation had a significant impact on the adoption of climate change adaptation strategies. The net farm income of individuals who adopted agricultural practices was found to be affected by various factors, which includes marital status, farm size, off-farm income, farming experience, and level of education. On the other hand, the net farm income of individuals who did not adopt these practices was observed to be influenced by farm size, mean annual precipitation, and the age of smallholder rice farmers. The findings of this study also suggested that farmers who experienced prolonged drought and frequent floods were more likely to implement adaptation strategies on their agricultural assets.

Salam et al. (2021) investigated the nexus between vulnerability and adaptive capacity of drought-prone rural households. During study, 400 survey data respondents of Northern Bangladesh was used to analyze the relationship through extensive review of literature. Co-occurrence network, Spearman correlation analysis was applied to perform the nexus between capacity and vulnerability. The findings revealed that the vulnerabilities throughout livelihood assets (human, social, financial, physical and natural) but capacity follows similar pattern. A noteworthy inverse relationship was found between vulnerability and adaptive capacity, whereas strong correlations were identified among the livelihood assets. The application of the support vector machine algorithm was utilized to observe potential future drought scenarios. This approach is expected to enhance the overall capacity for drought adaptation while concurrently reducing vulnerability.

2.10 Research Gap

There are a number of studies regarding climate modeling, farmers' perception, impacts and adaptation strategies to climate change in drought prone areas in Bangladesh. However, most of the studies are based on overall climate-related risk and can't identify the particular drought risk analysis and its severity for rising temperature and insufficient rainfall. Improper drought forecasting always creates poor drought management, hence there is urgent need to build fast, reliable and appropriate models for drought prediction and mitigation. Although regional climate scenario of our country is not identical. The northwest area of Bangladesh mainly suffers from drought severity and extreme climate variability over last few decades. So, drought assessment and its adaptation strategies are not much focused rather other climate disaster, that's why our main aim of this research is to identify regional climatic scenario of drought prone area and its characterization by using suitable probabilistic approach model and classify every month of drought prediction. Furthermore, find out the sustainable adaptation techniques in different upazilas according to influential factors which will help local farmers for crop cultivation in future. The expected models have been accurately predicted drought scenario based on the expecting future changes in drought indices using current and previous hydro-meteorological data. In addition, the farmers, agriculture related stakeholders, policy makers, environmental researcher will get adequate information in advance about the study area that the region will be crop prospective area or not. So, they apply drought-resistant varieties of different crops or not, depending on whether they want to increase crop production and ensuring country's food security.

Chapter Three

Materials and Methods

3.1 Introduction

To achieve the goal of the research, different materials and methods have been applied on temperature and rainfall data. To obtain better outcomes, several tests were applied prior to evaluate the data. Furthermore, different index for drought characterization and adaptation models have been developed to complete the study. This chapter unveils a sequential presentation of sources of the data and the methods employed.

3.2 Selection of Study Area

The research study has been carried out on northwest part of Bangladesh because agricultural production is on critical situation due to the changes in weather and unpredictable climate conditions (Karim et al., 2020). According to Banglapedia (2003), the country belongs to a sub-tropical climate region with hot, humid, and erratic rainfall occurring throughout the year, mostly influenced by monsoon weather as well as pre- and post-monsoon exchanges. The country undergoes three climatic seasons such as, (1) the month of November to February known as dry winter season, (2) the month of March to May known as pre-monsoon hot summer season, and (3) lastly the month of June to October regarded as rainy monsoon season (Rashid, 1991). Geographically, the study area has mainly covered by 34,359km^2 under Rajshahi and Rangpur division with 16 administrative districts (Fig. 3.1) (Uddin et al., 2020; BBS 2019a). Inadequate rainfall and extreme temperature are very common indices over the last few decades; therefore, drought occurs recurrently in the northwest region. Rainfall in the said country is highly seasonal and most of it falls during the monsoon summer season, almost 80% of the annual precipitation happens during the monsoon summer season (Islam et al., 2020). In the study area, five meteorological stations (Rangpur, Dinajpur, Rajshahi, Ishwardi and Bogura) are chosen based on their geographical distributions, with the aim of representing the geographical features of the entire northwestern area. The climate of the region is semi-arid, with little rainfall and high temperatures. The annual rainfall varies between 1400 and 1700 mm, with most regions of the country receiving more than 2000 mm (Alam, 2015). According to Zinat et al. (2020), during summer season the mean temperature ranges from 23.8°C to 32.1°C but in winter it varies from 7.2°C to 12.8°C. sometimes, temperature increases up to 45°C in extreme hot summer season, however during winter temperature decreases up to 5°C in northwest region.

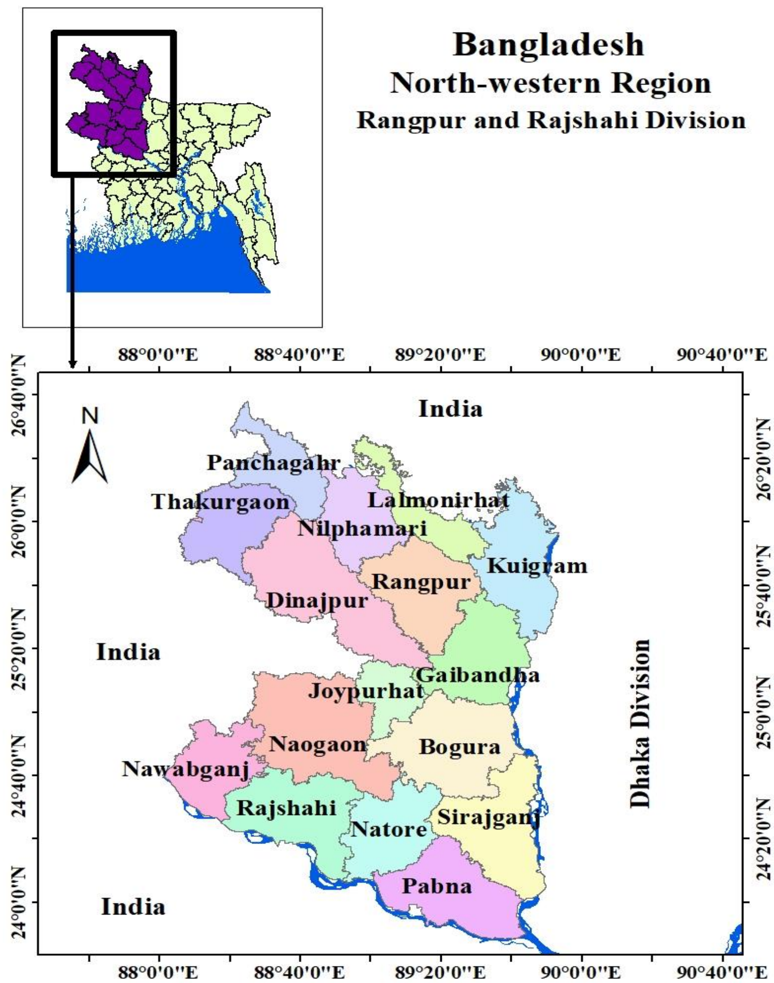


Fig. 3.1 Northwest Area of Bangladesh
(*Developed by the researcher using ArcGIS 10.2.2)*

The location, name, station ID and agro-ecological zone of the meteorological stations are given in the Table 3.1. The district wise study area map of northwest area with meteorological stations is shown in Fig. 3.2.

Table 3.1 Location, agro-ecological zone, name and meteorological station ID of the study area

Division	Station Name	Station ID	Location		Agro-ecological Zone
			Latitude	Longitude	
Rangpur	Dinajpur	10120	25.65	88.68	AEZ 1,25,27
	Rangpur	10208	25.73	89.27	AEZ 3,27
Rajshahi	Rajshahi	10320	24.37	88.7	AEZ 11
	Bogura	10408	24.85	89.37	AEZ 4,25
	Ishwardi	10910	24.15	89.06	AEZ 11

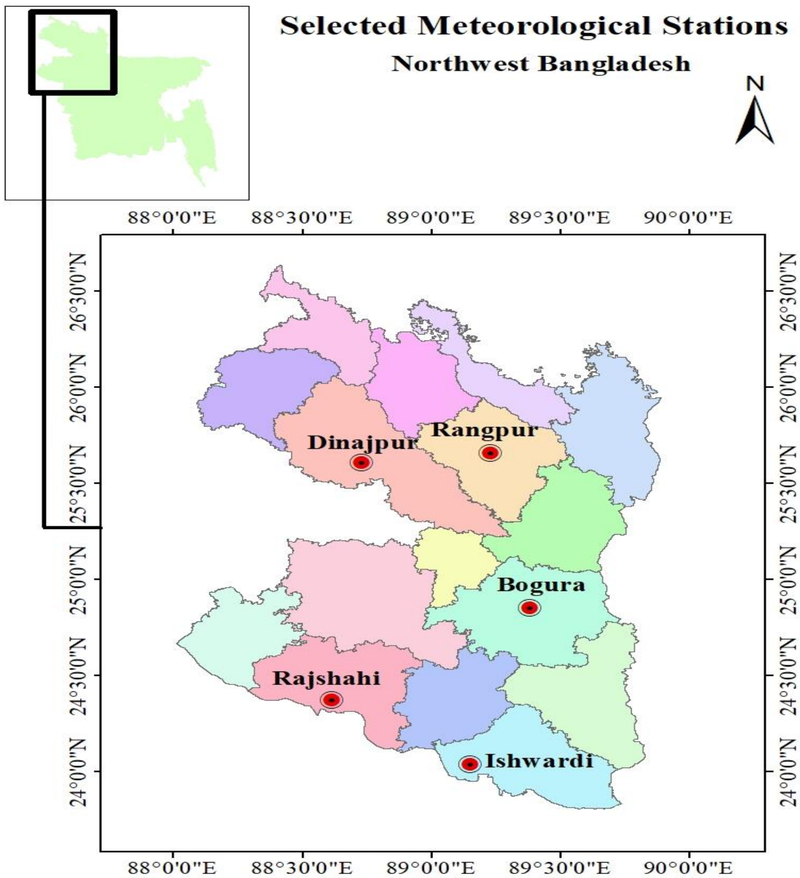


Fig 3.2 Meteorological stations in northwest region of Bangladesh
(*Developed by the researcher using ArcGIS 10.2.2)*

3.3 Sampling Design, Questionnaire and Sample Size Determination

A cross-sectional survey was adopted for the data collection from different households in respective upazilas (sub-district or part of district). The target group of the survey was primarily drought affected farmers' who cultivated different types of crops on their own and rental properties as well as took at least one adaptation measure by their own initiative. More than 90% of the people directly depend on agriculture in this region. In terms of geographical location, the climate condition of the area is sub-tropical wet and dry, and there has been little rainfall over the last 30 years (Mamun et al., 2021). At first, four districts were selected based on the degree of severity of drought-prone zone that was identified review of literature, historical evidence, reports in newspaper, internet and in consultation with local farmers. Because for long time the agricultural productions of the selected districts were always at risk due to the high likelihood of drought severity and recurring water shortages. Then the research work was conducted on four upazilas (sub-districts or parts of district) under the selected districts by SRS without replacement method using random number table. Then, considering villages as strata under each union and choose one village in each stratum by SRS, where each household was taken as sampling unit of this study. Finally, the required samples were determined with 95% confidence intervals through PPS (Population Proportional to Size) sampling scheme. The questionnaire mainly focused on gathering information about adaptation strategies used by the farmers to ensure sustainable agriculture and livelihood patterns. Before designing a questionnaire, regular discussion was held with local government authorities, experienced farmers, NGO officers and policy makers etc. The questionnaire mainly included with personal profile of the respondent, socio-demographic characteristics of farmer, farmers' perceptions in response to drought and agricultural adaptation and knowledge about drought adaptation strategies and mitigation. Each question was organized chronologically to understand the relationship among different variables.

Both the closed-end (with multiple response options) and open-end (without multiple response options) structured questions were used to collect data from respondents. Household head was particularly the main respondent (farmer) of the data set because they usually took the decision-making power for farming and adaption policy. The key members of households were selected by PPS scheme using the list of farming households collected the Department of Agricultural Extension (DAE) Office of each upazila. The total number of respondents in all selected villages was 2725 *(N).* The estimated sample size was 375, by PPS scheme (i.e*;* 92 farmers from Narayanpur village of Bhadair union in Tanore upazila of Rajshahi district, 93 from Azaiyr village of Kasba Union in Nachole upazila of Chapainawabganj district, 90 for Horipur village of Tilna union in Shapahar upazila of Naogaon district, 100 for Suroil village of Vihial union in Chirirbandar upazila of Dinajpur district, Fig. 3.3) using equation 3.2. Then the required sample size for this study was calculated by using R.A. Fisher equation for known population.

$$n = \frac{Z^2.p.q.N}{e^2(N-1)+Z^2.p.q} \qquad (3.1)$$

Here, n = Size of the sample

N = Total number of households

Z = 95% Confidence level = 1.96

p = Estimated population proportion (0.5 as it maximizes the sample size)

q = 1-p

e = Error limit (5% = 0.05)

Here the size of the study population N = 2725 is known. Sample household for each village (n_i) was calculated by the following formula

$$n_i = \frac{N_i}{N} \times n \qquad (3.2)$$

N_i is the number of households in each selected village. All respondents (farmers) of the selected households (sampling unit) using SRS (without replacement) technique with random number table.

Reserve Sample

Due to migration and other demographic reasons household members could be unavailable during field survey. In some cases, the respondents are ineligible to response and it is difficult to predict the non-response rate.[1] So, researcher consider 20% of the total sample (375) as reserve sample. i.e. $n_s = n \times \frac{20}{100}$

$= 375 \times 20/100$

$= 74$

[1] Organization for Economic Co-operation and Development. (2013). Technical report of the survey of adult skills (PIAAC).

Finally, survey was conducted on (total sample + reserve sample) = (375+74) = 449 respondents.

Table 3.2 Sampling design in the study area

4 districts are selected by SRS	4 upazilas are selected by SRS technique	4 union are selected by SRS technique	Choose 1 village under each union of respective upazila by SRS technique	Respondents are selected by PPS Sampling
• *District-1* • *District-2* • *District-3* • *District-4*	• *Upazila-1* • *Upazila-2* • *Upazila-3* • *Upazila-4*	• *Union-1* • *Union-2* • *Union-3* • *Union-4*	• *Village-1* • *Village-2* • *Village-3* • *Village-4*	• $N_1 = 92$ • $N_2 = 93$ • $N_3 = 90$ • $N_4 = 100$ $Total = 375$

Developed by Researcher

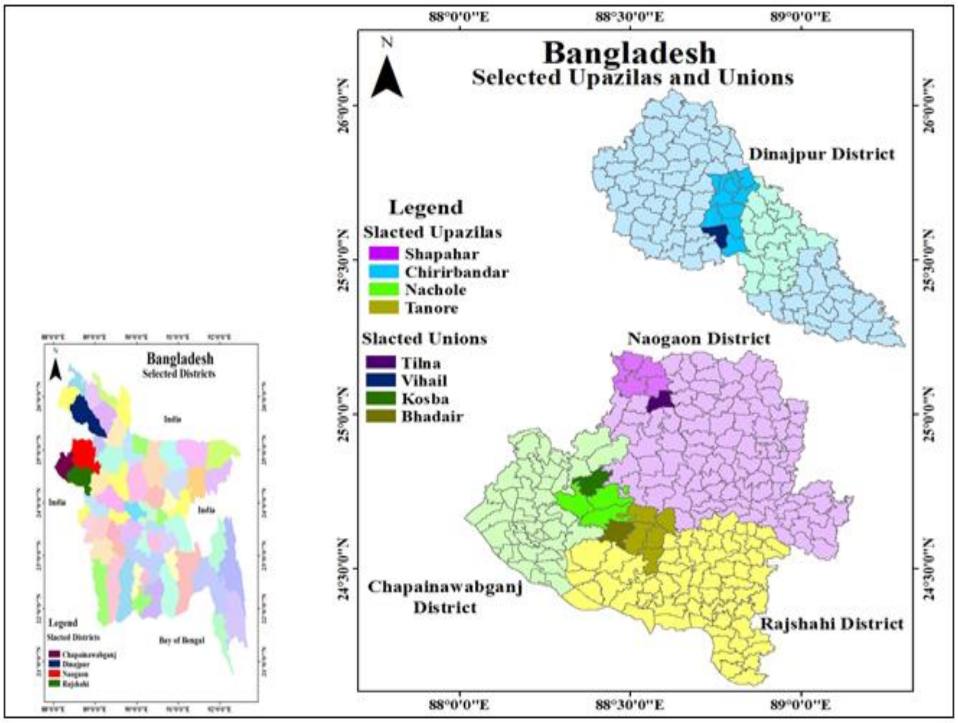


Fig. 3.3 Location map of the study area
(*Developed by the researcher using ArcGIS 10.2.2)*

3.4 Data Collection and Sources

Mixed method approach of data collection is included in this research. Primary data was collected using questionnaire and secondary data was collected from BMD.

3.4.1 Primary data

Primary data was collected through household survey, focus group discussions (FGD), key informant interviews (KII) and direct field observations. Both qualitative and quantitative data were accumulated in the proposed. The survey was conducted through a questionnaire using personal interviews during the month of March to April in 2022. Trained interviewers worked under the supervision of the researcher to conduct targeted interviews, either at participant's homes or a suitable place agreed upon. Additionally, in four upazilas (sub-districts or parts of district), four FGDs (each group consisting of 7 to 8 participants) were conducted including both male and female expertized farmers of household using FGD guideline. FGD Participants were purposively selected with the help of a Sub-Assistant Agriculture Officer of the respective upazilas and finally were chosen based on their willingness, availability and their farming experience. Collecting data and information regarding participants' perceptions about climate change over time, their farming operations, the effects of drought on crop cultivation, and indigenous adaptation practices in response to drought. Four KIIs were arranged with knowledgeable people and progressive farmers who had adequate knowledge about the study area and considerable farming experiences in order to gather expert opinion. The researcher also relied on a non-structured questionnaire to gather information in accordance with appropriate guidelines. These KII interviews were taken with individuals who had adequate access to information on weather forecasts, climate change impacts and difficulties of adaptation to climate change. Furthermore, the researcher participated in field observation as part of the primary data collection process. In the final phase, the household survey questionnaire was triangulated through the application of FGDs, KIIs, and field observations.

3.4.2 Secondary Data

The secondary data were collected from BMD to analyze the climate variability from 1960 to 2021. The five meteorological stations in the northwest region—Bogura, Ishawrdi, Rajshahi, Rangpur, and Dinajpur—were the main resources for collecting secondary data. In addition, secondary data were also collected from World Metrological Organization (WMO), Bangladesh Water Development Board (BWDB), census reports, official records, and archive of previous surveys.

3.5 Missing Data Estimation

During study, every station has a number of missing values but WMO claims that, less than 5% missing data is required and estimated successfully by using different estimating techniques. Due to the global nature of missing daily temperature and rainfall records, many climatological algorithms have encountered difficulties. There are three broad categories of missing data estimation methods, such as: a) within-stations b) between station, and c) regression-based (Allen and DeGaetano, 2001). The within-stations approach forecasts missing temperatures based on the previous and subsequent days' data. For example, to calculate the missing minimum temperature on 1st *October*, the minimum temperatures between *30th September*; and *2nd October;* could be averaged (Oliver, 1980). The within-station method is utilized to calculate the daily readings that are lost for maximum three days temperature. When more than three days of data are unavailable, regression-based methods should be used. This method uses data from nearby stations. Regression-based approaches are also appropriate, when monthly data are lost, because both monthly and daily data are constructed from this method (Eiseheid et al., 1995). According to Kemp et al., (1983), various regression techniques tend to provide more accurate results compared to other missing data estimation procedures. Multiple imputation techniques were used to both daily (Recha et al., 2012) and monthly (Ingsrisawang & Potawee, 2012) data for missing rainfall records because the standard error is correctly adjusted for missing data estimation (Enders, 2010).

3.6 Rainfall Climatological Features

3.6.1 Coefficient of Rainfall Variability

The coefficient of rainfall variability *CV (%)* are determined by the following formula

$$\mathrm{CV}(\%) = \frac{\sigma}{\mu} \times 100 \tag{3.3}$$

Where, *CV* is the co-efficient of variation in percentage, $\mu$is the annual average precipitation and σ is the standard deviation.

3.6.2 Precipitation Concentration Index (PCI)

The concentration of rainfall variability has been calculated by using the following formula of precipitation concentration index (Oliver, 1980; Michiels et al., 1992).

$$PCI_{annual} = \frac{\sum_{i=1}^{12} p_i^{\,2}}{(\sum_{i=1}^{12} p_i)^2} \tag{3.4}$$

PCI represents the monthly precipitation concentration index, and p_i is the monthly precipitation in the month i. It is observed that, When PCI values are less than 10%, the precipitation concentration should be identical or low precipitation; if PCI value range 11% to 15% indicates moderate concentration of precipitation; if it ranges 16% to 20% than precipitation continues irregularly (Oliver, 1980). If a PCI value greater than 20%, it means that the concentration of precipitation either high or strongly irregular.

3.7 Rainfall and Temperature Trend Analysis

Different statistical techniques and trend detection formula have been implemented for the required study. Mainly descriptive statistical analysis (maximum, minimum, mean/ average, standard deviation, coefficient of variation) have been executed to present the general characteristic of temperature and rainfall time series data.

3.7.1 Linear Regression

A popular parametric technique for finding linear trends in time series data is linear regression. It is used to determine the slope of time-dependent meteorological variables (Tabari & Talaee, 2011). Positive slope specifies increasing trend and vice versa. The linear monotonic change can be calculated as the following form

$$y = a + bx$$

Here, $a = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2}$ and

$$b = \bar{y} - a\bar{x} \qquad (3.6)$$

where, y is the dependent variable such as (temperature, rainfall) and x is the independent variable (year) ; a and b are the intercept term and slope coefficient an of the trend line; $\bar{x}$ and $\bar{y}$ are sample means (Rahman & Lateh, 2016).

3.7.2 Mann-Kendall (MK) Test

The rank-based non-parametric MK (Mann, 1945) test is applied as the primary method of trend detection. It is often used to check whether a time series data exhibits a monotonic rising and falling trend. (Das et al., 2021; Kamruzzaman et al., 2018, 2022; Sa'adi et al.,2019; Rahman et al., 2017 b). The test statistic *S* is identified by the following formula

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \qquad (3.7)$$

$$sgn(x_j - x_k) = \begin{cases} +1, if\left(x_j - x_k\right) > 0 \\ 0, if\left(x_j - x_k\right) = 0 \\ -1, if\left(x_j - x_k\right) < 0 \end{cases} \qquad (3.8)$$

Here *S* means the trend detection. A rising trend is indicated by a positive value of S, and vice versa. When sample size is greater than 10, then the test statistics ***S*** is normally distributed, with the following variance:

$$Var(S) = \frac{[(n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad (3.9)$$

Where ***m*** represents the total number of tied groups and t_i denotes the size of the i^{th} group. The Mann- Kendall **Z** statistic is calculated by the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, for\ S > 0 \\ 0, for\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, for\ S < 0 \end{cases} \qquad (3.10)$$

In general, the positive and negative Z value represents the rising and falling trends, respectively. According to the null hypothesis, there is no trend in records (either accepted or rejected) if the estimated Z value is smaller or greater than the critical value.

3.7.3 Kendall's Tau

Tau (Kendall, 1938, 1948) assesses the intensity of x and y's monotonic relationship. The Kendall's tau correlation formula is given by,

$$\tau = \frac{S}{n(n-1)/2} \qquad (3.11)$$

3.7.4 Sen's-Slope Estimator

Sen Slope estimator (Sen, 1968), which provides the robust estimation of time series, is used to evaluate the degree of change (slope Q). The estimation slope can be obtained from *N* pairs of data as:

$$Q_i = \frac{x_k - x_j}{k - j}, i = 1,2,3........N, k > j \qquad (3.12)$$

Where x_k and x_j represents values of data at *k* and *j* times and Q_i is the median slope, respectively.

3.7.5 Spearman's Rho (SR) Test

The spearman's rho (SR) test (Spearman, 2010) is another technique that uniformly detects tends and clearly indicates the lack of trends (Shadmani et al., 2012; Tonkaz et al., 2007; Yue et al., 2002a). According to Yue et al., (2002b), maximum trend test has same strength for long-term data when it comes to detecting monotonic hydrological time series trends. The test statistic D and standardized test statistic Z_{SR} are defined by:

$$D = 1 - \frac{6\sum_1^n [R(X_i - 1]^2}{n(n^2-1)} \tag{3.13}$$

$$Z_{SR} = D\sqrt{\frac{(n-2)}{(1-D^2)}} \tag{3.14}$$

Where, R is the i^{th} observation rank order in X_i time series and n is the sample size. The positive values Z_{SR} suggest rising trends and vice versa.

3.7.6 Sequential Mann-Kendall (SMK) Test

It is well known that trend identification techniques because sometimes the MK test approach does not produce an accurate trend image for entire series. By using the sequential test for each distinct time series, it is possible to identify any fluctuations in the trend during the course of the inquiry (Sneyers, 1990). This test establishes two series: a progressive series $u(t_i)$ and a backward series $u'(t_i)$. There is a statistically significant change point exists if they cross each other and diverge over predetermined the definite threshold value (95% confidence limit). Their intersection point provides an approximate idea of the trend beginning year (Mosmann et al., 2004)

The SMK test is computed using rank values. The actual values in the series (x_1, x_2, x_3........ x_n) with the rank value y_i, the magnitudes of y_i $(i = 1,2,3.....n)$ are compared with y_j($j = 1,2,3........i-1)$. The cases $y_i > y_j$ are enumerated and indicated for each comparison by n_i. Here t_i is test statistic of SMK test by applying the formula $t_i = \sum_j^i n_i$; The distribution of test statistic t_i has a mean $E(t_i) = \frac{i(i-1)}{4}$ and Variance, $Var(t_i) = \frac{i(i-1)(2i+5)}{72}$; then the following formula is employed to obtain the forward sequential results: (Sneyers, 1990).

$$u(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{Var(t_i)}} \tag{3.15}$$

Similar approaches are used to find the backward sequential statistics $u'(t_i)$, which starts at the end of the sequence. Occasionally the positive and negative trends are canceled by each other in SMK analysis but do not provide a substantial trend turning point (Nalley et al., 2013). This technique was widely used by many researchers to identify trends from the beginning point (Esteban-Parra et al., 1995; Makokha & Shisanya, 2010) rather than whole trend detection. Nalley et al., (2013) applied this technique in order to determine the periodicities in the temperature time series.

3.7.7 Spatial Distribution Analysis

The Inverse Distance Weighing (IDW) method was employed to evaluate the spatial pattern of trend magnitude (MK test, Sen's Slope estimates). This procedure is popular, and simple for spatial interpolation (Shahid & Behrawan, 2008; Rahman et al., 2017b; Kamruzzaman et al.,2018; Islam et al., 2019) and it is very reliable for displaying the spatial analysis of hydro-meteorological records (Praveen et al., 2020). Compared to other interpolation techniques, the IDW method is more effective (Islam et al., 2021). We have used the ArcGIS 10.0 software for performing the IDW method in this study.

3.7.8 ARIMA Modeling and Prediction

The ARIMA approach is recognized as a sophisticated and broadly used data analysis technique for forecasting time series (Box & Jenkins, 1976). In hydrological research, the ARIMA models are utilized to discover complexity in data series and forecast upcoming scenarios (Dimri et al., 2020; Rahman et al., 2017). Typically, ARIMA model consists of three components; AR is the autoregressive component, MA is the moving average component, and the differencing order (D) integrated with the model both AR and MA. The ARIMA model $(p.d.q)$ includes, p =autoregressive term, d =trend term, and q =moving average term. After attaining data stationary, ARIMA method usually proceeds via four major steps: model identification, parameter estimates, model adequacy diagnostics, and forecasting. For the seasonal ARIMA model, notation is like ARIMA $(p, d, q) \times (P, D, Q)S$ where p =non-seasonal autoregressive

(AR) order, d =non-seasonal differencing,q =non-seasonal moving average (MA) order, P =seasonal AR order, D =seasonal differencing,Q =seasonal MA order, and S =time span of repeating seasonal pattern. The fitted model performance is based on model selection criteria like log-likelihood, AIC (Akaike Information Criteria), and BIC (Bayesian Information Criteria). For this study, the Box Jenkins technique is implemented to forecast monthly rainfall and temperature data for the following five years based on 1960-2021.

3.7.9 Model Selection Criteria

The most appropriate ARIMA model has been selected relying on the value of AIC and BIC. Mainly, the differentiation between in-sample forecasting and out-of-sample forecasting may be predicated upon model selection criteria. In-sample forecasting describes how the chosen model fits the data in a given sample. On the other hand, forecasting future values of the regress and given the values of the regressors, an out-of-sample technique must be used. Both AIC and BIC incorporate a penalty for the inclusion of a greater number of regressors. Finally select this model that offers smallest value of AIC and BIC. The AIC as proposed by Sakamoto et al. (1986), is an essential criterion for assessing both the accuracy and lag order of a specific model. AIC is defined as:

$$AIC = e^{2k/n} \sum \frac{\hat{u}_i^2}{n} \qquad (3.16)$$

Where k is the number of regressors (including the intercept) and n is the number of observations. For mathematical convenience, Eq. (3.16) is written as

$$AIC = log\left(\frac{\sum \hat{u}_i^2}{n}\right) + \frac{2k}{n} \qquad (3.17)$$

Where $\sum \hat{u}_i^2$ indicates sum of squares of residuals. Theoretically, it is possible to determine an appropriate lag structure by gradually increasing the number of lags until the Akaike Information Criterion (AIC) attains its minimum value.

Schwarz (1978) proposed an alternative maximum likelihood criterion, known as the Bayesian Information Criteria (BIC). It is derived in a Bayesian context and approximates a variant of Laplace’s method. The BIC criterion is to be minimized and defined as:

$$BIC = log(\hat{\sigma}^2) + \frac{n\,log(N)}{N} \qquad (3.18)$$

Where, n is the dimensionality of the model, $(1 - \varphi_1 L - \varphi_2 L^2 - \dots\dots\dots\dots \varphi_p L^p) y_t = c + (1 - \theta_1 L - \theta_2 L^2 - \dots\dots\dots\dots\dots \theta_q L^q)\varepsilon_t$ is the estimate of the variance and N is the sample size.

3.8 Drought Forecasting Index and Drought Characterization

In recent times various studies have been conducted to identify and monitor droughts, but Palmer Drought severity Index (PDSI) and the Standardized Precipitation Index (SPI) are the two most widely used indices (Mishra et al., 2009). In this study SPI is used as the preferred index for describing meteorological droughts. It has been developed by the Colorado Climate center as a tool for defining and monitoring drought (McKee et al., 1993). The SPI is only based on long-term rainfall data, which it can be accumulated according to different time scales. In the present study, SPI for 3, 6, 9, 12- and 24-months' time steps computed for detecting and characterizing meteorological drought. The SPI can be used to identify the beginning and end for each drought, as well as an intensity level for each month in which the drought occurs.

Mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. To compute SPI, historic rainfall data of each station are fitted to a gamma probability distribution function, as the distribution has been found to fit the precipitation distribution quite well. The fitting of the gamma distribution to rainfall (x) can be expressed as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x > 0 \qquad (3.19)$$

Here, $x > 0$ it is the amount of precipitation, $\Gamma(\alpha)$ defines the gamma function. α and β are shape ($\alpha > 0$) and scale ($\beta > 0$) parameters determined by the maximum likelihood method (Eqs 3.10 and 3.11) (Thom, 1966). It is accurately estimating the gamma distribution parameters for each station and for each time step (3, 6, 9, 12 and 24 months):

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (3.10)$$

$$\beta = \frac{\bar{x}}{\alpha} \qquad (3.11)$$

$$A = ln(\bar{x}) - \frac{\sum ln(\bar{x})}{n} \tag{3.12}$$

Here, *n* is the number of precipitation observations. Afterwards, the resulting parameters are used to calculate the cumulative probability of a rainfall amount over a defined time scale. The cumulative

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1}\, e^{-\frac{x}{\beta}} dx \tag{3.13}$$

As gamma function cannot be defined for zero rainfall, and therefore, the cumulative probability becomes

$$H(x) = q + (1 - q)G(x) \tag{3.14}$$

Here, *q* is the probability of a zero. The cumulative probability *H(x)* is transformed to standard normal distribution to yield the SPI (McKee et.al., 1993). The drought is categorized to the SPI as presented in Table 5.1.

Firstly, the advantage of the SPI approach in this regard however, this technique is based on rainfall data alone, so that drought monitoring is possible even if other hydro meteorological measurements are not available. Second, it has a variable timescale and is thus conducive to describing drought conditions for a range of meteorological, hydrological and agricultural applications. Third, its standardization guarantees that the extreme event frequencies are consistent across any locations and anytime scales. Fourth, it can also detect moisture deficit more quickly than can PDSI, which has a response time scale of approximately 8–12 months (Hayes et al., 1999). Hughes & Saunders (2002) used monthly SPIs at the time scales of 3, 6, 9, 12, 18 and 24 months for the period of 1901-1999 for characterizing the drought climatology of Europe. Further the US National Drought Mitigation Center and the US Western Regional Climate Center advocate SPI over the traditional PDSI (Redmond, 2000).

3.9 Alternating Renewal Process

An SPI time series may be considered as a stochastic process with two states—dry and wet, having the characteristic that there are time points at which the process might resume. This process is also known as an alternating or two-stage renewal process (Mehedi, 2002). The system is considered to be in one of two states during this process, for instance, initially it is in a drought, and stays in that condition for period DL_1; it then switch to wet state for period WL_1. After then it enters to drought state for time DL_2, moves into wet state time WL_2; then drought state again and so on. The concept of the alternating renewal process is shown in Fig. 3.3. The sequence of droughts can be characterized by the inter-arrival time, which refers to the duration (L) between the onset of two consecutive droughts. This duration is computed as the sum of the length of a dry period (DL) and the length of a wet period (WL) (Gonzalez & Valdes, 2003), which is expressed as:

$$L = WL + DL \tag{3.15}$$

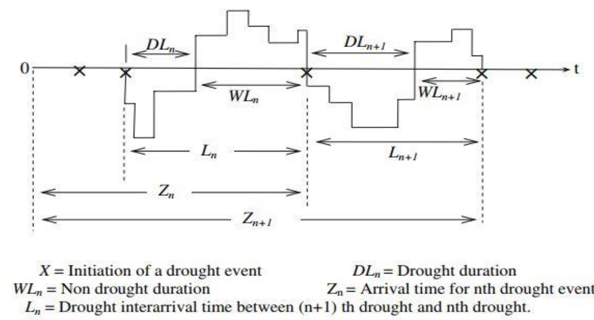


Fig. 3.4 Altering renewal process (Mishra et al., 2009)

Theoretically, it is possible to derive the distribution of drought duration (Yevjevich, 1967; Sen, 1976; Mathier et al., 1992). A two-state Markov process may be used to simulate this occurrence if the state at time *t* relies on the preceding state. Therefore, the drought duration for the two state Markov model is expressed as (Shiau & Shen, 2001):

$$f_{DL}(dl) = P_{DW} P_{DD}^{dl-1}, \quad dl = 1,2,3 \tag{3.16}$$

and the distribution of non-drought duration is written as

$$f_{WL}(dl) = P_{WD} P_{WW}^{wl-1}, \quad wl = 1,2,3 \tag{3.17}$$

Where dl is the drought duration and *wl* is non-drought duration; and

$$P_{DW} = P(S_t \geq 0/S_{t-1} \geq 0); \quad P_{DD} = P(S_t < 0/S_{t-1} < 0) \tag{3.18}$$

$$P_{WD} = P(S_t < 0/S_{t-1} \geq 0); P_{WW} = P(S_t \geq 0/S_{t-1} \geq 0) \tag{3.19}$$

S_t = SPI value at time *t*; S_{t-1} = SPI value at time *t-1*. Here zero is considered as a truncation level. It follows that

$$P_{DD} + P_{DW} = 1;\ P_{WW} + P_{WD} = 1$$

The values of P_{DW}, P_{DD}, P_{WD} and P_{WW} are the transition probability values of two sate Markov chain.

3.10 Generating Functions for Probability Distributions

Consider a sequence of real numbers denoted by $a_0, a_1, a_2 \ldots\ldots$ and so on. The generating function is defined as (Medhi, 2002) using the variable s.

$$A(s) = a_0 + a_1 s + a_2 s^2 + \ldots\ldots\ldots\ldots = \sum_{k=0}^{\infty} a_k\, s^k \qquad (3.20)$$

According to Shiau & Shen (2001), the distribution of drought interarrival time and mean drought interval time are derived by using the moment generating function, which are detailed below.

3.10.1 Distribution of Drought Interarrival Time

The generating function approach were used to determine the distribution of the sum of two independent random variables with given distributions (Wolf, 1989; Mehadi, 2002). The probability mass functions of drought duration and non-drought duration are given by Eqs (3.16) and (3.17), respectively. The generating function of a drought duration, DL, is expressed as

$$A_{DL}(s) = E(s^{DL}) = \sum_{dl=1}^{\infty} P_{DW}\, P_{DD}^{dl-1} s^{dl} = \frac{P_{DW}s}{1-p_{DD}s} \qquad (3.21)$$

$$A_{WL}(s) = E(s^{WL}) = \frac{P_{WD}s}{1-P_{WW}s} \qquad (3.22)$$

According to the important property of a moment generating function defines that the moment generating function of a sum of independent random variables is equivalent to the product of the individual moment generating functions (Ross, 2014). By considering DL and WL as two independent random variables and applying the principle property of Eq. (3.15), it is possible to express the drought interarrival time (L = DL + WL) as a product of $A_{DL}(s)$ and $A_{WL}(s)$:

$$A_L(s) = A_{DL}(s) A_{WL}(s) = \frac{P_{DW}s}{1-P_{DD}s}\frac{P_{DW}s}{1-P_{ww}s} \qquad (3.23)$$

$$= \frac{P_{DW}P_{WD}}{P_{DD}-P_{WW}}\left[\sum_{l=2}^{\infty}(P_{DD}^{l-1} - P_{WW}^{l-1})s^{l}\right] = E(s^{L}) \qquad (3.24)$$

Hence the distribution of drought interarrival time is described as

$$f_L(l) = \frac{P_{DW}P_{WD}}{P_{DD}-P_{WW}}\left(P_{DD}^{l-1} - P_{WW}^{l-1}\right), \qquad l = 2,3,4 \qquad (3.25)$$

3.10.2 Mean Drought Interarrival Time

Since the drought interval time is a discrete variable, so its expected value is mathematically represented as follows:

$$E(L) = \sum_{l=2}^{\infty} l f_L$$

$$= \sum_{l}^{\infty} l \frac{P_{DW}P_{WD}}{P_{DD}-P_{WW}}(P_{DD}^{l-1} - P_{WW}^{l-1})$$

$$= \frac{P_{WD}+P_{DW}}{P_{WD}P_{DW}} = \frac{1}{P_{DW}} + \frac{1}{P_{WD}} = E(DL) + E(WL) \qquad (3.26)$$

Hence, the mean of drought interarrival time is given by

$$E(L) = E(DL) + E(WL) = \frac{1}{P_{DW}} + \frac{1}{P_{WD}} \qquad (3.27)$$

3.10.3 Markov Chain Models and Transition Probabilities

A Markov chain is type of stochastic process that exhibits the property that the value of the process at given time *t*, denoted as a $X_{t,}$ depends only on its value at preceding time $t-1$, X_{t-1} and not on the sequence of values $X_{t-2}, X_{t-3}, \ldots\ldots, X_0$ that the process went through in reaching at $X_{t-1.}$ The process can be described as (Hann, 2002; Mishra et al., 2009).

$$\Pr(X_t = a_j / X_{t-1} = a_i, X_{t-2} = a_k, X_{t-3} = a_1 \ldots \ldots X_0 = a_q)$$

$$= \Pr(X_t = a_j / X_{t-1} = a_i) \qquad (3.28)$$

The concept of the conditional probability, denoted as Pr ($X_t = a_j / X_{t-1} = a_i$), refers to the probability that the process will be in "state *j*" at time *t*, given that at time *t-1* the process was in "state *i*". So, the conditional probability is commonly referred as one step transition probability. It is the probability that the process makes the transition from state a_i to state a_j in one time period or one step, which is denoted by p_{ij}. Transition probabilities are basic study of the structure of the Markov chain.

If a process is divided into m states, then m^2 transition probabilities must be defined. The m^2 transition probabilities can be represented by an $m \times m$ matrix which is given as P,

$$P = p_{ij} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ p_{31} & p_{32} & \cdots & p_{3m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix} \qquad (3.29)$$

P is called the transition probability matrix of the Markov chain process. The matrix P is classified as a stochastic matrix, which is a square matrix consisting of non-negative elements and unit row sums. The estimation of the transition probability matrix can be accomplished by observed data by tabulating the frequency of the observed data went from state i to state j, n_{ij}. Then, an estimated of p_{ij} would be

$$P_{ij} = \frac{n_{ij}}{\sum_{j=1}^{m} n_{ij}} \qquad (3.30)$$

3.11 Data Processing and Presentation

The research findings are provided in various formats including narratives, tables and graphs as required. For Primary data analysis using IBM SPSS version-25 software, Microsoft Excel and R-package, STATA-12, Arc-GIS software-10.2.2 using for secondary data analysis. Furthermore, data processing, analyzing and mapping are conducted in accordance with the underlying assumptions of various analysis tools.

3.12 Validity of the Research

For this research, the reliable and valid data were collected from the study population and other secondary sources. This research is completely free from personal biasness during the time of data collection. Data are not be manipulated during any phases of data coding or analysis.

3.13 Ethical Considerations

Before conducting the questionnaire survey, at the beginning, consent from study participants were taken. Then declaration was given to the respondents that their information was used only for research purposes and not for others. Besides, it had been declared that respondents' anonymity and confidentiality must be ensured.

3.14 Research Framework

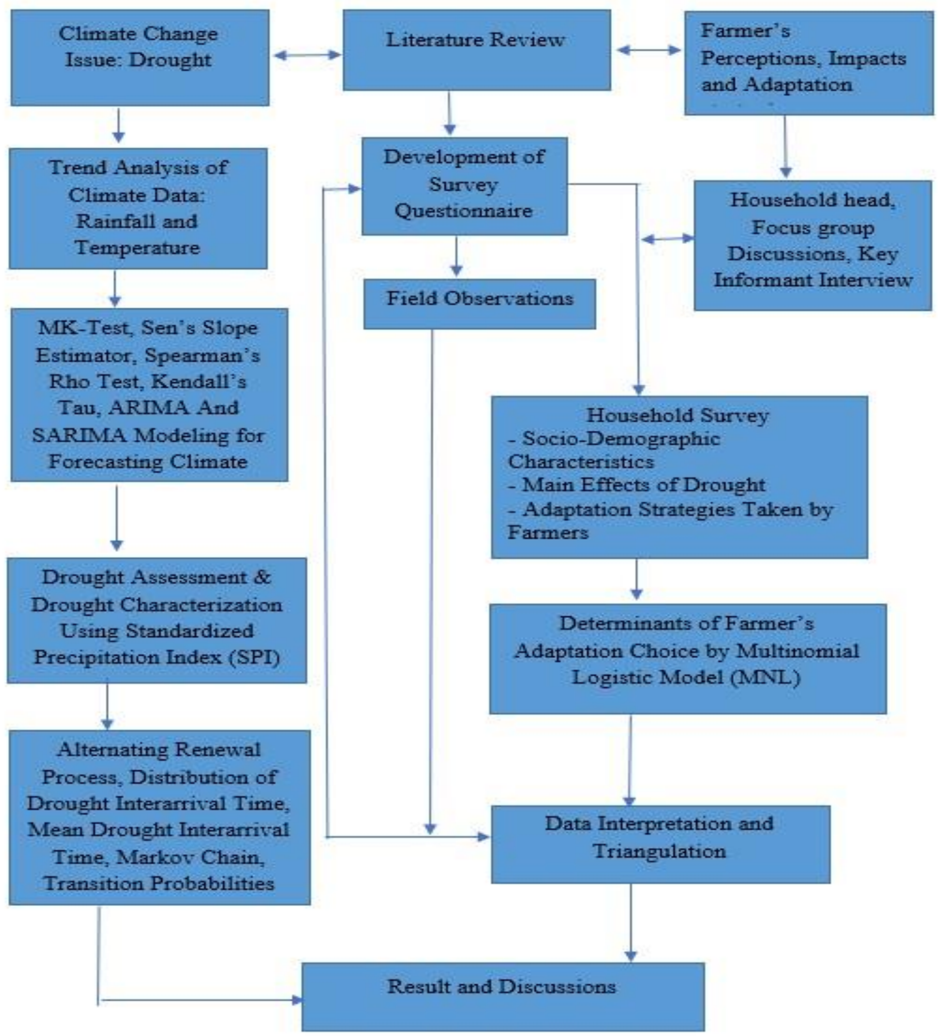


Fig. 3.5 Framework of the Research Study

(Developed by Researcher)

Chapter Four

Spatio-Temporal Variation of Rainfall and Temperature over Northwest Bangladesh

4.1 Introduction

Bangladesh is a country in South Asia that receives a significant quantity of precipitation during the monsoon season and less precipitation with extreme temperature in other seasons of the year. This unprecedented weather condition positively hits the food security and economic growth of the country (Akter & Rahman, 2012; Mondol et al., 2018; Rahman et al., 2017; Rahman et al., 2016b; Salam et al., 2020). Bangladesh is the fourth-largest rice producer in the world, with an annual production of over 34.7 million metric tons. Nearly 80% of all cultivated land (11.7 million hectares) is planted with rice (Mainuddin et al., 2022). Rice is used to make 91% of all food grains and 60% of overall agricultural products (Rahman et al., 2016 a; Yu et al., 2010).

Despite advancements in agricultural technology such as better crop varieties, irrigation practices, ICT farming and other sustainable adaptation strategies have established food security. Globally, climate conditions still contribute unpredictability to agricultural productivity of the country (Mainuddin & Kirby, 2015; Kirby et al., 2015). For this reason, regional rainfall and temperature trend analysis and future prediction have become important issues of research in todays' world, because accurate trend detection directly effects on establishment of long-term food security, agriculture based economy, and infrastructural development. In our country environmental researchers conducted various types of climate research to understand the rainfall and temperature patterns. A number of studies exhibited significant rising or falling trends of temperature and rainfall on a large scale using the MK test, Sen's slope estimator, Kendall's tau (Shahid & Khairulmaini, 2009; Zhang et al., 2009; Shahid, 2010; Rahman & Lateh, 2016; Rahman et al., 2017; Kamruzzaman et al., 2018; Das et al., 2021). Shahid (2010) demonstrated a significant upward trend in annual and pre-season rainfall at 17 rain gauge stations in Bangladesh by using the MK test and Sen's slope estimator between 1958 and 2007. Similarly, Hossain et al. (2014) observed rising trends in seasonal rainfall variability in the southwest coastal area of

Bangladesh during the years 1948–2007. Rahman & Lateh, (2016) constructed a regression model for trend detection from 1971 to 2010 and forecasting ten-year period of rainfall by using ARIMA method of 34 meteorological stations in Bangladesh. Their findings observed that between 2011 and 2020, forecasting annual rainfall was declined by 153 mm. As a result, almost dry conditions would continue during pre-monsoon and post-monsoon season in northwestern, western and southwestern regions of Bangladesh. Rahman et al., (2017) used 60 years of monthly rainfall data to estimate rainfall trends of selected stations by applying the MK test, Sen’s slope estimates and Sequential MK test. In their study, they found unnoticeable trends in precipitation rather than upward trends for Khulna, Satkhira and Cox's Bazar stations but they discovered downward trends for Srimongal stations by using the ARIMA approach.

The northwest region of Bangladesh produces huge quantity of crops and the agriculture mostly relies on rainwater. Historically, inadequate rainfall, extreme temperature, surface water scarcity, and groundwater depletion for irrigation purposes are the common problems in this part of the world (Salam et al., 2020; Karim et al., 2020; Uddin et al., 2020a , 2020b). To address this problem, several studies have been done locally and country-wide to determine future trends and policies. Kamruzzaman et al., (2018) identified the changing rainfall and temperature patterns in different cropping seasons in the NW Bangladesh. Almost identical results were found in different studies of Bangladesh in different region (Bariet al., 2016; Rahman et al., 2016 a, 2016 b, Yu et al., 2017; Islam et al., 2021; Kamruzzaman et al., 2022). It is traditionally accepted that, drought is the outcome of decreasing trends of rainfall and increasing trends of extreme temperature. However, many environmental researchers do not agree with the above statement. To address the issue, many previous studies were conducted based on zone-wise or country-wise methods. However, some limitations have been found in the local and regional studies. To overcome the limitations the present chapter primarily aims to identifying annual and seasonal trend fluctuations of five meteorological stations (i.e. Bogura, Rangpur, Dinajpur, Rajshahi, and Ishwardi) during 1960-2021, and predicts monthly behavioral change in rainfall and temperature to obtain approximate results for next five years. Sixteen administrative districts, consisting 34,359 km^2 and residing 38 million people in northwest Bangladesh are considered as study area of this research (BBS, 2019 a; Uddin et al., 2020 a). It is observed that, the average maximum temperature of northwest zone goes up to 24°C in January and 34°C in June. Meanwhile, the average temperature does not go beyond 27°C from November to February but exceeds 32°C from April to October (Bhuyan et al., 2018). In this study, BMD has provided rainfall and temperature data from 1960 to 2021. Different statistical techniques and trend detection methods (*Mann-Kendall Test, Sen's Slope Estimator, Kendall's Tau, Spearman's Rho (SR) test, Sequential Mann-Kendall (SMK) Test, Spatial Distribution Analysis*) were applied in the required study. Furthermore, ARIMA approach was used for forecasting monthly time series climate variables.

4.2 Results and Discussion

4.2.1 Annual Rainfall Features

Rainfall is not constant across the country. Historically, the northwest region received the least amount of rainfall as compared to the northeast. Around 75% of rainfall happens during the monsoon season (Alamgir et al., 2015). The results in Table 4.1 indicates that the mean annual rainfall ranges from 2171 to 1460 mm with mean value of 1767.80 mm. In the year 2010, Rajshahi station received the lowest amount of annual rainfall, 792 mm. Meanwhile, Rangpur station received the highest amount of annual precipitation 3748 mm; in 1984. Moreover, Rangpur station observed a maximum annual rainfall amount of 2171 mm, whereas the other stations received less than 2000 mm amount of annual rainfall. During the study period, rainfall data was found positively skewed. The coefficient of variation found low in Rajshahi station (19.93%) and high in Ishwardi station (26.12%) which means maximum rainfall variation observed in Ishwardi. The standard deviation of annual rainfall was high in Rangpur station, with 463.87 mm, and low in Rajshahi station, with 291 mm (Fig. 4.1).

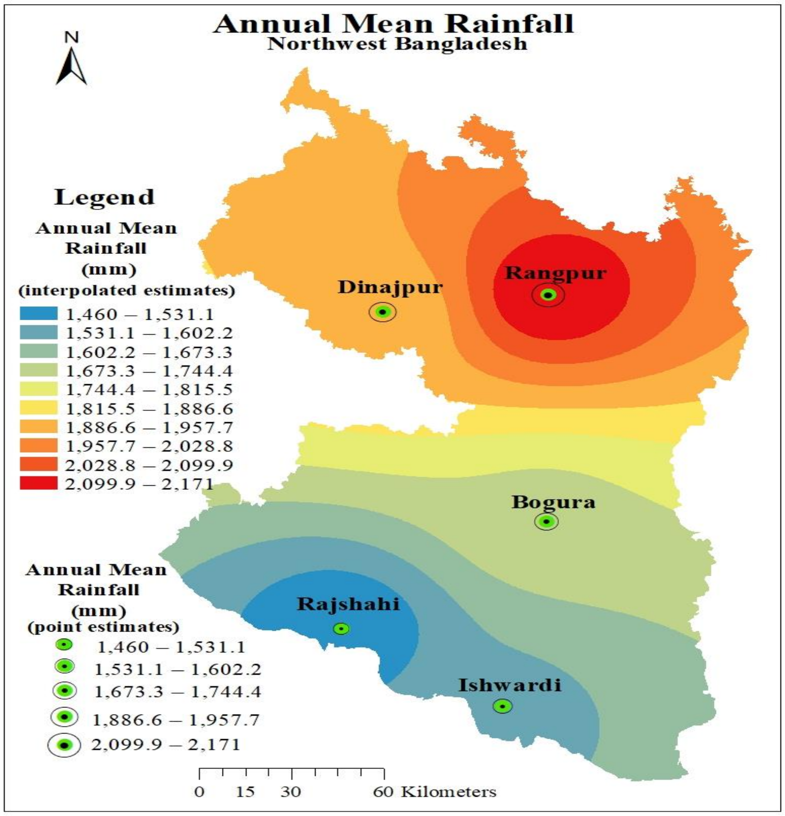


Fig. 4.1 Distribution of annual mean rainfall in northwest Bangladesh

From the statistical analysis, about 80% stations in the study area were covered by irregular precipitation concentration index (PCI=16-20), except Dinajpur station carried a high precipitation concentration, which was more than 20%. Finally, all the stations were found to be positively skewed. The study area's annual rainfall descriptive statistics are provided in the following tables (Table 4.1).

Table 4.1 Descriptive statistics of annual rainfall in the study area (1960-2021)

Station	Annual Rainfall (mm)							
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis	PCI_{Annual}
Bogura	1081	2601	1719	21.92	376.77	0.307	-0.635	19.47
Dinajpur	920	3179	1906	23.77	453.08	0.395	0.525	20.58
Ishwardi	893	3021	1583	26.12	413.42	1.30	2.530	17.80
Rajshahi	792	2241	1460	19.93	291.00	0.069	0.114	18.16
Rangpur	1231	3748	2171	21.37	463.87	0.905	1.510	19.63

4.2.2 Trend Analysis of Annual Rainfall

The MK test result revealed that 40% stations exhibit a positive trend, while the rest of the stations showed negative trend. Moreover, a positive slope specified increasing amount of rainfall, while a negative slope designated decreasing trends in rainfall analysis (Table 4.2). According to MK test result *(Z)* Rajshahi station showed the highest amount of significant decreasing trend (-2.654) at 5% level of significance, followed by Bogura (-0.176) and Ishwardi (-0.808), but they were found statistically insignificant. The magnitude of change was estimated at the rates of -5.50, -0.59 and -1.71 mm/year in Rajshahi, Bogura and Ishwardi stations, respectively but only Rajshahi station showed statistically significant in annual rainfall. In contrast, Rangpur and Dinajpur stations found insignificant positive trend, and the degree of change by Sen’s slope estimates were at the rates of 3.68 and 2.59 mm/year respectively.

Table 4.2 Long-term annual rainfall trend test results

Station	MK test	Sen’s Slope	Kendall’s Tau	SR test
Bogura	-0.176	-0.59	-0.016	-0.195
Dinajpur	0.692	2.59	0.061	0.501
Ishwardi	-0.808	-1.71	-0.071	-0.830
Rajshahi	-2.654*	-5.50*	-0.232*	-2.813*
Rangpur	1.178	3.68	0.103	1.063

*Significant trends at 5% significance level, Sen’s slope unit is in mm per year

Besides, Kendall’s tau revealed a monotonic trend of weak relationships in all stations. The linear regression trends of annual precipitation graph are shown in (Fig. 4.6). The MK test results (Z statistic) and the Sen’s estimator of different stations are presented by the spatial distribution analysis (Fig. 4.2). It is observed that annual average rainfall decreases in the Rajshahi division (Rajshahi, Bogura and Ishwardi), but increases in the Rangpur division (Dinajpur and Rangpur).

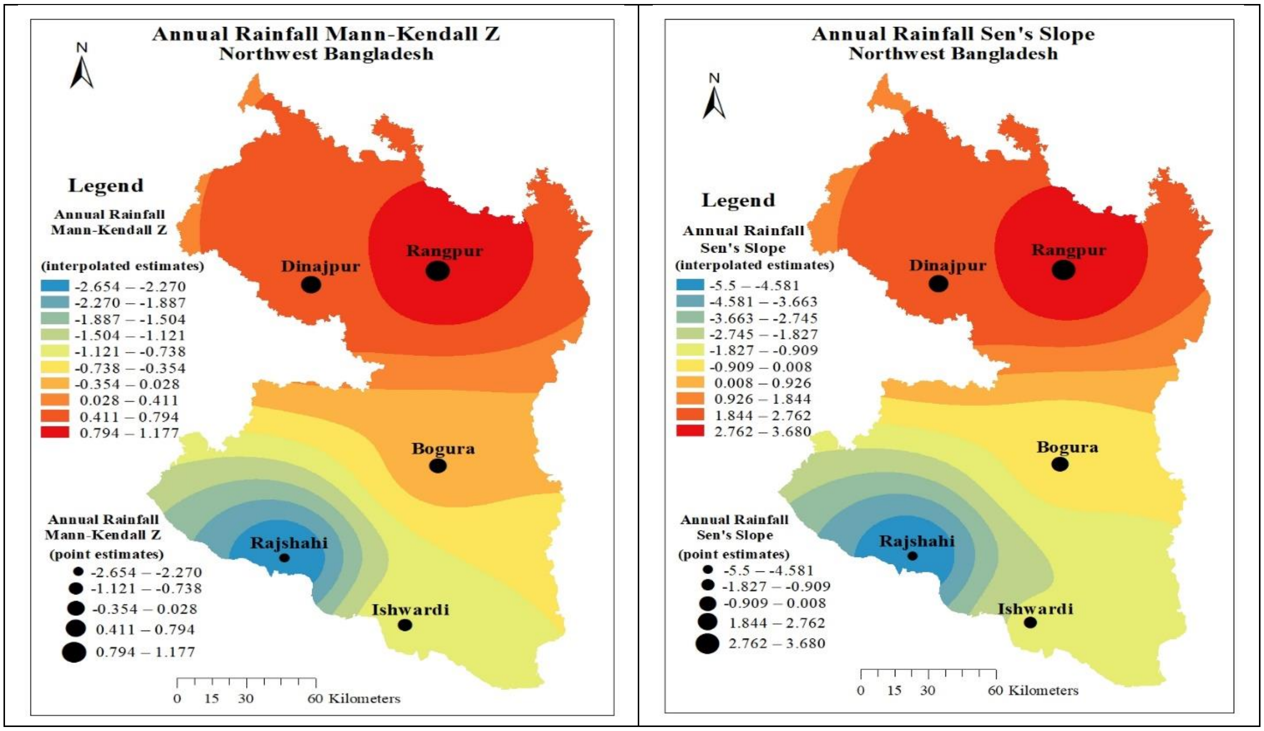


Fig. 4.2 Spatial distribution of MK test statistic and Sen’s slope estimates for annual mean rainfall

4.2.3 Trend Analysis of Seasonal Rainfall

4.2.3.1 Rabi Season Rainfall

During the *Rabi* season, the northwest zone received on average 37.8 mm of annual rainfall, which was notably lower compared to other parts of the country. In the study domain, annual average rainfall ranged from 30 mm to less than 50 mm in all stations. According to the regional distribution (Fig. 4.3a) of *Rabi* season rainfall analysis, Dinajpur station found the lowest quantity of annual rainfall (30 mm), whereas Ishwardi station received the highest quantity of rainfall, 48 mm. The standard deviation was high in Rajshahi station (38 mm) and low in Dinajpur station (25.85 mm). Moreover, the co-efficient of variation revealed that 95.22% variation occurred in Bogura station, whereas Ishwardi station found lowest amount of rainfall variation (78.37%).

Table 4.3 Descriptive statistics of *Rabi* season rainfall of Bangladesh (1960-2021)

Station	*Rabi* Season Rainfall (mm)				
	Min	Max	Mean	SD	CV (%)
Bogura	0	146	38	36.13	95.22
Dinajpur	0	123	30	25.85	86.38
Ishwardi	0	159	48	37.71	78.37
Rajshahi	0	214	42	38.00	89.63
Rangpur	0	123	31	26.98	85.83

The results of the MK test (*Z* statistics) result exhibited that almost all the stations showed insignificant downward trend ranges from -0.176 to -0.966 at 95% confidence interval. The magnitude of change by Sen's slope estimator revealed declining trends at a rates of -0.029, -0.034, -0.167, and -0.136 mm/year in Bogura, Dinajpur, Rajshahi, and Rangpur, respectively, except Ishwardi station observed at a rate of change 0.107 mm/year (Table 4.6). Spearman Rho's test also showed similar trend in all the station ranged from 0.537 to -1008.

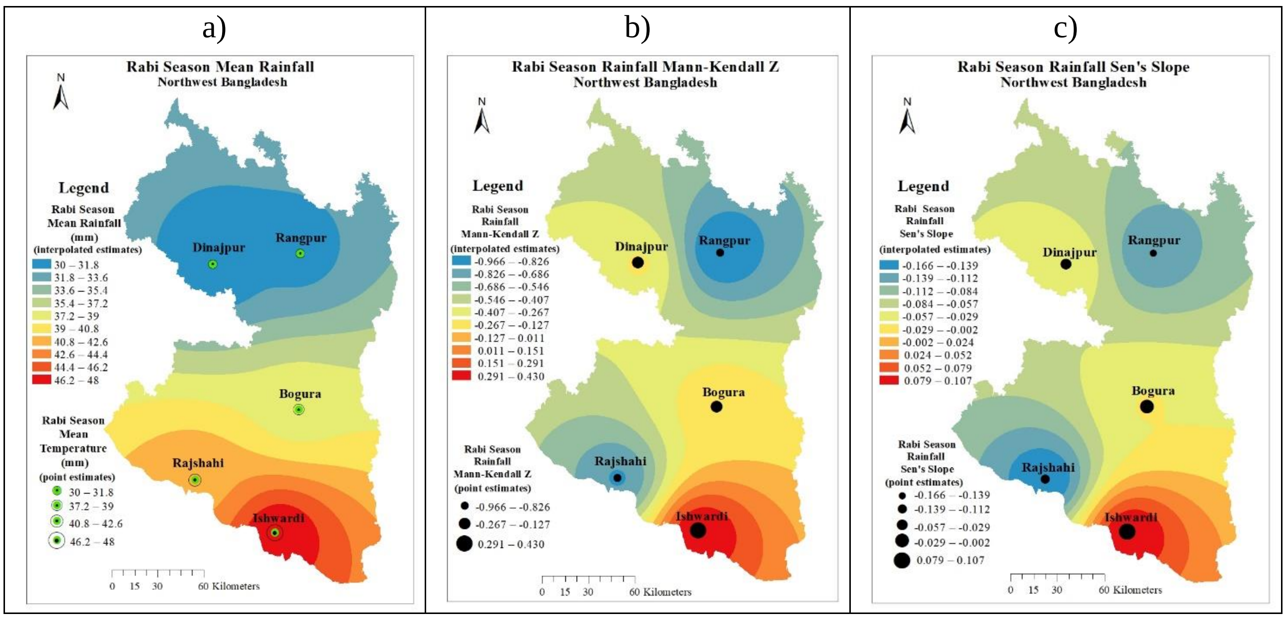


Fig. 4.3 Spatial distribution of *Rabi* season rainfall a) annual average b) MK test statistic and c) Sen's Slope estimates

The Spatial distribution map of Z statistics and Sen's slope estimates of the *Rabi* season annual rainfall are presented in (Fig. 4.3 b and 4.4 c). The findings of the study exhibited that the northwest region is experienced a declining amount of rainfall in the Rabi season, which is particularly harmful for Boro rice production.

4.2.3.2 Pre-Kharif Season Rainfall

The annual average rainfall at different stations in the pre-*Kharif* period varied 477 mm to 817 mm and the standard deviation varied from 153 mm to 240 mm. The pre-Kharif season rainfall analysis of spatial distribution (Fig. 4.4a, Table 4.4) clearly showed that Rangpur station received significant amount of maximum rainfall with 1667 mm. Meanwhile, Rajshahi station found lowest amount of rainfall 96 mm in the study period (1960–2021). From the coefficient of variation (CV) Rangpur station received minimum variation 28.7 but Ishwardi station found 41.66. The northwest region had experienced both rising and falling trends in pre-*Kharif* season. The result obtained from different trend analysis test (MK test, Sen's slope and SR test) point out that 60% of stations showed increasing trend, and 40% found insignificant decreasing trend.

Table 4.4 Descriptive statistics of Pre- *Kharif* season rainfall of Bangladesh (1960-2021)

Station	Pre- *Kharif* Season Rainfall (mm)				
	Min	Max	Mean	SD	CV (%)
Bogura	262	1280	619	240.30	38.79
Dinajpur	252	1204	635	203.86	32.11
Ishwardi	223	1752	564	234.88	41.66
Rajshahi	96	1013	477	153.00	32.03
Rangpur	378	1667	817	234.55	28.70

The MK test results *(Z)* revealed that rainfall varied from -0.905 (Ishwardi) to 1.208 (Rangpur). The Sen's slope estimates of Bogura, Dinajpur, and Rangpur stations identified insignificant rising trends at a rate of changes 1.73, 1.59 and 1.54 mm/year, respectively, while stations like Ishwardi, and Rajshahi achieved insignificant falling trends at a magnitude of change -0.905 and-0.954 mm/year, respectively (Table 4.6). Spearman's rank correlation test (SR test) observed the same increasing and decreasing trend for the all stations. The spatial analysis of (Z statistics) and Sen's slope estimates are shown in (Fig. 4.4 b and 4.4 c). From above discussion, it is clear that the pre-*Kharif* season rainfall in Bangladesh is shown downward trend in the northwest but strongly predicts upward trend in the north.

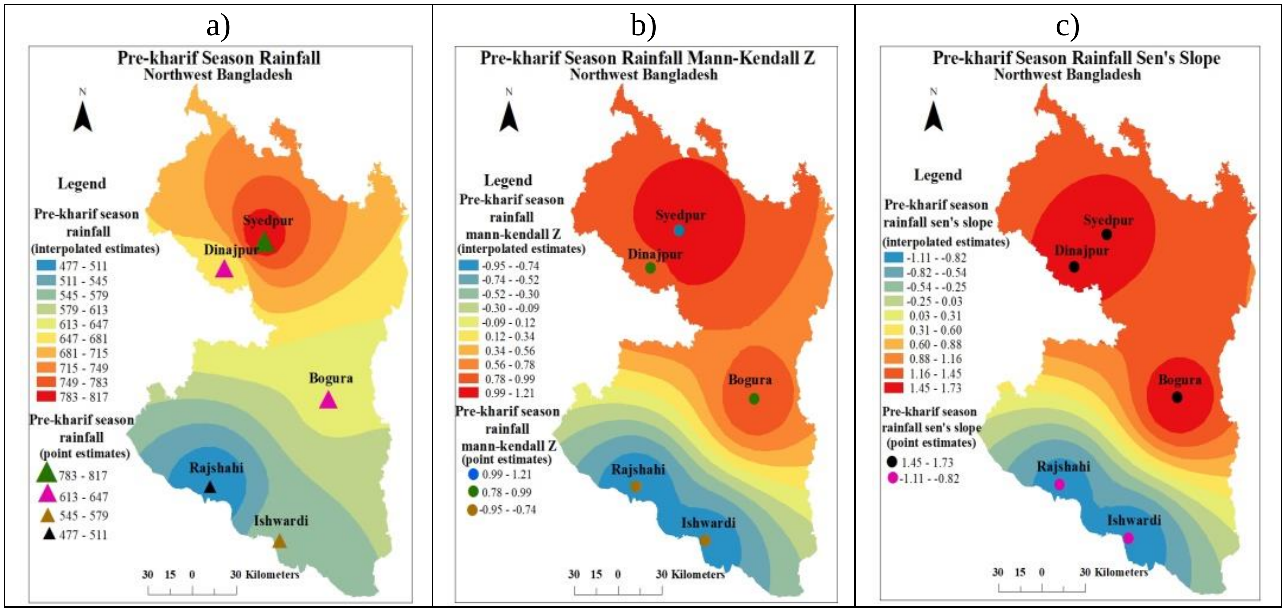


Fig. 4.4 Spatial distribution of pre-*Kharif* season rainfall a) annual average b) MK test statistic and c) Sen's Slope estimates

4.2.3.3 Kharif Season Rainfall

The *Kharif* rainfall is very important for Aman rice production because rice is the main staple food in our country. During the month of July to October is considered as the *Kharif* season. The overall average annual rainfall during this season was 1104.8 mm. During study period in a year, Rajshahi station received minimum rainfall (423 mm), and Rangpur station found maximum rainfall (2440 mm) (Table 4.5). The coefficient of variation is high (29.87) at Dinajpur station and low (24.98) at Rajshahi station (Fig. 4.5 a).

Table 4.5 Descriptive statistics of *Kharif* season rainfall of Bangladesh (1960-2021)

Station	*Kharif* Season Rainfall (mm)				
	Min	Max	Mean	SD	CV (%)
Bogura	573	1948	1062	277.85	26.17
Dinajpur	532	2536	1241	370.82	29.87
Ishwardi	440	1710	958	268	28
Rajshahi	423	1583	941	235	24.98
Rangpur	540	2440	1322	365.30	27.64

In the present study, long-term *Kharif* season was dominated by a mixed rainfall trends in all stations. The MK test and SR test results were detected same trend directions in the northwest region. From trend analysis Rajshahi station showed the most significant decreasing trend with -2.53 at 5% level of significance; on the contrary, Bogura and Ishwardi stations also observed decreasing trend in all trend analysis test but they were not statistically significant. Moreover, the degree of change obtained by Sen's slope results was -3.80, -2.18, and -1.24 mm/year at Rajshahi, Bogura, and Ishwardi stations, respectively. Dinajpur and Rangpur stations were exhibited insignificant positive trends of 0.20 and 0.935 in accordance with the MK test statistic (Z) and the magnitude of change assessed by Sen's slope estimates of these two stations were 0.50 and 2.53 mm/year, respectively. According to the SR test results all stations was found a downward trend varied from -2.711 to 0.717 (Table 4.6). The Spatial distribution of MK *(Z)* statistic and Sen's slope estimates of the *Kharif* rainfall trends are presented in (Fig. 4.5 b and c)

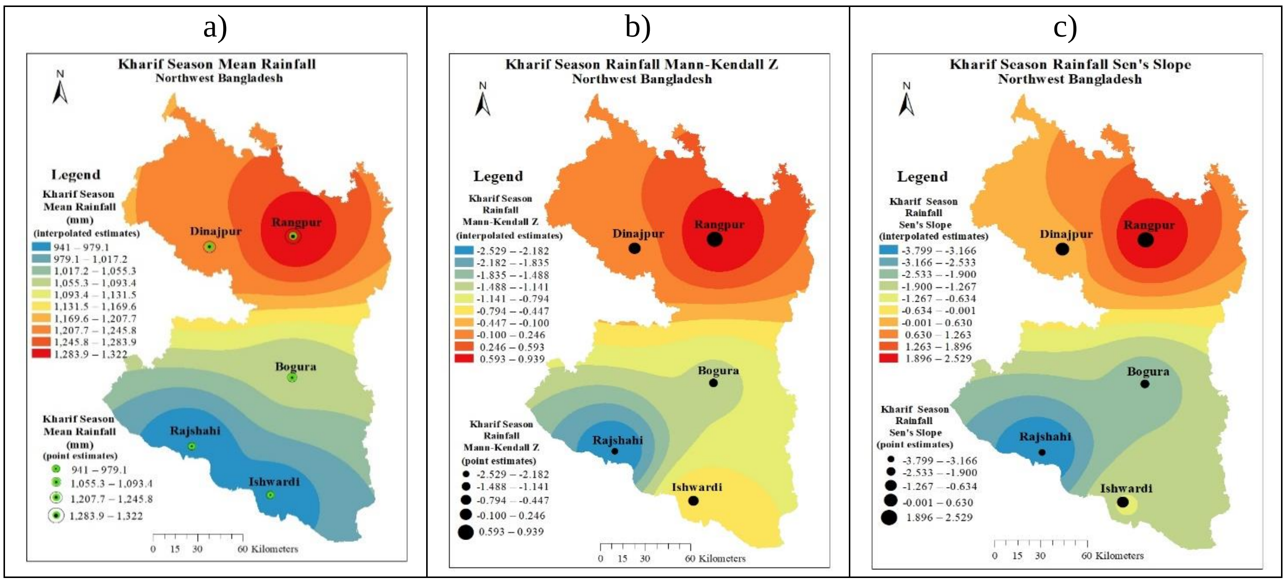


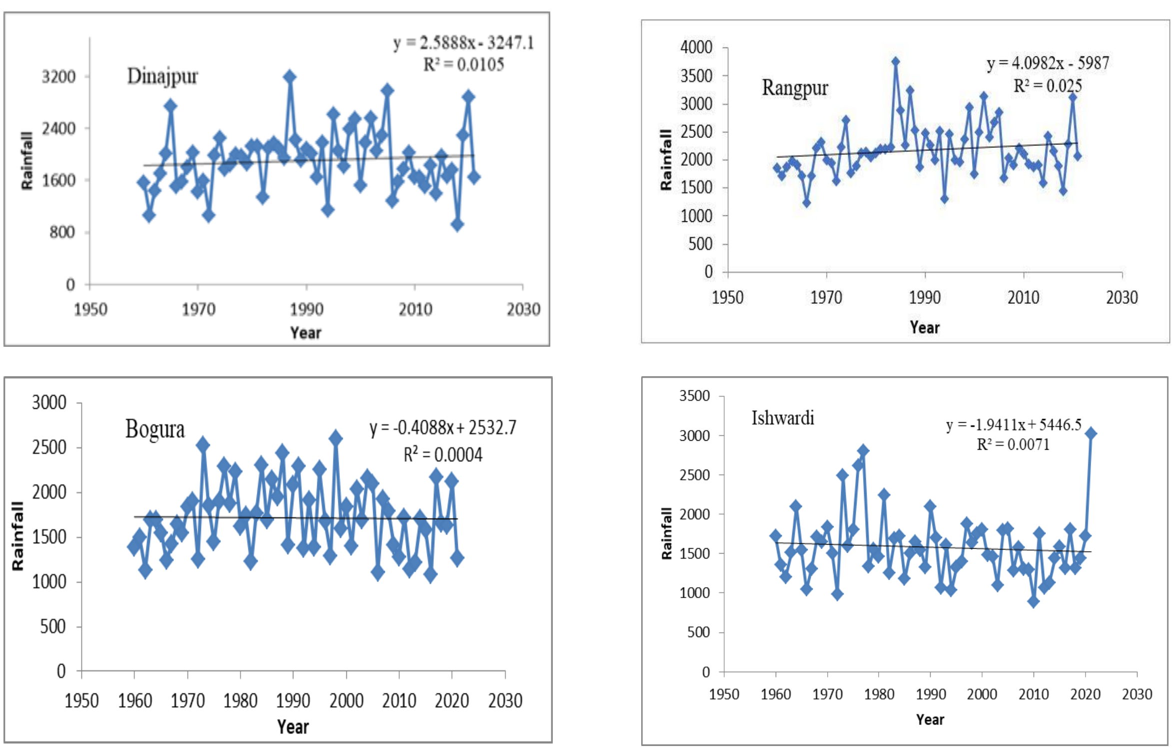
Fig. 4.5 Spatial distribution of *Kharif* season rainfall a) annual average b) MK test statistic and c) Sen's Slope estimates

Table 4.6 Long-term seasonal rainfall trend test results

Station	*Rabi* Season			Pre-*Kharif* Season			*Kharif* Season		
	MK test	Sen's Slope	SR test	MK test	Sen's Slope	SR test	MK test	Sen's Slope	SR test
Bogura	-0.176	-0.029	-0.147	0.966	1.73	1.008	-1.227	-2.18	-1.432
Dinajpur	-0.255	-0.034	-0.031	0.947	1.59	0.995	0.20	0.50	-0.007
Ishwardi	0.431	0.107	0.537	-0.905	-1.105	-0.838	-0.486	-1.24	-0.421
Rajshahi	-0.838	-0.167	-0.886	-0.954	-1.00	-0.903	-2.53*	-3.80*	-2.711*
Rangpur	-0.966	-0.136	-1.008	1.208	1.54	1.330	0.94	2.53	0.717

*Significant trends at 5% level, Sen's slope unit is in mm per year

The linear trend line of yearly rainfall in the northwest region during 1960-2021 are displayed in (Fig. 4.6). The graph indicates that the trend line is decreasing at Bogura, Ishwardi, and Rajshahi stations, while an increasing annual total rainfall at Rangpur and Dinajpur stations. It is observed that Rangpur station received highest amount of rainfall above 3500 mm in the year 1984 and after 2010, yearly total rainfall of this station varied from 1850 to 3100 mm. During the period Rajshahi station is predicted 792 mm lowest amount of rainfall in the year 2010. After 2010 to 2020, annual rainfall is varied below 900 mm to 1450 mm.



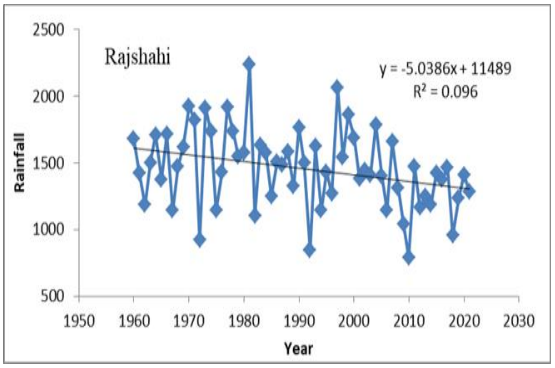


Fig. 4.6 Linear regression trends of annual total rainfall in northwest Bangladesh at five stations during 1960-2021

4.2.4 Annual Temperature Features

The long-term annual average temperature varied from 24.30°C (Rangpur) to 25.30°C (Rajshahi) with a mean value 24.96°C. Based on historical temperature data, the average extreme temperature varied from 26.57°C and 25.35°C and the average minimum temperature lied between 20.64°C and 24.67°C. It was evident that (Table 4.7) along with other descriptive analysis of annual temperature, the standard deviation was high (0.75°C) at Rangpur station and low (0.31°C) at Bogura station. The coefficient of variation of temperature data varied 1.24% to 3.07% at different stations. It means Rangpur station observed maximum temperature variation. The long-term annual mean temperature is shown in (Fig. 4.7) by spatial distribution analysis.

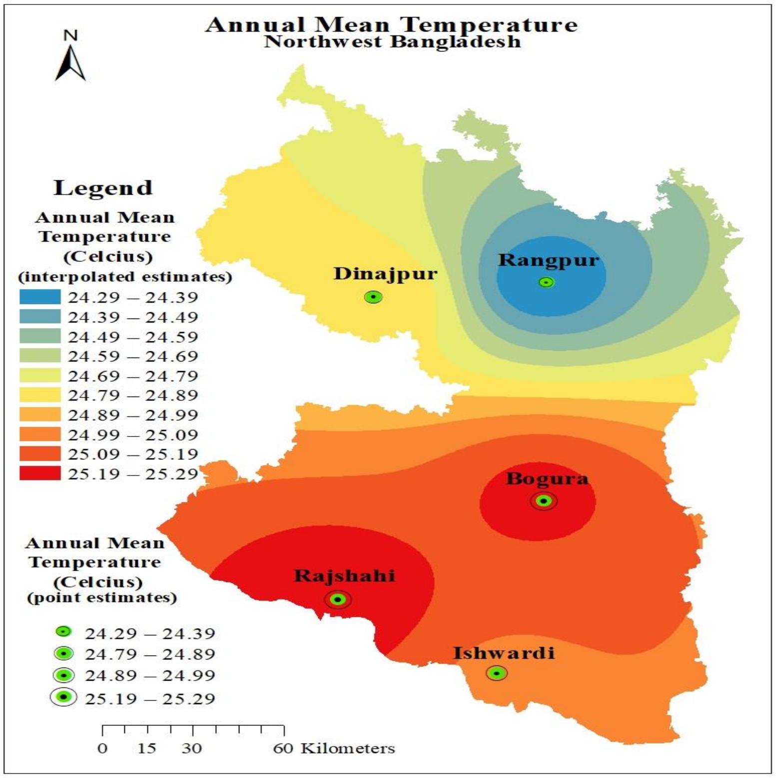


Fig. 4.7 Distribution of annual mean temperature in northwest Bangladesh

The temperature dataset was positively skewed in four stations, except Rangpur stations found negative skewness. Similar results were identified for kurtosis. From the analysis, it is clearly said that the datasets are leptokurtic not mesokurtic.

Table 4.7 Descriptive statistics of the annual mean temperature of Bangladesh (1960-2021)

Station	Annual Temperature (°C)						
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis
Bogura	24.67	26.08	25.24	1.24	0.31	0.613	0.204
Dinajpur	24.10	26.03	24.90	1.75	0.43	0.835	0.521
Ishwardi	24.12	26.26	25.08	1.52	0.38	0.242	1.369
Rajshahi	24.43	26.57	25.30	1.84	0.47	0.856	0.369
Rangpur	20.64	25.35	24.30	3.07	0.75	-2.504	9.380

4.2.5 Trend Analysis of Annual Temperature

The annual mean temperature observed that 80% of the stations showed an increasing trend but only Dinajpur station found decreasing trend (Table 4.8). During 60 years period, the highest significant rising trend was found at Bogura and Rangpur stations by the MK test statistic *(Z)*, and SR test and the magnitude of changes discovered by the Sen's slope estimates were 0.0095°C/year and 0.017°C/year, respectively. Ishwardi and Rajshahi stations also offered rising tendencies in annual temperature analysis, but not statistically significant. Apart from that only Dinajpur station was shown falling trend with the MK test (-1.014) and SR test (-1.655) and the rate of change assessed by the Sen's estimates was -0.003°C/year. Meanwhile, Kendall's tau received positive relationships over time except Dinajpur station (Table 4.8).

Table 4.8 Long-term annual temperature trend test results

Station	MK test	Sen's slope	Kendall's Tau	SR test
Bogura	4.514*	0.0095*	0.395*	5.040
Dinajpur	-1.014	-0.003	-0.089	-1.655
Ishwardi	1.451	0.004	0.130	1.390
Rajshahi	1.233	0.004	0.109	1.044
Rangpur	5.674*	0.017*	0.495*	7.259*

*****Significant trends at 5% level, Sen's slope unit is in mm per year

The spatial distribution of annual mean temperature is displayed in Fig. 4.8. Over the years, upward trend of temperature is dominating in this part of the country which will create more dry years and extreme temperature in the future. Finally, linear trend analyses of the long-term annual temperature are shown in (Fig. 4.12), which indicates the temperature increases day by day at different stations in northwest region.

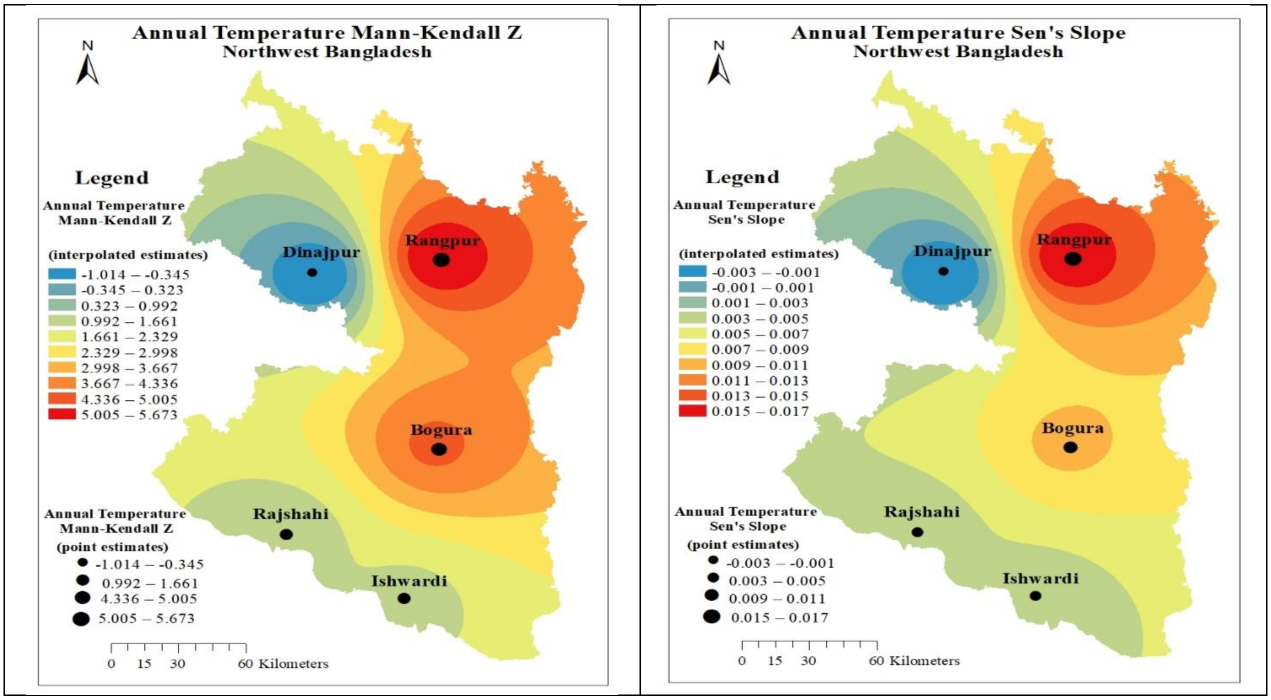


Fig. 4.8 Spatial distribution of MK test statistic and Sen's slope estimates for annual mean temperature

4.2.6 Trend Analysis of Seasonal Temperature

4.2.6.1 Rabi Season Temperature

This season is characterized by the coldest temperature in Bangladesh, generally referred to as winter. The average temperature during *Rabi* season fluctuates from 18.97°C to 19.95°C with an average value 19.32°C. In this season, the minimum temperature at different stations varied from 16.91°C (Rangpur) to 18.78°C (Bogura), and the maximum temperature ranged from 20.60°C (Rangpur) to 21.52°C (Rajshahi) (Table 4.9; Fig. 4.9 a).

Table 4.9 Descriptive statistics of *Rabi* season temperature of Bangladesh (1960-2021)

Station	*Rabi* Season Temperature ($°C$)				
	Min	Max	Mean	SD	CV (%)
Bogura	18.78	20.96	19.95	0.50	2.51
Dinajpur	17.67	21.44	19.09	0.79	4.16
Ishwardi	17.54	21.37	19.21	0.66	3.43
Rajshahi	18.03	21.52	19.42	0.74	3.83
Rangpur	16.91	20.60	18.97	0.71	3.73

The coefficient of variation of temperature data varied from 2.51 to 4.16, i.e. low-temperature variability was found at Bogura station, and high-temperature variability was described at Dinajpur station, which means temperature varies more frequently at Dinajpur. The MK and SR test findings indicated that the trend fluctuations were identified by both positive and negative direction. By analyzing 60 years of historical data 60% stations (Dinajpur, Ishwardi, and Rajshahi) showed decreasing trend and 40% stations (Rangpur and Dinajpur) experienced rising trend with the MK test or SR test results. The values of MK test statistic *(Z)* ranged from -0.83 to 2.81. The degree of change evaluated by Sen's slope estimates were decreased -0.09, -0.004, and-0.01°C/year at Dinajpur, Ishwardi, and Rajshahi stations, respectively but statistically insignificant. From the study, only Rangpur station was revealed a significant increased rate of change with 0.014°C/year. The spatial distribution of MK test statistic *(Z)* and Sen's slope estimates are displayed in (Fig. 4.9 b and 4.9 c).

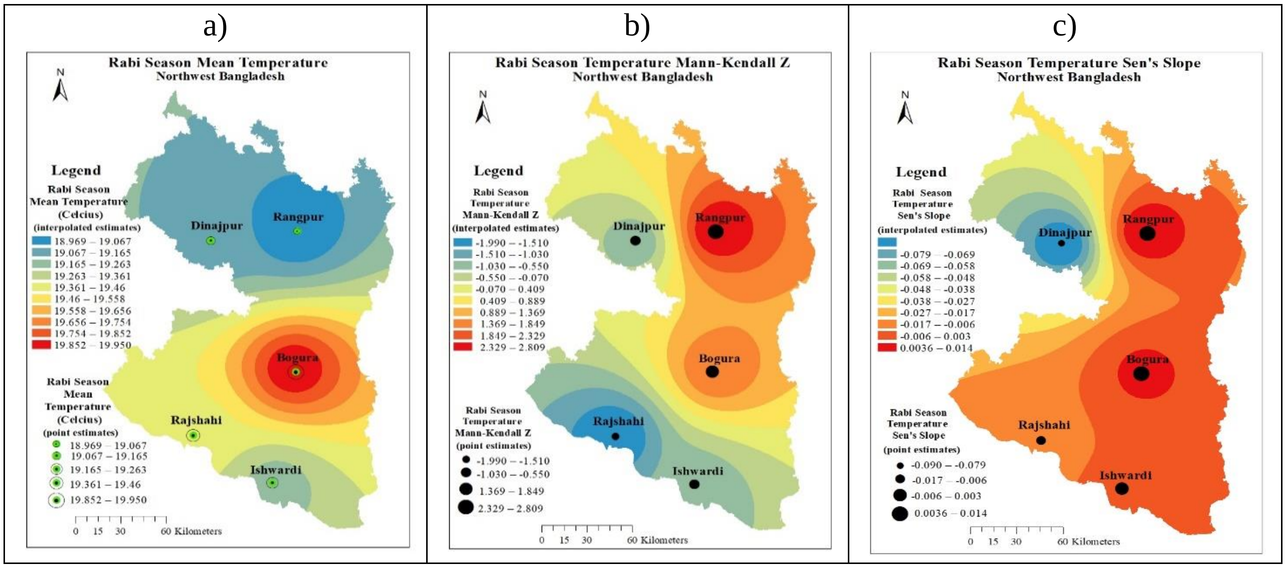


Fig. 4.9 Spatial distribution of *Rabi* season temperature a) annual average b) MK test statistic and c) Sen's Slope estimate

4.2.6.2 Pre-Kharif Season Temperature

During the pre-*Kharif* season temperature analysis, Rajshahi station found average maximum temperature of 30.66°C, while Rangpur station received 20.68°C minimum average temperature. The overall mean temperature ranged from 26.14°C to 28.25°C with a mean value of 27.47°C.

The standard deviation of pre-*Kharif* season temperature varied from 0.63°C to 1.27°C, and the CV showed 2.27% at Bogura station and high 4.85% at Rangpur station (Table 4.10; Fig. 4.10 a).

Table 4.10 Descriptive statistics of Pre-*Kharif* season temperature of Bangladesh (1960-2021)

Station	Pre-*Kharif* season temperature (°C)				
	Min	Max	Mean	SD	CV (%)
Bogura	26.38	29.04	27.62	0.63	2.27
Dinajpur	23.85	29.31	27.39	0.88	3.19
Ishwardi	26.43	29.78	27.97	0.69	2.47
Rajshahi	26.68	30.66	28.25	0.81	2.86
Rangpur	20.68	28.15	26.14	1.27	4.85

In the study area, 80% of stations observed a strongly positive trend while 20% station showed negative trend. From trend analysis Dinajpur, Rajshahi and Rangpur were statistically significant, but only Dinajpur station was found negative trend. Both the MK test and SR test revealed identical result except the Rajshahi station, which showed decreasing trend of -0.744 in the SR test. The rate of change among the stations assessed by the Sen's slope estimates ranged from -0.02 to 0.02°C/year. However, Dinajpur station showed only a significant downward trend with the magnitude of change identified by -0.02°C/year (Table 4.9). The spatial distribution of different stations indicates that trend of temperature is more challenging to survive in the northwest region (Fig. 4.10 b, and 4.10 c).

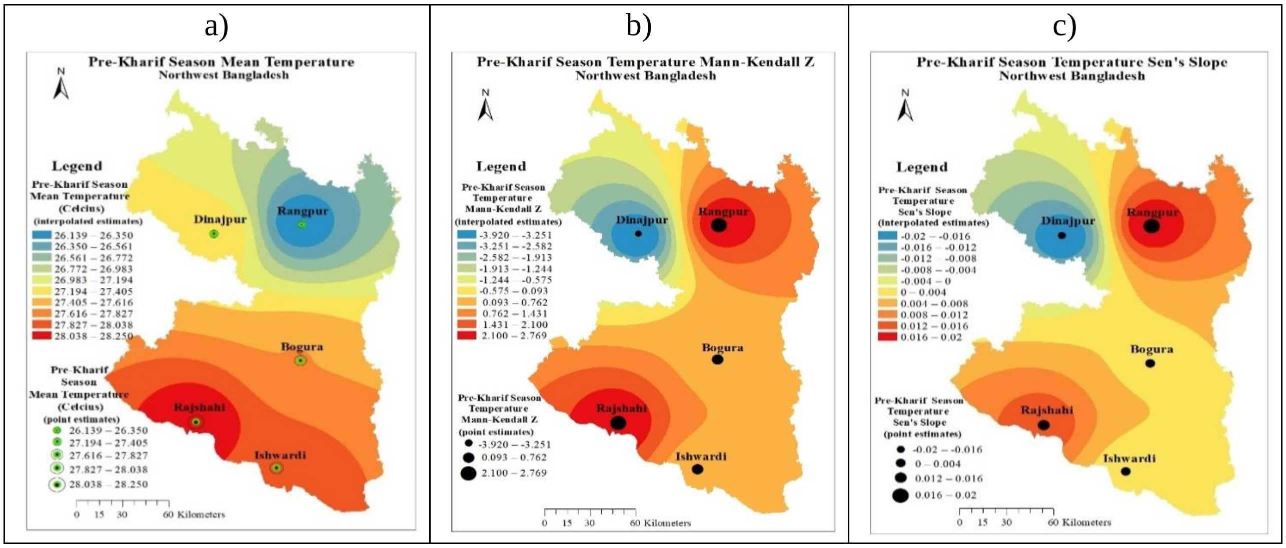


Fig. 4.10 Spatial distribution of *pre-Kharif* season temperature a) annual average b) MK test statistic and c) Sen's Slope estimates

4.2.6.3 Kharif Season Temperature

The *Kharif* season is primarily referred to as a rainy season of Bangladesh. From descriptive analysis the annual mean temperature varied from 27.28 °C (Rangpur) to 28.23°C (Dinajpur), with a mean value of 28.08°C. The maximum mean temperature ranged from 29.33°C to 29.03°C and the minimum mean temperature varied from 21.78°C to 26.70°C (Table 4.8; Fig. 4.11 a). The standard deviation indicated that temperature wasn't too much fluctuate during this season. Among all the stations, the coefficient of variation was maximum at Rangpur station with 4.08% and minimum at Ishwardi station 1.25%, which indicated that temperature was more fluctuate in *Kharif* season at Rangpur station than the others.

Table 4.11 Descriptive statistics of *Kharif* season temperature of Bangladesh (1960-2021)

Station	*Kharif* season temperature (°C)				
	Min	Max	Mean	SD	CV (%)
Bogura	26.70	29.33	28.16	0.53	1.87
Dinajpur	27.45	29.06	28.23	0.38	1.35
Ishwardi	27.45	29.19	28.06	0.35	1.25
Rajshahi	27.60	29.29	28.21	0.37	1.32
Rangpur	21.78	29.03	27.78	1.13	4.08

Trend analysis of different meteorological stations revealed that, significant rising trend of temperature was found during *Kharif* season. The MK test results identified that Ishwardi station experienced with the highest positive trend (6.16), while Dinajpur station observed by lowest positive trend (4.81) at 95% confidence interval. Almost similar result was predicted by the SR test analysis. Sen's slope analysis points out that the degree of change varied from 0.01 to 0.02°C/year with an average 0.014°C/year (Table 4.12). The spatial map of MK test and Sen's slope estimates are shown in (Fig. 4.11 b and 4.11 c) which indicates the upward trend continues in the northwest region and the future temperature is uncomfortable for livelihood activities.

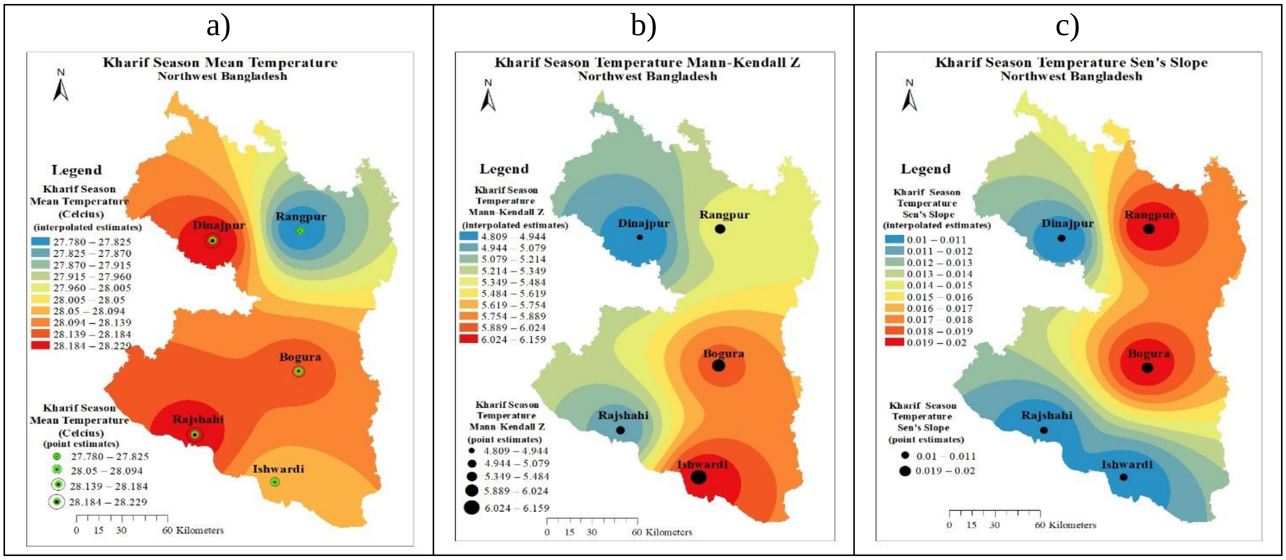


Fig. 4.11 Spatial distribution of *Kharif* season temperature a) annual average b) MK test statistic and c) Sen's Slope estimates

Table 4.12 Long-term seasonal temperature trend test results

Stations	*Rabi* Season			Pre-*Kharif* Season			*Kharif* Season		
	MK test	Sen's Slope	SR test	MK test	Sen's Slope	SR test	MK test	Sen's Slope	SR test
Bogura	1.85	0.007	1.875	0.48	0.003	0.512	5.95*	0.02*	7.542*
Dinajpur	-0.890	-0.09	-1.130	-3.92*	-0.02*	-4.9*	4.81*	0.01*	5.529*
Ishwardi	-0.834	-0.004	-0.799	0.24	0.001	0.227	6.16*	0.01*	8.016*
Rajshahi	-1.99	-0.01	-1.671	2.77*	0.015*	-0.744	4.96*	0.01*	6.118*
Rangpur	2.81*	0.014*	2.956*	2.77*	0.02*	2.753*	5.41*	0.02*	6.216*

*****Significant trends at 5% level, Sen's slope unit is in mm per year

The linear trend analysis during 1960-2021 are displayed in (Fig. 4.12). The graphical analysis indicates that annual average temperature trend lines are decreasing at Dinajpur and Rajshahi stations, and increasing at Rangpur, Bogura, and Ishwardi stations. It is clearly observed that in the year 1976 the annual average temperature hits 20.64°C, which is the minimum during the period 1960-2021. On the other hand, Rajshahi station predicts annual maximum temperature 26.57°C in the year 1972.

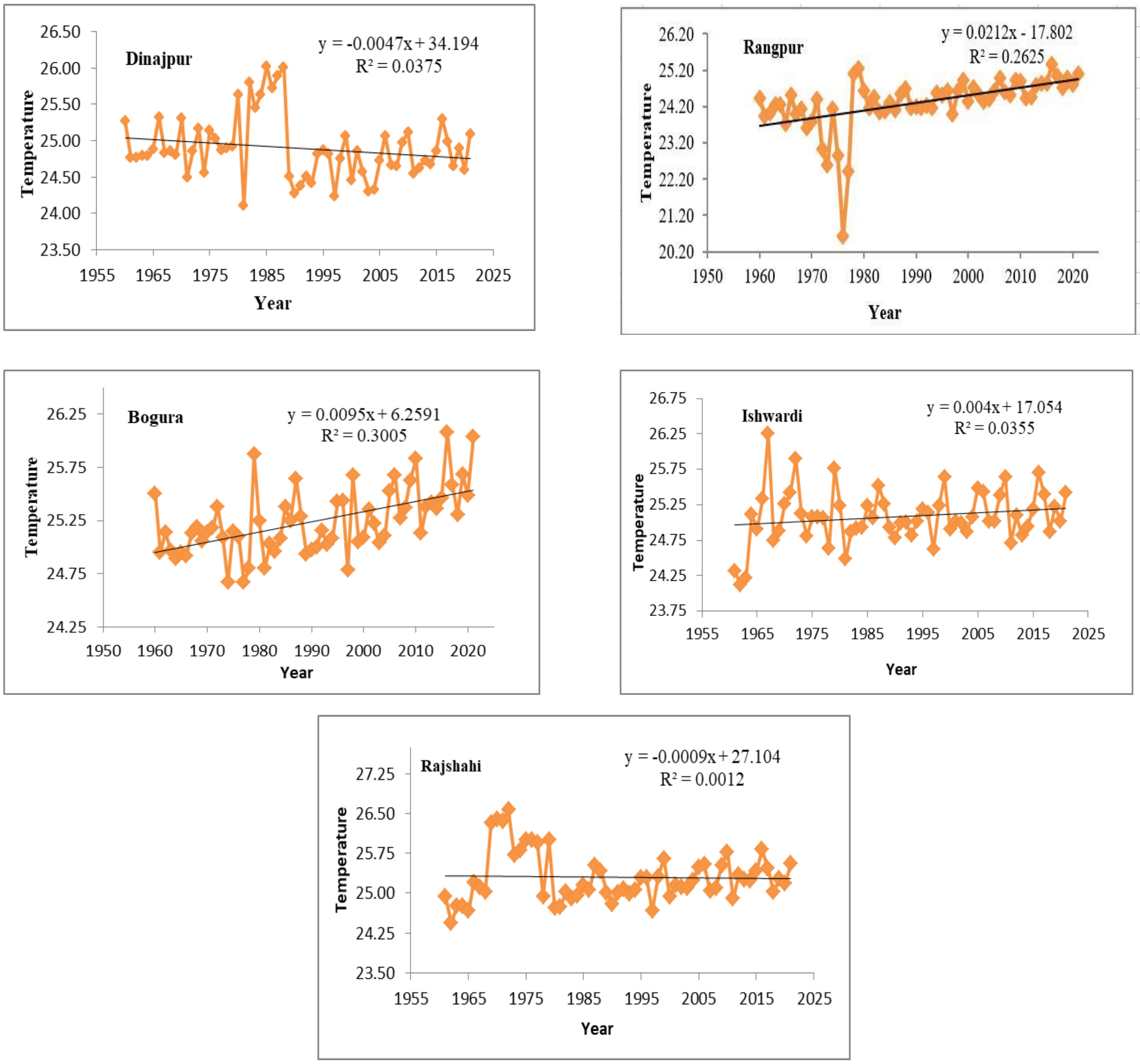


Fig. 4.12 Linear regression trends of annual average temperature during 1960-2021

4.2.7 Sequential Mann-Kendall (SMK) Analysis for Annual Rainfall and Temperature

4.2.7.1 Annual Rainfall

The SMK test determines the approximate year where the trend begins at 95% confidence limit. Results from the SMK test revealed that considering *u(t)* statistics had almost similar to the MK test with decreasing trend at Bogura, Rajshahi, and Ishwardi stations. Here, no-significant change of points portrayed in Bogura and Ishwardi station but approximately,15 years ago some abrupt change of annual rainfall was found at Rajshahi station with a significant change point. Meanwhile, the rest of the stations (Dinajpur and Rangpur) showed rising trend that start early year of 60's but after 2004 noticeable decreasing changes also discovered. The SMK plot of different meteorological stations of northwest zone is exhibited in (Fig. 4.13).

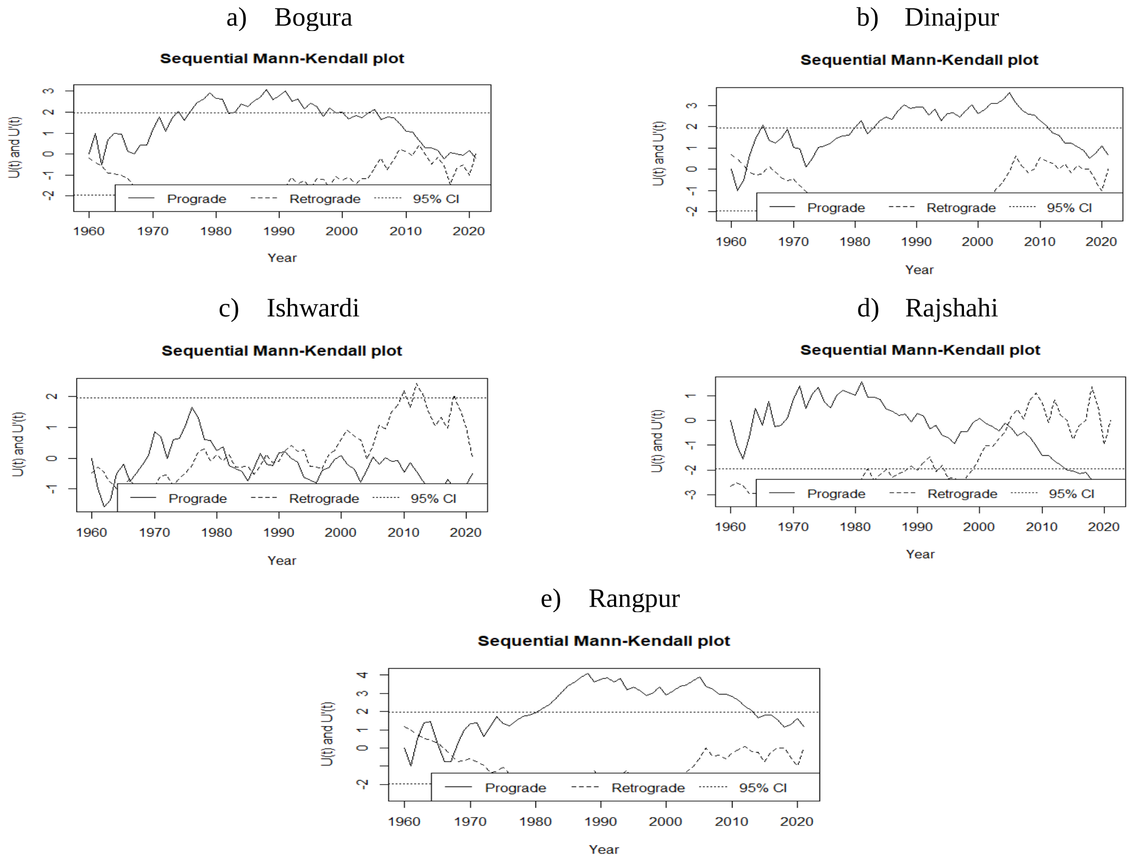


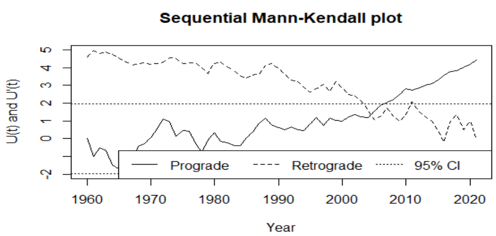
Fig. 4.13 Detection of annual rainfall trends a) Bogura b) Dinajpur c) Ishwardi d) Rajshahi e) Rangpur by SMK test

4.2.7.2 Annual Temperature

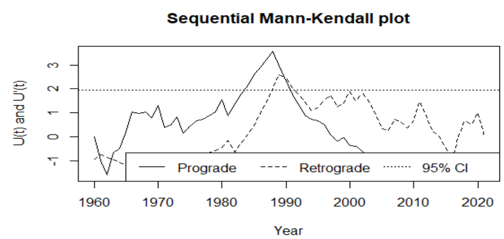
The annual temperature analysis of the SMK test showed an upward trend in almost all stations except Dinajpur. From trend analysis, more than one non-significant trend turning points was described at Dinajpur, Ishwardi, and Rajshahi stations but only Dinajpur station discovered decreasing trend which starts from 1988 to 1990 and it continued till 2020. On the other hand, Rajshahi and Ishwardi stations also found periodic fluctuations between the late 1990s and 2020. A periodic trend turning point was detected at Bogura and Rangpur stations in the year 2003-

2004 and the increment significantly continued. In a nutshell, the temperature trend analysis was dominant after 2003 for both Bogura and Rangpur stations. The following Fig. 4.14 represents SMK trend plot of annual temperature of different meteorological stations.

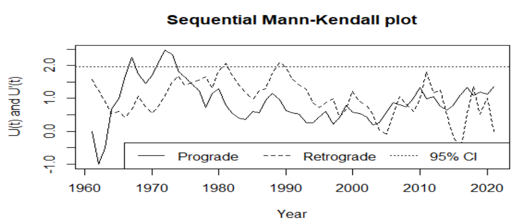
a) Bogura



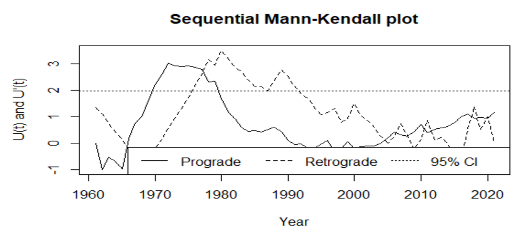
b) Dinajpur



c) Ishwardi



d) Rajshahi



e) Rangpur

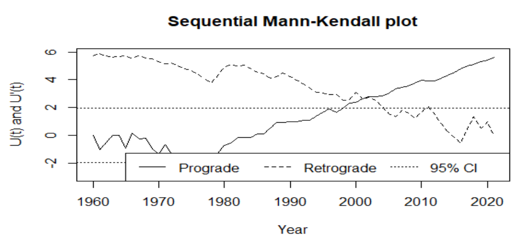


Fig. 4.14 Detection of annual temperature trends a) Bogura b) Dinajpur c) Ishwardi d) Rajshahi e) Rangpur by SMK test

4.3 Forecast from ARIMA Models

According to different trend analysis methods, the northwest zone experiences high temperatures and less rainfall throughout the year. The country's economy mostly depends on agricultural production and about 80% of the population, directly and indirectly, depends on primary economic activities (Kamruzzaman et al., 2018). In our country, the summer monsoon receives the most precipitation, which directly affecting our agricultural productivity. Adequate information on total rainfall and temperature characteristics help our farmers and policymakers to draw a comprehensive picture of the monsoon and dry seasons. Early climate prediction lessens significant crop damage from drought, flood, and other climatic calamities. Moreover, if the total annual rainfall is normal, the intra-seasonal variability, such as early monsoon onset or usual monsoon throughout the year may cause unavoidable disruption of agricultural activities, hydro-electric power supply, groundwater depletion, or even drinking water supply. The ARIMA technique is applied here to forecast monthly rainfall and temperature data for next five years (60 months) based on previous sixty years data. Previous years' data are cast-off to articulate the seasonal ARIMA model in determining model parameters.

4.3.1 Monthly Rainfall Forecast

Sixty years of monthly rainfall data are analyzed and predict future rainfall scenarios. The following table provides the estimated parameters for the ARIMA model of monthly rainfall (Table 4.13).

Table 4.13 ARIMA models of monthly rainfall data

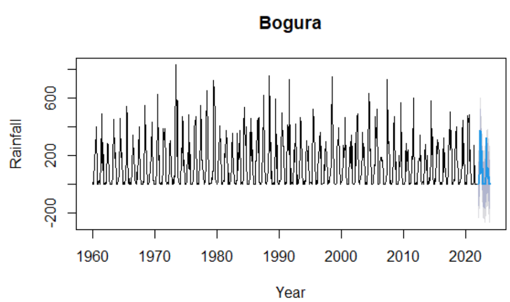
Station	Month January 1960-December 2021				
	Model	Sigma^2 Estimated	Log likelihood	AIC	BIC
Bogura	ARIMA (0,0,1) (1,1,0) [12]	14253	-4540.04	9086.09	9099.87
Dinajpur	ARIMA (0,0,3) (2,1,0) [12]	17660	- 4618.73	9249.45	9277.0
Ishwardi	ARIMA (1,0,0) (1,1,0) [12]	13235	-4513.08	9032.16	9045.95
Rajshahi	ARIMA (1,0,0) (1,1,0) [12] with drift	9365	-4386.2	8780.4	8798.78
Rangpur	ARIMA (1,0,0) (1,1,0) [12] with drift	21813	-4695.41	9398.83	9417.21

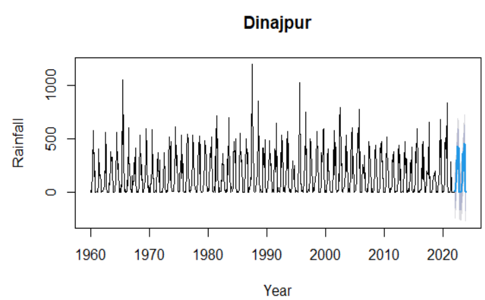
The station-wise forecasting values of the next five years monthly rainfall of different stations is displayed in (Table 4.14). In our study, monthly rainfall varied one station to another due to the diverse geographical locations. It is clearly observed that yearly average rainfall of between the year 2022 to 2026 is decreasing in Bogura, Rajshahi, Rangpur, Dinajpur station but increasing in Ishwardi station. The time series plot of five meteorological stations are clearly described the future trend detection (Fig 4.15)

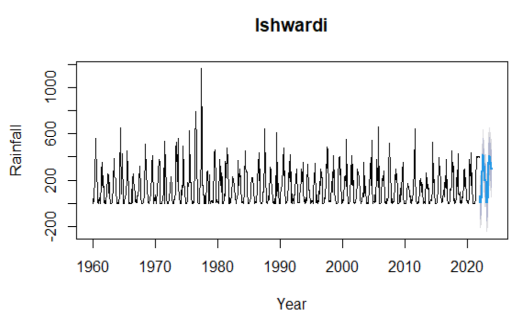
Table 4.14 Monthly average rainfall forecast for next 5 years (2022-2026)

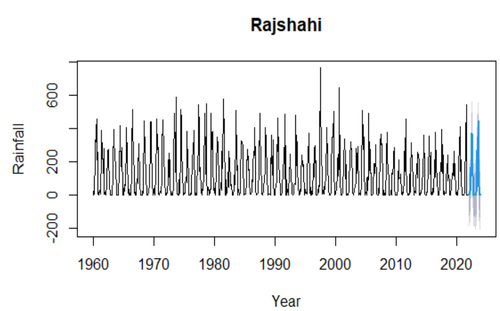
Month	Year	Bogura	Dinajpur	Ishwardi	Rajshahi	Rangpur
Jan	2022	6	5	66	8	3
Feb	2022	1	18	7	0	0
Mar	2022	17	10	12	14	17
Apr	2022	66	83	35	23	111
May	2022	375	297	282	165	346
Jun	2022	216	225	314	273	199
Jul	2022	240	432	420	371	410
Aug	2022	82	214	277	325	92
Sep	2022	118	421	328	114	529
Oct	2022	78	84	281	52	60
Nov	2022	0	1	193	0	0
Dec	2022	0	0	198	0	0
Jan	2023	3	3	32	3	0
Feb	2023	0	9	4	0	0
Mar	2023	12	14	6	6	9
Apr	2023	45	70	38	18	67
May	2023	325	355	229	151	345
Jun	2023	109	229	356	267	96
Jul	2023	121	380	411	346	199
Aug	2023	41	193	342	442	44
Sep	2023	60	457	363	52	257
Oct	2023	39	64	344	23	28
Nov	2023	0	1	297	0	0
Dec	2023	0	0	303	0	0
Jan	2024	4	2	50	5	0
Feb	2024	1	8	6	0	0
Mar	2024	15	8	9	9	12
Apr	2024	56	56	36	20	89
May	2024	350	310	256	157	345
Jun	2024	162	141	335	270	147
Jul	2024	180	251	416	359	306
Aug	2024	62	126	308	378	67
Sep	2024	89	274	345	85	395
Oct	2024	58	46	311	38	43
Nov	2024	0	1	244	0	0
Dec	2024	0	0	249	0	0
Jan	2025	4	4	41	3	0
Feb	2025	1	12	5	0	0
Mar	2025	13	10	8	7	10
Apr	2025	50	70	37	18	77
May	2025	337	318	242	153	344
Jun	2025	136	197	346	267	120

Jul	2025	151	356	414	351	250
Aug	2025	52	178	325	412	54
Sep	2025	74	381	354	66	323
Oct	2025	49	65	328	29	35
Nov	2025	0	1	271	0	0
Dec	2025	0	0	277	0	0
Jan	2026	4	3	45	3	0
Feb	2026	1	10	5	0	0
Mar	2026	14	11	9	7	10
Apr	2026	53	66	37	19	82
May	2026	344	330	250	155	343
Jun	2026	149	193	340	268	133
Jul	2026	165	335	415	354	278
Aug	2026	57	169	317	393	60
Sep	2026	81	380	350	76	359
Oct	2026	53	59	319	33	38
Nov	2026	0	1	257	0	0
Dec	2026	0	0	263	0	0









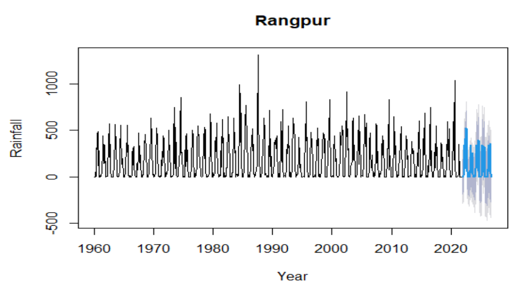


Fig. 4.15 Forecasting monthly rainfall of different stations located in northwest Bangladesh

4.3.2 Monthly Temperature Forecast

The monthly temperature predictions of all stations are detailed below (Table 4.14). The expected parameters of the ARIMA model for the next five years based on the previous sixty years data.

Table 4.14 ARIMA models of monthly temperature data

Stations	Month January 1960-December 2021				
	Model	Sigma^2 Estimated	Log-likelihood	AIC	BIC
Bogura	ARIMA (2,0,2) (2,1,0) [12] with drift	1.103	-1073.5	2163	2199.76
Dinajpur	ARIMA (0,0,3) (2,1,2)12]	0.9458	-1023.63	2063.27	2100.03
Ishawrdi	ARIMA (2,0,2) (2,1,2) [12]	0.6953	-897.94	1813.89	1855.1
Rajshahi	ARIMA (0,0,2) (0,1,1) [12] with drift	0.8151	-954.94	1919.88	1942.78
Rangpur	ARIMA (0,0,1) (0,1,1) [12] with drift	1.317	-1146.91	2301.82	2320.2

It has been detected that the monthly forecasting temperature is not only fluctuates in one station with a small margin (Fig. 4.16) but also fluctuating from one station to another. Moreover, in the northwest zone, yearly average temperature will increase gradually but future temperature of Bogura, Rajshahi and Ishwardi stations are much higher than Dinajpur and Rangpur stations Table 4.15.

Table 4.15 Monthly average temperature forecast for next 5 years (2022-2026)

Month	Year	Bogura	Dinajpur	Ishwardi	Rajshahi	Rangpur
Jan	2022	17.80	15.77	16.07	16.57	16.01
Feb	2022	20.82	19.60	20.08	20.20	19.93
Mar	2022	25.54	23.95	25.24	25.13	24.04

Apr	2022	27.94	26.74	28.68	28.62	26.55
May	2022	28.37	28.04	29.22	29.23	27.60
Jun	2022	29.22	29.43	29.52	29.78	29.09
Jul	2022	29.43	29.35	29.04	29.26	29.32
Aug	2022	29.81	29.62	29.18	29.48	29.59
Sep	2022	29.29	28.83	28.79	28.99	28.85
Oct	2022	28.11	26.81	26.78	27.01	27.12
Nov	2022	24.21	22.28	22.35	22.44	22.86
Dec	2022	18.93	17.62	17.85	18.09	18.35
Jan	2023	17.59	15.63	15.97	16.30	16.40
Feb	2023	20.85	19.52	20.01	20.05	19.95
Mar	2023	25.71	24.00	25.11	25.13	24.06
Apr	2023	28.06	26.77	28.55	28.62	26.57
May	2023	28.17	27.95	29.20	29.24	27.61
Jun	2023	29.13	29.41	29.53	29.78	29.11
Jul	2023	29.49	29.35	29.01	29.26	29.34
Aug	2023	29.73	29.64	29.18	29.48	29.61
Sep	2023	29.38	28.85	28.76	29.00	28.87
Oct	2023	28.38	26.89	26.74	27.02	27.13
Nov	2023	24.19	22.21	22.32	22.45	22.88
Dec	2023	19.04	17.64	17.82	18.09	18.37
Jan	2024	17.61	15.73	15.96	16.31	16.42
Feb	2024	21.06	19.58	19.97	20.05	19.97
Mar	2024	25.92	24.00	25.08	25.14	24.07
Apr	2024	28.32	26.81	28.50	28.62	26.59
May	2024	28.25	28.00	29.16	29.24	27.63
Jun	2024	29.08	29.42	29.53	29.79	29.13
Jul	2024	29.52	29.39	29.02	29.27	29.36
Aug	2024	29.64	29.60	29.20	29.49	29.63
Sep	2024	29.44	28.89	28.78	29.00	28.89
Oct	2024	28.33	26.87	26.77	27.02	27.15
Nov	2024	24.26	22.25	22.32	22.45	22.90
Dec	2024	19.11	17.64	17.81	18.10	18.38
Jan	2025	17.67	15.67	15.96	16.31	16.43
Feb	2025	20.95	19.54	19.95	20.06	19.98
Mar	2025	25.77	24.00	25.07	25.14	24.09
Apr	2025	28.15	26.77	28.47	28.63	26.61
May	2025	28.27	27.97	29.14	29.24	27.65
Jun	2025	29.15	29.41	29.53	29.79	29.14
Jul	2025	29.51	29.36	29.03	29.27	29.38
Aug	2025	29.73	29.63	29.22	29.49	29.65
Sep	2025	29.40	28.86	28.81	29.00	28.91
Oct	2025	28.31	26.88	26.79	27.02	27.17
Nov	2025	24.24	22.23	22.33	22.45	22.92
Dec	2025	19.06	17.64	17.80	18.10	18.40

Jan	2026	17.65	15.71	15.97	16.31	16.45
Feb	2026	20.98	19.57	19.94	20.06	20.00
Mar	2026	25.82	24.00	25.07	25.14	24.11
Apr	2026	28.20	26.80	28.45	28.63	26.62
May	2026	28.25	27.99	29.13	29.25	27.67
Jun	2026	29.14	29.42	29.53	29.79	29.16
Jul	2026	29.52	29.38	29.05	29.27	29.40
Aug	2026	29.72	29.61	29.23	29.49	29.66
Sep	2026	29.43	28.88	28.82	29.01	28.93
Oct	2026	28.35	26.87	26.81	27.03	27.19
Nov	2026	24.25	22.24	22.34	22.46	22.94
Dec	2026	19.09	17.64	17.80	18.10	18.42

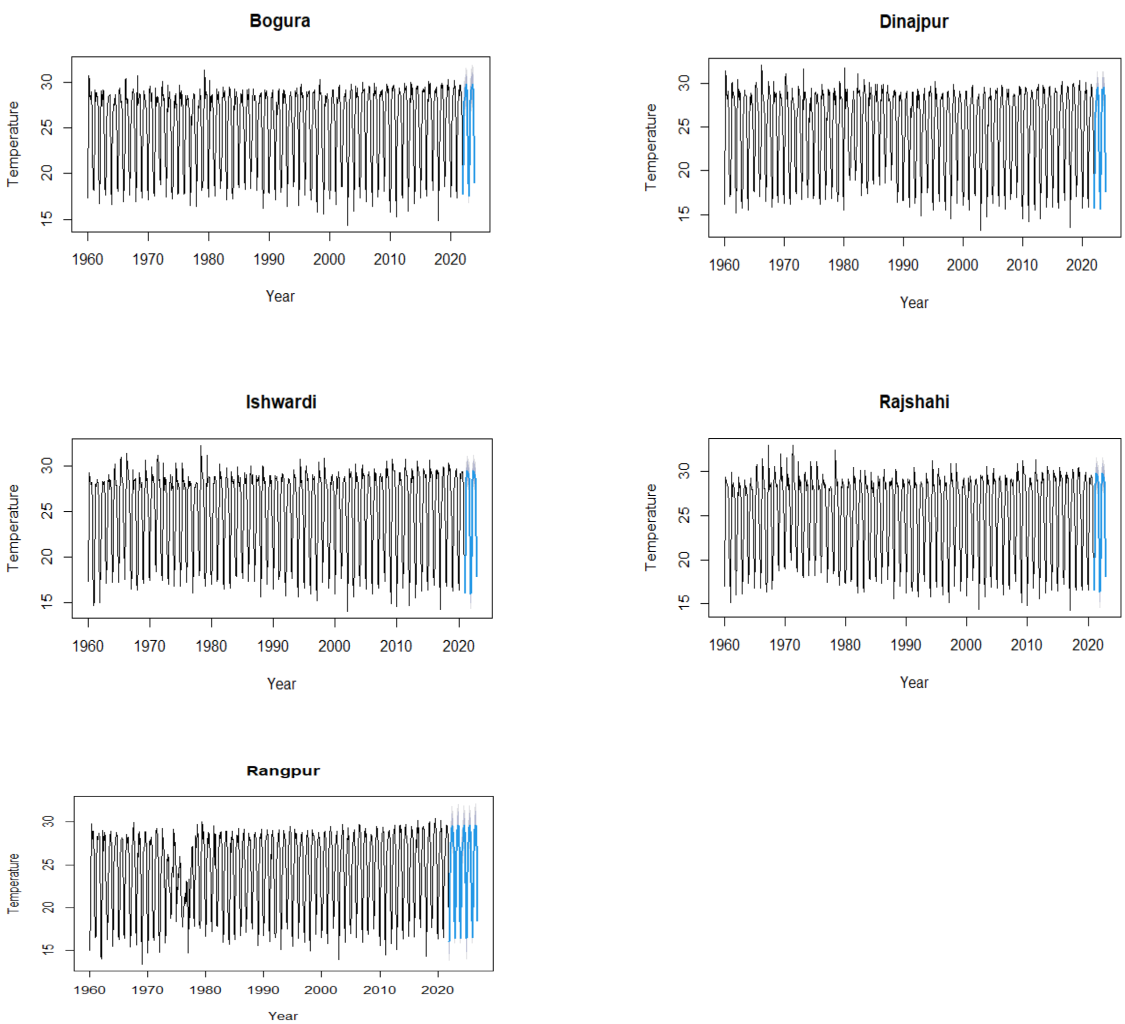


Fig. 4.16 Forecasting monthly temperature of different stations located in northwest Bangladesh

4.4 Conclusion

The present chapter elaborates on latest trends in rainfall variability and temperature during 1960-2021 at five distinguished weather stations in northwest Bangladesh. The MK test and SR test are equally effective in assessing rainfall and temperature trends. Sen's estimation also gives excellent results, and it is almost identical to the MK test statistic and SR test results. From study, the annual average rainfall is 1768 mm and temperature is 24.96°C. Rangpur station shows the highest amount of annual average rainfall and Rajshahi station receives the maximum average temperature in the northwest zone. The study findings discover that only Rajshahi station shows maximum significant downward trend of annual rainfall (-5.50 mm/year), as well as the *Kharif* season (-3.80 mm/year) also by Sen's estimation. However, other stations represent increasing/decreasing trend by the MK test, SR test and Sen's slope estimator, but they are not statistically significant. The total rainfall statistic exhibits a substantial change during the research period. These kinds of changes in most of the stations placed the northwest region in danger and increased drought frequency.

However, Climate variable like temperature also observe an increasing trend 80% of stations, but Dinajpur station reveals a falling trend with a magnitude of change -0.003°C/year. From cropping season temperature trend analysis, both upward and downward trends are found during the *Rabi,* and pre-*Kharif* seasons. But *Kharif* season shows significant increasing trend at 5% level of significance. The degree of change is assessed by Sen's slope estimates differ from 0.01 to 0.02°C/year with a mean value of 0.014°C/year. Additionally, S-MK analysis has illustrated the starting and turning points of the annual trends. In this chapter, the ARIMA models are used for long-term monthly rainfall and temperature data to forecast future trend in the northwest region. Based on the findings, the information is gathered consistent with the previous studies, and this will be supportive for farmers, policymakers and researchers for scheduling climate change scenarios in local scale. Therefore, sustainable adaptation practices are mandatory for agricultural development which ensures food security of huge population within limited resources and extreme climate variability.

Chapter Five

Drought Characterization using Standardized Precipitation Index and Markov Chain Process

5.1 Introduction

Drought is a recurring extreme event which is totally different from any other natural disaster. It is one of the most important issues for local and regional management around the world, especially in sub-continental regions that suffers lack sufficient water (Van Loon & Van Lanen, 2013). Drought mainly effects agriculture, environment and livelihood patterns of people, even though its characteristics and impacts differ so widely from region to region (Wilhite, 1997). Because of geographic location, Bangladesh carries high population density, extreme poverty and a high percentage of dependency on livelihoods such as climate-sensitive industries agriculture, fisheries and food grain products (Nury & Hasan, 2016). According to Habiba et al. (2011), drought mainly occurs a dry period of seven months (November-May), when rainfall is insufficient. Moreover, it happens when evaporation and transpiration exceed the amount of rainfall for a certain period. After the independent war 1971, Bangladesh has experienced many extreme and severe droughts from 1980 to 2010 (Miah et al., 2017). Therefore, it is necessary to find out the drought monitoring and drought severity level through statistical tools.

Various types of indices have been developed to identify and quantify drought occurrences. Globally, most of the drought indices are based on meteorological or hydrological data variables. These includes the Palmer Drought Severity Index (PDSI) (Palmer, 1965), the Standardized Precipitation Index (SPI) (McKee, 1993), and the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010). PDSI is rely on temperature and precipitation as its information sources; however, in contrast to SPI, it is unable to evaluate multi-scale drought features (Belayneh & Adamowski, 2013; Wang Q. et al., 2015). In order to address this problem, McKee (1993), developed the SPI index, which connects to the multi-scale character of droughts. Despite World Meteorological Organization (WMO) regarded that the SPI as the most reliable and useful drought indicator, since it could be observed for different time periods and used to analyze various drought categories (Capra & Scicolone, 2012). Furthermore, SPI is very easy to calculate and less complex than the PDSI (Hayes et al., 1999) ; because it depends on only precipitation data and makes it possible to compare drought conditions across various time periods and geographical regions (Wu et al., 2005). According to the definition, SPI is the number of standard deviations that the observed value would deviate from the long-term average (or median) for a normally distributed random variable. Since precipitation series are typically not normally distributed, however, a transformation is initially used to make the transformed precipitation data follow a normal distribution. SPI is a precipitation-based index and it can measure the severity of the lack of precipitation at several points of time, which are usually 1, 3, 6, 9, 12 and 24 months, respectively. Such as: 3-month time scales SPI represents the standard deviation of precipitation 1-3 months and 12-month timescales SPI represents the standard deviation of precipitation 1-12 months. It is recommended that 1-month, 3-month and 6-month SPI time scales may reflect seasonal drought and 9-month, 12-month and 24-month SPI time scales may reflect a regional long-term drought condition. One month SPI values can be expressed as (SPI 1), 3-month as (SPI 3), 6-month (SPI 6), 9-month (SPI 9), 12-month (SPI 12) and 24-month (SPI 24), respectively (McKee et al., 1993).

A common way is to analyze the frequency of droughts is to derive the distribution of drought duration and drought severity separately (Mathier et al., 1992, Stedinger et al., 1993). A drought analysis is a multivariate event that can be describe by its frequency, intensity and duration, which are mutually correlated (Salas, 1993). Many researchers observed the drought frequency and severity by applying different method. González & Valdés, (2003) developed a theoretical formulation of the recurrence interval for the general case of drought durations and severities using an alternate renewal procedure. In the Indian Kansabati River Basin, Mishra et al., (2009) investigated the distribution of drought interval time, mean drought interval time, joint probability density function and transition probabilities of drought event by using alternating renewal process and run theory. Markov model is also used in various fields to anticipate drought. A Markov Chain model is created by using daily rainfall data and incorporating a variety of rainfall-related factors. Zhang & Zhou, (2010) used to predict drought occurrences by dual-criteria decision methods and Markov Chain models. Now-a-days, machine learning approach apply with the help of SPI and SPEI for drought forecasting (Rhee & Im, 2017; Yaseen et al., 2021). In our country very few researcher recently applied SPI to identify drought conditions and assessment (Alamgir et al., 2015; Nury & Hasan, 2016; Rahman & Lateh, 2016; Shahid & Behrawan, 2008; Uddin et al., 2020). In this section, drought characteristics are developed by indexing precipitation data, which is utmost important for agriculture and water resources sector. The objective of the study is to understand the nature of SPI using alternating renewal process, drought interarrival time and mean drought interarrival time, probability models and transition probabilities of drought events in the northwest region of Bangladesh. The monthly rainfall values are used to determine the SPI values. The study only takes wet and dry conditions into account. A transition probability technique is used to assess the probability of a change and the persistence of drought in the dry state, which is separated into the four states (D1, D2, D3, and D4) (Mishra et al., 2009). In many cases, higher months of SPI series is used for drought characterization by using Markov first order model.

Monthly rainfall data for the period 1960-2021 of selected rainfall stations (Bogura, Dinajpur, Ishwardi, Rajshahi and Rangpur) have been used for characterizing drought and drawing probability models. The SPI values of different time scales (1, 3, 6, 9, 12 and 24 months) established on monthly precipitation data are shown in Fig. (5.1-5.5). Das et al. (2020) explained drought monitoring by using SPI of various time scales over Luni River Basin in Rajastan; India. The drought episodes and the proportion of the Rajastan area were calculated SPI for short-term (1, 3, 6 month) and long-term (9, 12 and 24 month) in their study. It is highly recommended that if any of the meteorological stations are exceeded (SPI > 2) the extreme wet event and extreme drought event (SPI < -2) with different SPI values. In this study, the horizontal line is indicated by years; starting from (0=1960, 1=1961 ………….60=2020, 61=2021 and so on) and the vertical line assigned with SPI values ranges from -3 to +3 for the selected stations.

5.2 Results and Discussions on Different Stations of Northwest Bangladesh

It is necessary to identify drought characterization of different by using SPI index values, two state Markov model process, distribution of drought interarrival time, mean drought interarrival time, transition probabilities of drought states. The SPI was developed primarily for defining and monitoring drought. It allows an analyst to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. It can also be used to determine periods of anomalously wet events. A drought event is considered to occur at a time when the value of SPI continuously negative and end when SPI becomes positive. Table 5.1 provides a drought classification based on SPI.

Table 5.1 Drought categorization based on the SPI

SPI Values	Class
2.00 or more	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderate wet
-0.99 to 0.99	Mild drought
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.0 or less	Extreme drought

Another important thing is the probabilistic characterization of the progression and recession of droughts with the help of transition probabilities of dry state. A dry state is classified into four states based on the SPI values, as shown in (Table 5.2). Finally in order to explore the probabilistic characteristics of dry spells, a four state Markov model is useful to SPI series. Furthermore, it is possible to determine the transition probability matrix of different station that an event currently in state *'i'* will move to state *'j'* in the next time period.

Table 5.2 Classification of drought states

Drought Category	SPI values
D1(Mild drought)	0 to -0.99
D2(Moderate drought)	-1.00 to -1.49
D3(Severe drought)	-1.50 to -1.99
D4(Extreme drought)	< -2.0

5.2.1 Bogura Station

SPI values of different scales from 1960 to 2021 at Bogura stations of northwestern Bangladesh are shown in Fig (5.1). The SPI series of short-time (SPI 1, SPI 3, SPI 6) values reveals that during 1970 to 2010 moderate, severe and extreme wet conditions are happened with high percentage rather than dry periods. According to long term SPI series (SPI 9, SPI 12, SPI 24) it is clearly observed that maximum extreme and severe droughts are occurred during the decades of the year 1960 to 1970 and 2010 to 2020. From the graphical analysis, the blue spike and the red spike indicates wet spells and dry spells respectively.

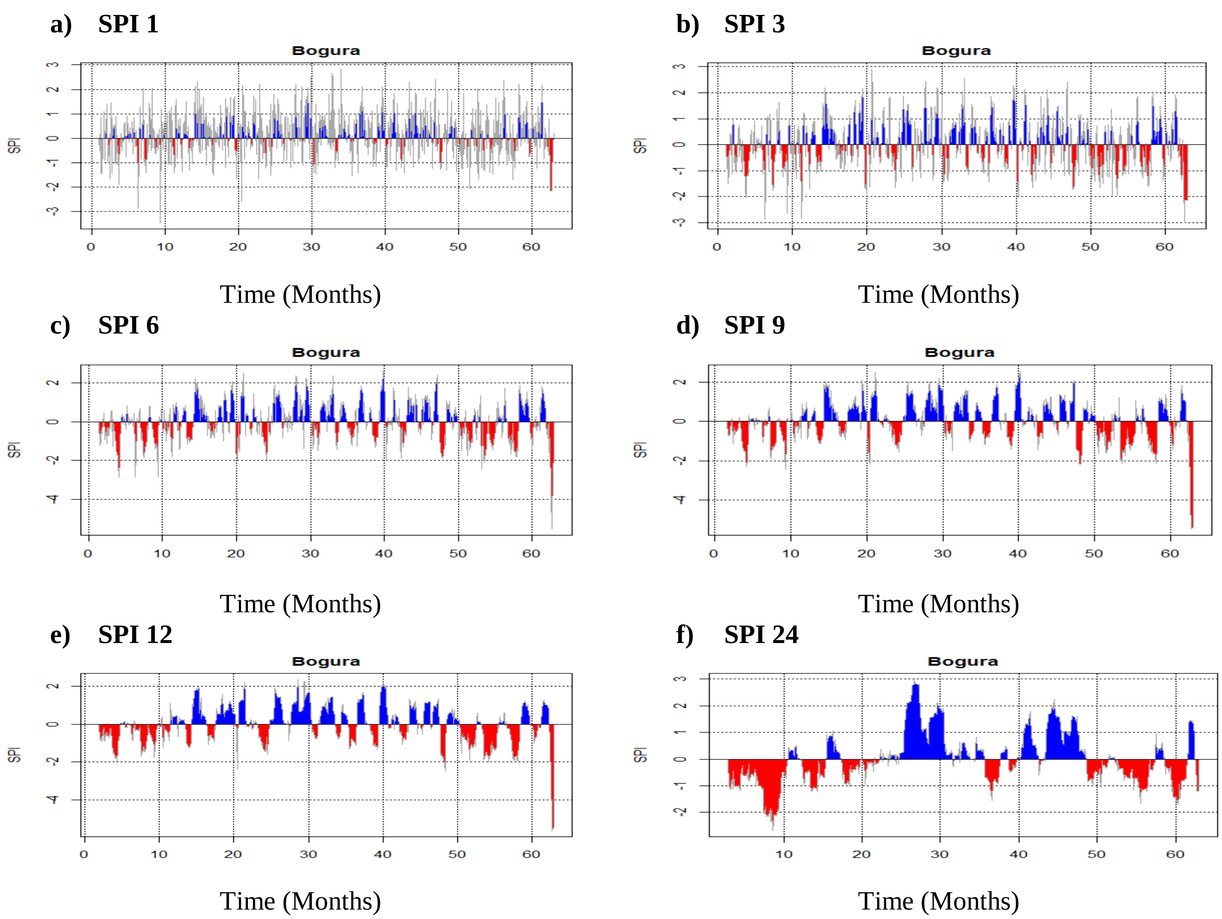


Fig. 5.1 SPI series based on monthly rainfall of Bogura station in the study area (a) SPI 1 (b) SPI 3 (c) SPI 6 (d) SPI 9 (e) SPI 12 (f) SPI 24

5.2.2 Two State Markov Model for Bogura Station

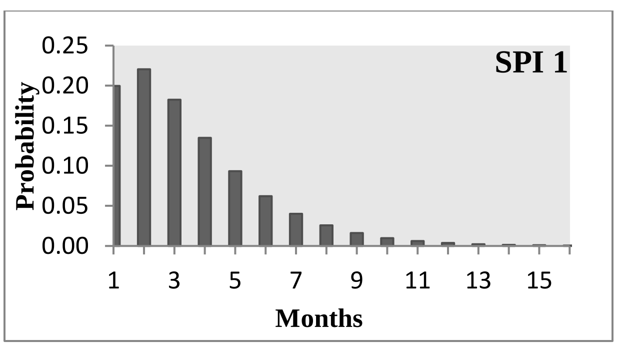
Different SPI series of stochastic process with associated transition probabilities of two states (dry and wet) can be treated as alternating renewal process. Table 5.3 depicts that the distribution of drought duration between two states are listed below according to different SPI series. Here two state Markov process is used for the analysis of drought duration. Therefore the results of drought distribution of two state Morkov model are shown in Table 5.1.The values of P_{DD}, P_{WD}, P_{DW}, and P_{WW} for different SPI series are classified according to the percentage of the transition probabilities. It is clearly observed that during the period 1960-2021 P_{DD} and P_{WW} have increased for longer SPI series at Bogura station with 95% probability but P_{WD} and P_{DW} have decreased with low percentage of probabilities with 4.91% and 4.55% respectively.

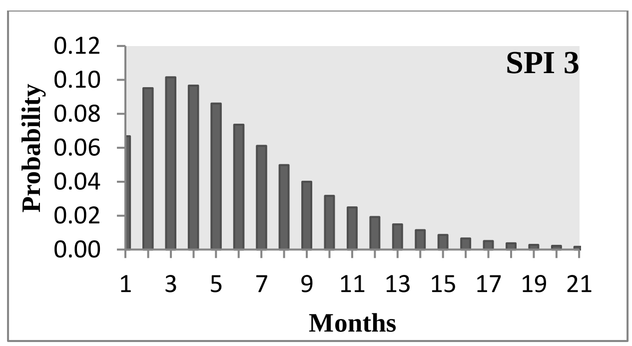
Table 5.3 Transition probabilities values of two state Markov chain for Bogura station

SPI	P_{DW}	P_{DD}	P_{WD}	P_{WW}
SPI 1	0.4840	0.5160	0.4125	0.5875
SPI 3	0.2873	0.7127	0.2876	0.7124
SPI 6	0.2143	0.7857	0.2086	0.7914
SPI 9	0.1524	0.8476	0.1471	0.8529
SPI 12	0.0944	0.9056	0.0914	0.9086
SPI 24	0.0455	0.9545	0.0491	0.9509

5.2.3 Distribution of Drought Interarrival Time at Bogura Station

By using the equation (3.25) of drought distribution interarrival time, a model was developed for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, and SPI 24 to estimate parameters. As shown in Fig. 5.2, the model outputs results are contrast with the historical data set of observe drought interarrival times for various SPI series. The historical data set is insufficient for higher SPI series since it is unable to identify greater number of drought events than the synthetic data collection, which is utilized to estimate more drought occurrences. It is observed that the drought interarrival time of 2 months has the highest probability for SPI 1. The drought interarrival time of 3 months has the highest probability in between 2- and 4-months SPI 3. In SPI 6 the drought interarrival time of 4 months has the highest probability. For higher SPI series, the drought interarrival time of 6 months, 11 months are observed highest probability for SPI 9 and SPI 12 series. The drought interarrival time for SPI 24, 20 months are predicted highest probability.





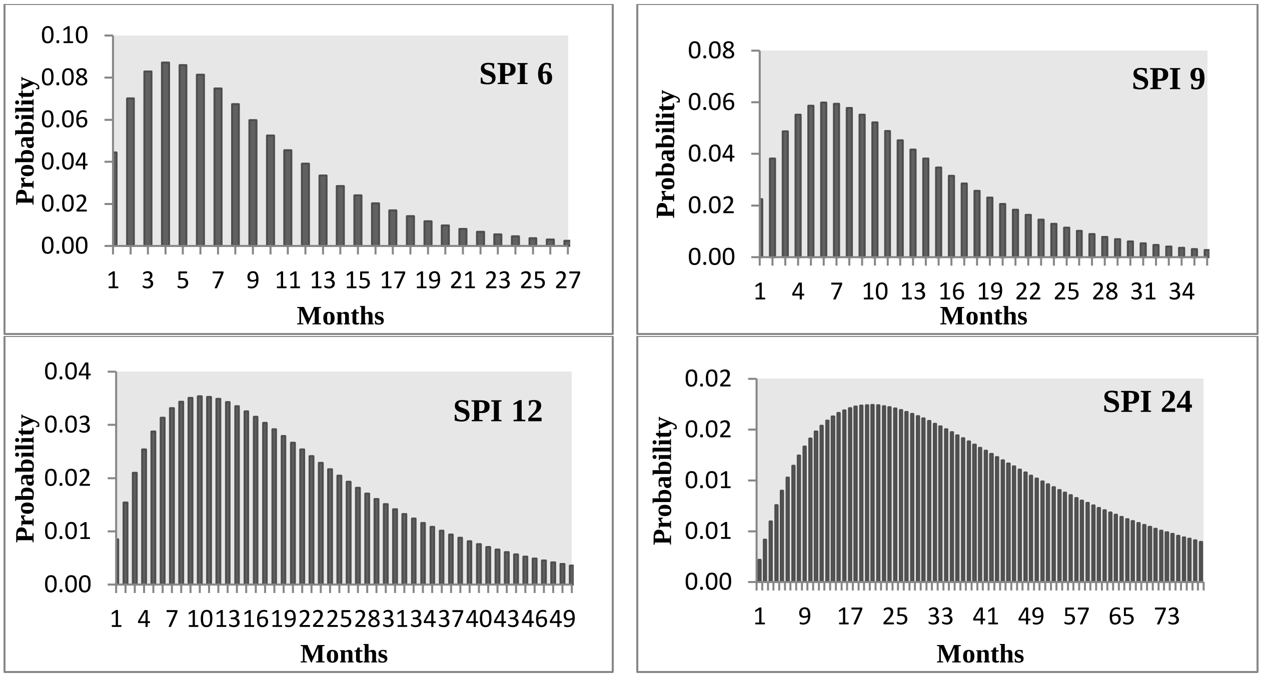


Fig. 5.2 Drought interarrival time distribution of historical data for SPI1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24 (Bogura)

5.2.4 Transition Probabilities Matrix of Different SPI Series of Bogura Station

The transition probability matrix of SPI 1 Table 5.4 (a) reveals that a state ‘D1’ will follow a state ‘D1’ with a probability 0.8000, which is very high percentage of transition around 80% in comparison to other states. So there is high chance that ‘mild drought’ period would follow a ‘mild drought’ period. State ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.2895 and 0.7105, respectively. Thus after moderate dry period there is a high chance that would follow ‘moderate drought’ period then after very low chance to follow ‘mild drought’ period. Again states ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1667 and 0.8333. However, after a ‘severe drought period’ there is very high chance that would follow ‘severe drought period’ then after would follow mild drought period. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.2000 and 0.8000, respectively. Therefore, after an ‘extreme drought period’ there is a high chance that ‘extreme drought period’ would follow with the next probability that a ‘mild drought’ period will follow. For SPI 1 it is found that a ‘mild drought’ period follows after every dry period and extremely dry period would follow an extremely dry period.

The transition probability matrix for SPI 3 is shown in Table 5.4 (b). It is observed that a state ‘D1’ would follow a state ‘D1’ with probability 0.7152, which is very high percentage of transition around 72% in comparison to other states. So there is high chance that ‘mild drought’ period would follow a ‘mild drought’ period. State ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.3254 and 0.6746, respectively. Hence after a moderate dry period the chance of a moderate drought period would be high in comparison to ‘mild drought’ period. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1034 and 0.8966. After a ‘severe drought period’ there is nearly very high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.0909 and 0.9091 respectively. Therefore, after an ‘extreme drought period’ the chance that an ‘extreme drought period’ would follow is more than a ‘mild drought period’.

Table 5.4 (c) displays the transition probability matrix for SPI 6. In contrast to other states like ‘D2’, ‘D3’ and ‘D4’ it is noticed that a state ‘D1’ would follow a state ‘D1’ with probability 0.8171, which is a very high percentage of transition probability approximately 82%. So, there is very high chance that a ‘mild drought’ would follow a ‘mild drought’ period. States ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.2755 and 0.7245, respectively. Hence after a ‘moderate drought period’ the chance of a ‘mild drought period’ would be marginal in comparison to ‘moderate drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1176 and 0.8824 respectively. A ‘severe drought period’ is followed by either a ‘mild drought period’ or ‘severe drought period’ with an almost high chance of probability. The chances of ‘D1’ and ‘D4’ coming after ‘D4’ are 0.0714 and 0.9286, respectively. So, after an ‘extreme drought period’ the chance that another ‘extreme drought period’ would follow is higher than after a ‘mild drought period’.

Table 5.4 Transition probability matrix for different SPI series of Bogura station

a) SPI 1

State	D1	D2	D3	D4
D1	0.8000	0.1692	0.0154	0.0154
D2	0.2895	0.7105	0.0000	0.0000
D3	0.1667	0.0000	0.8333	0.0000
D4	0.2000	0.0000	0.0000	0.8000

b) SPI 3

State	D1	D2	D3	D4
D1	0.7152	0.2595	0.0190	0.0063
D2	0.3254	0.6746	0.0000	0.0000
D3	0.1034	0.0000	0.8966	0.0000
D4	0.0909	0.0000	0.0000	0.9091

c) SPI 6

State	D1	D2	D3	D4
D1	0.8171	0.1543	0.0229	0.0057
D2	0.2755	0.7245	0.0000	0.0000
D3	0.1176	0.0000	0.8824	0.0000
D4	0.0714	0.0000	0.0000	0.9286

d) SPI 9

State	D1	D2	D3	D4
D1	0.8680	0.0964	0.0305	0.0051
D2	0.2209	0.7791	0.0000	0.0000
D3	0.1875	0.0000	0.8125	0.0000
D4	0.0526	0.0000	0.0000	0.9474

e) SPI 12

State	D1	D2	D3	D4
D1	0.8920	0.0704	0.0329	0.0047
D2	0.1852	0.8148	0.0000	0.0000
D3	0.1556	0.0000	0.8444	0.0000
D4	0.1000	0.0000	0.0000	0.9000

f) SPI 24

State	D1	D2	D3	D4
D1	0.9504	0.0372	0.0124	0.0000
D2	0.1324	0.8676	0.0000	0.0000
D3	0.0667	0.0000	0.9333	0.0000
D4	0.0000	0.0000	0.0000	1.0000

The transition probability matrix for SPI 9 is shown in Table 5.4 (d). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8680, which is usually high in contrast to other states. So there is high chance that ‘mild drought’ would follow a ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2209 and 0.7791. Therefore, after a moderate drought period the chance of a moderate drought period would be high in comparison to near ‘mild drought’ period. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1875 and 0.8125 respectively. After a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.0526 and 0.9474 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would be higher in comparison to other states.

For SPI 12 the transition probability matrix is exposed in Table 5.4 (e). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8920, which is unusually high in contrast to other states. So there is very high chance that ‘mild drought period’ would follow a near ‘mild drought' period. State 'D2' is followed by states 'D1' and 'D2' respectively, with probabilities of 0.1852 and 0.8148. Therefore, after a moderate drought period the chance of a moderate drought period would be high in comparison to near mild drought period. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.1556 and 0.8444 respectively. After a 'severe drought period' there is almost high chance of probability that 'severe drought period' or 'mild drought period' would follow. Lastly, states 'D1' and 'D4' are followed by state 'D4' with a probability of 0.1000 and 0.9000 respectively. Hence, after an 'extreme drought period' the probability of an 'extreme drought period' would be much higher in comparison to 'mild drought period'.

For SPI 24 the transition probability matrix is exposed in Table 5.4 (f). It is clearly evident that a state 'D1' would follow similar state 'D1' with a probability 0.9504, which is normally high in contrast to other states and nearly close to perfect. So there is very high chance that mild drought period would follow exactly mild drought period. State 'D2' is followed by states 'D1' and 'D2' respectively, with probabilities of 0.1324 and 0.8676. Therefore, after a moderate drought period the chance of a moderate drought period would be high in comparison to near 'mild drought period'. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.0667 and 0.9333 respectively. After a 'severe drought period' there is exactly high chance of probability that 'severe drought period' or 'mild drought period' would follow. Lastly, states 'D4' is followed by state 'D4' with a probability of 1.000, which is perfect. Hence, after an 'extreme drought period' the probability of an 'extreme drought period' would be perfect and much higher probability in comparison to other states.

The persistence of drought is also studied using the transition probability matrix. Similar to the probability that the current drought category will remain the same in the future. This can be noticed by examining the transition probabilities from state 'D1'–'D1', 'D2'–'D2', 'D3'–'D3' and 'D4'–'D4' for all SPI series. Consequently, the persistence values corresponding to various dry states are represented by the diagonal of each transition probability matrix. The persistence probabilities for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24 are shown in Table 5.5. It is observed that the persistence of 'extreme drought state' and 'severe drought state' is very high for all SPI series. When SPI series are examined for persistence; SPI 24 has the highest persistence for staying in the same state, followed by SPI 12 and SPI 9. From the persistence matrix SPI 9, SPI 12, and SPI 24 have strong persistence, since they are based on 9-month, 12-month, and 24-month moving averages because of less variation. The persistence of SPI 1, SPI 3 and SPI 6 are less value because these are based on 1, 3 and 6-month moving average, respectively. So, these values are affected when there is variation in rainfall over shorter period of time. The persistence of drought in an ‘extreme dry state’ and ‘severe dry state’ for SPI 9, SPI 12 and SPI 24 would affect more agricultural area due to shortage of water resources.

Table 5.5 Persistence probability matrix of Bogura station

SPI Series	D1	D2	D3	D4
SPI 1	0.8000	0.7105	0.8333	0.8000
SPI 3	0.7152	0.6746	0.8966	0.9091
SPI 6	0.8171	0.7245	0.8824	0.9286
SPI 9	0.8680	0.7791	0.8125	0.9474
SPI 12	0.8920	0.8148	0.8444	0.8444
SPI 24	0.9504	0.8676	0.9333	1.0000

5.2.5 Dinajpur Station

Dinajpur station shows almost evenly dry and wet periods in short term SPI values (SPI 1, SPI 3, SPI 6) rather than long term periods (SPI 9, SPI 12, SPI 24). Extreme and moderate wet periods are slightly higher percentage during the year 1980-1990, 1990-2000, 2000-2010 (Fig. 5.3 a, b and c). The northwest part based on short term SPI couldn’t detect extreme and severe drought events properly, that’s why higher values of SPI values used for identifying drought periods. It is clearly evident that extreme and severe drought events are occurred 1960-1970, 1970-1980 and 2010-2020. According to SPI 24, after 2010 Dinajpur stations highly identify significant extreme droughts and it still continues present decade also (Fig. 5.3 f). The graphical analysis is shown the distribution of different SPI values by using blue (wet periods) and red (dry periods) spikes.

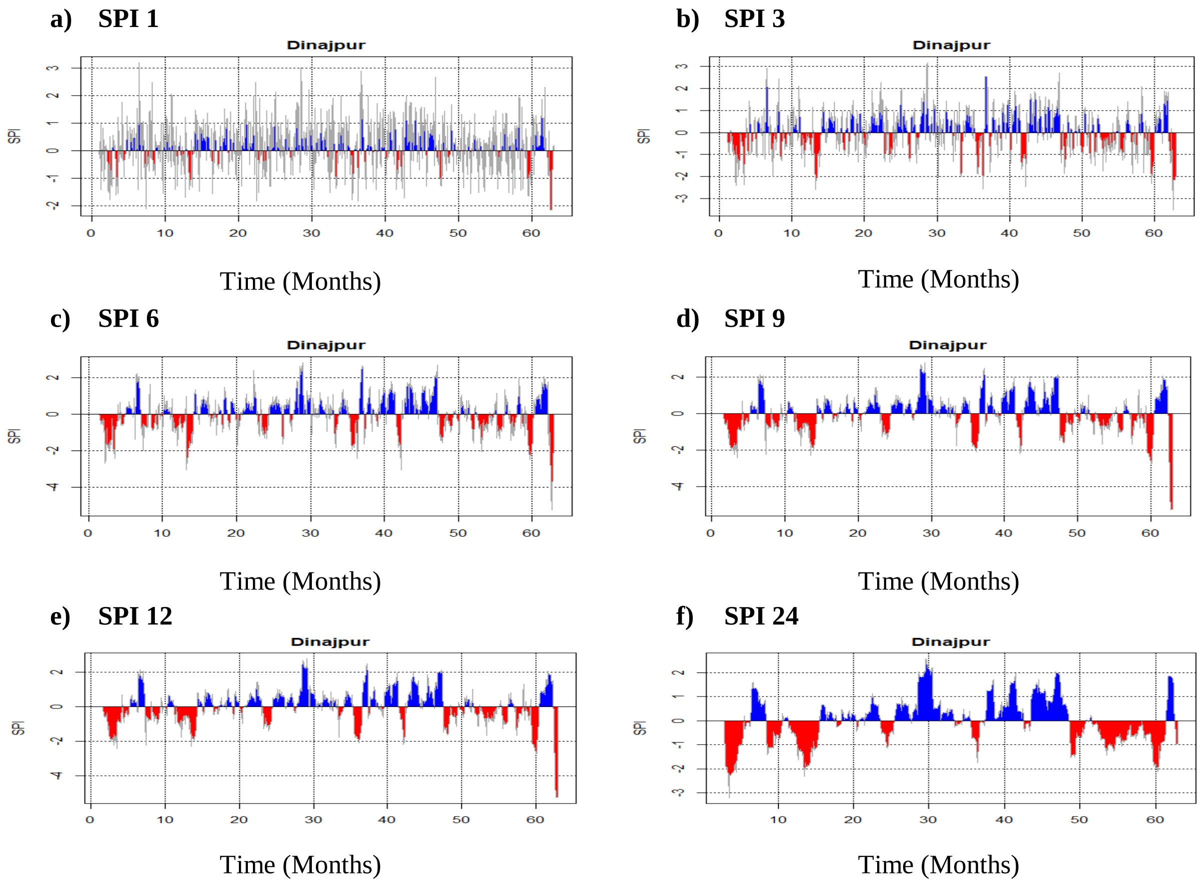


Fig. 5.3 SPI series based on monthly rainfall of Dinajpur stations in the study area (a) SPI 1 (b) SPI 3 (c) SPI 6 (d) SPI 9 (e) SPI 12 (f) SPI 24

5.2.6 Two State Markov Model for Dinajpur Station

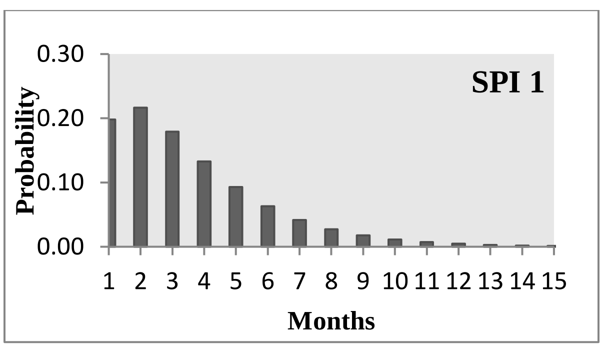
Two state (dry and wet) transition probabilities of different SPI series is used for detecting drought duration. Analysis of drought duration of two state Markov model are presented in (Table 5.6). The transition probabilities of two state Markov model categorized the values of P_{DD}, P_{WD}, P_{DW}, and P_{WW} according to their respective probabilities. During the study period, the probability of dry state P_{DD} are increased for longer SPI series like SPI 12, SPI 24 about 89% and 94% but the transition probabilities of dry to wet state P_{DW} and wet to dry state P_{WD} are initially increased for short term SPI series like SPI 1, SPI 3 and SPI 6, after that these two states are decreased up to 5.7% and 5.9% respectively but P_{WW} reveals highest transition probability ranges from 63% to 94.26%.

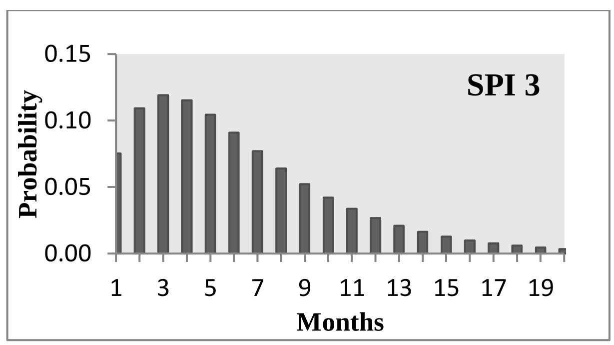
Table 5.6 Transition probabilities values of two state Markov chain for Dinajpur station

SPI	P_{DW}	P_{DD}	P_{WD}	P_{WW}
SPI 1	0.5362	0.4638	0.3690	0.6310
SPI 3	0.2845	0.7155	0.2642	0.7358
SPI 6	0.2046	0.7954	0.1816	0.8184
SPI 9	0.1623	0.8377	0.1436	0.8564
SPI 12	0.1066	0.8934	0.0961	0.9039
SPI 24	0.0593	0.9407	0.0574	0.9426

5.2.7 Distribution of Drought Interarrival Time at Dinajpur Station

A model was established for various SPI series to estimate parameters by using the equation of drought distribution interarrival time. In Dinajpur station the model results are compared with the historical data set of observe drought interarrival times for SPI series. For higher SPI series the synthetic data set are used to predict more drought occurrences and can detect more number of drought events, than the historical data set which is unable for long term SPI outcomes. According to the distribution of drought interarrival time, it is evident that 2 months has the highest probability for SPI 1 followed by 3 months for SPI 3. Meanwhile the drought interarrival time 5 months has the highest probability. The distribution of drought Interarrival time for long term SPI series as 6 months for SPI9, 9 months for SPI 12, 19 months for SPI 24 are anticipated the highest probability of experiencing drought occurrences (Fig. 5.4).





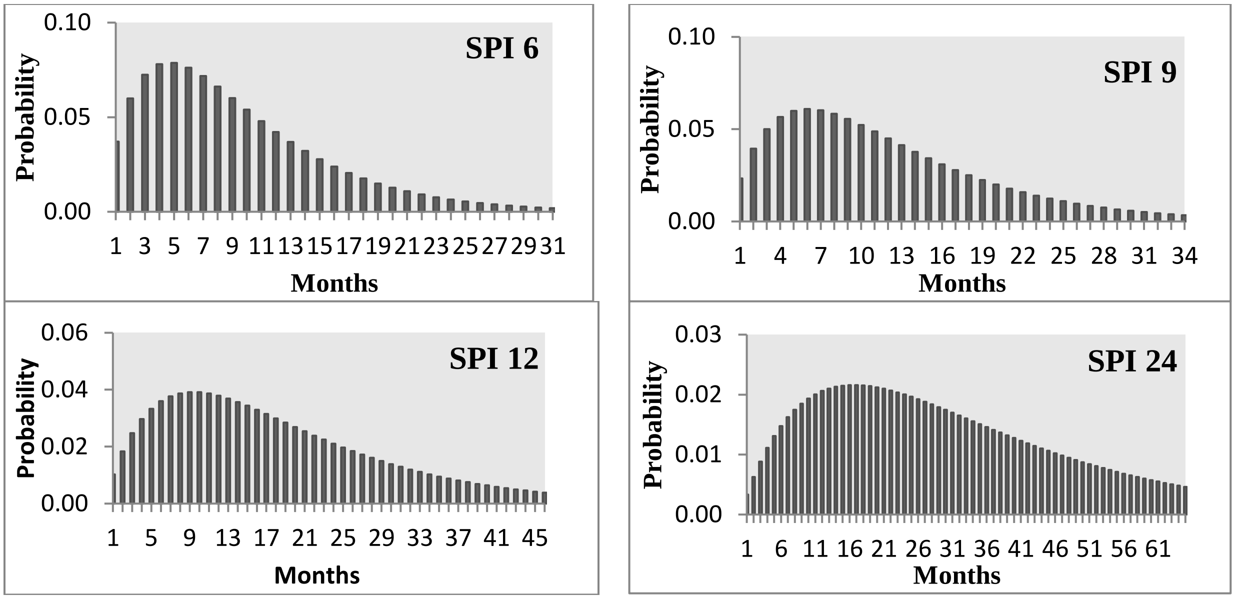


Fig. 5.4 Drought interarrival time distribution of historical data for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24 (Dinajpur)

5.2.8 Transition Probability Matrix of Different SPI Series of Dinajpur Station

According to the SPI 1 transition probability matrix (Table 5.7 a), a state 'D1' will follow a state 'D1' with a probability of 0.7593, which is a relatively high percentage of transition compared to other states. So there is high chance of 'mild drought' period exits that would follow a 'mild drought' period. State 'D1' and 'D2' follow state 'D2' with a probability of 0.2667 and 0.7333, respectively. Thus, after moderate drought period there is a high chance that would follow moderate drought period then after low chance to follow mild drought period. Again states 'D1' and 'D3' follow state 'D3' with a probability of 0.3333 and 0.6667. However, after a 'severe drought period' there is very high chance that would follow 'severe drought period' then after mild drought period would follow. States 'D1' and 'D4' follow state 'D4' with a probability of 0.0000 and 1.0000, respectively. Therefore, after an 'extreme drought period' there is a high chance that 'extreme drought period' would continue same state with perfect probability and there is very low chance to next state would follow mild drought period. For SPI 1 it is found that a mild drought period follows after every dry period and extreme drought period would follow an extreme drought period.

The transition probability matrix for SPI 3 is shown in (Table 5.7 b). It is observed that a state ‘D1’ would follow a state ‘D1’ with probability 0.7325, which is very high percentage of transition around 74% in comparison to other states. So there is high chance that ‘mild drought’ period would follow a ‘mild drought’ period. State ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.3301 and 0.6699, respectively. Hence after a ‘moderate dry period’ the chance of a moderate drought period would be high in comparison to ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.2581 and 0.7419. After a ‘severe drought period’ there is nearly very high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.000 and 1.000 respectively. Therefore, after an ‘extreme drought period’ there is a chance of perfect probability that an ‘extreme drought period’ would follow or very low chance of ‘mild drought period’ begins.

Table 5.7 (c) displays the transition probability matrix for SPI 6. In contrast to other states like ‘D2’, ‘D3’ and ‘D4’ it is noticed that a state ‘D1’ would follow a state ‘D1’ with probability 0.8315, which is a very high percentage of transition probability approximately 83%. So, there is very high chance that a ‘mild drought’ would follow a ‘mild drought’ period. States ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.3056 and 0.6944, respectively. Hence after a ‘moderate drought period’ the chance of a ‘mild drought period’ would be marginal in comparison to ‘moderate drought period’. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.1795 and 0.8205 respectively. So after ‘severe drought period’ the chance of ‘severe drought period’ would be more in comparison to ‘mild drought period’. States 'D1' and 'D4' follow state 'D4' with a probability of 0.0435 and 0.9565, respectively. Therefore after an ‘extreme drought period’ it is more likely that another ‘extreme drought period’ will happen than a ‘mild drought period’.

Table 5.7 Transition probability matrix for different SPI series of Dinajpur station

a)		SPI 1		
State	D1	D2	D3	D4
D1	0.7593	0.1481	0.0926	0.0000
D2	0.2667	0.7333	0.0000	0.0000
D3	0.3333	0.0000	0.6667	0.0000
D4	0.0000	0.0000	0.0000	1.0000

b)		SPI 3		
State	D1	D2	D3	D4
D1	0.7325	0.2166	0.0510	0.0000
D2	0.3301	0.6699	0.0000	0.0000
D3	0.2581	0.0000	0.7419	0.0000
D4	0.0000	0.0000	0.0000	1.0000

c)		SPI 6		
State	D1	D2	D3	D4
D1	0.8315	0.1236	0.0393	0.0056
D2	0.3056	0.6944	0.0000	0.0000
D3	0.1795	0.0000	0.8205	0.0000
D4	0.0435	0.0000	0.0000	0.9565

d)		SPI 9		
State	D1	D2	D3	D4
D1	0.9037	0.0749	0.0107	0.0107
D2	0.2500	0.7500	0.0000	0.0000
D3	0.0571	0.0000	0.9429	0.0000
D4	0.0769	0.0000	0.0000	0.9231

e)		SPI 12		
State	D1	D2	D3	D4
D1	0.9015	0s.0690	0.0296	0.0000
D2	0.2295	0.7705	0.0000	0.0000
D3	0.1765	0.0000	0.8235	0.0000
D4	0.0000	0.0000	0.0000	1.0000

f)		SPI 24		
State	D1	D2	D3	D4
D1	0.9498	0.0457	0.0046	0.0000
D2	0.1351	0.8649	0.0000	0.0000
D3	0.0303	0.0000	0.9697	0.0000
D4	0.0000	0.0000	0.0000	1.0000

The transition probability matrix for SPI 9 is shown in (Table 5.7 d). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.9037, which is usually high in contrast to other states. So there is high chance that ‘mild drought period’ would follow a ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2500 and 0.7500.As a result, the chance of a ‘moderate drought period’ would occur after a ‘moderate drought period’ and it would be greater in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.0571 and 0.9429 respectively. After a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.0769 and 0.9231 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would be higher in comparison to other dry states.

According to SPI 12 different dry state are clearly describe the transition probability matrix Table 5.7 (e). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.9015 which is very high in contrast to other states. So there is very high chance that ‘mild drought period’ would follow a near ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2295 and 0.7705. Therefore, after a moderate drought period the chance of a moderate drought period would be high in comparison to near mild drought period. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.1765 and 0.8235 respectively. So, after a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. Lastly, states ‘D1’ and ‘D4’ are followed by state ‘D4’ with a probability of 0.0000 and 1.000 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would follow perfect and very low chance to follow other dry states.

For SPI 24 the transition probability matrix is visible in (Table 5.7 f) and the transition probability of the diagonal element is very high nearly close to 1. It is clearly evident that a state "D1" would follow similar state ‘D1’ with a probability 0.9498, which is normally high in contrast to other states. So there is very high chance that ‘mild drought period’ would follow exactly ‘mild drought period’ rather than very low chance to follow other states. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.1351 and 0.8649. Therefore, after a ‘moderate drought period’ the chance of a moderate drought period would be high in comparison to near ‘mild drought period’ States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.0033 and 0.9697 respectively. After a ‘severe drought period’ there is perfectly high chance of probability that ‘severe drought period’ would follow but very low chance to follow ‘mild drought period’. The last state ‘D4’ is followed by state ‘D4’ with a probability of 1.000, which is perfect. Hence, after an ‘extreme drought period’ the chance of extreme drought period would follow perfectly and there is no chance to follow other dry states.

The transition probability matrix is also implemented to explore the drought persistence. Like the probability future time period would remain identical as the current drought category. This can be done by examining diagonal transition probabilities of different state for all SPI series. Therefore, the diagonal element of each transition probability matrix represents the persistence values corresponding to different dry states. The persistence probability matrix for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24 are depicted in Table 5.8. According to the persistence matrix 'mild drought state', 'severe drought state' and 'extreme drought state' are high for all SPI series but 'moderate drought state' slightly lower transition than other dry states. When all SPI series are examined for persistence, SPI 24 has the highest persistence for staying in the same state, which is varied from 0.9498 to 1.000 followed by SPI 12 and SPI 9. The high persistence of SPI 9, SPI 12, and SPI 24 are not fluctuated much in their values, because these are based on 9-month, 12-month, and 24-month moving averages. The persistence of short-term SPI series (SPI 1, SPI 3 and SPI 6) are less value because these are based on 1, 3 and 6-month moving average, respectively. So, these values are affected because of high rainfall variability over a longer period of time. The persistence of drought in an 'extreme dry state' and 'severe dry state' for SPI 12 and SPI 24 would be highly affecting ground water resources as well as crop production.

Table 5.8 Persistence probability matrix of Dinajpur station

SPI Series	D1	D2	D3	D4
SPI 1	0.7593	0.7333	0.6667	0.6667
SPI 3	0.7325	0.6699	0.7419	1.0000
SPI 6	0.8315	0.6944	0.8205	0.9565
SPI 9	0.9037	0.7500	0.9429	0.9231
SPI 12	0.9015	0.7705	0.8235	1.0000
SPI 24	0.9498	0.8649	0.9697	1.0000

5.2.9 Ishwardi Station

According to Ishwardi station, SPI values reflect the maximum frequency of mild droughts that occurred over all decades. The short-term SPI values (SPI 1, SPI 3, SPI 6) show that wet periods persisted between the years 1970-1980 and 1980-1990 due to the frequency of significant precipitation during those years. After that, as the temperature increased, dry periods also increased more than in previous decades (Fig. 5.5 a, b, c, d, e, and f). From the distribution of graphical analysis of higher order SPI values, in recent decades extreme and severe drought was also observed at Ishwardi station. The distribution of wet spells and dry spells are presented by blue and red spikes with corresponding SPI values.

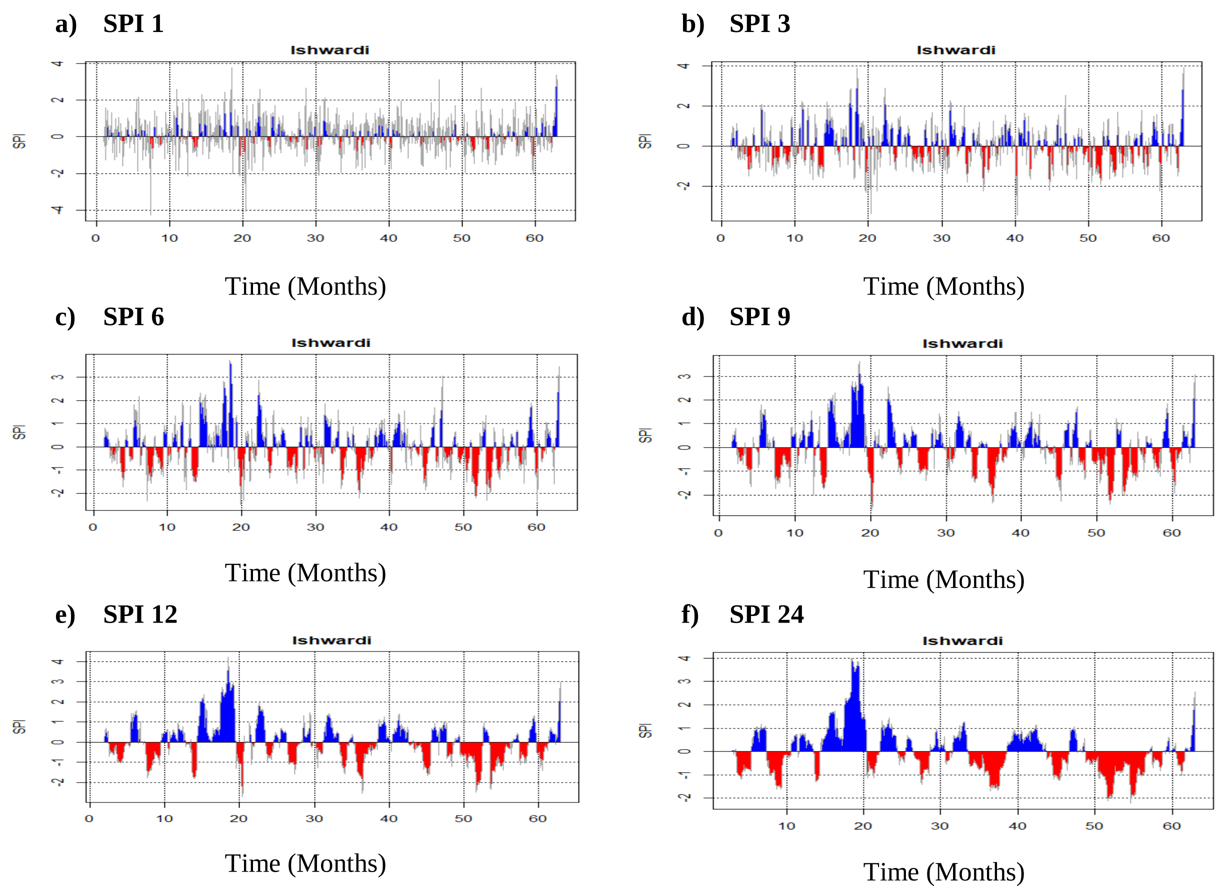


Fig. 5.5 SPI series based on monthly rainfall of Ishwardi station in the study area (a) SPI 1 (b) SPI 3 (c) SPI 6 (d) SPI 9 (e) SPI 12 (f) SPI 24

5.2.10 Two State Markov Model for Ishwardi Station

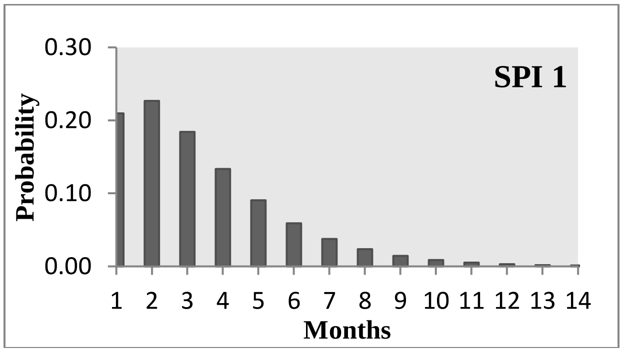
An alternating renewal process was applied to various SPI series of stochastic processes with relevant transition probabilities between two states (dry and wet). From Table 5.9 the distribution of drought duration is displayed in two states based on transition probabilities of different SPI series. Two state Markov process was applied for the analysis of drought duration. At Ishwardi station, the transition probability values for P_{DD}, P_{WD}, P_{DW}, and P_{WW} are shown by various SPI series. Initially, the transition probabilities of P_{DD} and P_{WW} are shown around 50% but after the SPI 6 series P_{DD} and P_{WW} are climbed up to around 93% for long term SPI series. Meanwhile, P_{DW} and P_{WD} both have marginal the transition probability values below 50%. As the transition probability value increases for different SPI series, P_{DW} and P_{WD} are revealed very low percentage of probabilities 6.4% and 6.7% respectively

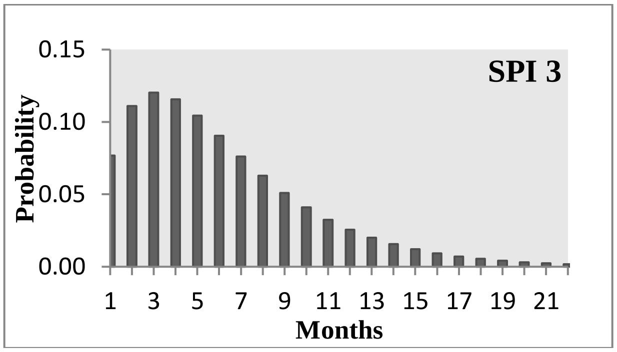
Table 5.9 Transition probabilities values for two state Markov chain for Ishwardi station

SPI	P_{DW}	P_{DD}	P_{WD}	P_{WW}
SPI 1	0.4971	0.5029	0.4214	0.5786
SPI 3	0.2725	0.7275	0.2837	0.7163
SPI 6	0.2053	0.7947	0.2094	0.7906
SPI 9	0.1545	0.8455	0.1557	0.8443
SPI 12	0.0909	0.9091	0.0950	0.9050
SPI 24	0.0638	0.9362	0.0669	0.9331

5.2.11 Distribution Drought Interarrival Time at Ishwardi Station

In order to estimate parameters for different SPI series, a model was created for drought distribution interarrival time at Ishwardi station. The model data set is more accurate in forecasting droughts than the historical data set, which is not suitable for long-term SPI series. The graphical chart reveals that 2 months have the highest probability based on the distribution of drought interarrival time (Fig.5.6). The drought interarrival time of 3 months and 4 months have the highest probability for SPI 3 and SPI 6 respectively. On the other hand, the distribution of drought Interarrival time for long-term SPI series predicts the highest probability of experiencing drought occurrences at 6 months for SPI 9, 10 months for SPI 12, and 16 months for SPI 24 (Fig. 5.5).





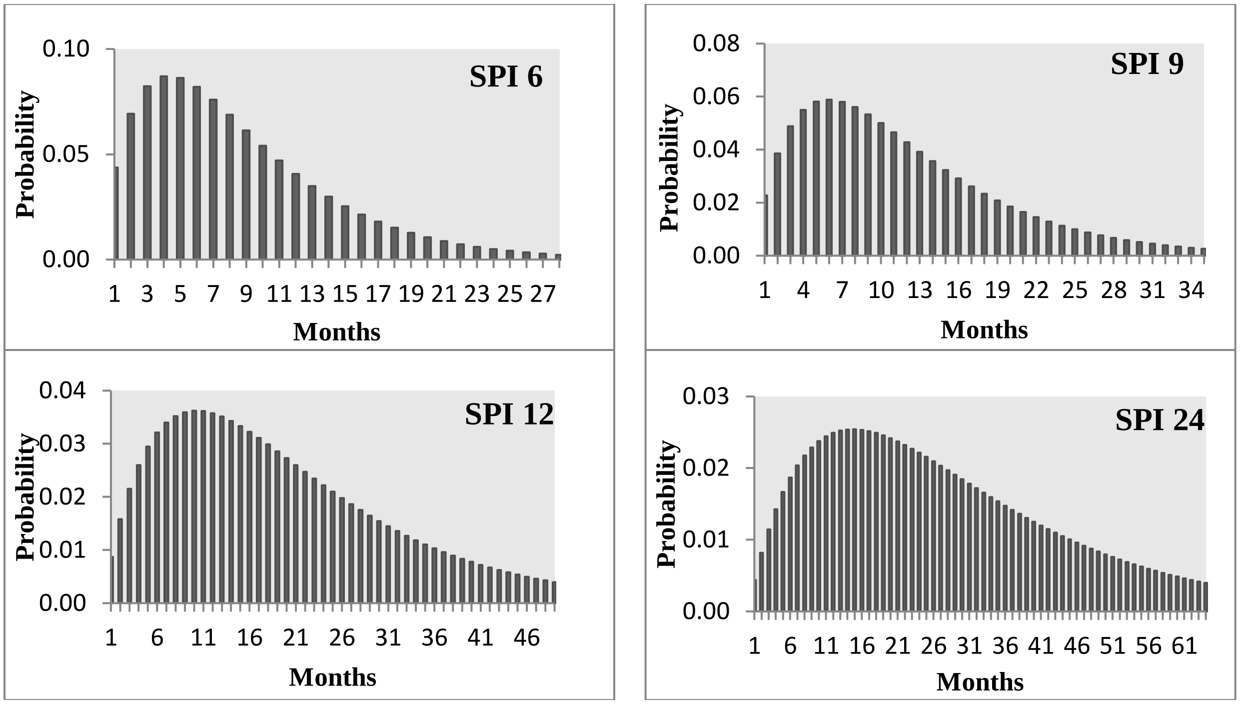


Fig. 5.6 Drought interarrival time distribution of historical data for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24 (Ishwardi)

5.2.12 Transition Probability Matrix of Different SPI Series of Ishwardi Station

The SPI 1 transition probability matrix of Ishwardi station in (Table 5.10 a) indicates that a state 'D1' will follow a state 'D1' with a probability of 0.8345, which is a relatively high percentage of transition compared to other states, so there is high chance of 'mild drought' period exits that would follow a 'mild drought' period. State 'D1' and 'D2' follow state 'D2' with a probability of 0.2553 and 0.7447, respectively. Hence, after a moderate drought period the chance of a 'moderate drought' would be high in comparison to near 'mild drought period'. Again states 'D1' and 'D3' follow state 'D3' with a probability of 0.3235 and 0.6765. However, after a 'severe drought period' there is very high chance that would follow 'severe drought period' then after 'mild drought period' would follow. States 'D1' and 'D4' follow state 'D4' with a probability of 0.0000 and 1.0000, respectively. Therefore, after an 'extreme drought period' there is a high possibility that 'extreme drought period' would continue same state with perfect probability and there is very low chance to the next state would follow 'mild drought period'.

For SPI 1 it is found that a ‘mild drought period’ follows after every drought period and extreme drought period would follow an extreme drought period.

The transition probability matrix for SPI 3 is shown in Table 5.10 (b). It is observed that a state ‘D1’ would follow a state ‘D1’ with probability 0.7310, which is very high percentage of transition in comparison to ‘D2’, ‘D3’ and ‘D4’ states. So there is high possibility that ‘mild drought’ period would follow a ‘mild drought’ period. State ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.3017 and 0.6983, respectively. Hence after a ‘moderate dry period’ the chance of a ‘moderate drought period’ would be high in comparison to ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1875 and 0.8125. After a ‘severe drought period’ there is nearly very high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.3846 and 0.6154 respectively. Therefore, after an ‘extreme drought period’ there is almost double chance of possibility that an ‘extreme drought period’ would follow than ‘mild drought period’.

The transition probability matrix for SPI 6 is displayed in (Table 5.10 c). It is noticed that a state "D1" would follow a state "D1" with probability 0.8446, which is a very high in comparisons to other states like ‘D2’, ‘D3’ and ‘D4’. So, there is very high chance of possibility that a ‘mild drought period’ would follow a ‘mild drought period’. States ‘D1’ and ‘D2’ follow state ‘D2’ with a probability of 0.2472 and 0.7528, respectively. Hence after a ‘moderate drought period’ the chance of a ‘mild drought period’ would be low in comparison to ‘moderate drought period’. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.1389 and 0.8611 respectively. So after ‘severe drought period’ the chance of ‘severe drought period’ would be more in comparison to ‘mild drought period’. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.2308 and 0.7692, respectively. Therefore after an ‘extreme drought period’ the chance that an ‘extreme drought period’ would follow is more than ‘mild drought period’.

Table 5.10 Transition probability matrix for different SPI series of Ishwardi station

a) SPI 1

State	D1	D2	D3	D4
D1	0.8345	0.0863	0.0791	0.0000
D2	0.2553	0.7447	0.0000	0.0000
D3	0.3235	0.0000	0.6765	0.0000
D4	0.0000	0.0000	0.0000	1.0000

b) SPI 3

State	D1	D2	D3	D4
D1	0.7310	0.2047	0.0351	0.0292
D2	0.3017	0.6983	0.0000	0.0000
D3	0.1875	0.0000	0.8125	0.0000
D4	0.3846	0.0000	0.0000	0.6154

c) SPI 6

State	D1	D2	D3	D4
D1	0.8446	0.1140	0.0259	0.0155
D2	0.2472	0.7528	0.0000	0.0000
D3	0.1389	0.0000	0.8611	0.0000
D4	0.2308	0.0000	0.0000	0.7692

d) SPI 9

State	D1	D2	D3	D4
D1	0.8955	0.0796	0.0249	0.0000
D2	0.1860	0.8140	0.0000	0.0000
D3	0.1471	0.0000	0.8529	0.0000
D4	0.0000	0.0000	0.0000	1.0000

e) SPI 12

State	D1	D2	D3	D4
D1	0.8919	0.1036	0.0000	0.0045
D2	0.2212	0.7788	0.0000	0.0000
D3	0.0000	0.0000	1.0000	0.0000
D4	0.0833	0.0000	0.0000	0.9167

f) SPI 24

State	D1	D2	D3	D4
D1	0.9405	0.0556	0.0040	0.0000
D2	0.1892	0.8108	0.0000	0.0000
D3	0.0357	0.0000	0.9643	0.0000
D4	0.0000	0.0000	0.0000	1.0000

The transition probability matrix for SPI 9 is shown in (Table 5.10 d). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8955, which is usually high in contrast to other states. So there is high chance that ‘mild drought period’ would follow a ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.1860 and 0.8140. As a result, the chance of a ‘moderate drought period’ would occur after a ‘moderate drought period’ and it would be higher in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.1471 and 0.8529 respectively. After a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. States ‘D1’ and ‘D4’ follow state ‘D4’ with a probability of 0.0000 and 1.000 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would be perfect in comparison to other dry states.

According to SPI 12 the transition probability matrix is clearly described in (Table 5.10 e). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8919 which is very high in contrast to other states. So there is very high chance that ‘mild drought period’ would follow a near ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2212 and 0.7788. Therefore, after a ‘moderate drought period’ the chance of a moderate drought period would be high in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.000 and 1.000 respectively. So, after a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ would follow perfect probability. Lastly, states ‘D1’ and ‘D4’ are followed by state ‘D4’ with a probability of 0.0833 and 0.9167 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would follow more than a ‘mild drought period’.

For SPI 24 the transition probability matrix is noticeable in (Table 5.10 f) and the transition probability of the diagonal element is very high nearly close to 1. It is clearly evident that a state "D1" would follow similar state ‘D1’ with a probability 0.9405, which is normally high in comparison to other states. So there is very high chance that ‘mild drought period’ would follow exactly ‘mild drought period’ rather than very low chance to follow other states. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.1892 and 0.8108. Therefore, after a ‘moderate drought period’ the chance of a moderate drought period would be higher in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.0357 and 0.9643 respectively. After a ‘severe drought period’ there is high chance of probability that ‘severe drought period’ would follow nearly close to perfect but very low chance to follow ‘mild drought period’. ‘D1’ and ‘D4’ is followed by state ‘D4’ with a probability of 1.000, which is perfect. Hence, after an ‘extreme drought period’ the chance of extreme drought period would follow perfect probability and there is no chance to follow other dry states.

The transition probability matrix is also implemented to explore the drought persistence. The probability of future time period would remain identical as the current drought category. This process can be applied by observing diagonal transition probabilities of different state for all SPI series. Therefore, the diagonal element of each transition probability matrix represents the persistence values corresponding to different dry states. The persistence probability matrix for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24 are presented in (Table 5.11). According to the persistence matrix ‘mild drought state’ and ‘severe drought state’ are high but ‘extreme drought state’ and ‘moderate drought state’ slightly lower transition than other dry states for all SPI series. When all SPI series are analyzed for persistence, it is observed that SPI 24 has the highest persistence for staying in the same state, which varies from 0.8108 to 1.000, followed by SPI 12. The high persistence of SPI 9, SPI 12, and SPI 24 are not fluctuated much in their values, because these are based on 9-month, 12-month, and 24-month moving averages. The persistence of short-term SPI series (SPI 1, SPI 3, and SPI 6) is considered to have less value because these series are affected by high rainfall variability over a longer period of time and they are based on 1, 3, and 6-month moving average, respectively. For SPI 12 and SPI 24, the persistence of the drought in an ‘extreme dry state’ and ‘severe dry state’ would have a huge impact on agricultural productivity and ground water supplies.

Table 5.11 Persistence probability matrix Ishawrdi station

SPI Series	D1	D2	D3	D4
SPI 1	0.8345	0.7447	0.6765	1.0000
SPI 3	0.7310	0.6983	0.8125	0.6154
SPI 6	0.8446	0.7528	0.8611	0.7692
SPI 9	0.8955	0.8140	0.8529	1.0000
SPI 12	0.8919	0.7788	1.0000	0.9167
SPI 24	0.9405	0.8108	0.9643	1.0000

5.2.13 Rajshahi Station

In the northwest region, Rajshahi region is observed most frequent droughts in recent years. The results of the SPI values are depicted by graphical chart (Fig 5.7). In the earlier decades 1960-1970 and 1970-1980 short terms SPI indicates that, most of the years are continued with moderate and extreme wet conditions than dry spells. But as the temperature increases, Rajshahi region falls into extreme drought spells due to lack of rainfall. From the distribution of graphical analysis, the higher SPI values (SPI 9, SPI 12, SPI 24) are clearly depicted severe and extreme drought periods for the years. After 2000 extreme drought spells are more occurred than wet spells (Fig 5.7 d, e, f).

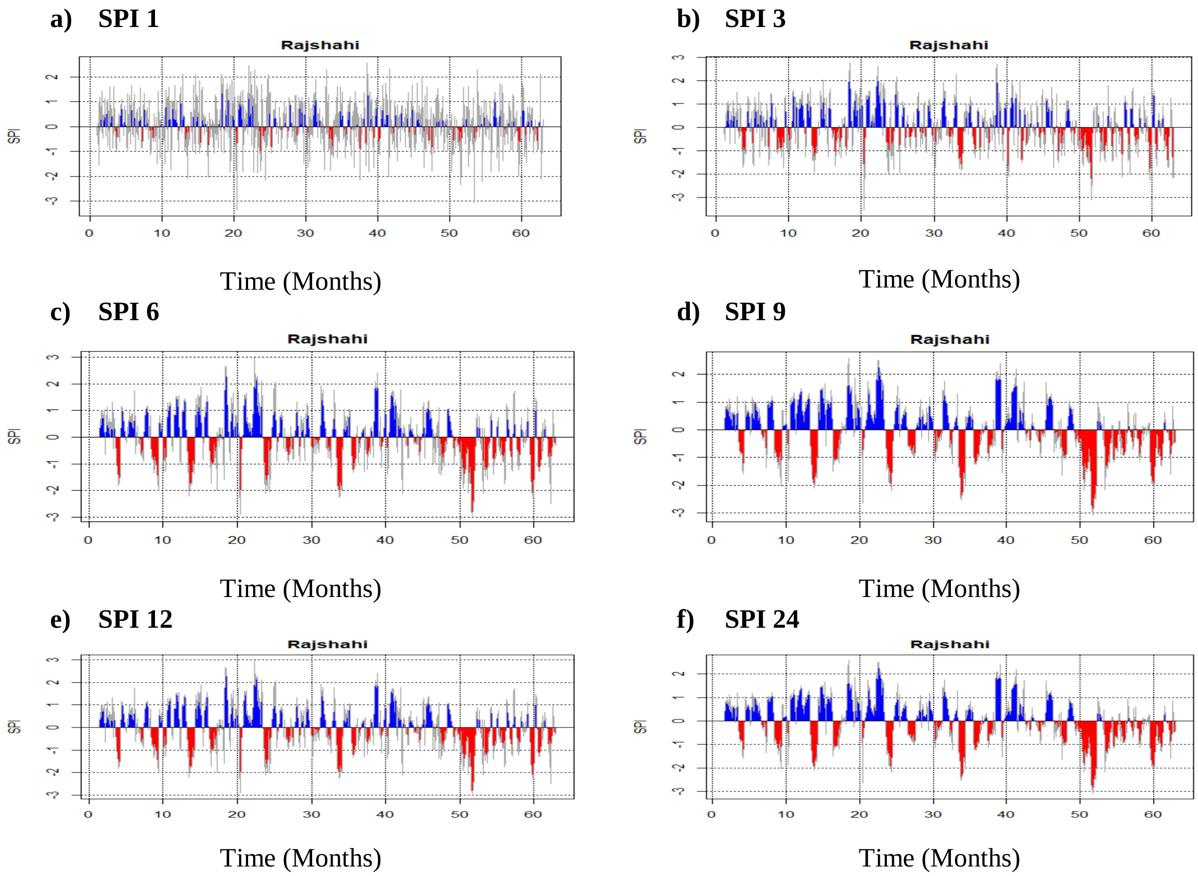


Fig. 5.7 SPI series based on monthly rainfall of Rajshahi station in the study area (a) SPI 1 (b) SPI 3 (c) SPI 6 (d) SPI 9 (e) SPI 12 (f) SPI 24

5.2. 14 Two State Markov Model for Rajshahi Station

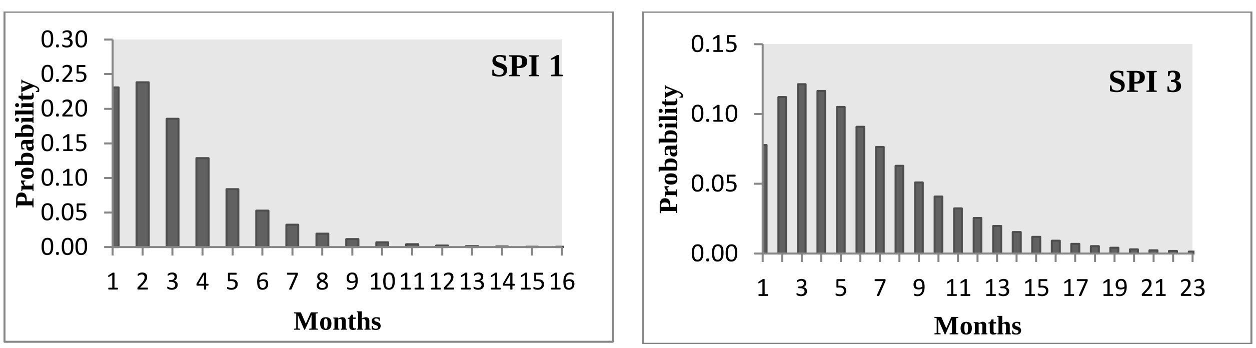
For Analyzing drought duration two state Markov model is applied to know the frequency of drought percentage of different SPI series. The transition probabilities of two state Markov model are categorized by the values of P_{DD}, P_{WD}, P_{DW}, and P_{WW} according to various SPI series. The results of transition probability are shown in (Table 5.12). It is clearly depicted that the probability of transition dry to wet state P_{DW} and wet to dry state P_{WD} are primarily increased for short term SPI series like SPI 1, SPI 3 and SPI 6 but decreased in long term SPI series (SPI 12, SPI 24). The other two state P_{DD} and P_{WW} initially observed low percentage of transition below 50% but after SPI 3 series they increased rapidly with 94% and 92% respectively.

Table 5.12 Transition probabilities values of two state Markov chain for Rajshahi station

SPI	P_{DW}	P_{DD}	P_{WD}	P_{WW}
SPI 1	0.5361	0.4639	0.4307	0.5693
SPI 3	0.2853	0.7147	0.2737	0.7263
SPI 6	0.2107	0.7893	0.1990	0.8010
SPI 9	0.1477	0.8523	0.1384	0.8616
SPI 12	0.1086	0.8914	0.1072	0.8928
SPI 24	0.0597	0.9403	0.0716	0.9284

5.2.15 Distribution of Drought Interarrival Time at Rajshahi Station

By using the equation of drought distribution interarrival time a model was developed for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, and SPI 24 to estimate parameters. As shown in (Fig. 5.8), the model outputs results are contrast with the historical data set of observe drought interarrival times for various SPI series. The historical data set is insufficient for higher SPI series since it is unable to identify more number of drought events than the synthetic data collection, which is utilized to estimate more drought occurrences. It is observed that the drought interarrival time of 2 months has the highest probability for SPI 1. The drought interarrival time of 3 months has the highest probability in between 2 and 4 months SPI 3. In SPI 6 the drought interarrival time of 4 months has the highest probability. For higher SPI series, the drought interarrival time of 6 months, 9 months are observed highest probability for SPI 9 and SPI 12 series. The drought interarrival time for SPI 24, 15 months are predicted highest probability.



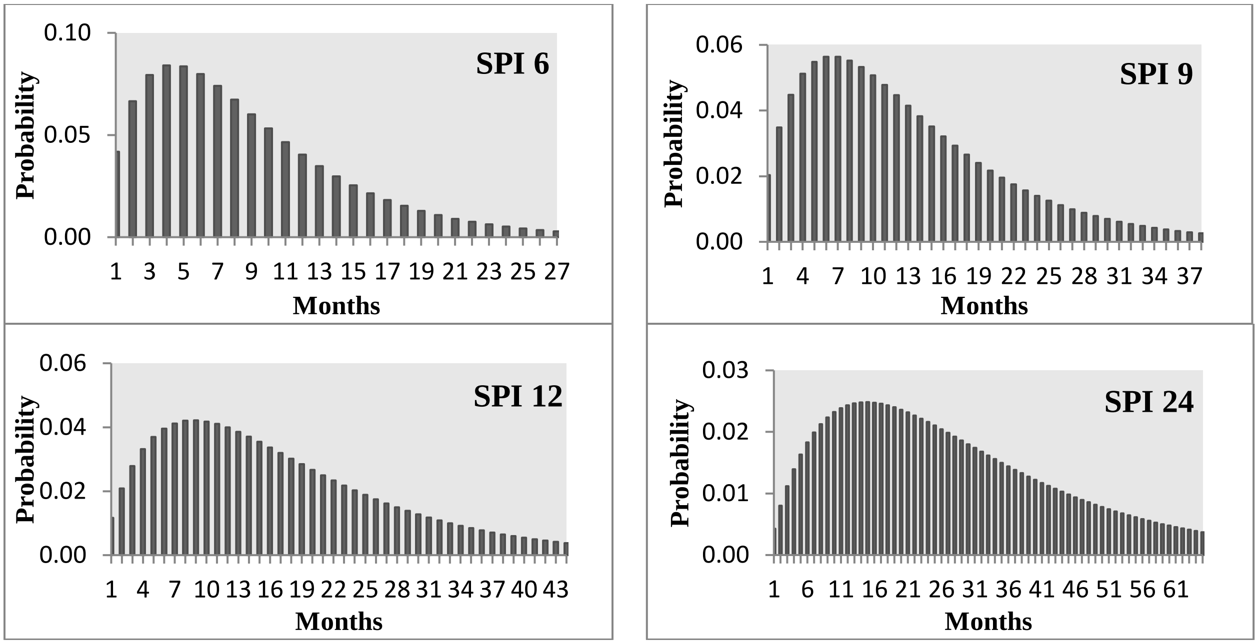


Fig. 5.8 Drought interarrival time distribution of historical data for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24 (Rajshahi)

5.2.16 Transition Probability Matrix of Different SPI Series of Rajshahi Station

The SPI 1 transition probability matrix of Rajshahi station is shown in (Table 5.13 a). It is clearly observed that a state 'D1' will follow a state 'D1' with a probability of 0.7724, which is a relatively high percentage of transition compared to other dry states, So there is high chance that 'mild drought period' would follow a 'mild drought period'. States 'D1' and 'D2' follow state 'D2' with a probability of 0.2733 and 0.7234, respectively. Hence, after a 'moderate drought period' the chance of a 'moderate drought period' would be high in comparison to near 'mild drought period'. Again states 'D1' and 'D3' follow state 'D3' with a probability of 0.2727 and 0.7273. However, after a 'severe drought period' there is very high chance that would follow 'severe drought period' then after 'mild drought period' would follow. States 'D1' and 'D4' follow state 'D4' with a probability of 0.3333 and 0.6667, respectively. Therefore, after an 'extreme drought period' there is a high possibility that 'extreme drought period' would follow with the next probability that 'mild drought period' will follow. For SPI 1 it is found that a 'mild drought period' follows after every dry period and an 'extreme drought period' would follow an 'extreme drought period'.

The transition probability matrix for SPI 3 is shown in (Table 5.13 b). It is observed that a state 'D1' would follow a state 'D1' with probability 0.6558, which is very high percentage of transition in comparison to 'D2', 'D3' and 'D4' states. So there is high possibility that 'mild drought' period would follow a 'mild drought' period. States 'D1' and 'D2' follow state 'D2' with a probability of 0.3363 and 0.6637, respectively. Hence after a 'moderate dry period' the chance of a 'moderate drought period' would be high in comparison to 'mild drought period. States 'D1' and 'D3' follow state 'D3' with a probability of 0.2558 and 0.7442. After a 'severe drought period' there is very high chance of probability that 'severe drought period' would follow then after 'mild drought period' would follow. States 'D1' and 'D4' follow state 'D4' with a probability of 0.2667 and 0.7333 respectively. Therefore, after an 'extreme drought period' there is high chance that an 'extreme drought period' would follow than after 'mild drought period'.

According to SPI 6, the transition probability matrix noticed that a state 'D1' would follow a state 'D1' with probability 0.7977, which is a very high in comparisons to other states like 'D2', 'D3' and 'D4' (Table 5.13c). So, there is very high chance of possibility that a 'mild drought period' would follow a 'mild drought period'. States 'D1' and 'D2' follow state 'D2' with a probability of 0.3000 and 0.7000, respectively. Hence after a 'moderate drought period' the chance of a 'mild drought period' would be low in comparison to 'moderate drought period'. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.1579 and 0.8421 respectively. So after 'severe drought period' the chance of 'severe drought period' would be more than 'mild drought period'. States 'D1' and 'D4' follow state 'D4' with a probability of 0.0870 and 0.9130, respectively. Therefore after an 'extreme drought period' the chance that an 'extreme drought period' would follow is close to perfect than a 'mild drought period' and the remaining states have zero chance of probability.

Table 5.13 Transition probability matrix for different SPI series of Rajshahi station

a)		SPI 1		
State	D1	D2	D3	D4
D1	0.7724	0.1057	0.0732	0.0488
D2	0.2766	0.7234	0.0000	0.0000
D3	0.2727	0.0000	0.7273	0.0000
D4	0.3333	0.0000	0.0000	0.6667

b)		SPI 3		
State	D1	D2	D3	D4
D1	0.6558	0.2468	0.0714	0.0260
D2	0.3363	0.6637	0.0000	0.0000
D3	0.2558	0.0000	0.7442	0.0000
D4	0.2667	0.0000	0.0000	0.7333

c)		SPI 6		
State	D1	D2	D3	D4
D1	0.7977	0.1561	0.0347	0.0116
D2	0.3000	0.7000	0.0000	0.0000
D3	0.1579	0.0000	0.8421	0.0000
D4	0.0870	0.0000	0.0000	0.9130

d)		SPI 9		
State	D1	D2	D3	D4
D1	0.8722	0.1111	0.0167	0.0000
D2	0.2439	0.7561	0.0000	0.0000
D3	0.0938	0.0000	0.9063	0.0000
D4	0.0000	0.0000	0.0000	1.0000

e)		SPI 12		
State	D1	D2	D3	D4
D1	0.9015	0.0887	0.0099	0.0000
D2	0.2169	0.7831	0.0000	0.0000
D3	0.0667	0.0000	0.9333	0.0000
D4	0.0000	0.0000	0.0000	1.0000

f)		SPI 24		
State	D1	D2	D3	D4
D1	0.9496	0.0504	0.0000	0.0000
D2	0.1688	0.8312	0.0000	0.0000
D3	0.0000	0.0000	1.0000	0.0000
D4	0.0000	0.0000	0.0000	1.0000

The transition probability matrix for SPI 9 is presented in (Table 5.13 d). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8722, which is usually high in comparison to other dry states. So there is high chance that ‘mild drought period’ would follow a ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2439 and 0.7561. Therefore, after a ‘moderate drought period’ the chance of a ‘moderate drought period’ would be high then near ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.0938 and 0.9093 respectively. After a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. State ‘D4’ follow state ‘D4’ with a perfect probability of 1.000. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would follow absolutely perfect and there is very low chance to move on next state.

For SPI 12 the transition probability matrix is visible in (Table 5.13 e). A state ‘D1’ would follow state ‘D1’ with a chance of probability 0.9015, which is unusually high in contrast to other states. So there is very high chance that ‘mild drought period’ would follow a near ‘mild drought' period. State 'D2' is followed by states 'D1' and 'D2' with probabilities of 0.2169 and 0.7831. Therefore, after a 'moderate drought period' the chance of a 'moderate drought period' would be high in comparison to 'mild drought period'. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.0667 and 0.9333 respectively. So, after a 'severe drought period' there is very high chance of probability that 'severe drought period' would follow again but very low chance to follow 'mild drought period'. The last state 'D4' is followed by state 'D4' with perfect probability 1.000. Hence, after an 'extreme drought period' the probability of an 'extreme drought period' would be perfect and there is no chance to follow other dry states.

The transition probability matrix for SPI 24 is presented in (Table 5.13f). It is clearly evident that a state 'D1' would follow similar state 'D1' with a probability 0.9496, which is normally high in contrast to other states and close to perfect probability. So there is very high chance that 'mild drought period' would follow 'mild drought period'. State 'D2' is followed by state 'D1' and 'D2' with probabilities of 0.1688 and 0.8312. Therefore, after a 'moderate drought period' the chance of a 'moderate drought period' would be high in comparison to near 'mild drought period'. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.and 0.9333 respectively. State 'D3' and State 'D4' would follow similar state 'D3' and 'D4' with perfect probability 1.000, so after a 'severe drought period' there is exactly high chance of 'severe drought period' and also after an 'extreme drought period' the probability of an 'extreme drought period' would be perfect and there is no chance to follow other dry states.

The persistence of drought is also studied using the transition probability matrix. Like the probability that the drought category for future time would be the same as the current drought category. This may be seen through considering the transition probabilities between different states of all SPI series. Consequently, the diagonal elements of each transition probability matrix represent the persistence values of different dry states. The persistence probabilities for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24 are shown in (Table 5.14). It is observed that the persistence of 'extreme drought state' and 'severe drought state' is very high for all SPI series. When SPI series are compared for persistence; then the persistence for continuing in the same state is high for SPI 24 followed by SPI 12, SPI 9 and SPI 6. Because of less fluctuation, the high persistence matrix of SPI 9, SPI 12, and SPI 24 are based on 9-month, 12-month, and 24-month moving averages. The persistence of SPI 1, SPI 3 and SPI 6 are less value because these are based on 1, 3 and 6-month moving average, respectively. Hence, these values are changed by variations in rainfall during shorter time periods. Due to water shortages, drought in 'extreme dry' and 'severe dry' states for SPI 12, and SPI 24 would affect more agricultural areas.

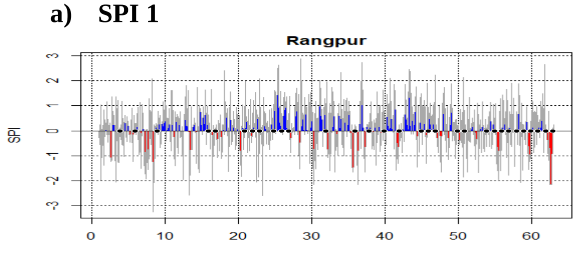
Table 5.14 Persistence probability Matrix of Rajshahi station

SPI Series	D1	D2	D3	D4
SPI 1	0.7724	0.7234	0.7273	0.6667
SPI 3	0.6558	0.6637	0.7442	0.7333
SPI 6	0.7977	0.7000	0.8421	0.9130
SPI 9	0.8722	0.7561	0.9063	1.0000
SPI 12	0.9015	0.7831	0.9333	1.0000
SPI 24	0.9496	0.8312	1.0000	1.0000

5.2.17 Rangpur Station

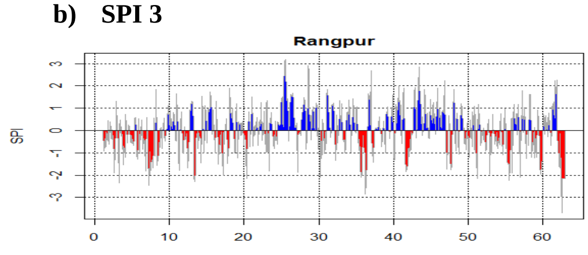
According to SPI, Rangpur station is clearly affected by extreme and severe drought conditions during the year 1960 to 1970, 1990 to 2000 and 2010-2020. On the other hand, extreme wet condition is occurred during 1980 to 1990, 2000 to 2010 decades. The SPI values of short-term (SPI 1, SPI 3, SPI 6) period has not detect severe and extreme drought properly but it could exactly recognize by extreme and severe droughts in long-term SPI values (Fig. 5.8 d, e, f) for long-term (SPI 9, SPI 12, SPI 24) periods. The most devastating drought episodes are discovered in the year 1960 to 1970 and 2010 to 2020 throughout Rangpur meteorological stations.

a) SPI 1



Time (Months)

b) SPI 3



Time (Months)

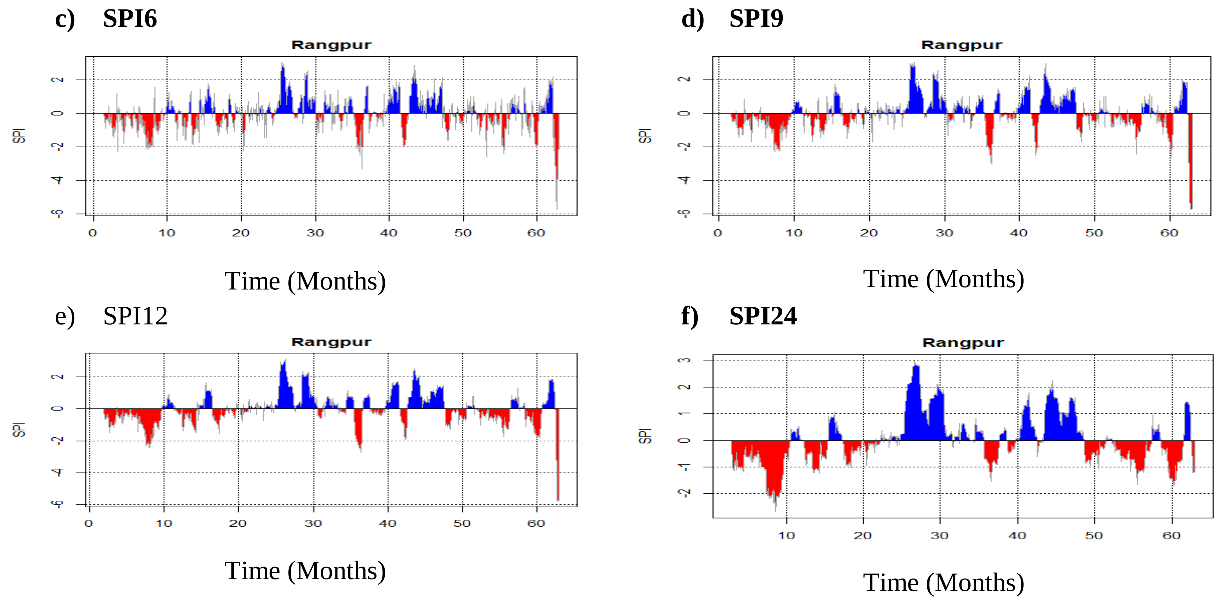


Fig. 5.9 SPI series based on monthly rainfall of Rangpur stations in the study area (a) SPI 1 (b) SPI 3 (c)SPI 6 (d) SPI 9 (e) SPI 12 (f) SPI 24

5.2.18 Two State Markov Model for Rangpur Station

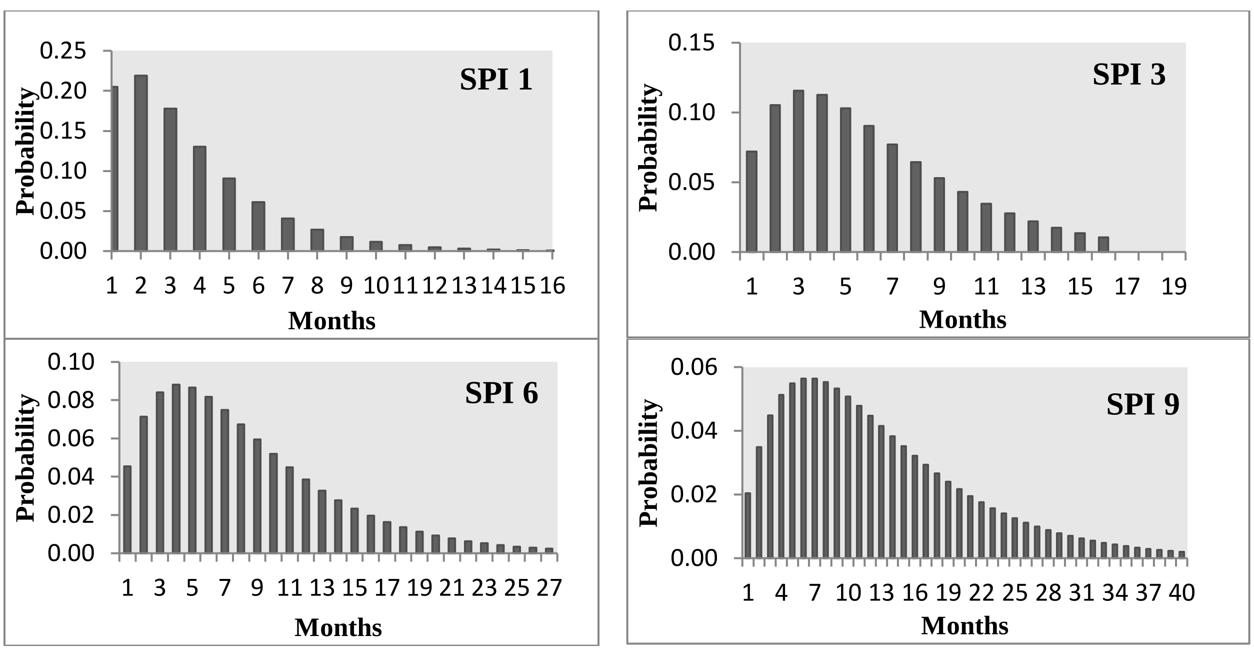
To estimate drought percentages in different SPI series, a two-state Markov model is employed for assessing drought duration. The transition probabilities of two state Markov model are categorized by the values of P_{DD}, P_{WD}, P_{DW}, and P_{WW}, according to various SPI series. The results of transition probability are shown in (Table 5.15). It is clearly depicted that the transition between dry to wet state P_{DW} and wet to dry state P_{WD} are primarily increased for short term SPI series like SPI 1, SPI 3 and SPI 6 but decreased in long term SPI series (SPI 12, SPI 24). The other two states P_{DD} and P_{WW} initially start with low percentage of transition but after SPI 3 series these states increased rapidly with 95% and 94% respectively.

Table 5.15 Transition probabilities values of two state Markov chain for Rangpur station

SPI	P_{DW}	P_{DD}	P_{WD}	P_{WW}
SPI 1	0.5775	0.4225	0.3551	0.6449
SPI 3	0.2765	0.7235	0.2611	0.7389
SPI 6	0.2164	0.7836	0.2118	0.7882
SPI 9	0.1477	0.8523	0.1384	0.8616
SPI 12	0.0890	0.9110	0.0971	0.9029
SPI 24	0.0544	0.9456	0.0629	0.9371

5.2.19 Distribution of Drought Interarrival Time at Rangpur Station

A model was established by using the equation of drought distribution interarrival time for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, and SPI 24 to estimate parameters. As shown in Fig. 5.9, the output results of the model are comparison with the historical data set of observe drought interarrival times for various SPI series. The historical data set is insufficient for higher SPI series since it is unable to identify more number of drought events than the synthetic data set, which is utilized to estimate more drought occurrences. It is found that, for SPI 1 the drought interarrival time of 2 months has the highest probability. The drought interarrival time of 3 months has the highest probability for SPI 3. In SPI 6 the drought interarrival time of 4 months has the highest probability. For higher SPI series, the drought interarrival time of 7 months, 11 months are observed   highest probability for SPI 9 and SPI 12 series. For SPI 24 the drought interarrival time 17 to 19 months are predicted highest probability.



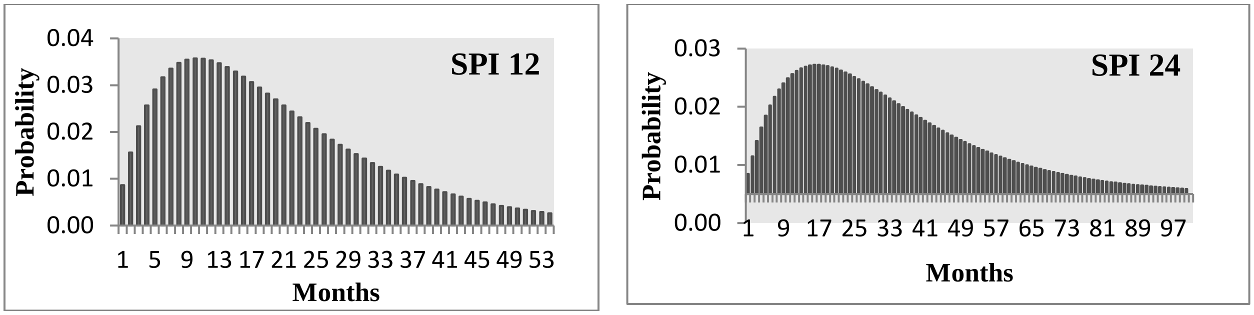


Fig. 5.10 Drought interarrival time distribution of historical data for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24 (Rangpur)

5.2.20 Transition Probabilities Matrix of Different SPI Series of Rangpur Station

The transition probability matrix of SPI 1 is shown in (Table 5.15a). It is observed that a state 'D1' will follow a state 'D1' with a probability 0.7470, which is very high in comparison to other states. So there is high chance that 'mild drought period' would follow a 'mild drought period. State 'D1' and 'D2' follow state 'D2' with a probability of 0.2292 and 0.7708, respectively. Thus after 'moderate dry period' there is a high chance that 'moderate drought period' then after very low chance 'mild drought period' would follow. Again states 'D1' and 'D3' follow state 'D3' with a probability of 0.2000 and 0.8000. However, after a 'severe drought period' there is very high chance that would follow 'severe drought period' then after would follow 'mild drought period'. States 'D1' and 'D4' follow state 'D4' with a probability of 0.2000 and 0.8000, respectively; which is similar as pervious transition states between 'D1' and 'D3'. Therefore, after an 'extreme drought period' there is a high chance that 'extreme drought period' would follow with the next probability that a 'mild drought period' will follow. For SPI 1 it is found that a 'mild drought period' follows after every dry period and 'extreme dry period' would follow an 'extreme dry period'.

It is observed that SPI 3 transition probability matrix is described in (Table 5.15b). A state 'D1' would follow a state 'D1' with probability 0.7305, which is very high transition in comparison to other states. So there is high chance that 'mild drought period' would follow a 'mild drought period'. State 'D1' and 'D2' follow state 'D2' with a probability of 0.3286 and 0.6714, respectively. Hence after a 'moderate dry period' the chance of a 'moderate drought period' would be double in comparison to 'mild drought period'. States 'D1' and 'D3' follow state 'D3' with a probability of 0.1795 and 0.8205. After a 'severe drought period' there is nearly very high chance of probability that 'severe drought period' would follow and then after 'mild drought period'. States 'D1' and 'D4' follow state 'D4' with a probability of 0.1667 and 0.8333 respectively. Therefore, after an 'extreme drought period' there is a more than 80% chance that an 'extreme drought period' would follow and then after 'mild drought period'.

The transition probability matrix for SPI 6 is displayed in (Table 5.15c). In contrast to other dry states like 'D2', 'D3' and 'D4' it is found that a state 'D1' would follow a state 'D1' with probability 0.8376.So, there is very high chance that a 'mild drought period' would follow a 'mild drought period'. States 'D1' and 'D2' follow state 'D2' with a probability of 0.3286 and 0.6714 respectively. Hence after a 'moderate drought period' the chance of a 'mild drought period' would be low in comparison to 'moderate drought period'. States 'D1' and 'D3' follow state 'D3' with a probability of 0.1212 and 0.8788 respectively. So, after a 'severe drought period' the chance of 'severe drought period' would be more in comparison to mild drought period. The chances of 'D' and 'D4' coming after 'D4' are 0.1786 and 0.8214, respectively. So, after an 'extreme drought period' the chance that an 'extreme drought period' would follow is more than after a 'mild drought period'

Table 5.16 Transition probability matrix for different SPI series of Rangpur station

a)	SPI 1			
State	D1	D2	D3	D4
D1	0.7470	0.1325	0.0843	0.0361
D2	0.2292	0.7708	0.0000	0.0000
D3	0.2000	0.0000	0.8000	0.0000
D4	0.2000	0.0000	0.0000	0.8000

b)	SPI 3			
State	D1	D2	D3	D4
D1	0.7305	0.2036	0.0419	0.0240
D2	0.3820	0.6180	0.0000	0.0000
D3	0.1795	0.0000	0.8205	0.0000
D4	0.1667	0.0000	0.0000	0.8333

c)	SPI 6			
State	D1	D2	D3	D4
D1	0.8376	0.1168	0.0203	0.0254
D2	0.3286	0.6714	0.0000	0.0000
D3	0.1212	0.0000	0.8788	0.0000
D4	0.1786	0.0000	0.0000	0.8214

d)	SPI 9			
State	D1	D2	D3	D4
D1	0.8722	0.1111	0.0167	0.0000
D2	0.2439	0.7561	0.0000	0.0000
D3	0.0938	0.0000	0.9063	0.0000
D4	0.0000	0.0000	0.0000	1.0000

e)	SPI 12			
State	D1	D2	D3	D4
D1	0.9336	0.0586	0.0078	0.0000
D2	0.2679	0.7321	0.0000	0.0000
D3	0.0741	0.0000	0.9259	0.0000
D4	0.0000	0.0000	0.0000	1.0000

f)	SPI 24			
State	D1	D2	D3	D4
D1	0.9478	0.0522	0.0000	0.0000
D2	0.1842	0.8158	0.0000	0.0000
D3	0.0000	0.0000	1.0000	0.0000
D4	0.0000	0.0000	1.0000	1.0000

The transition probability matrix for SPI 9 is shown in (Table 5.16d). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.8722, which is usually high in comparison to other dry states. So there is high chance that ‘mild drought period’ would follow a ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2439 and 0.7561. Therefore, after a ‘moderate drought period’ the chance of a ‘moderate drought period’ would follow more in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ follow state ‘D3’ with a probability of 0.0938 and 0.9063 respectively. After a ‘severe drought period’ the chance that a ‘severe drought period’ would follow is high compare to ‘mild drought period’. At last stage, states ‘D4’ would follow state ‘D4’ with a probability of 1.000, which is perfect, compare to other states. Hence, after an ‘extreme drought period’ the chance of ‘extreme drought period’ is high with perfect probability.

For SPI 12 the transition probability matrix is visible in (Table 5.16 e). A state ‘D1’ would follow similar state ‘D1’ with a chance of probability 0.9336, which is unusually high compare to other dry states. So there is very high chance that ‘mild drought period’ would follow a near ‘mild drought period’. State ‘D2’ is followed by states ‘D1’ and ‘D2’ respectively, with probabilities of 0.2679 and 0.7321. Therefore, after a ‘moderate drought period’ the chance of a ‘moderate drought period’ is high in comparison to near ‘mild drought period’. States ‘D1’ and ‘D3’ would follow state ‘D3’ with a probability of 0.0741 and 0.9259 respectively. After a ‘severe drought period’ there is almost high chance of probability that ‘severe drought period’ or ‘mild drought period’ would follow. Lastly, states‘D4’ followed by state ‘D4’ with probability 1.000 respectively. Hence, after an ‘extreme drought period’ the probability of an ‘extreme drought period’ would follow perfect probability.

For SPI 24 the transition probability matrix is exposed in (Table 5.16 f). It is clearly evident that a state ‘D1’ would follow similar state ‘D1’ with a probability 0.9478, which is normally high, compare to other states. So there is very high chance that 'mild drought period' would follow 'mild drought period'. State 'D2' is followed by states 'D1' and 'D2' respectively, with probabilities of 0.1842 and 0.8158. Therefore, after a 'moderate drought period' the chance of a 'moderate drought period' would be high in compare to near 'mild drought period'. States 'D1' and 'D3' would follow state 'D3' with a probability of 0.0667 and 0.9333 respectively. After a 'severe drought period' there is exactly high chance of probability that 'severe drought period' or 'mild drought period' would follow. Lastly, states 'D4' is followed by state 'D4' with a probability of 1.000, which is perfect. Hence, after an 'extreme drought period' the probability of an 'extreme drought period' would be perfect and much higher probability in comparison to other states.

The persistence of drought is also studied using the transition probability matrix. Like the probability that the drought class for the next time will be the same as the current drought class. This can be noticed by examining the transition probabilities from state 'D1'–'D1', 'D2'–'D2', 'D3'–'D3' and 'D4'–'D4' for all SPI series. Consequently, the persistence values corresponding to various dry states are represented by the diagonal of each transition probability matrix. The persistence probabilities for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24 are shown in Table 5.17. It is observed that the persistence of 'mild drought state', 'extreme drought state' and 'severe drought state' is very high for all SPI series. When SPI series are detected for persistence; it is found that, SPI 24 has the highest persistence for staying in the same state, followed by SPI 12 and SPI 9. The persistence matrix SPI 9 based on 9-months, SPI 12 based on 12-months, and SPI 24 based on 24-months moving average showed high persistence because of low fluctuations. The persistence of SPI 1, SPI 3 and SPI 6 are represented less value because these are based on 1, 3 and 6-month moving average, respectively. So, these values are affected when there is variation in rainfall over shorter period of time. Therefore, due to water scarcity and ground water depletion the persistence of drought in an 'extreme dry state' and 'severe dry state' for SPI 9, SPI 12 and SPI 24 would affect more agricultural area in Rangpur.

Table 5.17 Persistence probability matrix of Rangpur station

SPI Series	D1	D2	D3	D4
SPI 1	0.7470	0.7708	0.8000	0.8000
SPI 3	0.7305	0.6180	0.8205	0.8333
SPI 6	0.8376	0.6714	0.8788	0.8214
SPI 9	0.8722	0.7561	0.9063	1.0000
SPI 12	0.9336	0.7321	0.9259	1.0000
SPI 24	0.9478	0.8158	1.0000	1.0000

5.3 Mean Drought Interarrival Time Distribution

The mean drought interarrival time distributions of different SPI series are shown in (Table 5.18) and (Fig. 5.10). Based on the theoretical model and historical droughts the mean drought interarrival time is calculated from the following equation:

$$E(L) = E(DL) + E(WL) = \frac{1}{P_{DW}} + \frac{1}{P_{WD}}$$

It is found that the mean drought interarrival time of different stations based on different SPI series are very close to each other. For SPI 1 the mean drought interarrival time of different stations are approximately 5 months durations. For SPI 3, it is of less than 7.5 months duration. For SPI 6, it is of more than 10 months duration in Dinajpur station but on average it is of 9.5 months duration in other four stations. For SPI 9 it is near to 14 months duration in Rangpur and Rajshahi stations on the other hand Dinajpur, Bogura and Ishwardi station are close to 13-month duration. For SPI 12, the mean drought interarrival time are observed near to 19- and 20-month duration in Dinajpur and Rajshahi stations; meanwhile Rangpur, Bogura and Ishwardi stations are found more than 21-month duration. For SPI 24, Rajshahi and Ishwardi station are found near to 31-month duration but Rangpur and Dinajpur station are discovered more than 34-month duration. It is clearly defined that, mean drought interarrival time is very high in Bogura station (43-month duration) for SPI 24.

Table 5.18 Mean drought interarrival time distribution of study stations

SPI Series	**Rangpur**	**Dinajpur**	**Bogura**	**Rajshahi**	**Ishwardi**
SPI 1	4.5477	4.5749	4.4905	4.1872	4.3845
SPI 3	7.4462	7.2992	6.9578	7.1587	7.1942
SPI 6	9.3418	10.3944	9.4615	9.7730	9.6464
SPI 9	13.9956	13.1250	13.3636	13.9956	12.8947
SPI 12	21.5294	19.7838	21.5294	18.5301	21.5294
SPI 24	34.2857	34.2857	42.3529	30.6975	30.6232

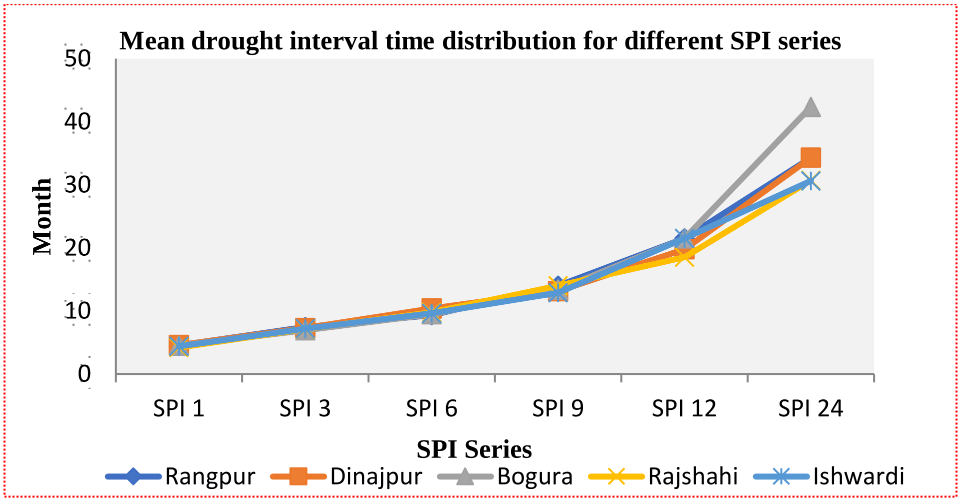


Fig. 5.11 Line graph of different stations by SPI series (Mean drought interarrival time distribution)

5.4 Frequency Analysis of Different SPI Series of Study Station

The frequency of drought months of five meteorological stations is obtained for observed and model data during 1960-2021 for 1-month, 3-month, 6-month, 9-month,12-month and 24-month SPI scales as shown in (Table 5.19). From the following frequency table, it is clearly depicted that the drought scenario is more visible for higher SPI series such as SPI 9, SPI 12, SPI 24. The classification of every state (wet and dry) are arranged according to the months. From the following Table 5.19 it is clearly observed that, drought scenario is more (mild drought to extreme drought) severe in Rajshahi and Ishwardi station rather than others. The distribution of frequency clearly depicted the drought severity level. So, during the study period if extreme temperature and less rainfall continues upto next decade this region fall into a great deal of drought severity and water scarcity. Furthermore, forecasting drought scenario for next decades, we are really concern about our food security and agricultural activities.

Table 5.19 Frequency of drought in Bangladesh for different month using SPI calculated from the observed data

YEAR: 1960-2021								
Bogura								
		Extremely wet	Very wet	Moderately Wet	Mild Drought	Moderate drought	Severe drought	Extreme drought
	SPI 1	49	0	189	331	157	0	18
	SPI 3	53	0	169	294	190	0	36
	SPI 6	13	35	65	507	74	30	13
	SPI 9	13	37	76	490	76	26	18
	SPI 12	24	15	139	376	132	19	28
	SPI 24	49	0	207	244	165	0	56
	Dinajpur							
		Extremely wet	Very wet	Moderately Wet	Mild Drought	Moderate drought	Severe drought	Extreme drought
	SPI 1	46	0	179	372	115	0	20
	SPI 3	40	0	198	275	184	0	33
	SPI 6	46	0	178	294	163	0	46
	SPI 9	48	0	164	308	154	0	50
	SPI 12	47	0	160	314	149	0	51
	SPI 24	54	0	152	274	181	0	48
	Ishwardi							
		Extremely wet	Very wet	Moderately Wet	Mild Drought	Moderate drought	Severe drought	Extreme drought
	SPI 1	17	26	73	563	35	23	7
	SPI 3	44	0	177	299	188	0	34
	SPI 6	58	28	47	464	74	33	35
	SPI 9	68	9	74	423	97	19	46
	SPI 12	62	17	38	461	84	29	42
	SPI 24	57	18	48	484	63	30	21
	Rajshashi							
		Extremely wet	Very wet	Moderately Wet	Mild Drought	Moderate drought	Severe drought	Extreme drought
	SPI 1	13	38	73	549	34	24	12
	SPI 3	46	0	187	280	186	0	43
	SPI 6	33	11	165	327	150	9	44
	SPI 9	19	22	139	380	122	14	40
	SPI 12	35	0	216	265	163	0	54
	SPI 24	46	11	159	279	180	1	44

	Rangpur							
		Extremely wet	Very wet	Moderately Wet	Mild Drought	Moderate drought	Severe drought	Extreme drought
	SPI 1	47	0	192	334	131	0	40
	SPI 3	49	0	173	315	151	0	54
	SPI 6	50	0	151	339	145	0	54
	SPI 9	49	0	152	340	149	0	46
	SPI 12	56	0	134	352	147	0	44
	SPI 24	74	0	99	318	200	0	30

5.5 Conclusion

In this chapter, drought characterization and monitoring based on Markov model and SPI are clearly described. Six-time scales of SPI values of northwest region of Bangladesh during 1960-2021 are computed and analyzed. The short time scales, such as SPI 1, SPI 3, SPI 6 can reflect changes in seasonal drought. The long time-scale such as SPI 9, SPI 12, SPI 24 can provide better long-term continuous monitoring of drought and play an important role in monitoring and characterizing droughts. Alternating renewal process is used to study the distribution of drought interval time and mean drought interarrival time, probability of drought duration of n-year droughts by considering wet and dry states. Further, the transition probability approach is used to evaluate the probability of drought duration and persistence of drought with the help of four dry states divided into (D1, D2, D3, and D4). The drought interarrival time and mean drought interarrival are increasing from lower to higher SPI series i.e SPI 12 and SPI 24 is found the drought duration for longer months in all study stations. It is discovered that there is a significant chance that a "mild drought period" would follow a "mild drought period" for all SPI series when transition probabilities are used to determine the change from one state to the next. For SPI 12 and SPI 24 there is a high probability that the same state will continues for the next state, like ‘severe drought’ would follow ‘severe drought’ and ‘extreme drought’ would follow ‘extreme drought’ period respectively.

Chapter Six
Farmers' Perceptions, Climate Change Impacts, and Adaptation Strategies

6.1 Introduction

Bangladesh is supposed to be the most vulnerable countries in the world due to its geographical location, very low elevation, poor income, high population density, and insufficient adaptive capacity (Thomas et al., 2013; IPCC, 2014c; Sikder & Xiaoying, 2014; Islam et al., 2018). Agriculture is the main pillar of the Bangladesh economy and contributing a notable percentage (14.7%) of gross domestic product (GDP) and about 51.88% of people are directly engaged in agricultural activities (BBS, 2019b). More than half (57.60%) of farming categories constitute small farm holdings, whereas total farming community of medium and large farm holdings are represented by 5.17% and 0.34%, respectively (BBS, 2019b; Bangladesh Economic Review, 2017; Sultana et al., 2020). In addition, the disparities between rural and urban areas in development are comparatively far worse, than in urban areas (Habiba et al., 2014). Approximately, 70% of the populations live in rural areas and they are extremely marginalized and vulnerable to climate change and extreme weather events (Islam et al., 2019). According to Banglapedia (2017), agriculture in Bangladesh typically depends on the quantity and distribution of precipitation (in the form of rain) brought on by southwest monsoon winds. As a result, seasonal variations and climate variability have an impact on agricultural activities of our country (Sikder & Xiaoying, 2014). By the year 2100, climate change is expected to reduce crop yields by 33%, which is highly risk for our national economy and agriculture (Karim et al., 2012; Anik et al., 2021). Due to the previously mentioned threat, the gross crop loss of small and marginal farmers, who account for 84% of the country's total farm holds are more at climate-related risk (BBS, 2019b). The reason behind this they are more dependent on agriculture for their livelihoods and have lesser adaptation capacity (Wood et al., 2014; Huq, 2015).

According to the National Drought Mitigation Center (NDMC) climate change is one of the factors contributing towards the severity of droughts in an agro-based country *like* Bangladesh (Mardy et al., 2018). Drought has become a major phenomenon in Bangladesh, particularly in northern Bangladesh. Every year, Bangladesh suffers a dry spell of seven months from November to May (Habiba et al., 2011), with very little rainfall. Most of the regions in Bangladesh are more and less facing climate related risk but the northwest region is more susceptible to the impacts of climate change and climate variability due to the geo-climatic and regional differentiation (Abdullah et al., 2015; Rahman et al., 2016; Salam et al., 2019; Kamruzzaman et al., 2022). This study region has experienced high rainfall variability, extreme temperature, and consequently, farming activities are mostly depending on groundwater irrigation (Shahid, 2008; Shahid & Behrawan, 2008; Kamruzzaman et al., 2018). As a result, exploitation of groundwater resources exposes the region to regular occurrence of drought. In the said region the average depth of the groundwater level has amplified from 3.7 m in 1981 to 7.3 m in 2016 (MoF, 2017). Previous droughts have affected 47% of the country's total land area and 53% of the population is negatively affected (Anik et al., 2021). Furthermore, drought is recognized as the major risk to the expected agricultural productivity in Bangladesh over several decades. Between 1980 and 2019, nearly 12 million people were affected by drought, which caused US$ 21 billion economic losses (Uddin et al., 2020).

The 2006 data indicates that in the northwest part of Bangladesh drought reduce 25-30% agricultural crop (Rahman et al., 2007). The said phenomenon (drought) has triggered the damage of millions of hectares of cultivated land that causes loss of crop production, which negatively impacts the livelihood of poor farmers who depend primarily on agriculture. Thus, the rural livelihood faces significant challenge due to decrease staple food-crop production, abnormal price hike of basic foods, reducing job opportunity, low accessibility of safe drinking water, and losses of cattle rearing and poultry farming (Habiba et al., 2014). This phenomenon also has long-term effects on the environment, socio-economic system, human health and water management policy (Dey et al., 2012). Farmers, with small land holding, are directly depends on subsistence type of agricultural activities for their livelihoods, but lack of resources makes it more difficult for them to access food and nutrition security (McDowell & Hess, 2012). They are the primary stakeholder of an underdeveloped country like Bangladesh. The farming community of northwest region faces challenge of frequent droughts, because it adversely affects their livelihood patterns by reducing crop harvest, livestock, and fisheries (Habiba et al., 2014).

Resultantly, drought not only impacts agricultural losses of the farmers but also reduce yields, income and investment on agricultural production. In the cropping season, surface water bodies like ponds, canals and rivers dry up due to lack of rainfall and extreme temperature. Extensive ground water depletion has hampered the total farming system and caused serious jeopardy to crop production and income generating activities (Dey et al., 2012; Alam, 2015). In these circumstances, most of the countries have implemented green agriculture technology, which offers sustainable adaptation strategies, to combat the risk and consequences of global warming (Ikram et al., 2021).

Beyond the smart-use of remotely sensed data for detecting drought phenomenon, incurring the ground level perception on climate change as well as 'drought' is presently become significant. While, perception and adaptation strategies are the two-key component of the adaptation process (Maddison, 2007). Farmer's perception of climate change and drought is an important element for evaluating the adaptation strategies (Sultana et al., 2020). At first, farmers' must understand to perceive the impact of climate change in order to implement effective adaptation measures to mitigate their vulnerability and increase the overall resilience of the agro-ecological system (Taylor et al., 1988; Bryan et al., 2009; Hasan & Kumar, 2019; Roy et al., 2021). However, inadequate and misleading perceptions can cause inappropriate adaptation strategies (Alam et al., 2017). Given such vulnerabilities, appropriate adaptation strategies are needed to minimize drought effects and sustain agricultural system, particularly for the sake of poor farming communities (Alam, 2015; Anik et al., 2021). Adaptation in agriculture is the process through perceptions of climate change of the respondents are integrated into agricultural systems for decision-making (Bryant et al., 2000; Ali et al., 2021). According to IPCC (2007), adaptation to climate change is the modification of natural or human systems in response to present or anticipated climatic stimuli or their effects, which mitigates harm or takes benefit of favorable opportunities. There are other definitions that are also often used. "A process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed and implemented" (UNDP, 2005). There are two autonomous or anticipated adaptive reactions. Individual farmers' or agricultural organizations' action is referred to as autonomous adaptation, whereas planned adaptation is carried out by regional, national, and international organizations (IPCC, 2007). Thus, understanding location-specific opportunities, comprehending challenges, and the principal forces are influencing adaptation decisions for the implementation of effective interventions (Kamruzzaman et al., 2022).

To address climate change and drought occurrences, a significant number of academics around the world emphasis that farmers' practice variety of adaptation measures (Hassan & Nhemachena; 2008; Deressa et al., 2009; Shankar et al., 2013; Belay et al., 2017; Alam et al., 2017; Fadina & Barjolle, 2018; Rymbai & Sheikh, 2018; Mamun et al., 2021; Ibrahim & Menash, 2022; Redda et al., 2022; Sohail, 2022); which are universally acknowledged and valid in the respected research areas. In Bangladesh, small number of studies have been conducted on farmers' perceptions, drought and adaptive strategies (Habiba et al., 2012; 2014; Alauddin & Sarker, 2014; Alam, 2015; Hossain et al., 2016; Ara, 2018; Mardy et al., 2018). However, only few of them study on farmers' perceptions towards drought, and adaptation strategies with actual meteorological patterns and specifically drought adaptation in the study area (Roy et al., 2020). So, it is really difficult to draw a complete scenario on drought adaptation because no single strategy or solution fit for all regions or country. Sarker et al. (2013) described that, climate variability varied from one climatic zone to another, so it was the utmost importance to focus on more location-based adaptation strategies in a country like Bangladesh. Because, each agro-ecological zone has its own specific geography, socio-economic condition, and climatic circumstances, and each locality or community must have its own adaptation techniques. Meanwhile, most of the adaptation studies were African based which completely different from other regions (Hassan & Nhemachena, 2008; Deressa et al., 2009; Bryan et al., 2009; Belay et al., 2017; Fadina & Barjolle, 2018). The mentioned studies mainly used most common adaptation strategies such as crop diversification, changing planting date, tree planting, soil-water conservation, integrating crops with livestock, and irrigation system for African regions. In Bangladesh some researchers used the terms "adaptation" and "coping" were interchangeably. For example, Alam (2015) focused on increasing use of surface water, crop diversification, and land use change as a primary adaptation strategy whereas Habiba et al. (2012) and Selvaraju et al. (2006) considered agronomic practices such as weeding, seedbed method, manure and compositing, and mulching method for their adaptation strategy. In some research supplementary irrigation was used as an adaptation strategy, while it was coping strategy when rainfall wasn't sufficient in drought prone areas (Alauddin & Sarker, 2014; Al-Amin et al., 2019). Recently, Anik et al. (2021) identified six common adaptation strategies which influence education, subsistence pressure, income from livestock and poultry, extension service, involvement in organizations, and the use of ICT for farming. These factors were significantly and positively related to the selected adaptation strategies but increasing women's participation in farming activities was inversely related. All the above noted studies only measure adaptation strategy based on farmer's perception using different statistical model. It is clear to say that, Farmers' individual adaptation decisions are mutually exclusive by taking univariate modeling techniques, however in our country, farmers normally apply multiple adaptation strategies for their agricultural plan simultaneously without any idea of the present meteorological trend and other climate related factors. To overcome this research gap our aimed in this chapter to focus at northwest drought prone area with the following objectives (1) examining a complete scenario of the study areas to assess farmers' perception and awareness of present climatic trends, which helps them a deeper knowledge about current weather and adaptation policy (2) identifying main impacts of drought on agriculture by ranking (3) investigating what adaptation practice used in selected upazilla (sub-district or part of district) (4) determining influential factor on choice of adaptation strategies, and (5) exploring farmers' opinion to combat future drought adaptation strategies and policy implication.

6.2 Modeling, Perceptions and Impacts

6.2.1 Theoretical and Empirical Model

The determinants of farmer's choice of adaptation strategy due to drought are analyzed using a multinomial logit model (MNL) in the northwest region (Abid et al., 2015). The MNL model is widely used in adaptation research and crop cultivation(Deressa et al., 2009; Mamun et al., 2021; Sarker et al., 2013; Tessema et al., 2013). The main benefit of this model is that it permits the study of choices over more than two categories and allows the determination of choice likelihoods for various classes (Wooldridge 2002; Islam et al., 2021). However, the model requires that households must associate with only their available preferred option from a particular set of adaptation policies. In this study MNL model is used to analyze the choice of farmer's adaptation strategies utilizing discrete dependent variables with different choice of strategies. These choices are deriving from farmer's behavior to maximize utility (or profit). Assume that U_m and U_n denote the utility of farmer, who chooses between any two alternatives, then the linear random utility model, can be presented as:

$$U_{im} = V_{im} + \varepsilon_{im} \quad (6.1)$$

$$U_{in} = V_{in} + \varepsilon_{in} \quad (6.2)$$

Where U_{im} and U_{in} are the farmer random utility of farmer's selected options *m* and *n* respectively; V_{im} and V_{in} indicate the deterministic (explainable) or systematic utility components ε_{im} and ε_{in} are the stochastic (random) variables that represents unobservable effect on individual selections and measurement errors. This random component or error term of the utility function is assumed to be independently and identically distributed (Greene, 2012).Here the utility V_{im} and V_{in} depends on the attribute vector *x*, for example, $V_{im} = x_{im}^{/}\beta$ and $V_{in} = x_{in}^{/}\beta$ are the function of observable attributes of alternatives.

Moreover, farmers are also encouraged to choose the alternative that has the maximum utility. However, utility V_{im} and V_{in} are not directly observed, for this reason adaptation options are detected by the choices of farmers. When there are numerous options, the probability of an individual choosing the alternative *i*, among the set of several adaptations can be expressed as:

$$P_{im} = Pr(U_{im} > U_{in}) = Pr[x_{im}^{/}\beta + \varepsilon_{im} - x_{in}^{/}\beta - \varepsilon_{in} > 0|x|]$$

$$= Pr[(x_{im}^{/} - x_{in}^{/})\beta + \varepsilon_{im} - \varepsilon_{in}] > 0|x| = \Pr[x_i\beta + \varepsilon > 0|x|] \quad (6.3)$$

Where β represents an unknown vector coefficient, *x* denotes a vector of explanatory factors influencing adaptation choice, and ε indicates a random error term. The probability that a farm household will select option *m* for a given *x* is provided as follows:

$$Pr(Y_i = m/x) = \frac{e^{\beta_m x_i}}{1+\sum_{k=1}^{M} e^{x_i \beta_n}} \quad (6.4)$$

Equation (6.4) can be calculated by means of MNL regression which means that choices are reliable with the 'Independence of Irrelevant Alternatives' (IIA) property. It implies that the likelihood of a certain farmer adopting a specific adaptation approach is independent from the probability of choosing an alternative adaptation strategy. The estimated parameters of the MNL model do not directly interpret the data; rather, they simply provide an idea of the direction of the effects of explanatory variables. Finally, the marginal effects of different exogenous factor computed by differentiating equation (6.4) with respect to k^{th} explanatory variable:

$$\frac{\partial P_m}{\partial x_k} = P_m(\beta_{mk} - \sum_{m=1}^{M-1} P_m \, \beta_{mk}) \tag{6.5}$$

Marginal effects determine the likelihood of variation in the probability of adapting to a specific choice in response to a unit change in an explanatory variable (Greene, 2012). The model was estimated using STATA version 17. The final MNL model of factors determining farmers' adaptation behavior is specified as:

$$Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots + \beta_n X_n \tag{6.7}$$

Where the *X's* are the explanatory variables and $\beta's$ denote the parameter estimates.

6.2.2 Demographic, Socio-economic and Farm Characteristics of The Respondents

The socio-economic characteristics of the respondents were collected from four villages (namely Narayanpur, Azaiyr, Suroil and Haripur) under four selected unions of four upazilas (sub-districts or parts of districts). Table 6.1 included respondent age category, years of education, average monthly income, family size, firm size, firming experience, and others farm characteristics of the respondents. The socio-economic characteristics are dominated by the age level 30 to 50 years of respondents. In the study villages, about 55% to 60% of farmers had completed primary and secondary school, while 28% to 42% farmers were still illiterate. During the survey, 62% of farmers of Narayanpur village in Tanore upazila earned very low amount less than 12000 tk, while 68.9% of farmers earned more than 25000 tk in a month in Haripur village of Shapahar upazila. In the study area, on average 54% family size were small (<4) and 31.9% family size were middle (4-6) whereas large family (>6) ranged from 8.9% to 18.5%. During study Narayanpur, Azaiyr and Suroil village had 38% to 39% landless farmers, while maximum farmers of Haripur village of Shapahar upazila had in total 84.4% small, medium and large firm rather than landless and marginal (Table 6.1). Less than 20% of farmers in Suroil and Haripur village were more than (>25 years) experience in farming and 42% of farmers of Azaiyr village of Nachole upazila had low farming experience and 50% of farmers had medium experience of farming in Narayanpur village of Tanore upazila. Climate information is the primary objective for farming and adaptation policy. That's why, in survey study 'access to climate information' almost observed similar result in all selected villages under the respective upazila. In other words, on average more than 80% climate accessibility found in the research area. Among all the villages, Suroil village of Chirirbandar upazila under Dinajpur district found better electric accessibility (80%) than other sample villages. Social interaction in a community developed our knowledge and decision-making capability, in this current work high social mobility varied from 66.7% to 83.7%. Another important characteristic of farming activity was 'farmer to farmer extension' service. On an average 59% of farmers were highly engaged with farmer to farmer extension. More than 80% of respondents took loan subsidies in Narayanpur and Haripur village under Tanore and Shaparar upazila but 91.4% of farmers in Azaiyr village of Nachole upazila did not take any loan whereas the farmers of Suroil village were likely to take.

Table 6.1 Socio-economic and farm characteristics of the respondents

Category	**Selected Villages Respondents**			
	Narayanpur (%)	**Azaiyr (%)**	**Suroil (%)**	**Haripur (%)**
Age (Year)				
Less than 30	7.6	7.5	14	23.3
30-40	28.3	38.7	26	44.4
40-50	35.9	28	27	22.2
>50	28.3	25.8	33	10
Education (Years)				
Illiterate	28.3	38.7	42	28.9
Primary	37	33.3	24	20
Secondary	23.9	21.5	17	34.4
Higher Secondary or Graduate	10.9	6.5	17	16.7
Income ('000' BDT)				
Low Income (<12000)	62	45.2	46	5.6
Middle (12000-25000)	38	49.5	51	25.6
High Income (>25000)	0	5.4	3	68.9
Family size				

Small (less than 4)	48.9	54.8	66	55.6
Middle (4-6)	32.6	31.2	24	35.6
Large (more than 6)	18.5	14	10	8.9
Firm size (ha)				
Landless (0)	39.1	38.7	39	13.3
Marginal (0.0-0.20)	19.6	16.1	21	3.3
Small (0.20-0.40)	31.5	30.1	27	21.1
Medium (0.40-0.60)	8.7	8.6	12	30
Large (> 0.60)	1.1	6.5	1	32.2
Firming experience (years)				
Low (less than 15)	26.1	41.9	39	41.1
Medium (15-25)	50	22.6	42	44.4
High (> 25)	23.9	35.5	19	14.4
Climate accessibility				
High	77.2	94.6	75	82.2
Low	22.8	5.4	25	17.8
Access to electricity				
High	68.5	60.2	80	68.9
Low	31.5	39.8	20	31.1
Social mobility				
High	83.7	66.7	76	70
Low	16.3	33.3	24	30
Farmer to farmer extension				
High	65.2	53.8	67	50
Low	18.5	40.9	27	35.6
No	16.3	5.4	6	14.4
Loan subsidies				
Yes	82.6	8.6	40	86.7
No	17.4	91.4	60	13.3

6.2.3 Farmer's Perception on Climate Change and Drought

Information about the 'climate change' and 'drought' from the farmers is the most important section of this current study. Mainly, the head of the household were questioned about meteorological changes on various climatic variables. In total 375 respondents from four upazilas (sub-districts or parts of district) in the northwest district were interviewed. About

95.6% farmers claimed that the climate has changed dramatically over the last 30 years. The change observed in rainfall and temperature disturbances like dry season longer, low rainfall, increasing of temperature, increasing number of warm days, decreasing number of rainy days, manmade reason etc. According to survey results, 98.1% respondents mentioned that temperature is rising, and 86.7% said the frequency of warm days has been rising quickly. In addition, 80.3% farmers agreed that, substantial percentages of cold days have been reduced since 1991. The majority of respondents (95.9%) identified that the summer and winter rainfall have been decreasing significantly due to the increasing temperature in the northwest part of Bangladesh. Moreover, 45.1% of respondents claimed that manmade reasons (*like* deforestation, urbanization, and industrialization) were also involved for rising temperature. When farmers were asked about the rainfall pattern of the study area almost 94.5% reported that rainfall is decreasing over the last 30 years. Furthermore, 72.5% respondents of four villages answered that the timing of rainfall has been changed in different seasons and 72.7% respondents said that number of rainy days decreased over the last three decades. A large margin of farmers (95%) identified increasing summer temperatures and man-made events were the main reasons behind decreasing rainfall (Source: Questionnaire Survey). To investigate the farmer's perception on drought, we categorized their responses by five-point Likert Scale (*i.e* strongly disagree, disagree, no idea, agree, strongly agree) according to four individual questions: (a) If dry seasons are longer (b) If drying up streams/rivers/ponds/khals (c) If low rainfall in rainy season (d) If delayed onset of rainfall. Most of the farmers agree and strongly agree of the above four questions. From (Fig. 6.1) clearly depicts the farmers' perceptions of drought during the study period. From bar diagram 62.4% are strongly agreed that dry season are longer on the other hand only 0.2% strongly disagree about drying up streams/rivers/ponds/kharies. Another two perceptions are low rainfall in the rainy season and delayed onset of rainfall. In both questions above 50% respondents (farmer) strongly agree on low rainfall and delayed onset of rainfall. The percentage of strongly disagree on low rainfall is very low (less than 1%).

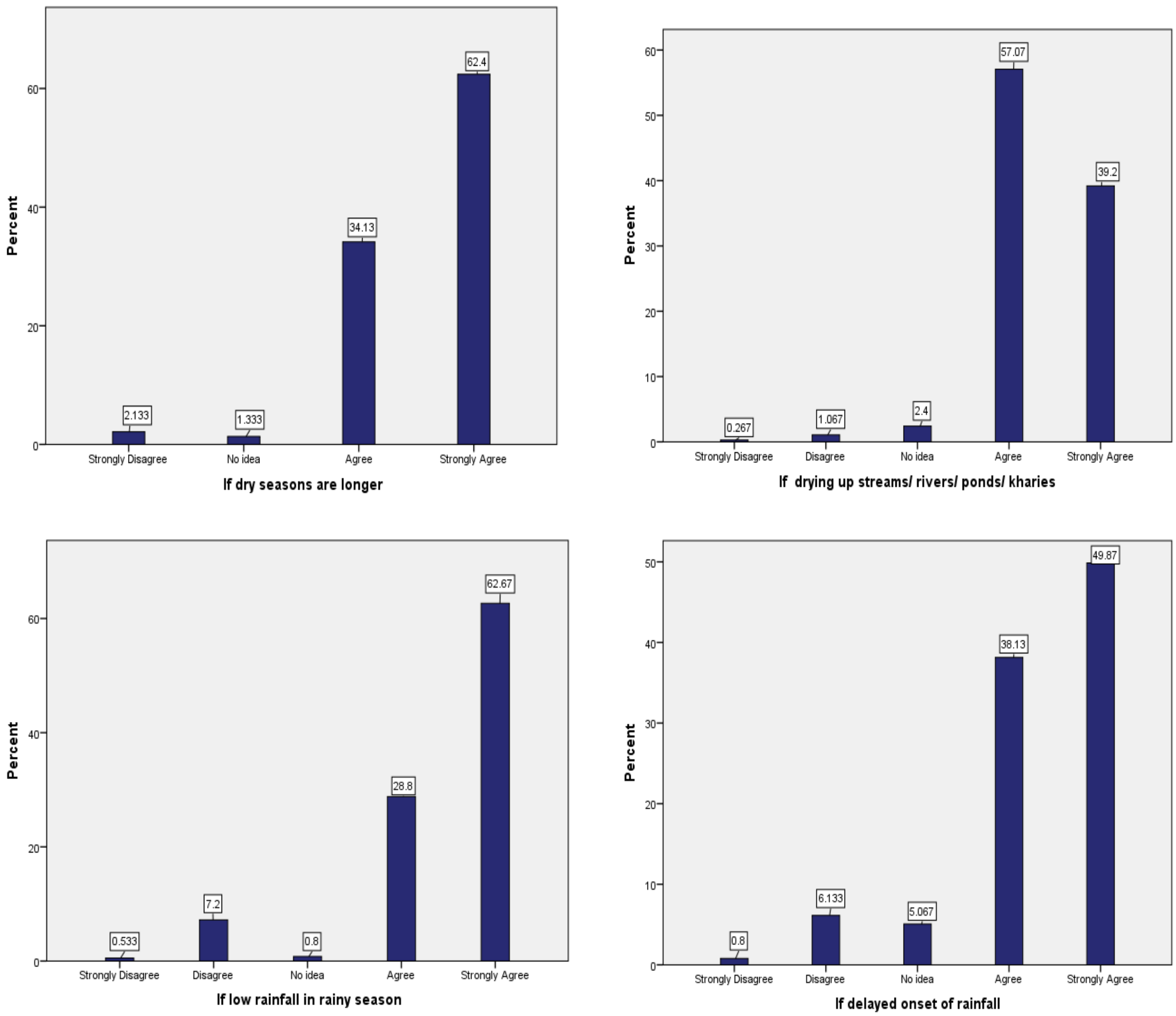


Fig. 6.1 Farmers' perception on drought and climate change

6.2.4 Changes in Temperature and Rainfall During 1960-2021

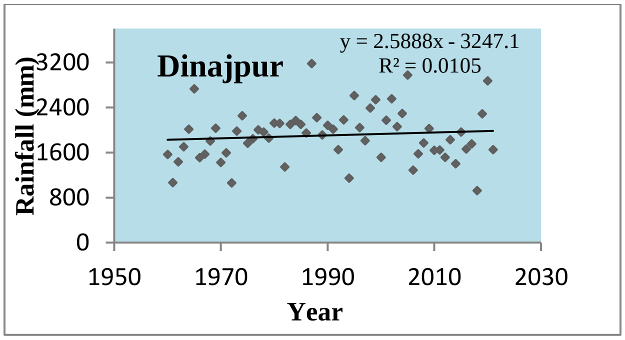
To analyze the temperature and rainfall trend, three indices like annual average, maximum and minimum range of temperature and rainfall, non-parametric Mann-Kendall and Sen's slope analysis are considered (Table 6.2). The annual average rainfall of Dinajpur and Rajshahi stations are 1906 mm and 1460 mm respectively whereas annual average temperature is high at Rajshahi district (25.3°C) and low at Dinajpur district (24.9°C).

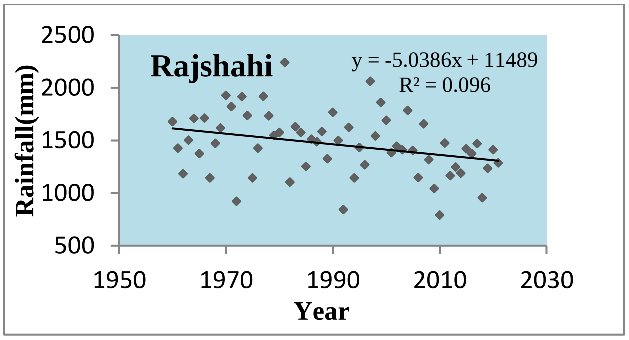
Table 6.2 Results of MK test and Sen's slope analysis during the period (1960-2021) in Dinajpur and Rajshahi districts in the northwest region Bangladesh

	Annual Average	Maximum	Minimum	MK test	Sen's slope	Kendall's Tau	Trend
Rainfall output							
Dinajpur	1906 mm	3179 mm	920 mm	0.692	2.59	0.061	Increasing
Rajshahi	1460 mm	2241 mm	792 mm	-2.654*	-5.50*	-0.232*	Decreasing
Temperature output							
Dinajpur	24.9°C	26.03°C	24.10°C	-1.014	-0.003	-0.089	Decreasing
Rajshahi	25.3°C	26.60°C	24.43°C	1.233	0.004	0.109	Increasing

*Significant trend at 5% level of significance

From rainfall output analysis, Dinajpur station shows an increasing trend in MK test (0.692) and the degree of change by Sen's slope estimates is 2.59 mm/year but statistically insignificant. On the other hand, Rajshahi station reveals that MK test shows significant decreasing trend (-2.654) at 5% level of significance. The rate of change obtained from the analysis of Sen's slope estimates is -5.50 mm/year, which shows negative trend. The Kendall-tau reveals a monotonic trend of weak relationship in both districts during the study. From temperature output analysis, a negative trend (-1.014) is observed in Dinajpur district, but a positive trend (1.233) is detected in Rajshahi district in the results of MK test analysis. The magnitude of changes in these two districts discovered by Sen's slope estimates are -003°C/year and 0.004°C/year, respectively.





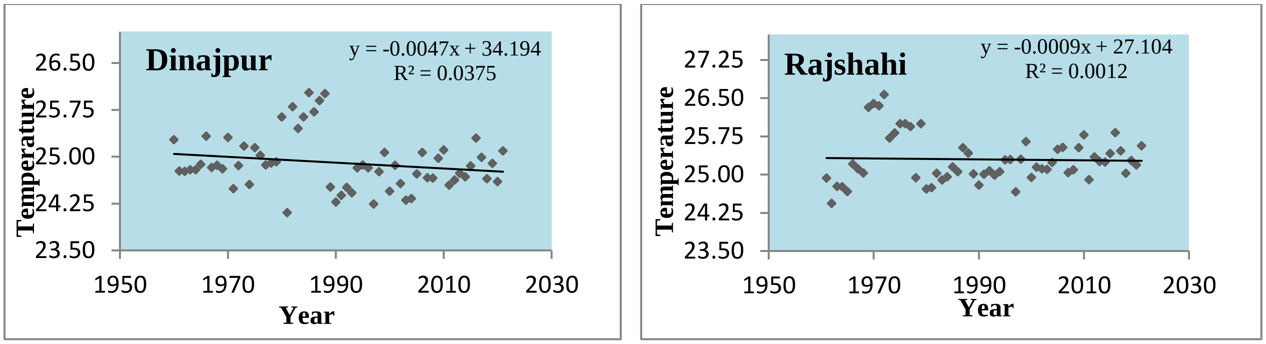


Fig. 6.2 Linear trend analysis of annual average (temperature and rainfall) during the period of 1960-2022 in Dinajpur and Rajshahi districts **(Source: Bangladesh Meteorological Department)**

The linear trend analysis clearly shows the upward and downward trend of Dinajpur and Rajshahi district. During the 1960-2021, the linear trend line of annual average rainfall of Dinajpur district shows positive trend (or increasing) after the early year 1990's and negative trend (or decreasing) significantly continues almost from the starting year 1960 in Rajshahi district. For temperature analysis the trend line depicts downward trend after the year 1975 while in the same trend line also shows upward trend after 2015. Although in Rajshahi district the generalized trend is slightly negative (Fig. 6.2).

6.2.5 Main Effects of Drought on Agricultural Production

Farmers were very vulnerable during drought and their livelihood patterns were risky which mainly effects agricultural production, income activity, cost of production, soil and ground water levels. A five-point rating scale was established to identify the perceived effects of drought in four drought-prone villages under four upazilas (sub-districts or parts of district).

a) **Overall Effects of Drought:** The farmers were offered to rank the main effects of drought on agricultural production using very high, high, medium, low, and very low with corresponding score 4,3,2,1 and 0 respectively. The statements were ranked in order to give highest priority to the remarks that described situations in which the effects of the drought are extreme. To compute the main effects of drought it is possible to formulate a weighted average index (WAI) for finding out the ranking of main effects.

$$WAI = \frac{F_{vh}\times4+F_h\times3+F_m\times2+F_l\times1+F_{vl}\times0}{N} \quad (6.8)$$

Where, *WAI* = weighted average index, F_{vh} = frequency of responses with very high effect, F_h = frequency of responses with high effect, F_m = frequency of responses with medium effect, F_l = frequency of responses with low effect, F_{vl} = frequency of responses with very low effect, N = Total number of responses.

The rank order of perceived impacts of drought is shown in (Table 6.3). In all four upazilas (sub-districts or parts of district) a list of statements of possible effects of drought were interviewed to the respondents of the respective village under each upazila to collect preliminary data and the responses were analyzed by WAI method, as mention in the equation (6.8). Overall farmers identified that increased cost of production as having the highest effect by drought with WAI 3.68. Most of the farmers cultivated their land using traditional instruments and different types of crop seeds, sharing irrigation water during the dry spells, but the global price hike of all the products heated up the agricultural sector, although governmental subsidies were given to each upazila. The second main effects were the declining ground water level with WAI 3.63, almost all the farmers relied on ground water for their rice cultivation, so the ground water shortage during the crop growing season might have an impact on agricultural output. One of the FGD participants of Azayir village under Nachole upazila (sub-district or part of district) said that:

"During drought the ground water are not satisfactory level for irrigation, because of less rainfall pond/ khals, river is mainly dry all the year and longer dry season as well as delay onset of rainfall effects crop production during peak cropping season we experience a water shortage, hence, we must extract groundwater for further irrigation. In addition, he told that, since 2018, the cost of an hour of field irrigation has been increased twice."

The third most effect observed by the researcher was crop failures with WAI 3.45. Most of the farmers in the study region were illiterate and few of them completed only primary or elementary level of education, meanwhile a big margin of the respondents was landless. Therefore, they had no idea about crop cultivation and mitigation the effect of crop failures. But according to Mardy et al. (2018), farmers reported crop failures were the least severe drought consequences in the northwest, which really differs above statements.

Table 6.3 Overall main effects of drought by rank order of farmers

Statements	Very High	High	Medium	Low	Very low	WAI	Rank
Increased cost of production	290	62	11	11	1	3.68	1
Declining ground water levels	289	45	33	4	4	3.63	2
Crop failures	250	69	37	13	6	3.45	3
Scarcity of soil water	203	124	34	14	0	3.38	4
Lower income	176	78	78	32	11	3.00	5
Food scarcity	166	29	123	44	13	2.78	6
Health impacts	111	45	162	46	11	2.53	7
Malnutrition	36	129	86	71	53	2.06	8
Loss of livestock	59	31	181	75	29	2.04	9
Water quality deterioration	45	68	142	65	55	1.95	10
Unemployment	41	49	105	159	21	1.81	11

Very high = 4, High = 3, Medium = 2, Low = 1, Very Low = 0

The farmers identified that scarcity of soil water is the fourth most major perceived effect during study with a WAI of 3.38. Due to the scarcity of soil water in the peak cropping season rice and mango cultivation were badly affected in most areas of Nacole and Shapahar upazila. Farmers also identified effects like lower income, food scarcity, health impacts, malnutrition, and losses of livestock with a rank order of WAI. During the study, water quality deterioration and unemployment reported least severe effects with WAI value 1.95 and 1.81. The above findings might differ to other research studies depending on time, spatial distribution and archeological environment.

b) Upazila Wise Effects of Drought*:* During survey period farmer's perceived impacts of drought at different upazila is shown in (Table 6.4). The highest main impacts of drought respond by the farmers is increased cost of production followed by declining ground water levels, crop failures, scarcity of soil water. In addition, lower income, food scarcity, health impacts, malnutrition, loss of livestock, water quality deterioration and unemployment are also affected by drought. So, it's an urgent need to mitigate drought impacts and other climate factors; otherwise agricultural sector faces many challenges in near future.

Table 6.4 Farmers perceived impacts of drought on agricultural crop production in different upazila

Main impacts of drought	**Upazila**				
Scarcity of soil water		Tanore (%)	Nachole (%)	Chirirbandar (%)	Shapahar (%)
	Very High	51.1	55.9	42	68.9
	High	30.4	36.6	35	30
	Medium	18.5	7.5	9	1.1
	Low	0	0	14	0
Unemployment	Very High	6.5	9.7	24	2.2
	Medium	45.7	51.6	6	10
	Low	7.6	31.2	55	75.6
	Very Low	2.2	1.1	12	6.7
	High	38	6.5	3	5.6
Crop failures	Very High	25	78.5	86	75.6
	High	38	11.8	9	15.6
	Medium	23.9	7.5	2	6.7
	Low	9.8	2.2	1	1.1
	Very Low	3.3	0	2	1.1
losses of livestock	Very High	3.3	9.7	42	5.60
	High	17.4	7.5	3	5.60
	Medium	39.1	79.6	26	50.00
	Low	27.2	3.2	22	27.80
	Very Low	13	0	7	11.1
Increased cost of production	Very High	50	82.8	94	81.1
	High	39.1	10.8	4	13.3
	Medium	5.4	4.3	0	2.2
	Low	5.4	2.2	1	3.3
	Very Low	0	0	1	0
Heath Impacts	Very High	11	34.4	51	20
	High	31.9	9.7	6	1.1
	Medium	47.3	46.2	25	56.7
	Low	6.6	7.5	18	16.7
	Very Low	3.3	2.2	0	5.6
Decline in groundwater levels	Very High	52.2	77.4	90	87.8
	High	33.7	2.2	5	7.8
	Medium	8.7	19.4	4	3.3
	Low	3.3	0	0	1.1
	Very Low	2.2	1.1	1	0
Water quality deterioration	Very High	10.9	24.7	4	8.9
	High	21.7	15.1	9	27.8
	Medium	40.2	36.6	33	42.2
	Low	18.5	8.6	26	15.6
	Very Low	8.7	15.1	28	5.6
Food scarcity	Very High	17.4	11.8	93	51.1
	High	17.4	5.4	4	4.4
	Medium	38	77.4	3	14.4
	Low	19.6	5.4	0	23.3
	Very Low	7.6	0	0	6.7

Malnutrition	Very High	7.6	2.2	1	28.9
	High	19.6	5.4	74	35.6
	Medium	25	40.9	12	14.4
	Low	30.4	23.7	10	12.2
	Very Low	17.4	28	3	8.9
Lower income	Very High	23.9	34.4	85	41.1
	High	48.9	15.1	14	5.6
	Medium	17.4	46.2	1	20
	Low	6.5	4.3	0	24.4
	Very Low	3.3	0	0	8.9

6.3. Adaptation Strategies Adopted by Farmers

6.3.1 At Least One Adaptation Strategy

Farmers are asked about their current adaptation strategy in response to drought. Based on the questionnaire survey, focused group discussions and key informant interviews, the farmers from different villages under selected upazila in the northwest region have been employing various strategies to lessen the impact of drought. Farmers' adaptation strategy to climate change can be affected by several factors, such as climate, social, and economic factors (Shrestha et al., 2017). The survey outcome across the four villages in the northwest drought-prone area are presented in Table 6.5. The majority of the respondents who are involved in farming activities are male and maximum farmers are over 30 years of age. The findings indicate that the most important practices are irrigation facility, agronomic management, drought tolerant rice varieties, adopting new technologies, alternative enterprise of land use change, respectively. The surveyed farmers also have used other adaptation strategies often like crop rotation and changing planting date, crop intensification, re-excavation of traditional pond/khals, harvesting rainwater, alternative enterprise of land use change, extra income generating activities. According to the distribution of the current adaptation strategies, the maximum number of farmers in Narayanpur (32.6%), Azaiyr (54.8%), and Suroil (49%) villages under Tanore, Nachole, and Chirirbandar upazilas (sub-districts or parts of district) have used irrigation facilities (deep tube wells) as their first prioritized strategy. During dry periods, huge amounts of groundwater are required in this region for rice cultivation. In the past, there hasn't been enough rain in the northwest, which has led to lowering of groundwater table and a water shortage for farming and other uses (Dey et al., 2012). In case of Horipur village under Shapahar upazila, irrigation facilities are not available for crop cultivation but agronomic management (*e.g.*, manure and composting, seedbed method, ail lifting, tillage, and shedding) and alternative enterprises of land use change get the highest priority for agricultural production. It is also evident that drought-tolerant rice varieties are mainly used at Narayanpur (27.2%) and Azaiyr (25.8%) villages, however other two villages under respective upazilas (sub-districts or parts of district) did not accustomed with this adaptation strategy. The remaining adaptation strategies mostly adopted by the farmers are new technologies of farming and extra income generating activities. Few farmers in the sample villages used traditional adaptation methods such as re-excavation of traditional ponds and khals, rainwater harvesting, crop intensification, and surface water use for crop cultivation during the drought. The right information about to know the weather forecast is needed to decide whether to plant early or late plantation, switch crops, or change the date of planting.

Table 6.5 Distribution of at least one adaptation strategy used by farmers

Adaptation strategy	Narayanpur	Azaiyr	Suroil	Horipur
Drought tolerant rice varieties	25(27.2%)	24(25.8%)	5(5%)	1(1.1%)
Agronomic management	13(14.1%)	7(7.5%)	4(4%)	35(38.9%)
Re-excavation of traditional ponds/khals	0(0%)	2(2.2%)	3(3%)	1(1.1%)
Increase amount of surface water	0(0%)	0(0%)	3(3%)	0(0.0%)
Rainwater harvesting	0(0%)	0(0%)	9((%)	2(2.2%)
Irrigation facility	30(32.6%)	51(54.8%)	49(49%)	0(0.0%)
Crop intensification	2(2.2%)	1(1.1%)	3(3%)	6(6.7%)
Alternative enterprise of land use change	9(9.8%)	1(1.1%)	1(1%)	26(28.9%)
Crop rotation and changing planting date	0(0%)	5(5.4%)	2(2%)	3(3.3%)
Extra income generating activities	4(4.3%)	0(0%)	15(15%)	4(4.4%)
Adopting new technologies	9(9.8%)	2(2.2%)	6(6%)	12(13.3%)

Source: Questionnaire Survey

In the study area, it is clearly demonstrated that the overall percentage of different upazila adopted by the farmers' is shown in (Fig. 6.3). Maximum number of respondents in different villages agreed that irrigation facility is their primary adaptation strategy (34%). Moreover, they also used another adaptation option like agronomic management (16%), adopting new technologies (8%) and drought tolerant rice varieties (15%), alternative enterprise of land use change (10%) for their crop cultivation simultaneously. They are not habituated popular adaptation option like re-excavation of traditional ponds (1%), rainwater harvesting (3%), crop rotation and changing planting date (3%), crop intensification (3%), and extra income generating activities (6%) during drought. There are also numerous adaptation strategies available in their respective upazilas (sub-districts or parts of district), but farmers are mostly familiar with their cost-effective adaptation for sustainable farming.

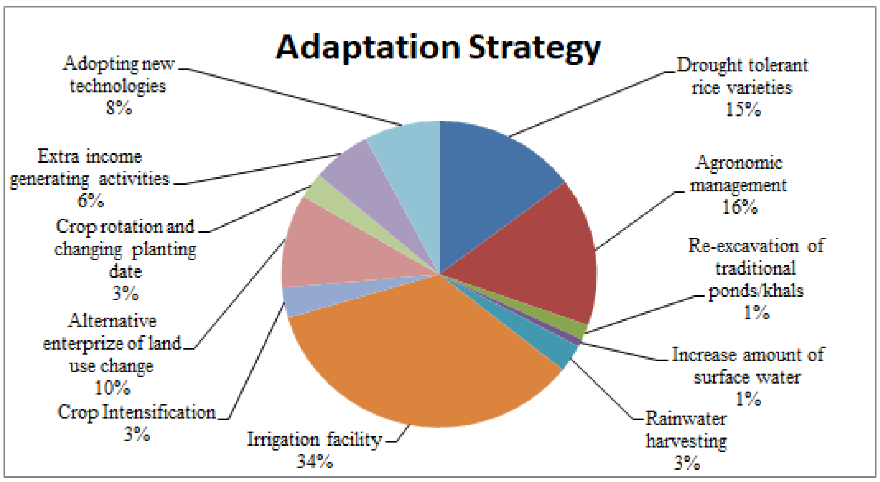


Fig. 6.3 Distribution of proportion of adaptation strategy adopted by the farmers' in the study area

6.3.2 Multiple Adaptation Strategy

The study participants in these four Upazila were used to practice multiple adaptation techniques for their agricultural production. As presented in Table 6.6, in all upazilas, farmers adopted different techniques, mainly based on the nature of problems and geographical locations. They used agronomic management, irrigation facility, drought tolerant rice varieties, crop rotation and changing planting date, extra income and adopting new technology for their highest priority as multiple adaptation purpose. In Narayanpur village of Tanore upazilla farmers used irrigation facility as their primary adaptation technique (94.6%) along with drought tolerant rice varieties (77.2%), agronomic management (78.3%), adopting new technologies (69.6%), and extra income generating activities (41.3%). In Horipur village of Shapahar upazilla agronomic management (92.2%) used as much in this upazila because irrigation facility was not sufficient due to lack of groundwater. They also used alternative enterprise of land use change (74.4%) followed by adopting new technology (83.3%), crop rotation and changing planting date (38.9%) and crop intensification (34.4%). Other two villages Azaiyr (Nachole) and Suroil (Chirirbandar) adopted almost similar adaptation techniques for their cultivation such as irrigation facility (83.9%, 94%), alternative enterprise of land use change (21.5%, 27%), crop rotation and changing planting date (23.7%, 24%), adopting new technologies (33.3%, 22%). It was clearly observed that in the study region, farmers didn’t apply as much rainwater harvesting, increase amount of surface water, re-excavation of traditional ponds as their prominent adaptation techniques.

Table 6.6 Multiple adaptation strategies adopted by farmers

Adaptation Strategy	Selected village			
	Narayanpur	Azaiyr	Suroil	Horipur
Drought tolerant rice varieties	71(77.2%)	33(35.5%)	11(11.0%)	26(28.9%)
Agronomic management	72(78.3%)	21(22.6%)	13(13.0%)	83(92.2%)
Re-excavation of traditional ponds/khals	5(5.4%)	16(17.2%)	12(12.0%)	1(1.1%)
Increase amount of surface water	2(2.2%)	23(24.7%)	23 (23.0%)	8(8.9%)
Rainwater harvesting	1(1.1%)	11(11.8%)	24(24.0%)	23(25.6%)
Irrigation facility	87(94.6%)	78(83.9%)	94(94.0%)	0(0%)
Crop Intensification	15(16.3%)	8(8.6%)	11(11.0%)	31(34.4%)
Alternative enterprise of land use change	21(22.8%)	20(21.5%)	27(27.0%)	67(74.4%)
Crop rotation and changing planting date	11(12.0%)	22(23.7%)	24(24.0%)	35(38.9%)
Extra income generating activities	38(41.3%)	20(21.5%)	26(26.0%)	17(18.9%)
Adopting of new technologies	64(69.6%)	31(33.3%)	22(22%)	75(83.3%)

6.3.3 Specification of the Variables

The empirical literature, focus group discussion and data availability were used to choose the independent variables. Various hypothesis have been created around explanatory variables in terms of the expected influence those variables on adaptation strategies (Alam, 2015; Mamun et al., 2021; Rakgase & Norris, 2014). Twelve explanatory variables were incorporated in the model *i.e.* age, education, monthly average household income, family size, farming experience, firm size, access to climate information, access to electricity, training experience, social mobility, farmer to farmer extension and loan subsidies. Respondents were asked to respond to list of the questions by multiple choices. Including explanatory variables into the model was a challenging issue but with the help of data reduction technique (factor analysis) and variance inflation factor was run to check for possible multicollinearity of the explanatory variables. The predicted VIF results range from 1.07 and 2.9. Due to the fact that these values of the explanatory variables are less than less than 10, multicollinearity isn't an issue in the present model. The definition and summary statistics of the explanatory variables used in this study is shown in Table 6.7.

Table 6.7 Definition and summary statistics of explanatory variable used in the model

Explanatory Variable	Measure	Mean	Std
Age of the respondent	Continuous (years)	43.54	11.13
Education	Continuous (years)	5.17	4.722
Average household income (Monthly)	Continuous (BDT)	18086.67	10204.91
Family size	Continuous (number)	4.53	1.453
Farming experience	Continuous (years)	20.09	8.1
Firm size	Continuous (hectare)	.278	.289
Access to climate information	Dummy, 1= high, 2 = low	1.18	.384
Access to electricity	Dummy, 1= high, 2 = low	1.30	.461
Training experience	Dummy, 1= experienced, 2 = not experienced	1.46	.499
Social mobility	Dummy, 1= high, 2 = low	1.26	.437
Farmer to farmer extension	Dummy, 1= high, 2 = medium, 3= no	1.51	.678
Loan subsidies	Dummy, 1= yes, 2 = no	1.47	.50

Twelve explanatory variables were incorporated in the model *i.e.* age, education, monthly average household income, family size, farming experience, firm size, access to climate information, access to electricity, training experience, social mobility, farmer to farmer extension and loan subsidies. Respondents were asked to respond to list of the questions by multiple choices. Including explanatory variables into the model was a challenging issue but with the help of data reduction technique (factor analysis) and variance inflation factor was run to check for possible multicollinearity of the explanatory variables. The predicted VIF results range from 1.07 and 2.9. Due to the fact that these values of the explanatory variables are less than 10, multicollinearity isn't an issue in the present model. The definition and summary statistics of the explanatory variables used in this study is shown in (Table 6.6).

6.3.4 Determinants of Farmers' Choices of Adaptation Strategies to Drought

Respondents in the study area said that declining rainfall and extreme temperature in the crop growing season affects crop cultivation and experienced crop failures, scarcity of soil water and ground water depletion over last 30 years (Alam, 2015; Islam et al., 2021). Henceforth, the farmers were found using a variety of adaptation techniques to cope with drought-prone environments. Farmers in each upazila were required to implement at least one of the twelve identified adaptation techniques in order to continue farming and livelihood activities. In total, 375 respondents were selected according to PPS sampling and they were asked to identify their most commonly used measure from a range of options which were adopted by total surveyed respondents. In some cases, the adaptation strategy followed by the farmers was at very low frequency and it made difficult to make an effective model. According to Alam (2015) and Sarker et al., (2013), the model was recognized by categorizing closely related choices into the same category. For instant, re-excavation of traditional ponds/khals, increase amount of surface water and rainwater harvesting were not widely practiced in the study area but they used these adaptation strategies for irrigation crop cultivation. So, these adaptation strategies were merged with popular irrigation facility to increase the capacity of adaptation with drought. One of the adaptation strategy crop intensification merged with alternative enterprise of land use change because of low percentage. It was also evident that crop rotation and changing planting date carried very low percentage and merged with agronomic management (*like* manure and composting, seedbed method, ail lifting, tillage and shedding). This is because farming calendar adjustment or replanting helped agronomic policy. In the study area, some respondents were taken extra income generating activities to live better life and carried sustainable livelihood patterns but the overall percentage wasn’t enough to build up an adaptation model, for that reason it was merged with adoption new technologies of farming. The five outcomes of this re-categorization are irrigation facility, alternative land use enterprise, drought tolerant rice varieties, and agronomic management. These strategies are mutually exclusive and exhaustive as they are intended to improve farming practices. Therefore, the farmer should designate one and only one of the options as their primary method.

The MNL model was used to estimate the parameter of farmers' decisions regarding adaptation strategies to lessen the effects of drought and climate change. The empirical results of the MNL adaptation model are displayed in (Table 6.8). The marginal effects along with the level of significance of the explanatory variables are displayed and discussed. In this analysis “drought tolerant rice varieties” was used as a base category and the estimated coefficients compared with the base category. The likelihood ratio statistics indicted by the chi-square test was found to be significant as represented in (Table 6.8). Finally, the Hausman specification test approach was used to determine whether the independence of the irrelevant alternatives (IIA) applied for the model (Alam, 2015). The use of the MNL model specification was found to be appropriate for the rural farmers in the northwest region of drought–prone area. This model had been used previously by different studies to estimate the determinants of climate change adaptation options taken by the rural farmers (Sarker et al., 2013; Obayelu et al., 2014; Alam, 2015; Mamun et al., 2021). The direction of the independent variables' effects on the dependent (response) variable given by the parameter estimates of the MNL model for adaptation decisions, whereas estimates represent neither the actual magnitude of change nor the probabilities (Table 6.8). The marginal effects were depended on the probabilities and measures expected to the change within the probabilities. Table 6.9 re-presents the marginal effects along with levels of statistical significance.

The age of the respondents has positively impacted all of the adaptation strategies except the adoption of new technologies. For instant, a unit increase of age of the household head (years) is significantly increased by 1.6% of irrigation facility but it is negatively associated with the adoption of new technologies by 0.7% because older farmers are not interested to adopt new technologies of rice cultivation (Table 6.9). So, farmers of the study area primarily choose irrigation facility for their crop cultivation.

The result in Table 6.8 shows that education has positive effect on farmers' adaptation strategies and hence it is significantly increasing agronomic management policy and adoption of new technologies. The marginal effect in Table 6.9 shows that a unit increases of years of education likely to increases the adoption of agronomic management by 0.8% as well as increased option of new technologies of crop cultivation by 0.6%. Because of educated farmers are expected to use agronomic management and new technologies of adaptation based on their experience, skill, and knowledge (Hassan & Nhemachena, 2008; Belay et al., 2017).

Table 6.8 Parameter estimates of multinomial logistic model for drought adaptation decision

Explanatory Variable	Agronomic management	Irrigation facility	Adoption of new technologies	Alternative enterprise of land use
Age	0.028 (0.031)	0.088 (0.028) **	-0.019 (0.038)	0.048 (0.033)
Education	0.077 (0.046) ***	0.031 (0.043)	0.104 (0.053) ***	-0.027 (0.051)
Monthly income	0.0001 (0.000) **	0.000 (0.00) **	0.000 (0.000) **	0.0001 (0.00) **
Family size	- 0.206 (0.137) ***	-0.30 (0.123) **	-0.115 (0.159)	-0.126 (0.148)
Farming experience	0.114 (0.007) **	0.164 (0.037) **	-0.149 (0.053) **	-0.096 (0.046) **
Farm size	-1.30 (0.20)	-2.19 (0.196)	-0.344 (0.36)	-2.526 (0.037) ***
Access to climate	1.25 (0.619) **	0.669 (0.586) ***	0.944 (0.702) ***	1.322 (0.659) ***
Access to electricity	-0.297 (0.467)	0.216 (0.419)	0.477 (0.509)	-0.295 (0.533)
Training experience	-0.210 (0.461)	-0.670 (0.418)	-0.608 (0.541)	-0.347 (0.507)
Social mobility	1.259 (0.0568) **	0.446 (0.554)	-0.027 (0.645)	0.945 (0.659)
Farmer to farmer Extension	-0.64 (0.313) **	-0.996 (0.309) **	0.3476 (0.360)	-0.8849 (0.364) **
Loan subsidy	-1.38 (0.430) **	0.490 (0.391) **	0.070 (0.492)	1.565 (0.488) **

Note: ** and ***are significant at 5% and 10% respectively. Drought tolerant rice variety is used as base category. Standard errors are in the parenthesis.

Base category	Drought tolerant rice varieties
Log Likelihood	-452.912
Prob>λ^2	0.000
Pseudo R^2	0.1937
N	375

The monthly average household income increases the probability of taking adaptation strategies of the respondents. The findings in Table 6.8 demonstrate that agronomic management, irrigation facility, adoption of new technologies, and alternative enterprise of land use change are positively significant at 5% level of significance. The marginal effect results show that a unit increases in household income can significantly increases the likelihood of agronomic management, adoption of new technologies and alternative enterprise of land use by 0.1%, although not a greater extent but irrigation facility significantly decreases by 0.1% (Table 6.9). The finding highlighted that, farming is the primary source of income because there is limited area of land available for agricultural cultivation; farmers likely to invest on productivity efficiency options like adoption of new technology, alternative use of land use rather than irrigation facility.

Table 6.9 Marginal effect due to explanatory variables

Explanatory Variable	Agronomic Management	Irrigation Facility	Adoption new technologies	Alternative enterprise of land use
Age	0.005 (0.004)	0.016 (0.004) **	-0.007 (0.003) **	0.001 (0.003)
Education	0.008 (0.006) ***	0.006 (0.007)	0.006 (0.004) **	-0.003 (0.005)
Monthly income	0.001 (0.00) **	-0.001 (0.00) ***	0.001 (0.00) ***	0.001 (0.00) ***
Family size	-0.002 (0.0206)	-0.037 (0.021) ***	0.009 (0.012)	0.010 (0.14)
Farming experience	0.0024 (0.006) **	-0.015 (0.006) **	-0.003 (0.004)	0.004 (0.004)
Farm size	0.077 (0.158)	-0.226 (0.191)	0.140 (0.04) ***	-0.136 (0.121)
Access to climate	0.103 (0.012) ***	0.083(0.018) ***	0.005 (0.047)	0.060 (0.044) ***
Access to electricity	-0.087 (0.063)	0.077(0.066)	0.04 (0.036) ***	-0.042(0.048)
Training experience	0.061 (0.034) **	-0.091 (0.068)	-0.021(0.040)	0.010(0.046)
Social mobility	0.174 (0.034) **	-0.077(0.087)	-0.075 (0.045) ***	0.041(0.06)
Farmer to farmer extension	0.020 (0.045)	-0.104 (0.044) ***	0.040 (0.028) **	-0.025(0.034)
Loan subsidy	-0.274 (0.038) **	0.337 (0.040) **	0.056 (0.036)	0.160 (0.042) **

** and *** are significant at 5% and 10% respectively

Most of the climate change studies, family size does not affect on adaptation strategies taken by the respondents although it can be identified that larger family size does have the better chance of adapting to climate change. The marginal effect results in (Table 6.9) indicates that irrigation facility and agronomic management negatively associated with family size but positively related with adopting new technologies and alternative land use change. A unit increase of family size clearly decreases irrigation facility by 3.7% which is statistically significant.

The results in Table 6.8 shows that farming experience has positive effect on agronomic management and irrigation facility but negatively associated with adoption of new technologies and alternative enterprise of land use change. If the marginal effect of farming experience increases a year then the agronomic management significantly increases by 0.3%. This suggests that when farmers got more experienced about weather information, their management capacity of farming increases by a little margin.

It is clearly depicted that firm size is negatively linked with preferable adaptation strategies. From the marginal effect result means only adoption of new technology significantly increase, that means if we increase a unit of firm size than new technology adoption postively increses by 14% but other adaptation strategies do not significantly increase.

Access to climate information is an important variable that effects adaptation decisions. Agricultural production and different crop varieties are mainly depending on exact information of weather. Farmers who have better access to climate information implementing effective drought adaptation strategies like agronomic management, irrigation facility and alternative enterprise of land use change. From the marginal effect result in (Table 6.9), if we increase unit information on climate access, then agronomic management availability, irrigation facility, and alternative enterprise of land use significantly increases by 10%, 8%, and 6% respectively. These findings are almost similar to other studies (Deressa et al., 2009; Belay et al., 2017; Mamun et al., 2021).

Access to electricity has both positive and negative relation with the adaptation strategies. It shows positive effect on irrigation facility and adopting new technologies. The marginal effect indicates that access to electricity significantly increases the adoption of new technologies by 4% (Table 6.9). That means having more access to electricity increases new varieties of technology for farming.

Generally, farmers who have good training experience on adaptation policy, helps themselves to take sustainable strategies for agricultural production. In our study, training experience doesn’t affect much on our current adaption options because of lack of training facility. Only agronomic management strategies positively associate with training experience, which is significant at 95% confidence interval. Instantly, if we increase a unit training experience by year, agronomic management strategies increase by 6.1%. Other adaptation strategies like irrigation facility, adoption new technologies, and alternative enterprise of land use change are not significantly associated with training experience.

Now-a-days, socialization plays a big role in every community, especially for developing countries. Farmers learn about much more interaction and communication from social mobilization. The results of marginal effect (Table 6.9) indicates that, a unit increase of social mobility, the likelihood of adopting agronomic management capacity significantly increases by 17% but adoption of new technology significantly decreases by 8%, which really negative effect on social mobility.

For better adaptation decisions farmer to farmer extension is needed for developing country where agriculture is the primary occupation. In our study, access to farmer-to-farmer extension increases the likelihood of adopting new technologies by 4%. It also performs to improve agronomic management methods, despite the fact that the results are insignificant. But irrigation facility significantly decreases by 10%, because of groundwater depletion and climate variability are very common scenario in the study area.

The results in (Table 6.8) indicate that loan subsidy is positively related with maximum adaptation strategies except agronomic management. If loan subsidy increases by a unit, then irrigation facility and alternative enterprise of land change change significantly increases by 34% and 16% respectively at 5% level of significance. These two adaptation strategies significantly inter-connected with each other.

6.3.5 Farmers’ Opinion to Combat Future Drought Adaptation Strategies

The current study represents a number of potential recommendations based on respondents' perspectives for future adaptation to droughts in the northwest part of Bangladesh. Almost, 76% respondents agreed that if they get proper planning of adjustment of seeding and planting time they will be benefited in future to combat drought situation (Table 6.10). The local agricultural extension office could fix suitable time for seeding and planting for different crop growing seasons. It is clearly defined that 86% respondents agreed if new varieties of rice and mango cultivation introduced the production of crops will be doubled in the northwest region although groundwater depletion is a big problem for agricultural production. Overall 82% of respondents believed that supplementary irrigation is an important adaptation strategy for rice cultivation More than 50% farmers want to increase amount of organic fertilizer and insecticide for their land cultivation, it will help them proper use of chemical fertilizer and insecticide. Besides, 95.2% respondents mention that re-excavation of traditional ponds; khari and canals will help farmers to increase the capacity of irrigation. During drought kharis, canals and traditional ponds utilized for irrigational purpose. Nearly 90% of farmers emphasized on selecting less water consuming crops for their future adaptation options. Therefore, during the dry period irrigation is the main obstacle in this region. Due to lack of money, farmers faced trouble to produce crops. In our country farmers are very poor and they can't operate themselves with limited money. So, credit support is an ultimate need to adjust their livelihood pattern. Nearly, 72.8% respondents demanded for credit support from GOs and NGOs, particularly in the drought period. According to Huq et al. (1996), micro-credit organizations can be very helpful to farmers in drought-prone areas. Similarly, governmental and non-governmental research organizations must prioritize producing drought-tolerant crop varieties (Habiba et al., 2010). A new adaptation strategy is weather index-based crop insurance for rural farmers. It is highly responded by farmers (82.9%) in the selected villages. Crop insurance-based weather index is applied in many countries for farming. Moreover, maximum farmers (80.3%) in the selected upazilas responded that alternative sources of income help farmers to cope with the drought phenomenon.

Table 6.10 Farmers' opinion on future adaptation strategies

Farmers' opinion	Upazila				
	Tanore	Nachole	Chirirbandar	Shapahar	Total
Adjustment of seeding/ planting time	68 (73.90%)	59 (63.40%)	85 (85.00%)	71 (78.90%)	283 (75.50%)
Introduction of new varieties	79 (85.90%)	80 (86.00%)	81 (81.00%)	81 (90.00%)	321 (85.60%)
Provide supplemental irrigation	78 (84.80%)	76 (81.70%)	90 (90.00%)	60 (66.70%)	304 (81.10%)

Use increased amount of chemical, organic fertilizer and insecticide	67 (72.80%)	36 (38.70%)	68 (68.00%)	49 (54.40%)	220 (58.70%)
Re-excavation of traditional ponds and canals	83 (90.20%)	93 (100.00%)	98 (98.00%)	83 (92.20%)	357 (95.20%)
Selecting less water consuming crops	64 (69.60%)	89 (95.70%)	91 (91.00%)	89 (98.90%)	333 (88.80%)
Credit support for farmers	37 (40.20%)	80 (86.00%)	89 (89.00%)	67 (74.40%)	273 (72.80%)
Weather index-based crop insurance	56 (60.90%)	88 (94.60%)	88 (88.00%)	79 (87.80%)	311 82.90%
Seek alternative source of income	67 (72.80%)	64 (68.80%)	82 (82.00%)	88 (97.80%)	301 (80.30%)
Governmental assistance	81 (88.00%)	85 (91.40%)	87 (87.00%)	80 (88.90%)	333 (88.80%)

Source: Questionnaire Survey

The present study also reveals that majority of the farmers in the surveyed village are poor and illiterate, as a result, they are unable to apply modern technology of farming. Meanwhile without extra money they can’t change their livelihood style. For this reason, alternative sources of income encourage farmers to cope with better adaptation in the dry spells. Almost 90% farmers mention about governmental assistance for ensuring better facility because without government support rural farmers cannot survive with their own limited source of income. That’s why the government of Bangladesh should apply an integrating detail plan and offering credit support, arranging training facility, introducing diversified crop varieties and adopting new technologies of farming for rural farmers.

6.4 Conclusion and Discussion

Since its independence in 1971, farmers from northwest Bangladesh have experienced adverse effect of drought on their crop cultivation and livelihood pattern, therefore their existing adaptation strategies are not at satisfactory level. The findings of the study explain that respondents in different villages under respective upazilas (sub-district or part of district) have been implementing various types of strategies like irrigation facilities, agronomic management, drought-tolerant rice varieties, new technologies of farming and alternative enterprise of land use change to reduce adverse effects of drought. Furthermore, the survey study finds that Farmers' perception and climatic trends indicates, drought is frequently happened in northwest area over the last three decades due to extreme temperatures and insufficient rainfall. The trends of rainfall and temperature are almost identical with the farmers' perceptions, except in Dinajpur district. Because, Dinajpur station shows decreasing trend in temperature and increasing trend in rainfall pattern (Fig. 2) which really contradict farmers perception of Chirirbandar upazila in Dinazpur district. Farmers not only recognize climatic problems like increased or decreased rainfall and temperature, longer dry season, drying up rivers/ponds/khals, low rainfall or timing of rainfall change in different seasons delayed onset of rainfall but also mention increased cost of crop production, groundwater depletion, scarcity of soil water, crop failures, food scarcity, losses of livestock, health impacts etc. These are the main effects of drought for agricultural production, because drought directly influences their farming activities and livelihood patterns. In the drought-prone area, farmers are considered their adaptation choices based on socio-economic activities, firm characteristics and perceptions on climate change.

The MNL model clearly describes the factors that influence adaptation decisions. Age, education, monthly income, farming experience, access to climate, farmer to farmer extension, social mobility and loan subsidy are the most significant factors that directly influence the adaptation decisions (Table 6.8). However, family size, training experience, access to electricity do not influence the drought coping strategies. The findings of the result mentions that ‘irrigation facility’ is the highest prior adaptation strategy taken by the respondents (farmer) in the study area. Historically, the northwest region is the major food hub in our country. Bangladesh has improved significant progress in rice cultivation. But still food security faces formidable challenge against the adverse climate effects. That’s why, Governmental and non-governmental organization must collaborate to establish a comprehensive strategy for crop cultivation. However, increasing dependence on groundwater irrigation is not the right solution for farming. Therefore, a sustainable water management plan and improved surface water irrigation could be the proper solution. It is highly recommended that skilled manpower and trained human resources can improve farmers’ adaptation strategy as well as better social networking and credit support can facilitate better livelihood and increases income activity.

Therefore, based on the findings, the present study suggest for some sustainable adaptation strategies such as adjustment of seeding and planting time, introduction of new crop varieties, providing sustainable supplemental irrigation, using increased amount of fertilizer, re-excavation of traditional ponds/khals, selecting less water consuming crops, credit support for farmers, weather index-based crop insurance, seek alternative source of income and governmental assistance to lessen negative impacts of future climate change and drought condition in the northwest area. Finally, we need to develop a long-term database that will help the planners, researchers and policy makers to know the challenging relationship between climatic changes and farmers' adaptation strategies.

Chapter Seven

Conclusions and Policy Implications

7.1 Introduction

This chapter aims to provide a comprehensive overview of the primary findings of the study regarding various aspects of spatial-temporal analysis of rainfall and temperature, drought assessment, drought characterization, and different adaptation techniques in response to the current drought status in northwest Bangladesh. These aspects are organized into different chapters to meet the objectives of the research study. The chapter also suggests policy implications and offers recommendations for future research in the study.

7.2 Summary of Findings

The study investigates four objectives by using meteorological variables and finding sustainable adaptation strategies during the time period 1960 to 2021 in northwest region of Bangladesh. The first three objectives are based on secondary data collected from BMD of selected weather stations located in the northwest area. Spatio-temporal analysis, trend detection, ARIMA modeling, SPI analysis, Markov Chain analysis and its application on meteorological data are clearly described in previous chapter. The last objective investigates farmers perceptions, impacts and adaption strategies by collecting primary data through questionnaire of the study area. The following conclusions are derived from the findings of the overall study:

- ❖ The study area is very much affected by extreme climate variability, as a result rainfall and temperature are not evenly distrusted throughout the country. The area produces huge quantity of agricultural crops, which ensures food security and build an agricultural food hub for national economy. The annual rainfall features in the study area varies one stations to another. Dinajpur and Rangpur stations receives highest amount of precipitation but Rajshahi and Ishwardi stations show lowest amount of rainfall during the study period 1960-2021. From the descriptive analysis of rainfall, annual average rainfall varies from 2171 mm to 1460 mm in the area. Except Dinajpur station, irregular precipitation concentration index (PCI_{annual} = 6-20) continues all stations of northwest area. From the rainfall trend analysis, Rajshahi station receives only significant decreasing amount of rainfall at a rate of -5.50 mm/year. Ishwardi and Bogura stations also predicts negative trend during study period but they are not significant. The MK test results of other two stations (Dinajpur and Rangpur) represents highest amount of increasing trend with 0.692 and 1.178 but statistically insignificant.

- ❖ During *Rabi* season, the annual average rainfall of all stations is 37.8 mm, which is significantly less than other regions of the country. The Rajshahi station exhibits a relatively high standard deviation of 38 mm, whereas the Dinajpur station demonstrates a comparatively low standard deviation of 25.85 mm. The findings of MK test (Z statistics) reveals that nearly all the stations demonstrate statistically insignificant negative trend ranging from -0.176 to -0.966 at 95% confidence interval, except Ishwardi stations displays positive trend of 0.431. In the pre-*Kharif* season, 60% stations are found positive trend in different trend analysis test (MK test, Sen's slope and SR test). The annual average rainfall in this season is observed at 622.4 mm. The coefficient of variation varies from 28.70 to 41.66%. Rajshahi and Ishwardi stations displays insignificant decreasing trend in MK test analysis and Sen's slope estimate rather than rest of the stations at 5% level of significance. In the present study, the annual average rainfall during *Kharif* season varies from 941mm to 1322mm. Both upward and downward trend is discovered in all five weather stations but only Rajshahi station is found most significant decreasing trend in MK test results (*Z* statistics) with -2.53 at 95% confidence interval. The degree of change assessed by Sen's slope estimates of Dinajpur and Rangpur stations are 0.50 and 2.53 mm/year, respectively, which indicates positive trend of rainfall during the period 1960-2021.
- ❖ From the descriptive analysis, the annual average temperature in the northwest region 24.30°C to 25.30°C. It is revealed that Rajshahi and Ishwardi stations are found more warmer than other stations. Except Rangpur station, the coefficient of variation of annual average temperature lies between 1.24% to 1.84%. In the research area, 80% temperature data are identified positively skewed. During study period, only Rangpur and Bogura

stations follows rising trend in MK test results with 5.674 and 4.514 respectively, which is significant at 95% confidence interval. Meanwhile, the rate of change of Dinajpur station assessed by Sen's slope estimates is -0.003°C/year. The Kendall's tau receives positive relationship over time during temperature data analysis.

- *Rabi s*eason temperature is very low compare to the other cropping season of our country, generally this season is called winter. From descriptive analysis of seasonal temperature, annual mean temperature fluctuates from 18.97°C to 19.95°C. During the study period 60% stations are found downward trend at 95% confidence interval. The MK test result (*Z* statistics) of *Rabi* season temperature are observed -8.90, -8.34 and -1.99 at Dinajpur, Ishwardi and Rajshahi stations respectively, but these stations are insignificant. Rangpur station observes only significant positive trend with 2.81. Sen's slope estimates and SR test results almost identical to MK test results. During pre-*Kharif* season, the annual average temperature varies from 26.14°C to 28.25°C with an average value 27.47°C. The coefficient of variation is low at Bogura (2.27%) station and high at Rangpur (1.27%) stations, which means temperature fluctuates more at Rangpur stations rather than others. In the trend analysis test, 80% station is described rising trend at 95% confidence interval. However, Dinajpur station show decreasing trend at MK test and SR test results. Sen's slope analysis indicates that the magnitude of change at a rate of -0.02°C/year. The remaining stations are found positive trend with Sen's estimates ranges from 0.001 to 0.02°C/year. In the study domain, the annual mean temperature during *Kharif* season is observed at 28.08°C, which is very high compared to other parts of the country. All the stations are highly showed positive trend in Mk test results (*Z* statistics) varies from 4.81 to 6.16, which is significant at 95% confidence interval. The Spearman rho test and Sen's Slope estimates also predicts significant upward trend during this season.
- Sequential Mann-Kendall (SMK) analysis test is a very crucial trend test for change of point detection of rainfall and temperature. During 1960-2021, The SMK test results reveals that Bogura, Rajshahi and Ishwardi station are almost identical with MK test, which follows decreasing trend in rainfall data. The only argument is Rajshahi station shows some

abrupt changes with significant downward trend. The other two stations follow increasing trend early year but after certain time decreasing trend continues till today. Meanwhile, the SMK trend analysis test for temperature displays increasing trend at all recorded stations except Dinajpur. At the year 1990, the temperature of Dinajpur station show a decreasing trend and it continues to till 2020. Bogura and Rangpur stations both follow strong upward trend after the year 2003.

- ❖ The Box- Jenkins ARIMA technique is applied to forecast rainfall and temperature trend detection for next five years monthly data. The ARIMA model for monthly rainfall data of sixty years are clearly described in the previous chapter. The monthly rainfall data indicates that the annual average rainfall of located stations is not homogenous to the previous years. It is anticipated that the Bogura station will experience the lowest average annual rainfall of 943.8 mm, while the Ishwardi station will receive the highest amount of rainfall, reaching 2591.6 mm for the next five years. On the other hand, ARIMA technique clearly forecast the temperature data analysis that follows significantly increasing trend during the period 2022-2026. Based on the analysis, it has been determined that the annual average temperatures recorded at Bogura, Dinajpur, Ishwardi, Rajshahi, and Rangpur stations are 25.84°C, 24.84°C, 25.19°C, 25.38°C and 25.00°C, respectively. In a nutshell, extreme climate variability happens within 10 to 20 years in this region.
- ❖ The research study endeavor to assess the drought characteristics and its severity of different meteorological stations in northwest area by using Standardized Precipitation Index (SPI) and probabilistic approach model (Markov Chain). The SPI values have been computed and examined through six different time scales spanning from 1960 to 2021. It is very useful drought index for defining monitoring drought. The transition probability matrix for various SPI series of different stations is thoroughly explained in Chapter Five.
- ❖ During study, the long time-scale such as SPI 9, SPI 12, SPI24 can deliver better drought monitoring and play a vital role of characterizing droughts than the short time SPI scales (SPI 1, SPI 3, SPI 6). Frequency of drought analysis (Table 5.18) for different weather stations (Bogura, Rajshahi, Ishwardi, Rangpur and Dinajpur) are evidently calculated by

different SPI Indexing values. It has been observed that higher order Standardized Precipitation Index (SPI) values, specifically SPI 12 and SPI 24, provide a more accurate assessment of drought conditions. From SPI analysis, Ishwardi, Rajshahi and Rangpur stations provides more frequent droughts than the other stations during the study period 1960-2021.

- Alternating renewal process is applied in different stations with associated transition probabilities of two states dry and wet. The transition probabilities of two state Markov model P_{DD}, P_{WD}, P_{DW}, and P_{WW} for different SPI series are categorized based on the percentage of various transition states. It is found that P_{DD} and P_{WW} are increasing more than 90% for higher SPI series but P_{WD} and P_{DW} have decreased with low percentage of probabilities in all located stations of northwest region.
- Probability distribution of drought interarrival time and mean drought interarrival time are used to estimate the parameters of SPI series. The distribution of drought interarrival time can be achieved by analyzing the probabilities associated with different months of the SPI series. It is detected that different months have achieved the highest probability according to their SPI series. The mean drought interarrival time of various SPI series are varies one stations to other stations with little margin. The interarrival time and mean interarrival of droughts exhibit an increasing trend as the Standardized Precipitation Index (SPI) series progresses from lower to higher values, specifically SPI 12 and SPI 24. This trend is observed in all study stations, where drought durations tend to be longer during these months.
- The utilization of Markov chain models and the transition probability approach are employed to assess the probability of drought duration and the persistence of drought by considering four distinct dry states, namely D1, D2, D3, and D4. It has been determined that there exists a significant probability of a "mild drought period" being followed by another "mild drought period" in each SPI series, when using transition probabilities to determine the transition from one state to the following state. It has been noted that for long-term SPI series, there is a high probability that the same state will be carried over to the next state. The diagonal of each transition probability matrix reflects the persistence

values of the different dry states ('D1'– 'D1', 'D2'– 'D2', 'D3'– 'D3' and 'D4'– 'D4') in all stations. A very high percentage of probability around 75 to 100% being occurred in the diagonal transition probability matrix for SPI 1, SPI 3, SPI 6, SPI 9, SPI 12 and SPI 24.

- ❖ Farmers perception, impacts and sustainable adaptation strategies are clearly described in Chapter 6. Farmer's perception of climate change and drought is a vital component for assessing the adaptation decisions. The survey area is bounded by four districts (Rajshahi, Chapainawabganj, Dinajpur, Naogaon) of northwest area of Bangladesh. Four upazilas (subdistricts) are selected by simple random sampling techniques. At first the socio-economic characteristics of the respondents such as age category, years of education, average monthly income, family size, firm size, firming experience, and others farm characteristics of different villages are collected to compare their livelihood status.
- ❖ In total 375 respondents of 4 upazilas concern about the climate change of northwest area. In the survey area, more than 95% respondents are agreed that the climate variability affects in this region to great extent. Temperature and the duration of warm days has been rising over the last three decades. Almost 100% respondents of the study area agree that summer and winter rainfall is decreasing significantly and the number of rainy days shows downward trend in all selected upazilas. By using 5-point Likert scale, farmers make their perceptions towards drought according to (a) dry season longer (b) drying up streams/rivers/ponds/khals (c) low rainfall in rainy season (d) delayed onset of rainfall.
- ❖ Main impacts of drought in the northwest area are determined by *WAI* (Weighted Average Index) method and 5-point Likert scale techniques. Both the methods clearly identify that increased cost of production, declining groundwater levels, crop failures, scarcity of soil water, lower income, food scarcity, health impacts, malnutrition, losses of livestock, water quality deterioration and unemployment are the most significant category during the survey. In the study area, production cost of agricultural crops increases beyond imagine and get the highest ranking (*WAI* = 3.68) followed by declining groundwater levels (*WAI* = 3.63) and crop failures (*WAI* = 3.45). Water quality deterioration and unemployment are the least severe effect in the northwest region with *WAI* =1.95 and *WAI* = 1.81.

- Respondents of the survey villages (Narayanpur, Azaiyr, Suroil and Horipur) under respective upazilas have been used different adaptation techniques to adjust with extreme climate variability and drought situation. Numerous types of adaptation strategies are used by the farmers such as drought tolerant rice varieties (14.7%), agronomic management (15.7%), re-excavation of traditional ponds/ khals (1.6%), increase amount of surface water (0.8%), rainwater harvesting (2.9%), irrigation facility (34.7%), crop intensification (3.2%), alternative enterprize of land use change (9.9%), crop rotation and changing planting date (2.7%), extra income generating activities (6.1%), adopting new technologies(7.7%) etc. From the survey data, irrigation facility is used for popular adaptation techniques except Horipur village of Shapar upazila under Naogaon district, because of insufficient groundwater make it impossible for irrigation. That’s why, 92.2% farmers of Horipur village use agronomic management technique for their mango cultivation and other crop production.
- Determinants of farmer’s adaptation choices is determined by the Multinomial Logistic Regression Model (MLN). The marginal effects of MNL model depends on the probabilities and measures of the independent variables. From Table 6.8, the parameter estimates of MNL model demonstrates that age, education, monthly income, farming experience, climate accessibility, farmer to farmer extension and loan subsidy are positively related to the adaptation strategies that are taken by the survey area. The marginal effects of explanatory variables significantly increase the chance of probability of different adaptation strategies at 5% and 10% level of significance.

7.3 Recommendations and Policy Implications

Bangladesh has made outstanding efforts to construct the necessary legislative and policy frameworks for promoting drought management and climate-resilient sustainable development. Over the years, the Government has formulated policies, plans and program including the National Adaptation Program of Action (NAPA, in 2005 and later updated in 2009), National Adaptation Plan in 2015, Bangladesh Delta Plan 2100 in 2018. The IPCC Sixth Assessment Report predicts that future conditions will be far more severe and unpredictable despite the relentless efforts for climate adaptation. Effective medium- and long-term adaptation techniques are essential for minimizing the effects of drought in the northwest region and providing a viable path towards resiliency. Based on the findings, the following policy should be taken to lessen the adverse effects of droughts in the study area.

- Implementing drought resilience program through effective adaptation that reduces losses and damage that also supporting natural resource management, developing strong economic growth, promoting resilient eco-systems, and ensuring sustainable livelihoods.
- The drought-prone area already has implemented some conventional methods of adaptation but they are insufficient and time consuming. Therefore, the research strongly advocates policy interventions to introduce contemporary adaptation strategies in the context of drought.
- Changing climate and its adverse effects of drought pose significant challenges to agriculture, food security and livelihoods. When formulating viable adaptation strategies, it is essential to consider climate change scenarios, variations in rainfall and temperature and the potential adverse impacts of climate change, as well as the associated risks.
- Ensuring public awareness program about the drought severity and implementing impact-based early warning system and data management technology.
- The Ministry of Agriculture should take initiatives for extension of water saving technologies in drought prone areas, harvesting rainwater in canals or reservoirs for enhanced irrigation and increasing overall irrigation efficiency through improved distribution networks.
- By using solar power portable irrigation pump, improve water management plan and irrigation system, integrate organic and inorganic fertilizer for increasing soil carbon and introduce drought-stress tolerant plant etc.
- Appling technology-based Climate Smart Agriculture (CSA) such as Alternating Wetting & Drying (AWD), nature-based solutions are highly emphasized in development agenda

to ensure food & nutrition security, environmental sustainability and societal development in the drought prone area.

- Ministry of Water Resources is playing pivotal role in improving the surface water irrigation system.
- Both short-term and long-term training facilities should be incorporated. During the survey, farmers expressed their desire for improved training facilities from Governmental Organizations (GOs) and Non-governmental Organizations (NGOs) regarding drought conditions.
- Credit support for farmers and weather index-based insurance are desperately needed for fertilizer, seed, insecticides and fuel etc.

Bibliography

Abdullah, H. M., Mahboob, M. G., Rahman, M. M., & Ahmed, T. (2015). Monitoring natural Sal forest cover in Modhupur, Bangladesh using temporal Landsat imagery during 1972–2015. *International Journal of Environment*, *5*(1), 1–7.

Abid, M., Scheffran, J., Schneider, U. A., & Ashfaq, M. J. E. S. D. (2015). Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan. *Earth System Dynamics*, *6*(1), 225-243. https://doi.org/10.5194/esdd-5-1359

Abrams, M. D., Ruffner, C. M., & Morgan, T. A. (1998). Tree-ring responses to drought across species and contrasting sites in the ridge and valley of central Pennsylvania. *Forest Science*, *44*(4), 550-558. https://doi.org/10.1093/forestscience/44.4.550

Achour, K., Meddi, M., Zeroual, A., Bouabdelli, S., Maccioni, P., & Moramarco, T. (2020). Spatio-temporal analysis and forecasting of drought in the plains of northwestern Algeria using the standardized precipitation index. *Journal of Earth System Science*, *129*, 1-22. https://doi.org/10.1007/s12040-019-1306-3

Adams, R. M., Hurd, B. H., Lenhart, S., & Leary, N. (1998). Effects of global climate change on agriculture: an interpretative review. *Climate research*, 11(1), 19-30.

ADB (2005). *Country strategy and program 2006–2010*. Asian Development Bank. Dhaka, Bangladesh: Bangladesh Resident Mission.

Ahmed, A. U. (2004). *Adaptation to climate change in Bangladesh: learning by doing*. In UNFCCC workshop on adaptation, Bonn (Vol. 18).

Akter, K. S., & Rahman, Md. M. (2012). Spatio-temporal quantification and characterization of drought patterns in Bangladesh. *Journal of Water and Environment Technology*, 10(3), 277–288. https://doi.org/10.2965/jwet.2012.277

Alam, G. M. M., Alam, K., & Mushtaq, S. (2017). Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. *Climate Risk Management, 17*, 52–63. https://doi.org/10.1016/j.crm.2017.06.006

Alam, K. (2015). Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. *Agricultural Water Management*, *148*, 196–206. https://doi.org/10.1016/j.agwat.2014.10.011

Alamgir, M., Shahid, S., Hazarika, M. K., Nashrrullah, S., Harun, S. B., & Shamsudin, S. (2015). Analysis of meteorological drought pattern during different climatic and cropping seasons in Bangladesh. *Journal of the American Water Resources Association*, 51(3), 794–806. https://doi.org/10.1111/jawr.12276

Alauddin, M., & Sarker, M. A. R. (2014). Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh an empirical investigation. *Ecological Economics*, *106*, 204-213. https://doi.org/10.1016/j.ecolecon.2014.07.025

Ali, S., Ghosh, B. C., Osmani, A. G., Hossain, E., & Fogarassy, C. (2021). Farmers' climate change adaptation strategies for reducing the risk of rice production: Evidence from rajshahi district in Bangladesh. *Agronomy*, *11*(3), 600.https://doi.org/10.3390/agronomy11030600

Allen, R. J., & DeGaetano, A. T. (2001). Estimating missing daily temperature extremes using an optimized regression approach. *International Journal of Climatology*, 21(11), 1305–1319. https://doi.org/10.1002/joc.679

Al-Mamun, M. A., & Al-Pavel, M. A. (2014). Climate change adaptation strategies through indigenous knowledge system: aspect on agro-crop production in the flood prone areas of Bangladesh. *Asian Journal of Agriculture and Rural Development, 4*(393-2016-23936), 42-58. http://dx.doi.org/10.22004/ag.econ.198381

Anik, A. R., Rahman, S., Sarker, J. R., & Al Hasan, M. (2021). Farmers' adaptation strategies to combat climate change in drought prone areas in Bangladesh. *International Journal of Disaster Risk Reduction*, *65*, 102562.https://doi.org/10.1016/j.ijdrr.2021.102562

Ara, I. (2018). Perceptions and responses to climate change: Understanding adaptation strategies and multilevel capacities in Northern Bangladesh using livelihood resources. *Regional Problems, 3*(1), 124–131.

Ashraf, M., & Routray, J. K. (2015). Spatio-temporal characteristics of precipitation and drought in Balochistan Province, Pakistan. *Natural Hazards*, *77*, 229-254. https://doi.org/10.1007/s11069-015-1593-1

Aziz. A., A. R., Anokye, M., Kwame, A., Munyakazi, L., & Nsowah-Nuamah, N. N. N. (2013). Modeling and forecasting rainfall pattern in Ghana as a seasonal ARIMA process: The case of Ashanti region. *International Journal of Humanities and Social Science*, *3*(3), 224-233. http://hdl.handle.net/123456789/6004

Bangladesh Economic Review (2017). *Bangladesh economic review*. https:// cpd. org. bd/ wp-conte nt/ uploa ds/ 2017/ 06/ Bangladesh- Economy- in- FY201 6–17- Interim Review- of-Macroeconomic- Performance. pdf. (Accessed 19 January, 2022)

Banglapedia (2006). *Drought in Bangladesh*. http://banglapedia.search.com.bd/HT/D_0284. (Accessed 13 August, 2022).

Banglapedia (2017). *"Agriculture", The National Encyclopedia of Bangladesh*. http://en.banglapedia.org/index.php?title=Agriculture (Accessed 29 January, 2022).

Bari, S. H., Rahman, M. T. U., Hoque, M. A., & Hussain, Md. M. (2016). Analysis of seasonal and annual rainfall trends in the northern region of Bangladesh. *Atmospheric Research*, 176–177, 148–158. https://doi.org/10.1016/j.atmosres.2016.02.008

BBS (2019a). *Statistical Yearbook of Bangladesh 2018.* Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

BBS (2019b). *Report on Agriculture and Rural Statistics 2018.* Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

BBS (2022a). *Population and Housing Census 2022.* Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

BBS (2022b). *Structure of Agricultural Holdings and Livestock & Fisheries*. *Agricultural Census 2019.* Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

Belay, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*, *6*(1), 24. https://doi.org/10.1186/s40066-017-0100-1

Belayneh, A., & Adamowski, J. (2013). Drought forecasting using new machine learning methods / Prognozowanie suszy z wykorzystaniem automatycznych samouczących się metod. *Journal of Water and Land Development*, *18*(9), 3–12. https://doi.org/10.2478/jwld-2013-0001

Bhuyan, Md. D. I., Islam, Md. M., & Bhuiyan, Md. E. K. (2018). A trend analysis of temperature and rainfall to predict climate change for northwestern region of Bangladesh. *American Journal of Climate Change*, *07*(02), 115–134. https://doi.org/10.4236/ajcc.2018.72009

Box, G.E.P., & Jenkins, G.M. (1976). *Time Series Analysis: Forecasting and Control* (Revised edition), San Francisco: Holden Day.

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science & Policy, 12,* 413–426.https://doi.org/10.1016/j.envsci.2008.11.002

Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chiotti, Q., & Singh, B. (2000). Adaptation in Canadian agriculture to climatic variability and change. *Societal adaptation to climate variability and change*, 181-201.https://doi.org/10.1007/978-94-017-3010-5_10

Buttafuoco, G., & Caloiero, T. (2014). Drought events at different timescales in southern Italy (Calabria). *Journal of Maps*, *10*(4), 529-537. https://doi.org/10.1080/17445647.2014.891267

Capra, A., & Scicolone, B. (2012). Spatiotemporal variability of drought on a short–medium time scale in the Calabria Region (Southern Italy). *Theoretical and Applied Climatology*, *110*(3), 471–488. https://doi.org/10.1007/s00704-012-0720-0

CEGIS (2012) *Center for Environment and Geographic Information Service*. CEGIS, Dhaka, Bangladesh.

CEGIS (2022). *CEGIS Technical Note: Recent Climatic Trend in Bangladesh*, CEGIS, Dhaka, Bangladesh.

Cui, L., Wang, L., Lai, Z., Tian, Q., Liu, W., & Li, J. (2017). Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze River Basin, China during 1960–2015. *Journal of Atmospheric and Solar-Terrestrial Physics*, *164*, 48-59. https://doi.org/10.1016/j.jastp.2017.08.001

Dai, A. (2011). Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(1), 45-65. https://doi.org/10.1002/wcc.81

Das, J., Gayen, A., Saha, P., & Bhattacharya, S. K. (2020). Meteorological drought analysis using standardized precipitation index over Luni River Basin in Rajasthan, India. *SN Applied Sciences*, *2*, 1-17. https://doi.org/10.1007/s42452-020-03321-w

Das, J., Mandal, T., Rahman, A. S., & Saha, P. (2021). Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches. *Theoretical and Applied Climatology*, 1-23. https://doi.org/10.1007/s00704-020-03508-6

Dash, B. K., Rafiuddin, M., Khanam, F., & Islam, M. N. (2012). Characteristics of meteorological drought in Bangladesh. *Natural hazards*, *64*, 1461-1474. https://doi.org/10.1007/s11069-012-0307-1

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

Denevan, W. M. (1983). Adaptation, variation, and cultural geography. *The Professional Geographer*, *35*(4), 399-407.https://doi.org/10.1111/j.0033-0124.1983.00399.x

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers’ choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dey, N., Alam, M., Sajjan, A., Bhuiyan, M., Ghose, L., Ibaraki, Y., & Karim, F. (2012). Assessing environmental and health impact of drought in the northwest Bangladesh. *Journal of*

Environmental Science and Natural Resources, *4*(2), 89–97. https://doi.org/10.3329/jesnr.v4i2.10141

Dimri, T., Ahmad, S., & Sharif, M. (2020). Time series analysis of climate variables using seasonal ARIMA approach. *Journal of Earth System Science, 129*(1), 149. https://doi.org/10.1007/s12040-020-01408-x

Eischeid, J. K., Baker, C. B., Karl, T. R., & Diaz, H. F. (1995). The quality control of long-term climatological data using objective data analysis. *Journal of Applied Meteorology*, 34, 2787–2795.

Enders, C. K. (2010). *Applied missing data analysis*. New York: The Guilford Press. http://books.google.co.ke/. ISBN: 978-1 60623-639-0. (Accessed 10 May, 2023).

Esteban-Parra, M. J., Rodrigo, F. S., & Castro-Díez, Y. (1995). Temperature trends and change points in the northern Spanish Plateau during the last 100 years. *International Journal of Climatology*, *15*(9), 1031–1042. https://doi.org/10.1002/joc.3370150909

Fadina, A. M. R., & Barjolle, D. (2018). Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. *Environments*, *5*(1), 15. https://doi.org/10.3390/environments5010015

Forthofer, R. N., Lehnen, R. G., Forthofer, R. N., & Lehnen, R. G. (1981). Rank correlation methods. *Public program analysis: a new categorical data approach*, 146-163.

Germanwatch (2020). *Global Climate Risk Index 2020*. Germanwatch, Bonn, Germany. https://www.germanwatch.org/sites/germanwatch.org/files/202\01e%20Global%20Climate%20Risk%20Index%202020_14.pdf (Accessed 12 February 2021).

Giannini, A., Saravanan, R., & Chang, P. (2003). Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. *Science*, *302*(5647), 1027-1030. https://doi.org/10.1126/science.1089357

Gocic, M., & Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. *Global and Planetary Change*, *100*, 172-182. https://doi.org/10.1016/j.gloplacha.2012.10.014

Golian, S., Mazdiyasni, O., & AghaKouchak, A. (2015). Trends in meteorological and agricultural droughts in Iran. *Theoretical and applied climatology*, *119*, 679-688. https://doi.org/10.1007/s00704-014-1139-6

González, J., & Valdés, J. B. (2003). Bivariate drought recurrence analysis using tree ring reconstructions. *Journal of Hydrologic Engineering*, *8*(5), 247-258. https://doi.org/10.1061/(ASCE)1084-0699(2003)8:5(247)

Greene, W. H. (2012). *Econometric analysis*. Seventh ed. Prentice Hall, Upper Saddle River, NJ.

Haan, C., T. (1977). *Statistical methods in hydrology*. The Iowa State University Press.

Habiba, U., Shaw, R., & Takeuchi, Y. (2011). Drought risk reduction through a Socio-economic, Institutional and Physical approach in the northwestern region of Bangladesh. *Environmental Hazards*, *10*(2), 121–138. https://doi.org/10.1080/17477891.2011.582311

Habiba, U., Shaw, R., & Takeuchi, Y. (2012). Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh. *International Journal of Disaster Risk Reduction*, *1*, 72-84. https://doi.org/10.1016/j.ijdrr.2012.05.004.

Habiba, U., Shaw, R., & Takeuchi, Y. (2014). Farmers' adaptive practices for drought risk reduction in the northwest region of Bangladesh. *Natural hazards*, *72*(2), 337-359.

Habiba, U., Takeuchi, Y., & Shaw, R. (2010). Overview of drought risk reduction approaches in Bangladesh. In *Climate change adaptation and disaster risk reduction: an Asian perspective* (*Community, Environment and Disaster Risk Management, Vol. 5*), Emerald Group Publishing Limited, Bingley, 37-58. https://doi.org/10.1108/S2040-7262(2010)0000005

Hagman, G., Beer, H., Bendz, M., & Wijkman, A. (1984). *Prevention better than cure*. Report on human and environmental disasters in the Third World. Stockholm: Swedish Red Cross. https://doi.org/10.1175/1520-0477(1998)079%3C0815:DDASVA%3E2.0.CO;2

Hamed, K. H., & Ramachandra Rao, A. (1998). A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology*, *204*(1–4), 182–196. https://doi.org/10.1016/S0022-1694(97)00125-X

Hasan, M. K., & Kumar, L. (2019). Comparison between meteorological data and farmer perceptions of climate change and vulnerability in relation to adaptation. *Journal of Environmental Management*, *237*, 54–62. https://doi.org/10.1016/j.jenvman.2019.02.028

Hasan, M. K., & Kumar, L. (2019). Comparison between meteorological data and farmer perceptions of climate change and vulnerability in relation to adaptation. *Journal of Environmental Management*, *237*, 54–62. https://doi.org/10.1016/j.jenvman.2019.02.028

Hassan, R. M., & Nhemachena, C. (2008). Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. *African Journal of Agricultural and Resource Economics* *2*(311-2016-5521), 83-104.http://dx.doi.org/10.22004/ag.econ.56969

Hayes, M. J., Svoboda, M. D., Wiihite, 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

Hoerling, M., Hurrell, J., Eischeid, J., & Phillips, A. (2006). Detection and attribution of twentieth-century northern and southern African rainfall change. *Journal of climate*, *19*(16), 3989-4008. https://doi.org/10.1175/JCLI3842.1

Hossain, M. N., Chowdhury, S., & Paul, S. K. (2016). Farmer-level adaptation to climate change and agricultural drought: Empirical evidences from the Barind region of Bangladesh. *Natural Hazards*, *83,*1007–1026.https://doi.org/10.1007/s11069-016-2360-7

Hossain, Md., Roy, K., & Datta, D. (2014). Spatial and temporal variability of rainfall over the south-west coast of Bangladesh. *Climate*, *2*(2), 28–46. https://doi.org/10.3390/cli2020028

Hosseini, T. S. M., Hosseini, S. A., Ghermezcheshmeh, B., & Sharafati, A. (2020). Drought hazard depending on elevation and precipitation in Lorestan, Iran. *Theoretical and Applied Climatology*, *142*, 1369-1377. https://doi.org/10.1007/s00704-020-03386-y

Hounam, C. E., Burgos, J. J., Kalik, M. S., Palmer, W. C., & Rodda, J. (1975). *Drought and Agriculture*. Report of the Commission for agricultural meteorology Working group on the assessment of drought. Technical Note-World Meteorological Organization (WMO). no. 138.

Huq, N., Hugé, J., Boon, E., & Gain, A. K. (2015). Climate change impacts in agricultural communities in rural areas of coastal Bangladesh: A tale of many stories. *Sustainability*, *7*(7), 8437-8460.https://doi.org/10.3390/su7078437.

Huq, N., Hugé, J., Boon, E., & Gain, A. K. (2015). Climate change impacts in agricultural communities in rural areas of coastal Bangladesh: A tale of many stories. *Sustainability*, *7*(7), 8437-8460.https://doi.org/10.3390/su7078437.

Huq, S. U., Ahmed, A. U., & Koudstaal, R. (1996). Vulnerability of Bangladesh to climate change and sea level rise. In *Climate change and world food security*, Springer, Berlin, Heidelberg, 347-379.https://doi.org/10.1007/978-3-642-61086-8_14

Ibrahim, B., & Mensah, H. (2022). Rethinking climate migration in sub-Saharan Africa from the perspective of tripartite drivers of climate change. *SN Social Sciences*, *2*(6), 87.https://doi.org/10.1007/s43545-022-00383-y

Ikram, M., Ferasso, M., Sroufe, R., & Zhang, Q. (2021). Assessing green technology indicators for cleaner production and sustainable investments in a developing country context. *Journal of Cleaner Production*, *322*, 129090. https://doi.org/10.1016/j.jclepro.2021.129090

Ingsrisawang, L., & Potawee, D. (2012). Multiple imputation for missing data in repeated measurements using MCMC and copulas. In *Proceedings of the international multi conference of engineers and computer scientist*.

IPCC (2007). *Climate change 2007: impacts, adaptation and vulnerability*. In: Contribution of working group II to the fourth assessment report of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

IPCC (2013). *Summary for Policymakers. In: Climate Change 2013: The physical Science Basic.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2014 a). *Climate change 2013: The Physical Science Basis*. working group, I contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge

IPCC (2014 b). *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. *Part A: Global and Sectoral Aspects.* Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ, Mach KJ, Mastandrea MD et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp 1132

IPCC (2014 c). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (eds)]. IPCC, Geneva, Switzerland, p 151.

IPCC (2018). *Global warming of 1.5°C.* An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Geneva: Intergovernmental Panel on Climate Change, (616).

IPCC (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of the Working Group I to the Sixth Assessment Report.

IRRI (2010). *World Rice Statistics (WRS)*, Philippines. International Rice Research Institute, Manila.

Isaacson, D. L., & Madsen, R. W. (1985). Markov chains: Theory and Applications. *SIAM Review*, *20*(3), 606. John Wiley, New York.

Islam, M. S., Hossain, Md. Z., & Sikder, M. B. (2019). Drought adaptation measures and their effectiveness at Barind Tract in northwest Bangladesh: A perception study. *Natural Hazards*, *97*(3), 1253–1276. https://doi.org/10.1007/s11069-019-03704-2

Islam, M. T., Karim, M. R., & Mondol, A. H. (2021). Appraising trends and forecasting of hydroclimatic variables in the north and northeast regions of Bangladesh. *Theoretical and Applied Climatology*, *143*(1–2), 33–50. https://doi.org/10.1007/s00704-020-03411-0

Islam, M. T., Rahman, M. S., Khatun, R., & Hu, Z. (2020). Spatiotemporal trends in the frequency of daily rainfall in Bangladesh during 1975–2017. *Theoretical and Applied climatology*, *141*, 869-887. https://doi.org/10.1007/s00704-020-03244-x

Islam, M. T., Shen, S., & Yang, S. (2018). Predicting design water requirement of winter paddy under climate change condition using frequency analysis in Bangladesh. *Agricultural Water Management*,*195*(C), 58–70. https ://doi.org/10.1016/j.agwat .2017.10.003.

Islam, M. T., Shill, B. K., Salam, R., Siddik, Md. N. A., & Patwary, M. A. (2021). Insight into farmers' agricultural adaptive strategy to climate change in northern Bangladesh. *Environment, Development and Sustainability*, *23*(2), 2439–2464. https://doi.org/10.1007/s10668-020-00681-6

Islam, M., Hossain, M., & Sikder, M. (2019). Farmers' adaptation strategies to drought and their determinants in barind tract, Bangladesh. *SAARC Journal of Agriculture*, *17*(1), 161–174. https://doi.org/10.3329/sja.v17i1.42769

Jahan, C. S., Mazumder, Q. H., Islam, M. M., & Adham, M. I. (2010). Impact of irrigation in Barind area, NW Bangladesh—an evaluation based on the meteorological parameters and fluctuation trend in groundwater table. *Journal of the Geological Society of India*, *76*, 134-142.

Jiao, W., Tian, C., Chang, Q., Novick, K. A., & Wang, L. (2019). A new multi-sensor integrated index for drought monitoring. *Agricultural and Forest Meteorology*, *268*, 74-85. https://doi.org/10.1016/j.agrformet.2019.01.008

Jiao, W., Wang, L., & McCabe, M. F. (2021). Multi-sensor remote sensing for drought characterization: current status, opportunities and a roadmap for the future. *Remote Sensing of Environment*, *256*, 112313. https://doi.org/10.1016/j.rse.2021.112313

Kabir, H., & Golder, J. (2017). Rainfall variability and its impact on crop agriculture in southwest region of Bangladesh. *Journal of Climatology & Weather Forecasting*, *5*(1), 1-20.

Kamruzzaman, M., Almazroui, M., Salam, M. A., Mondol, M. A. H., Rahman, M. M., Deb, L., ... & Islam, A. R. M. T. (2022). Spatiotemporal drought analysis in Bangladesh using the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI). *Scientific Reports*, *12*(1), 20694. https://doi.org/10.1038/s41598-022-24146-0

Kamruzzaman, M., Rahman, A. S., Basak, A., Alam, J., & Das, J. (2022). Assessment and adaptation strategies of climate change through the prism of farmers' perception: A case study. *International Journal of Environmental Science and Technology*, 1-20. https://doi.org/10.1007/s13762-022-04254-0

Kamruzzaman, M., Rahman, A. T. M., Ahmed, M., Kabir, M., Mazumder, Q. H., Rahman, M. S., & Jahan, C. S. (2018). Spatio-temporal analysis of climatic variables in the western part of Bangladesh. *Environment, Development and Sustainability*, *20*(1), 89-108. https://doi.org/10.1007/s13762-022-04254-0

Karim, F., Mainuddin, M., Hasan, M., & Kirby, M. (2020). Assessing the potential impacts of climate changes on rainfall and evapotranspiration in the northwest region of Bangladesh. *Climate*, *8*(8), 94. https://doi.org/10.3390/cli8080094

Karim, M. F., & Mimura, N. (2008). Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change*, *18*(3), 490-500. https://doi.org/10.1016/j.gloenvcha.2008.05.002

Karim, M. R., Ishikawa, M., Ikeda, M., & Islam, M. (2012). Climate change model predicts 33% rice yield decrease in 2100 in Bangladesh. *Agronomy for Sustainable Development*, *32*(4), 821-830. https://doi.org/10.1007/s13593-012-0096-7

Karmalkar, A., McSweeney, C., New, M., & Lizcano, G. (2012). *UNDP Climate change country profiles: Bangladesh*.

Kaushik, I., & Singh, S. M. (2008). Seasonal ARIMA model for forecasting of monthly rainfall and temperature. *Journal of Environmental Research and Development*, *3*(2), 506-514.

Kemp, W. P., Burnell, D. G., Everson, D. O., & Thomson, A. J. (1983). Estimating missing daily maximum and minimum temperatures. *Journal of Applied Meteorology and Climatology*, *22*(9), 1587-1593.

Kendall, M.G. (1975). *Rank correlation methods*, 4th edition, Charles Griffin, London.

Keyantash, J. A., & Dracup, J. A. (2004). An aggregate drought index: Assessing drought severity based on fluctuations in the hydrologic cycle and surface water storage. *Water Resources Research*, *40*(9). https://doi.org/10.1029/2003WR002610

Khan, A. A., Zhao, Y., khan, J., Rahman, G., Rafiq, M., & Moazzam, M. F. U. (2021). Spatial and temporal analysis of rainfall and drought condition in Southwest Xinjiang in Northwest China, using various climate indices. *Earth Systems and Environment*, *5*(2),201-216. https://doi.org/10.1007/s41748-021-00226-5

Khan, M. H. R., Rahman, A., Luo, C., Kumar, S., Islam, G. M. A., & Hossain, M. A. (2019). Detection of changes and trends in climatic variables in Bangladesh during 1988–2017. *Heliyon*, *5*(3), e01268. https://doi.org/10.1016/j.heliyon.2019.e01268

Kirby, J. M., Ahmad, M. D., Mainuddin, M., Palash, W., Quadir, M. E., Shah-Newaz, S. M., & Hossain, M. M. (2015). The impact of irrigation development on regional groundwater resources in Bangladesh. *Agricultural Water Management*, *159*, 264–276. https://doi.org/10.1016/j.agwat.2015.05.026

Maddison, D. (2007). *The perception of and adaptation to climate change in Africa* (Vol. 4308). World Bank Publications.

Makokha, G. L., & Shisanya, C. A. (2010). Trends in mean annual minimum and maximum near surface temperature in Nairobi city, Kenya. *Advances in Meteorology*, *2010*, 1–6. https://doi.org/10.1155/2010/676041

Mamun, A. A., Roy, S., Islam, M. T., Alam, G. M. M., Alam, E., Chandra Pal, S., Sattar, Md. A., & Mallick, J. (2021). Smallholder farmers' perceived climate-related risk, impact, and their choices of sustainable adaptation strategies. *Sustainability*, *13*(21), 11922. https://doi.org/10.3390/su132111922

Manatsa, D., Mukwada, G., Siziba, E., & Chinyanganya, T. (2010). Analysis of multidimensional aspects of agricultural droughts in Zimbabwe using the Standardized Precipitation Index (SPI). *Theoretical and Applied Climatology*, *102*, 287-305. https://doi.org/10.1007/s00704-010-0262-2

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.

Mardy, T., Uddin, M., Sarker, Md., Roy, D., & Dunn, E. (2018). Assessing coping strategies in response to drought: a micro level study in the north-west region of Bangladesh. *Climate*, *6*(2), 23. https://doi.org/10.3390/cli6020023

Mathier, L., Perreault, L., Bobée, B., & Ashkar, F. (1992). The use of geometric and gamma-related distributions for frequency analysis of water deficit. *Stochastic Hydrology and Hydraulics*, *6*(4), 239-254.

McDowell, J. Z., & Hess, J. J. (2012). Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. *Global Environmental Change*, *22*, 342–352. https://doi.org/10.1016/j.gloenvcha.2011.11.002

McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology*, *17* (22) 179-183.

McKee, T., B. (1995). Drought monitoring with multiple time scales. In *Proceedings of 9th Conference on Applied Climatology*, American Meteorological Society, Boston.

Medhi, J. (2002). *Stochastic models in queueing theory*. Elsevier.

Meher, J., &Jha, R. (2013). Time-series analysis of monthly rainfall data for the Mahanadi River Basin, India. *Sciences in Cold and Arid Regions (SCAR)*, *5*(1), 0073-0084 https://doi.org/10.3724/SP.J.1226.2013.00073

Miah, M. G., Abdullah, H. M., & Jeong, C. (2017). Exploring standardized precipitation evapotranspiration index for drought assessment in Bangladesh. *Environmental Monitoring and Assessment*, *189*(11), 547. https://doi.org/10.1007/s10661-017-6235-5

Michiels, P., Gabriels, D., & Hartmann, R. (1992). Using the seasonal and temporal Precipitation concentration index for characterizing the monthly rainfall distribution in Spain. *CATENA*, *19*(1), 43–58. https://doi.org/10.1016/0341-8162(92)90016-5

Mishra, A. K., & Singh, V. P. (2011). Drought modeling–A review. *Journal of Hydrology*, *403*(1-2), 157-175. https://doi.org/10.1016/j.jhydrol.2011.03.049

Mishra, A. K., Singh, V. P., & Desai, V. R. (2009). Drought characterization: A probabilistic approach. *Stochastic Environmental Research and Risk Assessment*, *23*(1), 41–55. https://doi.org/10.1007/s00477-007-0194-2

Moazzam, M. F. U., Rahman, G., Munawar, S., Farid, N., & Lee, B. G. (2022). Spatiotemporal rainfall variability and drought assessment during past five decades in South Korea using SPI and SPEI. *Atmosphere*, *13*(2), 292. https://doi.org/10.3390/atmos13020292

MOEF (2009). *Bangladesh Climate Change Strategy and Action Plan (BCCSAP)-2009.* Ministry of Environment and Forests, Government of the People's Republic of Bangladesh.

MoEFCC (2022). *National Adaptation Plan of Bangladesh (2023-2050)*. Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh.

MoF (2017). *FPMU Food Security Monitoring Report 2017*. Ministry of Food, Government of the People's Republic of Bangladesh.

MoFA (2018). *Climate Change Profile: Bangladesh*. Ministry of Foreign Affairs, Government of the People's Republic of Bangladesh.

Mohsin, T., & Gough, W. A. (2010). Trend analysis of long-term temperature time series in the Greater Toronto Area (GTA). *Theoretical and Applied Climatology*, *101*(3–4), 311–327. https://doi.org/10.1007/s00704-009-0214-x

Mojid, M. A., Rannu, R. P., & Karim, N. N. (2015). Climate change impacts on reference crop evapotranspiration in North-West hydrological region of Bangladesh: *International Journal of Climatology*, *35*(13), 4041–4046. https://doi.org/10.1002/joc.4260

Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. *International Journal of Geology, Earth and Environmental Sciences*, *2*(1), 70-78.

Nalley, D., Adamowski, J., Khalil, B., & Ozga-Zielinski, B. (2013). Trend detection in surface air temperature in Ontario and Quebec, Canada during 1967–2006 using the discrete wavelet transform. *Atmospheric Research*, *132–133*, 375–398. https://doi.org/10.1016/j.atmosres.2013.06.011

NAP (2023). *National Adaptation Plan Bangladesh (2023-2050)*. Ministry of Environment, Forest and Climate Change, Bangladesh. https://www4.unfccc.int/sites/SubmissionsStaging/Documents/202211020942--National%20Adaptation%20Plan%20of%20Bangladesh%20(2023-2050).pdf

Nicholson, S. E., Tucker, C. J., & Ba, M. B. (1998). Desertification, drought, and surface vegetation: An example from the West African Sahel. *Bulletin of the American Meteorological Society*, *79*(5), 815-830.

NRDC (2021). *Global warming 101*. Natural Resources Defense Council, New York, USA.

Nury, A. H., & Hasan, K. (2016). Analysis of drought in northwestern Bangladesh using standardized precipitation index and its relation to Southern oscillation index. *Environmental Engineering Research*, *21*(1), 58-68. http://dx.doi.org/10.4491/eer.2015.115

Obayelu, O. A., Adepoju, A. O., & Idowu, T. (2014). Factors influencing farmers' choices of adaptation to climate change in Ekiti State, Nigeria. *Journal of Agriculture and Environment for International Development*, *108*(1). https://doi.org/10.12895/jaeid.20141.140

Ojo, T. O., & Baiyegunhi, L. J. S. (2020). Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. *Land Use Policy*, *95*, 103946. https://doi.org/10.1016/j.landusepol.2019.04.007

Oliver, J. E. (1980). Monthly precipitation distribution: a comparative index. *The Professional Geographer*, *32*(3), 300-309. https://doi.org/10.1111/j.0033-0124.1980.00300.x

Otok, B. W. (n.d.). *Development of Rainfall Forecasting Model in Indonesia by using ASTAR, Transfer Function, and ARIMA Methods*. 10.

Palmer, W. C (1968). Keeping track of crop moisture conditions, nationwide: the new crop moisture index. Weather wise 21:156–161

Palmer, W. C. (1965). Meteorological drought. US Weather Bureau Research Paper 45:1-58.

Park, S., Im, J., Jang, E., & Rhee, J. (2016). Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. *Agricultural and Forest Meteorology*, *216*, 157-169. http://dx.doi.org/10.1016/j.agrformet.2015.10.011

Paulo, A. A., & Pereira, L. S. (2007). Prediction of SPI drought class transitions using Markov chains. *Water Resources Management*, *21*, 1813-1827. https://doi.org/10.1007/s11269-006-9129-9

Pryor, S. C., & Schoof, J. T. (2008). Changes in the seasonality of precipitation over the contiguous USA. *Journal of Geophysical Research*, *113*(D21), D21108. https://doi.org/10.1029/2008JD010251

Quiring, S. M., & Papakryiakou, T. N. (2003). An evaluation of agricultural drought indices for the Canadian prairies. *Agricultural and Forest Meteorology*, *118*(1-2), 49-62. https://doi.org/10.1016/S0168-1923(03)00072-8

Radziejewski, M., & Kundzewicz, Z. W. (2004). Detectability of changes in hydrological records / Possibilité de détecter les changements dans les chroniques hydrologiques. *Hydrological Sciences Journal*, *49*(1), 39–51. https://doi.org/10.1623/hysj.49.1.39.54002

Rahman, A. A., Alam, M., Alam, S. S., Uzzaman, M. R., Rashid, M., & Rabbani, G. (2007). Risks, vulnerability and adaptation in Bangladesh. *Human Development Report*, *8*.

Rahman, A. S., Jahan, C. S., Mazumder, Q. H., Kamruzzaman, M., & Hosono, T. (2017a). Drought analysis and its implication in sustainable water resource management in Barind area, Bangladesh. *Journal of the Geological Society of India*, *89*, 47-56. https://doi.org/10.1007/s12594-017-0557-3.

Rahman, A. S., Kamruzzaman, M., Jahan, C. S., Mazumder, Q. H., & Hossain, A. (2016a). Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics. *Sustainable Water Resources Management*, *2*, 297-312. https://doi.org/10.1007/s40899-016-0057-4

Rahman, G., Rahman, A. U., Ullah, S., Dawood, M., Moazzam, M. F. U., & Lee, B. G. (2021). Spatio-temporal characteristics of meteorological drought in Khyber Pakhtunkhwa, Pakistan. *PloS one*, *16*(4), e0249718. https://doi.org/10.1371/journal.pone.0249718

Rahman, G., Samiullah, & Dawood, M. (2018). Spatial and temporal variation of rainfall and drought in Khyber Pakhtunkhwa Province of Pakistan during 1971–2015. *Arabian Journal of Geosciences*, *11*, 1-13. https://doi.org/10.1007/s12517-018-3396-7

Rahman, K. M., Ahmed, F. R. S., & Nazrul Islam, Md. (2016b). Modeling on climate induced drought of north-western region, Bangladesh. *Modeling Earth Systems and Environment*, *2*(1), 45. https://doi.org/10.1007/s40808-016-0089-7

Rahman, M. A., Yunsheng, L., & Sultana, N. (2017b). Analysis and prediction of rainfall trends over Bangladesh using Mann–Kendall, Spearman's rho tests and ARIMA model. *Meteorology and Atmospheric Physics*, *129*(4), 409-424. https://doi.org/10.1007/s00703-016-0479-4

Rahman, M. M., Haque, M. A., Nihad, S. A. I., Akand, M. M. H., & Howlader, M. R. A. (2016c). Morphophysiological response of Acacia auriculiformis as influenced by seawater induced salinity stress. *Forest Systems, 25*(3), e071. https ://doi.org/10.5424/fs/20162 53-09386

Rahman, Md. R., & Lateh, H. (2016). Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data. *Environmental Earth Sciences*, *75*(12), 1026. https://doi.org/10.1007/s12665-016-5829-5

Rahmat, S. N., Jayasuriya, N., & Bhuiyan, M. A. (2017). Short-term droughts forecast using Markov chain model in Victoria, Australia. *Theoretical and Applied Climatology*, *129*, 445-457.

Rakgase, M., & Norris, D. (2014). Factors that influence choice of drought coping strategies in limpopo province, South Africa. *Journal of Human Ecology*, *47*(2), 111–116. https://doi.org/10.1080/09709274.2014.11906743

Raziei, T., Saghafian, B., Paulo, A. A., Pereira, L. S., & Bordi, I. (2009). Spatial patterns and temporal variability of drought in western Iran. *Water Resources Management*, *23*, 439-455. https://doi.org/10.1007/s11269-008-9282-4

Recha, C. W., Makokha, G. L., Traore, P. S., Shisanya, C., Lodoun, T., & Sako, A. (2012). Determination of seasonal rainfall variability, onset and cessation in semi-arid Tharaka district, Kenya. *Theoretical and Applied Climatology*, *108*(3–4), 479–494. https://doi.org/10.1007/s00704-011-0544-3

Redda, A., Tana, T., Alemayehu, Y., Hadgu, G., Elias, B., & Girma, A. (2022). Maize farmers' perceptions of climate change and determinants of adaptation decisions in northern Ethiopia. *Sustainable Agriculture Research*, *11*(3), 38-53. https://doi.org/10.5539/sar.v11n3p38

Redmond, K., T. (2000). Integrated climate monitoring for drought detection. *Drought: A Global Assessment, edited by Wilhite, DA, Routledge*, 145-158.

Rhee, J., & Im, J. (2017). Meteorological drought forecasting for ungauged areas based on machine learning: Using long-range climate forecast and remote sensing data. *Agricultural and Forest Meteorology*, *237–238*, 105–122. https://doi.org/10.1016/j.agrformet.2017.02.011

Ross, S. M. (2014). *Introduction to probability models*. Academic press.

Roy, D., Datta, A., Kuwornu, J. K., & Zulfiqar, F. (2021). Comparing farmers' perceptions of climate change with meteorological trends and examining farm adaptation measures in hazard-prone districts of northwest Bangladesh. *Environment, Development and Sustainability*, *23*(6), 8699-8721. https://doi.org/10.1007/s10668-020-00989-3

Roy, K., Gain, A. K., Mallick, B., & Vogt, J. (2017). Social, hydro-ecological and climatic change in the southwest coastal region of Bangladesh. *Regional Environmental Change*, *17*, 1895-1906. https://doi.org/10.1007/s10113-017-1158-9

Rymbai, D., & Sheikh, F. M. (2018). The insight of agricultural adaptation to climate change: a case of rice growers in Eastern Himalaya, India. *International Journal of Biometeorology*, *62*(10), 1833-1845. https://doi.org/10.1007/s00484-018-1586-3

Sa'adi, Z., Shahid, S., Ismail, T., Chung, E. S., & Wang, X. J. (2019). Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test. *Meteorology and Atmospheric Physics*, *131*(3), 263-277. https://doi.org/10.1007/s00703-017-0564-3

Sakamoto, Y., Ishiguro, M., & Kitagawa, G. (1986). Akaike information criterion statistics. *Dordrecht, The Netherlands: D. Reidel*, *81*(10.5555), 26853.

Salam, R., Islam, A. R. M. T., & Islam, S. (2019). Spatiotemporal distribution and prediction of groundwater level linked to ENSO teleconnection indices in the northwestern region of Bangladesh. *Environment, Development and Sustainability*. https ://doi.org/10.1007/s1066 8-019-00395 -4.

Salam, R., Islam, M. T., Shill, B. K., Alam, G. M., Hasanuzzaman, M., Hasan, M. M., & Shouse, R. C. (2021). Nexus between vulnerability and adaptive capacity of drought-prone rural households in northern Bangladesh. *Natural Hazards*, *106*(1), 509-527. https://doi.org/10.1007/s11069-020-04473-z.s

Salas J.D. (1993). *Analysis and modeling of hydrologic time series*. In: Maidment DR (eds) Handbook of hydrology, McGraw Hill, New York, pp 19.1–19.72

Salehi, S., Dehghani, M., Mortazavi, S. M., & Singh, V. P. (2020). Trend analysis and change point detection of seasonal and annual precipitation in Iran. *International Journal of Climatology*, *40*(1), 308-323. https://doi.org/10.1002/joc.621

Sarker, Md. A. R., Alam, K., & Gow, J. (2013). How Does the Variability in *Aus* Rice Yield Respond to Climate Variables in Bangladesh? *Journal of Agronomy and Crop Science*, *199*(3), 189–194. https://doi.org/10.1111/jac.12011

Schneider, S. H. (2011). *Encyclopedia of Climate and Weather,* (Vol. 1). Oxford University Press.

Schubert, S. D., Suarez, M. J., Pegion, P. J., Koster, R. D., & Bacmeister, J. T. (2008). Potential predictability of long-term drought and pluvial conditions in the US Great Plains. *Journal of Climate*, *21*(4), 802-816. https://doi.org/10.1175/2007JCLI1741.1

Scott, C. A., & Sharma, B. (2009). Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin. *International Journal of River Basin Management*, *7*(2), 119-124. https://doi.org/10.1080/15715124.2009.9635374

Selvaraju, R., & Baas, S. (2007). *Climate variability and change: adaptation to drought in Bangladesh: a resource book and training guide* (Vol. 9). Food & Agriculture Org.

Selvaraju, R., Subbiah, A. R., Baas, S., & Juergens, I. (2006). *Livelihood adaptation to climate variability and change in drought-prone areas of Bangladesh: Developing institutions and options. Case study*, FAO, Institution for Rural Development, Rome.

Sem, G & Moore, R (2009). *The impact of climate change on the development prospects of the least developed countries and small island developing states.* United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States (UN-OHRLLS). https://www.un.org/ohrlls/sites/www.un.org.ohrlls/files/the_impact_of_cc_on_ldcs_and_sids_for_web.pdf (Accessed 7 January, 2023)

Sen, P. K. (1968). Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau.*Jour nal of the American statistical association*, *63*(324), 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Şen, Z. (1976). Wet and dry periods of annual flow series. *Journal of The Hydraulics Division*, *102*(10), 1503-1514.

Shadmani, M., Marofi, S., & Roknian, M. (2012). Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho tests in arid regions of Iran. *Water resources management*, *26*(1), 211–224. https://doi.org/10.1007/s11269-011-9913-z

Shafer, B. A. (1982). Development of a surface water supply index (SWSI) to assess the severity of drought conditions in snowpack runoff areas. In *Proceedings of the 50th Annual Western Snow Conference, Colorado State University, Fort Collins, 1982*.

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

Shahid, S. (2010). Rainfall variability and the trends of wet and dry periods in Bangladesh. *International Journal of Climatology*, *30*(15), 2299–2313.https://doi.org/10.1002/joc.2053

Shahid, S. (2010). Recent trends in the climate of Bangladesh. *Climate Research*, *42*(3), 185-193. https://doi.org/10.3354/cr00889

Shahid, S. (2011). Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. *Climatic change*, *105*(3–4), 433–453. https://doi.org/10.1007/s10584-010-9895-5

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

Shahid, S., & Khairulmaini, O, S. (2009). Spatio-temporal variability of rainfall over Bangladesh during the time period 1969-2003. *Asia-Pacific Journal of Atmospheric Science*, *45*(3), 375-389.

Shankar, K. R., Nagasree, K., Sankar, G. M., Prasad, M. S., Raju, B. M. K., Rao, A. S., & Venkateswarlu, B. (2013). *Farmers' Perceptions and Adaptation Measures towards Changing Climate in South India and Role of Extension in Adaptation and Mitigation to Changing Climate.* Central Research Institute for Dryland Agriculture, Hyderabad, India.

Shaw, R., Mallick, F., & Islam, A. (Eds.). (2013). *Climate change adaptation actions in Bangladesh*. New York: Springer.

Shiau, J. T., & Shen, H. W. (2001). Recurrence analysis of hydrologic droughts of differing severity. *Journal of water resources planning and management*, *127*(1), 30-40.

Shrestha, R. P., Chaweewan, N., & Arunyawat, S. (2017). Adaptation to climate change by rural ethnic communities of Northern Thailand. *Climate*, *5*(3), 57.

Sikder, R., & Xiaoying, J. (2014). Climate change impact and agriculture of Bangladesh. *Journal of Environment and Earth Science*, *4*(1), 35-40.

Sneyers, R. (1990). *On the statistical analysis of series of observations*. World Meteorological Organization.

Sohail, M. T. (2022). A PLS-SEM approach to determine farmers' awareness about climate change mitigation and adaptation strategies: pathway toward sustainable environment and agricultural productivity. *Environmental Science and Pollution Research*, 1-14. https://doi.org/10.1007/s11356-022-23471-1.

Spearman, C. (2010). The proof and measurement of association between two things. *International Journal of Epidemiology*, *39*(5), 1137–1150. https://doi.org/10.1093/ije/dyq1917.

Stedinger J.R. (1993). *Frequency analysis of extreme events*. In: Maidment DR (eds). Handbook of hydrology, McGraw Hill, New York, pp 18.1–18.66

Sultana M, Ahmed JU, Shiratake Y (2020). Sultana, M., Ahmed, J. U., & Shiratake, Y. (2020). Sustainable conditions of agriculture cooperative with a case study of dairy cooperative of Sirajgonj District in Bangladesh. *Journal of Co-operative Organization and Management*, *8*(1), https:// doi. org/ 10. 1016/j. jcom. 2019. 100105

Tabari, H., & Talaee, P. H. (2011). Temporal variability of precipitation over Iran: 1966–2005. *Journal of Hydrology*, *396*(3–4), 313–320. https://doi.org/10.1016/j.jhydrol.2010.11.034

Tannehill, I. R. (1947). *Drought, its causes and effects* (Vol. 64, No. 1, p. 83). Princeton, NJ: Princeton University Press.

Taylor, J. G., Stewart, T. R., & Downton, M. (1988). Perceptions of drought in the Ogallala Aquifer region. *Environment and Behavior*, *20*(2), 150-175. https://doi.org/10.1177/0013916588202002

Tazeze, A., Haji, J., & Ketema, M. (2012). Climate change adaptation strategies of smallholder farmers: the case of Babilie District, East Harerghe Zone of Oromia Regional State of Ethiopia. *Journal of Economics and Sustainable Development*, *3*(14), 1-12.

Tessema, Y. A., Aweke, C. S., & Endris, G. S. (2013). Understanding the process of adaptation to climate change by small-holder farmers: The case of east Hararghe Zone, Ethiopia. *Agricultural and Food Economics*, *1*(1), 13. https://doi.org/10.1186/2193-7532-1-13

Thom, H. C. S. (1966). *Some methods of climatological analysis* (Vol. 81, p. 53). Geneva: Secretariat of the World Meteorological Organization.

Thomas, T. S., Mainuddin, K., Chiang, C., Rahman, A., Haque, A., Islam, N., ... & Sun, Y. (2013). *Agriculture and adaptation in Bangladesh: Current and projected impacts of climate change* (Vol. 1281). Intl Food Policy Res Inst.

Tonkaz, T., Çetin, M., & Tülücü, K. (2007). The impact of water resources development projects on water vapor pressure trends in a semi-arid region, Turkey. *Climatic change*, *82*(1–2), 195–209. https://doi.org/10.1007/s10584-006-9160-0

Tosunoglu, F., & Kisi, O. (2017). Trend analysis of maximum hydrologic drought variables using Mann–Kendall and Şen's innovative trend method. *River Research and Applications*, *33*(4), 597-610.https://doi.org/10.1002/rra.3106

Uddin, M. A., Kamal, A. M., Shahid, S., & Chung, E. S. (2020a). Volatility in rainfall and predictability of droughts in northwest Bangladesh. *Sustainability*, *12*(23), 9810. https://doi.org/10.3390/su12239810

Uddin, M. J., Hu, J., Islam, A. R. M. T., Eibek, K. U., & Nasrin, Z. M. (2020b). A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. *Arabian Journal of Geosciences*, *13,* 1-10. https://doi.org/10.1007/s12517-020-05302-0

Uddin, M. N., Bokelmann, W., & Entsminger, J. S. (2014). Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh. *Climate*, *2*(4), 223-241. https://doi.org/10.3390/cli2040223

Udmale, P., Ichikawa, Y., Manandhar, S., Ishidaira, H., & Kiem, A. S. (2014). Farmers′ perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. *International Journal of Disaster Risk Reduction*, *10*, 250-269. https://doi.org/10.1016/j.ijdrr.2014.09.011.

UNDP (2005). *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures: Annexes.* United Nations Development Programme http://www.undp.org/gef/documents/publications/apf-annexes-a-b.pdf. (Accessed 4th February, 2022)

UNFCCC (2006). *United Nations framework convention on climate change: Handbook*. UNFCCC.

Van Loon, A. F., & Van Lanen, H. A. J. (2013). Making the distinction between water scarcity and drought using an observation-modeling framework: Distinguishing Between Water Scarcity and Drought. *Water Resources Research*, *49*(3), 1483–1502. https://doi.org/10.1002/wrcr.20147

Van Rooy, M. P. (1965). A rainfall anomaly index independent of time and space, notos. 14:43–48

Vergni, L., & Todisco, F. (2011). Spatio-temporal variability of precipitation, temperature and agricultural drought indices in Central Italy. *Agricultural and Forest Meteorology*, *151*(3), 301-313. https://doi.org/10.1016/j.agrformet.2010.11.005

Vicente-Serrano, S. M. (2006). Differences in spatial patterns of drought on different time scales: an analysis of the Iberian Peninsula. *Water resources management*, *20*, 37-60. https://doi.org/10.1007/s11269-006-2974-8

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

Vicente-Serrano, S. M., Lopez-Moreno, J. I., Beguería, S., Lorenzo-Lacruz, J., Sanchez-Lorenzo, A., García-Ruiz, J. M., ... & Espejo, F. (2014). Evidence of increasing drought severity caused by temperature rise in southern Europe. *Environmental Research Letters*, *9*(4), 044001. https://doi.org/ 10.1088/1748-9326/9/4/044001

Walsh, R. P. D., & Lawler, D. M. (1981). Walsh, R. P. D., & Lawler, D. M. (1981). Rainfall seasonality: description, spatial patterns and change through time. *Weather*, *36*(7), 201-208. *Weather*, *36*(7), 201–208. https://doi.org/10.1002/j.1477-8696.1981.tb05400.x

Wang, H., Rogers, J. C., & Munroe, D. K. (2015). Commonly used drought indices as indicators of soil moisture in China. *Journal of Hydrometeorology*, *16*(3), 1397-1408. https://doi.org/10.1175/JHM-D-14-0076.1

Wilhite, D. A. (1997). Responding to drought: common threads from the past, visions for the future. *Journal of the American Water Resources Association*, *33*(5), 951–959. https://doi.org/10.1111/j.1752-1688.1997.tb04116.x

Wilhite, D. A. (2000). *Drought as a natural hazard: concepts and definitions*. University of Nebraska – Lincoln

Wilhite, D. A., Rosenberg, N. J., & Glantz, M. H. (1986). Improving federal response to drought. *Journal of Applied Meteorology and Climatology*, *25*(3), 332-342. https://doi.org/10.1175/1520-0450(1986)025%3C0332:IFRTD%3E2.0.CO;2

WMO (2021). *State of the Climate in Asia 2020*. WMO-No. 1273. World Meteorological Organization.

Wolff, R. W. (1989). *Stochastic modeling and the theory of queues*. Prentice-Hall Inc., Englewood Cliffs

Wood, S. A., Jina, A. S., Jain, M., Kristjanson, P., & DeFries, R. S. (2014). Smallholder farmer cropping decisions related to climate variability across multiple regions. *Global Environmental Change*, *25*, 163-172. https://doi.org/10.1016/j.gloenvcha.2013.12.011

Wooldridge, J. M. (2002). Econometric analysis of cross section and panel data MIT press. *Cambridge, MA*, *108*(2), 245-254.

Wu, H., Hayes, M. J., Wilhite, D. A., & Svoboda, M. D. (2005). The effect of the length of record on the standardized precipitation index calculation. *International Journal of Climatology*, *25*(4), 505–520. https://doi.org/10.1002/joc.1142

Xenarios, S., Nemes, A., Sarker, G. W., & Sekhar, N. U. (2016). Assessing vulnerability to climate change: are communities in flood-prone areas in Bangladesh more vulnerable than those in drought-prone areas. *Water Resources and Rural Development*, *7,* 1-19. https://doi.org/10.1016/j.wrr.2015.11.001

Yao, N., Li, Y., Lei, T., & Peng, L. (2018). Drought evolution, severity and trends in mainland China over 1961–2013. *Science of the Total Environment*, *616*, 73-89. https://doi.org/10.1016/j.scitotenv.2017.10.327

Yaseen, Z. M., Ali, M., Sharafati, A., Al-Ansari, N., & Shahid, S. (2021). Forecasting standardized precipitation index using data intelligence models: Regional investigation of Bangladesh. *Scientific Reports*, *11*(1), 3435. https://doi.org/10.1038/s41598-021-82977-9

Yeh, H. F., & Hsu, H. L. (2019). Using the Markov chain to analyze precipitation and groundwater drought characteristics and linkage with atmospheric circulation. *Sustainability, 11*(6), 1817. https://doi.org/10.3390/su11061817

Yevjevich, V. M. (1967). *Objective approach to definitions and investigations of continental hydrologic droughts*, Hydrological Papers 23, Colorado State University Publication, Colorado State University, Fort Collins, Colorado, USA.

Yue, S., & Hashino, M. (2003). Long term trends of annual and monthly precipitation in Japan. *JAWRA Journal of the American Water Resources Association*, *39*(3), 587-596.

Yue, S., & Wang, C. (2002). The influence of serial correlation on the Mann–Whitney test for detecting a shift in median. *Advances in Water Resources*, *25*(3), 325–333. https://doi.org/10.1016/S0309-1708(01)00049-5

Yue, S., & Wang, C. (2004). The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. *Water Resources Management*, *18*(3), 201–218. https://doi.org/10.1023/B:WARM.0000043140.61082.60

Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, *259*(1–4), 254–271. https://doi.org/10.1016/S0022-1694(01)00594-7

Yue, S., Pilon, P., Phinney, B., & Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological processes*, *16*(9), 1807–1829. https://doi.org/10.1002/hyp.1095

Zakaria, S., Al-Ansari, N., Knutsson, S., & Al-Badrany, T. (2012). ARIMA Models for weekly rainfall in the semi-arid Sinjar District at Iraq. *Journal of Earth Sciences and Geotechnical Engineering*, *2*(3).

Zarenistanak, M., Dhorde, A. G., & Kripalani, R. H. (2014). Trend analysis and change point detection of annual and seasonal precipitation and temperature series over southwest Iran. *Journal of Earth System Science*, *123*(2), 281. https://doi.org/10.1007/s12040-013-0395-7

Zhai, L., & Feng, Q. (2009). Spatial and temporal pattern of precipitation and drought in Gansu Province, Northwest China. *Natural hazards*, *49*, 1-24. https://doi.org/10.1007/s11069-008-9274-y

Zhang, D. & H.C. Zhou. (2010). Prediction of drought based on index weighted Markov chain and dual-criteria decision. *Journal of Water Resources*, *28*(4): 5-8.

Zhao, R., Wang, H., Zhan, C., Hu, S., Ma, M., & Dong, Y. (2020). Comparative analysis of probability distributions for the Standardized Precipitation Index and drought evolution in China during 1961–2015. *Theoretical and Applied Climatology*, *139*, 1363-1377. https://doi.org/10.1007/s00704-019-03050-0

Appendix I

Programming Function in R-Package

Mann-Kendall and Sens-slope Trend Test

```
dd=read.csv(file.choose(), header=T)
dd
data=ts(dd, start=c(1960,1), frequency=1)
data
library(trend)
mk.test(data)
Sen. Slope(data)
summary(data)
```

Spearman Rho Test

```
dd=read.csv(file.choose(), header=T)
dd
attach(dd)
names(dd)
cor.test(dd$Year,dd$Prekharif,method="spearman",exact=FALSE)
```

Sequential Mann-Kendall Test

```
dd=read.csv(file.choose(), header=T)
dd
library(trend change)
sqmk(dd,1960)
```

Arima and Forecast

```
dd=read.csv(file.choose(), header=T)
dd
data=ts (dd, start=c(1960,1), frequency=12)
data
x1=data [,1]
x1
modx1=auto.arima(x1)
modx1
forecast(modx1,60)
plot(forecast(modx1), main="Dinajpur", xlab="Year", ylab="temperature")
```

Standardized Precipitation Index (SPI)

```
dd=read.csv(file.choose(), header=T)
dd
data=ts(dd, start=c(1960,1), frequency=1)
data
spi_1<-spi(dd$Rajshahi,1);
spi_1
plot(spi_1,main="Rajshai", xlab="Year", ylab="Spi_1")
```

SPI_transition matrix

```
dd=read.csv(file.choose(), header=T)
dd
data=ts(dd,start=c(1960,1), frequency=12)
data
data.final=na.omit(data)
data.final
is.na(data)
```

#Transition Matrix#

```
TPM<-function(x){
  dd<-0; ww<-0; dw<-0; wd<-0
  for (i in 1:(length(x)-1)) {
    if(x[i]<0 & x[i+1] <0)
      dd<-dd+1
    else
      0
    if(x[i]>=0 & x[i+1]>=0)
      ww<-ww+1
    else
      0
    if(x[i]<0 & x[i+1]>=0)
      dw<-dw+1
    else
      0
    if(x[i]>=0 & x[i+1]<0)
      wd<-wd+1
    else
0
}
dd; ww; dw; wd; matrix(c((dd/(dd+dw)),(wd/(wd+ww)),(dw/(dd+dw)),(ww/(wd+ww)))
,2,2)}

TPM_SPI<-TPM (data.final)

TPM_SPI
```

#Probability#

```
TPM<-function(x){
  p11<-0; p12<-0; p13<-0; p14<-0; p21<-0; p22<-0; p23<-0; p24<-0; p31<-0; p32
<-0; p33<-0; p34<-0; p41<-0; p42<-0; p43<-0; p44<-0;
```

```
for(i in 1:(length(x)-1)){
  if((x[i]<=0 &(-0.99)<=x[i]) & (x[i+1]<=0 & (-0.99)<=x[i+1]))
    p11<-p11+1
  else
    0
  if((x[i]<=0 &(-0.99)<=x[i]) & (x[i+1]<=(-1) & (-1.49)<=x[i+1]))
    p12<-p12+1
  else
    0
  if((x[i]<=0 &(-0.99)<=x[i]) & (x[i+1]<=(-1.5)&(-1.99)<=x[i+1]))
    p13<-p13+1
  else
    0
  if((x[i]<=0 &(-0.99)<=x[i]) & (x[i+1]<=(-2)))
    p14<-p14+1
  else
    0
  if((x[i+1]<=(-1) & (-1.49)<=x[i+1])& (x[i]<=0 &(-0.99)<=x[i]))
    p21<-p21+1
  else
    0
  if((x[i+1]<=(-1) & (-1.49)<=x[i+1])& (x[i+1]<=(-1) & (-1.49)<=x[i+1]))
    p22<-p22+1
  else
    0
  if((x[i+1]<=(-1) & (-1.49)<=x[i+1])& (x[i+1]<=(-1.5)&(-1.99)<=x[i+1]))
    p23<-p23+1
  else
    0
  if((x[i+1]<=(-1) & (-1.49)<=x[i+1])& (x[i+1]<=(-2)))
    p24<-p24+1
  else
    0
  if((x[i+1]<=(-1.5)&(-1.99)<=x[i+1])& (x[i]<=0 &(-0.99)<=x[i]))
    p31<-p31+1
  else
    0
  if((x[i+1]<=(-1.5)&(-1.99)<=x[i+1])& (x[i+1]<=(-1) & (-1.49)<=x[i+1]))
    p32<-p32+1
  else
    0
  if((x[i+1]<=(-1.5)&(-1.99)<=x[i+1])& (x[i+1]<=(-1.5)&(-1.99)<=x[i+1]))
    p33<-p33+1
  else
    0
  if((x[i+1]<=(-1.5)&(-1.99)<=x[i+1])& (x[i+1]<=(-2)))
    p34<-p34+1
  else
    0
  if((x[i+1]<=(-2)) & (x[i]<=0 &(-0.99)<=x[i]))
    p41<-p41+1
  else
    0
  if((x[i+1]<=(-2)) & (x[i+1]<=(-1) & (-1.49)<=x[i+1]))
    p42<-p42+1
  else
    0
  if((x[i+1]<=(-2)) & (x[i+1]<=(-1.5)&(-1.99)<=x[i+1]))
    p43<-p43+1
```

```
    else
      0
    if((x[i+1]<=(-2)) & (x[i+1]<=(-2)))
      p44<-p44+1
    else
      0
  }
  p11; p12; p13; p14; p21; p22; p23; p24; p31; p32; p33; p34; p41; p42; p43;
p44;
  r1<-p11+p12+p13+p14; r2<-p21+p22+p23+p24; r3<-p31+p32+p33+p34; r4<-p41+p42+
p43+p44;
  matrix(c(p11/r1,p21/r2,p31/r3,p41/r4, p12/r1,p22/r2,p32/r3,p42/r4, p13/r1,p
23/r2,p33/r3,p43/r4, p14/r1,p24/r2,p34/r3,p44/r4),4,4)}

TPM_Prob<-TPM (data.final)

TPM_Prob
```

STATA Function

Multinomial Logistic Model

```
mlogit ADAP_STRATEGY AGE EDUCATION MON_INC FAMILY_SIZE FARM_EXP FIRM_SIZE ACC
ESS_CLIMATE ACCESS_ELEC TRAIN_EXP SOCIAL_MOB FAR_TO_FAR LOAN_SUB,
baseoutcome(1)


mfx, predict (p outcome(2))

Marginal effects after mlogit
      y = Pr(ADAP_STRATEGY==Agronomic_management) (predict, p outcome(2))

mfx, predict (p outcome (3))

Marginal effects after mlogit
      y = Pr(ADAP_STRATEGY==Irrigation_facility) (predict, p outcome(3))

mfx, predict(p outcome(4))

Marginal effects after mlogit
      y = Pr(ADAP_STRATEGY==Adoption_of_new_technologies) (predict, p outcome
(4))

mfx, predict(p outcome(5))

Marginal effects after mlogit
      y = Pr(ADAP_STRATEGY==Alternative_enterprize_of_land_u) (predict, p out
come(5))
```

Appendix II

Bogura_ SPI_Classification (1960-2021)

Year	Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24	SPI_1_Class	SPI_3_Class	SPI_6_Class	SPI_9_Class	SPI_12_Class	SPI_24_Class
1960	1	0						Near normal					
1960	2	-1						Moderately dry					
1960	3	1	0					Moderately wet	Near normal				
1960	4	-1	-1					Moderately dry	Moderately dry				
1960	5	0	0					Near normal	Near normal				
1960	6	-1	-2	-1				Moderately dry	Extremely dry	Moderately dry			
1960	7	0	-1	-1				Near normal	Moderately dry	Moderately dry			
1960	8	0	-1	-1				Near normal	Moderately dry	Moderately dry			
1960	9	1	0	0	0			Moderately wet	Near normal	Near normal	Near normal		
1960	10	-1	0	-1	-1			Moderately dry	Near normal	Moderately dry	Moderately dry		
1960	11	0	0	-1	-1			Near normal	Near normal	Moderately dry	Moderately dry		
1960	12	0	-1	0	-1	-1		Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	
1961	1	1	0	0.339	-1	-1		Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	
1961	2	1	1	0.462	-1	-1		Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry	
1961	3	-1	1	-0.941	0	-1		Moderately dry	Moderately wet	Near normal	Near normal	Moderately dry	
1961	4	-1	0	-0.338	0	-1		Moderately dry	Near normal	Near normal	Near normal	Moderately dry	
1961	5	-1	-1	-0.738	0	-1		Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry	
1961	6	0	0	-0.318	-1	0		Near normal	Near normal	Near normal	Moderately dry	Near normal	
1961	7	-2	-1	-1.145	-1	-1		Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	
1961	8	1	0	-0.336	0	0		Moderately wet	Near normal	Near normal	Near normal	Near normal	
1961	9	-1	-1	-0.715	-1	-1		Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry	
1961	10	1	1	-0.363	0	0		Moderately wet	Moderately wet	Near normal	Near normal	Near normal	
1961	11	0	0	-0.236	-1	0		Near normal	Near normal	Near normal	Moderately dry	Near normal	

1961	12	0	1	-0.329	0	0	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1962	1	1	0	0.554	-0.495	-1	-1	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1962	2	0	0	-0.501	-0.271	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1962	3	-1	0	0.587	-0.418	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1962	4	-1	-1	-1.253	0.208	-1	-1	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry
1962	5	1	0	0.139	-0.341	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1962	6	-1	0	-0.336	-0.071	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1962	7	-1	0	-0.591	-0.662	-0.226	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1962	8	0	-1	-0.742	-0.764	-0.989	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1962	9	-2	-1	-1.217	-1.225	-0.953	-2	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Extremely dry
1962	10	-1	-2	-1.326	-1.474	-1.531	-2	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Severely dry	Extremely dry
1962	11	0	-2	-1.74	-1.507	-1.516	-2	Near normal	Extremely dry	Severely dry	Severely dry	Severely dry	Extremely dry
1962	12	0	-1	-1.736	-1.482	-1.485	-2	Near normal	Moderately dry	Severely dry	Moderately dry	Moderately dry	Extremely dry
1963	1	0	-1	-2.176	-1.575	-2	-2	Near normal	Moderately dry	Extremely dry	Severely dry	Extremely dry	Extremely dry
1963	2	-1	-1	-2.873	-2.066	-2	-2	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1963	3	0	-1	-1.864	-2.099	-2	-2	Near normal	Moderately dry	Severely dry	Extremely dry	Extremely dry	Extremely dry
1963	4	0	0	-0.823	-2.301	-2	-2	Near normal	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry
1963	5	0	0	-0.435	-1.999	-2	-2	Near normal	Near normal	Near normal	Moderately dry	Extremely dry	Extremely dry
1963	6	1	0	0.105	-0.384	-1	-2	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
1963	7	1	1	0.393	0.294	-0.869	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1963	8	0	0	0.179	0.079	-0.845	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	9	-1	0	-0.094	-0.162	-0.461	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	10	1	0	0.204	0.089	0.013	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	11	1	0	0.244	0.138	0.058	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	12	0	1	0.053	0.14	0.074	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1964	1	0	0	-0.41	0.127	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	2	0	-1	-0.048	0.178	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1964	3	0	0	0.83	-0.004	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry

1964	4	0	0	0.087	-0.408	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	5	0	0	-0.003	-0.049	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	6	0	0	-0.159	0.169	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	7	1	0	0.213	0.168	-0.161	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	8	-1	0	-0.08	-0.148	-0.178	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	9	0	0	-0.119	-0.138	0.08	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1964	10	1	0	0.088	0.081	0.05	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1964	11	0	0	0.027	0.063	0.01	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1964	12	0	1	0.192	0.043	0.022	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1965	1	0	-1	-0.229	-0.049	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	2	0	0	0.279	-0.038	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1965	3	-1	-1	0.454	0.079	0	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	4	-1	-1	-1.674	-0.594	0	0	Moderately dry	Moderately dry	Severely dry	Near normal	Near normal	Near normal
1965	5	-3	-3	-2.847	-0.98	-1	0	Extremely dry	Extremely dry	Extremely dry	Near normal	Moderately dry	Near normal
1965	6	0	-2	-1.632	-1.081	-1	-1	Near normal	Extremely dry	Severely dry	Moderately dry	Moderately dry	Moderately dry
1965	7	1	0	-0.415	-0.533	-0.616	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1965	8	1	1	0.173	0.112	0.205	0	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
1965	9	0	1	0.008	-0.059	0.079	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1965	10	-1	0	-0.082	-0.271	-0.353	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
1965	11	1	-1	0.37	-0.262	-0.31	0	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	12	1	-1	0.677	-0.228	-0.287	0	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Near normal
1966	1	2	1	0.243	-0.073	0	0	Extremely wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
1966	2	-1	1	-0.891	0.393	0	0	Moderately dry	Moderately wet	Near normal	Near normal	Near normal	Near normal
1966	3	-1	0	-0.912	0.67	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
1966	4	-1	-1	-0.565	-0.15	0	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
1966	5	-1	-2	-1.395	-1.693	0	-1	Moderately dry	Extremely dry	Moderately dry	Severely dry	Near normal	Moderately dry
1966	6	-1	-2	-1.605	-1.901	0	-1	Moderately dry	Extremely dry	Severely dry	Severely dry	Near normal	Moderately dry
1966	7	-1	-2	-1.864	-1.733	-1.408	-2	Moderately dry	Extremely dry	Severely dry	Severely dry	Moderately dry	Extremely dry

1966	8	1	-1	-1.317	-1.269	-1.693	-1	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Severely dry	Moderately dry
1966	9	-1	-1	-1.361	-1.315	-1.51	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Severely dry	Moderately dry
1966	10	0	0	-1.229	-1.409	-1.331	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1966	11	1	0	-0.885	-1.27	-1.229	-1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
1966	12	1	0	-0.439	-1.204	-1.168	-1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
1967	1	1	1	0.029	-1.246	-1	-1	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry
1967	2	-1	0	-0.401	-0.941	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1967	3	2	2	0.785	-0.241	-1	-1	Extremely wet	Extremely wet	Near normal	Near normal	Moderately dry	Moderately dry
1967	4	0	0	0.821	0.109	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1967	5	0	1	0.514	-0.017	-1	-1	Near normal	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry
1967	6	0	0	-0.026	0.001	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1967	7	0	0	0.071	0.176	-0.024	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1967	8	-1	0	-0.157	-0.179	-0.409	-2	Moderately dry	Near normal	Near normal	Near normal	Near normal	Extremely dry
1967	9	-1	-1	-0.594	-0.4	-0.348	-2	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
1967	10	-1	-1	-0.705	-0.599	-0.508	-2	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
1967	11	0	-1	-0.937	-0.584	-0.597	-2	Near normal	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
1967	12	0	-1	-0.834	-0.803	-0.612	-2	Near normal	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
1968	1	0	-1	-1.409	-0.892	-1	-2	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Extremely dry
1968	2	0	-1	-1.301	-1.074	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1968	3	0	0	-1.146	-0.958	-1	-2	Near normal	Near normal	Moderately dry	Near normal	Moderately dry	Extremely dry
1968	4	-1	-1	-1.279	-1.728	-1	-2	Moderately dry	Moderately dry	Moderately dry	Severely dry	Moderately dry	Extremely dry
1968	5	-3	-3	-2.847	-2.439	-2	-2	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1968	6	1	-1	-0.568	-0.926	-1	-1	Moderately wet	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry
1968	7	1	0	0.207	0.117	-0.709	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	8	0	1	0.247	0.159	-0.368	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1968	9	0	1	0.035	-0.006	-0.245	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1968	10	0	0	0.152	-0.021	-0.089	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	11	1	0	0.64	0.017	-0.054	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry

1968	12	0	0	0.403	-0.002	-0.039	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	1	0	0	-0.344	0.065	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	2	-1	-1	-0.563	0.56	0	-1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1969	3	0	0	-0.175	0.325	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	4	1	1	0.599	-0.123	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1969	5	-1	0	-0.347	-0.596	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	6	-1	-1	-0.639	-0.643	0	-1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1969	7	-1	-1	-1.005	-1.068	-1.194	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1969	8	1	0	-0.333	-0.429	-0.643	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	9	1	0	-0.025	-0.07	-0.113	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1969	10	-1	1	-0.486	-0.33	-0.369	0	Moderately dry	Moderately wet	Near normal	Near normal	Near normal	Near normal
1969	11	1	0	-0.209	-0.236	-0.31	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1969	12	0	-1	0.109	-0.254	-0.293	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	1	0	1	0.695	-0.569	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1970	2	-1	-1	-0.012	-0.32	0	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	3	-1	-2	-1.55	-0.052	0	0	Moderately dry	Extremely dry	Severely dry	Near normal	Near normal	Near normal
1970	4	-1	-3	-1.478	0.238	-1	-1	Moderately dry	Extremely dry	Moderately dry	Near normal	Moderately dry	Moderately dry
1970	5	-1	-2	-1.83	-0.878	-1	0	Moderately dry	Extremely dry	Severely dry	Near normal	Moderately dry	Near normal
1970	6	1	0	0.076	-0.31	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1970	7	2	1	0.88	0.883	1.115	0	Extremely wet	Moderately wet	Near normal	Near normal	Moderately wet	Near normal
1970	8	-1	1	0.553	0.456	0.417	0	Moderately dry	Moderately wet	Near normal	Near normal	Near normal	Near normal
1970	9	0	0	0.386	0.283	0.035	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	10	1	0	0.719	0.447	0.452	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1970	11	0	0	0.974	0.474	0.396	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	12	0	1	0.551	0.502	0.406	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------

--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
2010	1	0	-1	0.596	-0.694	-1	0	Near normal	Moderately dry	Near normal	Near normal	Moderately dry	Near normal
2010	2	-1	-1	-1.13	-0.77	-1	0	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal
2010	3	-1	-2	-1.097	-0.283	-1	-1	Moderately dry	Extremely dry	Moderately dry	Near normal	Moderately dry	Moderately dry
2010	4	-1	-1	-1.747	0.238	-1	-1	Moderately dry	Moderately dry	Severely dry	Near normal	Moderately dry	Moderately dry
2010	5	0	-1	-0.756	-1.238	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
2010	6	0	0	-0.485	-0.723	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2010	7	-2	-1	-1.465	-1.607	-0.849	-2	Extremely dry	Moderately dry	Moderately dry	Severely dry	Near normal	Extremely dry
2010	8	0	-1	-1.461	-1.579	-1.933	-2	Near normal	Moderately dry	Moderately dry	Severely dry	Severely dry	Extremely dry
2010	9	0	-1	-1.254	-1.348	-1.449	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2010	10	1	0	-0.911	-1.081	-1.175	-2	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
2010	11	0	0	-0.997	-1.056	-1.144	-2	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
2010	12	1	1	-1.064	-0.967	-1.058	-1	Moderately wet	Moderately wet	Moderately dry	Near normal	Moderately dry	Moderately dry
2011	1	0	0	-0.046	-1.046	-1	-2	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
2011	2	-1	0	0.213	-1.077	-1	-2	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
2011	3	0	-1	0.411	-1.282	-1	-2	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
2011	4	1	1	0.698	0.157	-1	-1	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry
2011	5	0	0	0.415	0.359	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2011	6	-1	0	-0.28	-0.037	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2011	7	-1	-1	-0.918	-0.948	-0.915	-1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2011	8	2	0	0.265	0.227	0.255	-1	Extremely wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2011	9	1	1	0.591	0.501	0.593	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2011	10	-2	1	0.052	0.171	0.155	-1	Extremely dry	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2011	11	1	0	0.042	0.204	0.175	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry

2011	12	0	-2	0.446	0.219	0.139	-1	Near normal	Extremely dry	Near normal	Near normal	Near normal	Moderately dry
2012	1	1	0	1.36	-0.002	0	-1	Moderately wet	Near normal	Moderately wet	Near normal	Near normal	Moderately dry
2012	2	-1	0	-0.012	-0.005	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2012	3	-1	-1	-2.454	0.359	0	-1	Moderately dry	Moderately dry	Extremely dry	Near normal	Near normal	Moderately dry
2012	4	0	0	-0.121	1.195	0	-1	Near normal	Near normal	Near normal	Moderately wet	Near normal	Moderately dry
2012	5	-1	-1	-0.985	-0.606	0	-1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2012	6	-1	-1	-1.392	-2.01	-1	-1	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
2012	7	-1	-2	-1.9	-1.895	-0.499	-1	Moderately dry	Extremely dry	Severely dry	Severely dry	Near normal	Moderately dry
2012	8	-1	-2	-2.109	-2.145	-1.889	-1	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Severely dry	Moderately dry
2012	9	1	-1	-1.42	-1.447	-1.8	-1	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Severely dry	Moderately dry
2012	10	0	0	-1.617	-1.603	-1.604	-1	Near normal	Near normal	Severely dry	Severely dry	Severely dry	Moderately dry
2012	11	1	0	-1.287	-1.464	-1.494	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	12	0	0	-0.934	-1.433	-1.459	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	1	0	1	-0.354	-1.749	-2	-1	Near normal	Moderately wet	Near normal	Severely dry	Extremely dry	Moderately dry
2013	2	1	0	0.323	-1.392	-2	-1	Moderately wet	Near normal	Near normal	Moderately dry	Extremely dry	Moderately dry
2013	3	-1	0	-0.447	-1.063	-2	-1	Moderately dry	Near normal	Near normal	Moderately dry	Extremely dry	Moderately dry
2013	4	-1	-1	-0.803	-0.736	-2	-1	Moderately dry	Moderately dry	Near normal	Near normal	Extremely dry	Moderately dry
2013	5	0	-1	-1.076	-0.384	-2	-2	Near normal	Moderately dry	Moderately dry	Near normal	Extremely dry	Extremely dry
2013	6	-1	-1	-1.103	-1.171	-2	-2	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Extremely dry
2013	7	-1	-1	-1.128	-1.102	-1.302	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	8	0	-1	-1.132	-1.159	-0.898	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Extremely dry
2013	9	-1	-1	-1.476	-1.482	-1.503	-3	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Severely dry	Extremely dry
2013	10	1	-1	-0.999	-1.17	-1.151	-2	Moderately wet	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
2013	11	0	-1	-0.99	-1.221	-1.239	-2	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
2013	12	0	1	-0.806	-1.201	-1.214	-2	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry	Extremely dry
2014	1	0	-1	-0.694	-1.222	-1	-2	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
2014	2	2	1	-0.481	-0.982	-1	-2	Extremely wet	Moderately wet	Near normal	Near normal	Moderately dry	Extremely dry

2014	3	0	1	0.684	-0.802	-1	-2	Near normal	Moderately wet	Near normal	Near normal	Moderately dry	Extremely dry
2014	4	0	0	-0.22	-0.7	-1	-2	Near normal	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
2014	5	0	0	-0.087	-0.582	-1	-2	Near normal	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
2014	6	1	1	1.035	1.051	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
2014	7	-1	0	0.405	0.307	-0.139	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	8	0	0	0.113	0.15	-0.192	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	9	1	-1	0.309	0.338	0.414	-1	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2014	10	-1	0	0.194	0.168	0.093	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	11	0	0	0.159	0.062	0.094	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	12	0	-1	-0.838	0.073	0.108	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2015	1	1	0	-0.299	0.099	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2015	2	2	2	0.318	0.301	0	-1	Extremely wet	Extremely wet	Near normal	Near normal	Near normal	Moderately dry
2015	3	0	2	-0.08	-0.625	0	-1	Near normal	Extremely wet	Near normal	Near normal	Near normal	Moderately dry
2015	4	2	2	1.745	0.536	1	0	Extremely wet	Extremely wet	Very wet	Near normal	Moderately wet	Near normal
2015	5	0	1	1.307	0.805	1	0	Near normal	Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal
2015	6	0	1	0.895	0.491	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2015	7	-1	0	0.246	0.182	-0.065	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
2015	8	0	0	0.083	0.233	0.144	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2015	9	0	-1	-0.102	0.075	-0.161	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2015	10	-1	-1	-0.75	-0.182	-0.231	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
2015	11	0	-1	-0.951	-0.362	-0.225	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2015	12	0	-1	-1.187	-0.387	-0.208	0	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
2016	1	1	0	-0.744	-0.905	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2016	2	-1	0	-1.172	-1.049	-1	0	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
2016	3	-1	-1	-1.7	-1.379	-1	0	Moderately dry	Moderately dry	Severely dry	Moderately dry	Moderately dry	Near normal
2016	4	-1	-1	-1.177	-1.104	-1	0	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2016	5	1	0	-0.065	-0.878	-1	0	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Near normal
2016	6	-2	-1	-1.109	-1.556	-2	-1	Extremely dry	Moderately dry	Moderately dry	Severely dry	Extremely dry	Moderately dry

2016	7	0	-1	-1.009	-1.077	-1.466	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2016	8	-1	-2	-1.421	-1.477	-1.914	-1	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Severely dry	Moderately dry
2016	9	-1	-1	-1.609	-1.639	-1.889	-2	Moderately dry	Moderately dry	Severely dry	Severely dry	Severely dry	Extremely dry
2016	10	0	-2	-1.525	-1.663	-1.715	-2	Near normal	Extremely dry	Severely dry	Severely dry	Severely dry	Extremely dry
2016	11	0	-1	-1.799	-1.642	-1.684	-2	Near normal	Moderately dry	Severely dry	Severely dry	Severely dry	Extremely dry
2016	12	0	0	-1.363	-1.621	-1.651	-2	Near normal	Near normal	Moderately dry	Severely dry	Severely dry	Extremely dry
2017	1	0	-1	-1.816	-1.79	-2	-2	Near normal	Moderately dry	Severely dry	Severely dry	Extremely dry	Extremely dry
2017	2	-1	-1	-1.266	-2.161	-2	-2	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2017	3	2	2	0.278	-1.2	-2	-2	Extremely wet	Extremely wet	Near normal	Moderately dry	Extremely dry	Extremely dry
2017	4	1	2	1.432	-0.777	-1	-2	Moderately wet	Extremely wet	Moderately wet	Near normal	Moderately dry	Extremely dry
2017	5	2	2	1.875	0.698	-1	-1	Extremely wet	Extremely wet	Very wet	Near normal	Moderately dry	Moderately dry
2017	6	0	1	1.078	0.806	0	-2	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Extremely dry
2017	7	1	1	1.273	1.194	0.224	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
2017	8	0	0	1.152	1.061	0.542	-1	Near normal	Near normal	Moderately wet	Moderately wet	Near normal	Moderately dry
2017	9	0	0	0.845	0.962	0.791	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2017	10	1	0	0.861	1.161	1.1	0	Moderately wet	Near normal	Near normal	Moderately wet	Moderately wet	Near normal
2017	11	0	1	0.395	1.166	1.092	0	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
2017	12	1	1	0.741	1.022	1.125	0	Moderately wet	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
2018	1	0	0	0.34	0.831	1	0	Near normal	Near normal	Near normal	Near normal	Moderately wet	Near normal
2018	2	1	1	0.702	0.44	1	0	Moderately wet	Moderately wet	Near normal	Near normal	Moderately wet	Near normal
2018	3	1	1	1.166	0.805	1	0	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal
2018	4	1	1	0.999	0.668	1	0	Moderately wet	Moderately wet	Near normal	Near normal	Moderately wet	Near normal
2018	5	2	1	1.549	1.357	1	0	Extremely wet	Moderately wet	Very wet	Moderately wet	Moderately wet	Near normal
2018	6	0	1	0.826	1.039	1	1	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet
2018	7	0	1	0.803	0.765	0.829	1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately wet
2018	8	-1	0	0.395	0.439	0.61	1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately wet
2018	9	-1	-1	0.07	0.13	0.356	1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately wet

2018	10	0	-1	-0.264	-0.021	-0.053	1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately wet
2018	11	0	-1	-0.898	-0.102	-0.057	1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately wet
2018	12	1	0	-0.826	-0.096	-0.034	1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately wet
2019	1	0	0	-1.455	-0.374	0	1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately wet
2019	2	1	1	-0.985	-0.892	0	1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately wet
2019	3	0	0	-0.558	-0.886	0	1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately wet
2019	4	0	0	-0.014	-1.42	0	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2019	5	0	0	-0.26	-1.051	-1	0	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Near normal
2019	6	0	0	-0.013	-0.29	-1	0	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
2019	7	1	0	0.287	0.243	-0.651	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2019	8	-1	0	-0.233	-0.197	-0.721	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
2019	9	-1	-1	-0.478	-0.466	-0.617	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
2019	10	1	0	-0.004	-0.026	-0.058	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2019	11	0	0	0.059	-0.079	-0.049	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2019	12	0	1	-0.065	-0.078	-0.077	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	1	1	0	-0.477	-0.099	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2020	2	0	0	0.257	0.007	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2020	3	1	0	1.267	-0.074	0	0	Moderately wet	Near normal	Moderately wet	Near normal	Near normal	Near normal
2020	4	1	1	0.507	-0.289	0	0	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	5	2	2	1.804	1.37	1	0	Extremely wet	Extremely wet	Very wet	Moderately wet	Moderately wet	Near normal
2020	6	1	2	1.63	1.827	1	0	Moderately wet	Extremely wet	Very wet	Very wet	Moderately wet	Near normal
2020	7	1	2	1.639	1.61	1.198	0	Moderately wet	Extremely wet	Very wet	Very wet	Moderately wet	Near normal
2020	8	-1	0	1.292	1.245	1.22	0	Moderately dry	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
2020	9	0	0	1.091	1.079	1.283	1	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet
2020	10	0	-1	1.044	1.068	1.042	1	Near normal	Moderately dry	Moderately wet	Moderately wet	Moderately wet	Moderately wet
2020	11	0	0	0.35	1.062	1.024	1	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet
2020	12	0	0	-0.015	1.035	1.025	1	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet
2021	1	0	-1	-0.657	0.982	1	1	Near normal	Moderately dry	Near normal	Near normal	Moderately wet	Moderately wet

2021	2	-1	-1	-0.151	0.255	1	1	Moderately dry	Moderately dry	Near normal	Near normal	Moderately wet	Moderately wet
2021	3	0	-1	-0.143	-0.166	1	1	Near normal	Moderately dry	Near normal	Near normal	Moderately wet	Moderately wet
2021	4	-1	-1	-1.605	-1.016	1	1	Moderately dry	Moderately dry	Severely dry	Moderately dry	Moderately wet	Moderately wet
2021	5	1	0	-0.007	-0.078	0	1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately wet
2021	6	-2	-1	-1.591	-1.332	-1	0	Extremely dry	Moderately dry	Severely dry	Moderately dry	Moderately dry	Near normal
2021	7	-2	-3	-3.124	-3.305	-2.978	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	8	-2	-2	-4.291	-4.441	-3.529	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	9	-2	-2	-5.062	-5.079	-4.355	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	10	-2	-2	-5.537	-5.464	-5.627	-2	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2021	11	0	-2	-2.141	-5.412	-5.532	-2	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2021	12	0	-2	-2.141	-5.442	-5.455	-2	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry

Dinajpur_SPI_Classification (1960-2021)

Year	Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24	SPI_1_Class	SPI_3_Class	SPI_6_Class	SPI_9_Class	SPI_12_Class	SPI_24_Class
1960	1	0						Near normal					
1960	2	0						Near normal					
1960	3	1	0					Moderately wet	Near normal				
1960	4	-1	-1					Moderately dry	Moderately dry				
1960	5	0	0					Near normal	Near normal				
1960	6	-1	-1	-1				Moderately dry	Moderately dry	Moderately dry			
1960	7	1	0	0				Moderately wet	Near normal	Near normal			
1960	8	-1	0	-1				Moderately dry	Near normal	Moderately dry			
1960	9	0	0	0	0			Near normal	Near normal	Near normal	Near normal		
1960	10	-1	-1	0	-1			Moderately dry	Moderately dry	Near normal	Moderately dry		
1960	11	0	0	-1	-1			Near normal	Near normal	Moderately dry	Moderately dry		
1960	12	0	-1	0	-1	-1		Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	

1961	1	0	-1	-1	-1	-1		Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	
1961	2	0	-1	0	-1	-1		Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	
1961	3	-1	-1	-1	0	-1		Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry	
1961	4	-1	-2	-3	-1	-1		Moderately dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry	
1961	5	-2	-2	-2	-1	-1		Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry	
1961	6	1	-1	-1	-1	-1		Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry	
1961	7	-2	-1	-2	-2	-2		Extremely dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	
1961	8	-1	-1	-2	-2	-2		Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	
1961	9	-1	-2	-2	-2	-2		Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	
1961	10	0	-1	-2	-2	-2		Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry	
1961	11	0	-1	-1	-2	-2		Near normal	Moderately dry	Moderately dry	Extremely dry	Extremely dry	
1961	12	1	0	-2	-2	-2	-2	Moderately wet	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1962	1	0	0	-2	-2	-2	-2	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1962	2	0	0	-1	-2	-2	-2	Near normal	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry
1962	3	0	0	0	-2	-2	-2	Near normal	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry
1962	4	-1	-1	-1	-2	-2	-2	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry
1962	5	-2	-2	-2	-2	-2	-2	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1962	6	-1	-2	-2	-2	-3	-2	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1962	7	-2	-2	-2	-2	-3	-3	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1962	8	1	-1	-1	-1	-1	-2	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1962	9	0	0	-1	-1	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1962	10	0	1	-1	-1	-1	-2	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1962	11	0	0	-1	-1	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1962	12	0	-1	0	-1	-1	-2	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
1963	1	0	-1	1	-1	-1	-2	Near normal	Moderately dry	Moderately wet	Moderately dry	Moderately dry	Extremely dry
1963	2	0	-1	0	-1	-1	-2	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Extremely dry
1963	3	2	1	0	0	-1	-2	Extremely wet	Moderately wet	Near normal	Near normal	Moderately dry	Extremely dry

1963	4	0	1	1	1	-1	-2	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Extremely dry
1963	5	-1	0	0	0	-1	-2	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
1963	6	-1	-1	-1	-1	-1	-2	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1963	7	0	-1	-1	-1	0	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Extremely dry
1963	8	0	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1963	9	0	0	-1	0	-1	-1	Near normal	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry
1963	10	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	11	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	12	0	1	0	0	0	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1964	1	0	0	0	-1	0	-1	Near normal	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
1964	2	0	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1964	3	0	-1	0	0	-1	-1	Near normal	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry
1964	4	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	5	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	6	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1964	7	1	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1964	8	-1	0	0	0	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
1964	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1964	10	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1964	11	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1964	12	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1965	1	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	2	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	3	2	1	1	0	0	0	Extremely wet	Moderately wet	Moderately wet	Near normal	Near normal	Near normal
1965	4	-1	0	-1	0	0	0	Moderately dry	Near normal	Moderately dry	Near normal	Near normal	Near normal
1965	5	-1	-1	-1	0	0	0	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
1965	6	3	2	2	2	1	1	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet	Moderately wet

1965	7	0	2	2	2	1	1	Near normal	Extremely wet	Extremely wet	Extremely wet	Moderately wet	Moderately wet
1965	8	2	3	2	2	2	2	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
1965	9	0	1	2	2	2	2	Near normal	Moderately wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
1965	10	-1	1	2	2	2	1	Moderately dry	Moderately wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet
1965	11	1	0	2	2	2	1	Moderately wet	Near normal	Extremely wet	Extremely wet	Extremely wet	Moderately wet
1965	12	0	-1	1	2	2	1	Near normal	Moderately dry	Moderately wet	Extremely wet	Extremely wet	Moderately wet
1966	1	1	1	1	2	2	1	Moderately wet	Moderately wet	Moderately wet	Extremely wet	Extremely wet	Moderately wet
1966	2	0	0	0	2	2	1	Near normal	Near normal	Near normal	Extremely wet	Extremely wet	Moderately wet
1966	3	0	0	-1	1	2	1	Near normal	Near normal	Moderately dry	Moderately wet	Extremely wet	Moderately wet
1966	4	-1	-1	-1	1	2	1	Moderately dry	Moderately dry	Moderately dry	Moderately wet	Extremely wet	Moderately wet
1966	5	0	-1	-1	-1	2	1	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely wet	Moderately wet
1966	6	-2	-2	-2	-2	0	1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Near normal	Moderately wet
1966	7	1	0	-1	-1	0	1	Moderately wet	Near normal	Moderately dry	Moderately dry	Near normal	Moderately wet
1966	8	0	-1	-1	-1	-1	1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1966	9	0	0	-1	-1	-1	1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1966	10	-1	-1	-1	-1	-1	1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1966	11	1	-1	-1	-1	-1	1	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1966	12	1	0	0	-1	-1	1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately wet
1967	1	0	1	-1	-1	-1	1	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1967	2	0	0	-1	-1	-1	1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately wet
1967	3	2	2	1	0	-1	1	Extremely wet	Extremely wet	Moderately wet	Near normal	Moderately dry	Moderately wet
1967	4	0	1	2	0	0	1	Near normal	Moderately wet	Extremely wet	Near normal	Near normal	Moderately wet
1967	5	-1	0	0	0	-1	1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately wet
1967	6	-1	-1	0	-1	0	0	Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal	Near normal
1967	7	0	-1	-1	0	-1	0	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal
1967	8	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1967	9	1	-1	-1	-1	-1	-1	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry

1967	10	0	0	-1	-1	0	-1	Near normal	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
1967	11	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1967	12	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1968	1	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
1968	2	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
1968	3	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
1968	4	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1968	5	0	-1	-1	0	-1	-1	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry
1968	6	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1968	7	1	1	1	1	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
1968	8	-1	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	9	-2	-1	0	0	0	-1	Extremely dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1968	10	1	-1	0	0	0	-1	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1968	11	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	12	0	1	0	0	0	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1969	1	0	0	-1	0	0	-1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
1969	2	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
1969	3	1	1	1	0	0	-1	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
1969	4	1	1	1	-1	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Near normal	Moderately dry
1969	5	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	6	0	0	0	1	0	0	Near normal	Near normal	Near normal	Moderately wet	Near normal	Near normal
1969	7	1	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1969	8	0	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1969	9	0	1	0	1	1	0	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
1969	10	-1	0	0	0	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
1969	11	2	0	0	0	0	0	Extremely wet	Near normal	Near normal	Near normal	Near normal	Near normal
1969	12	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal

1970	1	2	2	0	0	0	0	Extremely wet	Extremely wet	Near normal	Near normal	Near normal	Near normal
1970	2	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1970	3	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	4	0	0	1	0	0	0	Near normal	Near normal	Moderately wet	Near normal	Near normal	Near normal
1970	5	-1	-1	-1	-1	0	0	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
1970	6	0	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
1970	7	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1970	8	-1	0	-1	-1	-1	0	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
1970	9	-1	0	-1	-1	-1	0	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
1970	10	0	-2	-1	-1	-1	-1	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1970	11	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1970	12	0	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
2010	2	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2010	3	-1	-1	1	0	0	0	Moderately dry	Moderately dry	Moderately wet	Near normal	Near normal	Near normal
2010	4	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	5	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	6	1	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2010	7	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	8	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	9	-2	-1	0	0	0	0	Extremely dry	Moderately dry	Near normal	Near normal	Near normal	Near normal

2010	10	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2010	11	0	-2	0	0	0	0	Near normal	Extremely dry	Near normal	Near normal	Near normal	Near normal
2010	12	0	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2011	1	0	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2011	2	1	0	-2	0	0	0	Moderately wet	Near normal	Extremely dry	Near normal	Near normal	Near normal
2011	3	1	1	0	-1	0	0	Moderately wet	Moderately wet	Near normal	Moderately dry	Near normal	Near normal
2011	4	0	1	0	-1	0	0	Near normal	Moderately wet	Near normal	Moderately dry	Near normal	Near normal
2011	5	1	0	0	-1	0	0	Moderately wet	Near normal	Near normal	Moderately dry	Near normal	Near normal
2011	6	0	0	0	0	-1	0	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
2011	7	-1	0	0	0	-1	0	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Near normal
2011	8	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2011	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2011	10	-2	0	0	0	0	-1	Extremely dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2011	11	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2011	12	0	-2	-1	0	0	-1	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Moderately dry
2012	1	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	2	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	3	0	-1	-2	-1	-1	-1	Near normal	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2012	4	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2012	5	-1	-1	-1	-2	-1	-1	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
2012	6	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2012	7	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2012	8	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	9	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	10	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	11	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2012	12	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry

2013	1	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	2	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	3	-1	-1	0	-1	-1	-1	Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	4	1	0	0	-1	-1	-1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	5	-1	0	0	0	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2013	6	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2013	7	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	8	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2013	9	-1	-1	0	0	-1	-1	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry
2013	10	1	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2013	11	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2013	12	0	1	0	0	0	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2014	1	0	-1	1	0	0	-1	Near normal	Moderately dry	Moderately wet	Near normal	Near normal	Moderately dry
2014	2	1	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2014	3	0	0	1	0	0	-1	Near normal	Near normal	Moderately wet	Near normal	Near normal	Moderately dry
2014	4	-1	-1	-1	0	0	-1	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2014	5	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2014	6	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2014	7	-1	-1	-1	-1	0	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2014	8	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	9	1	-1	-1	-1	0	-1	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2014	10	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	11	0	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	12	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	1	1	0	-1	-1	-1	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	2	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2015	3	1	1	-1	-1	-1	-1	Moderately wet	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry

2015	4	1	1	1	0	-1	-1	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry
2015	5	1	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2015	6	0	1	1	0	0	-1	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2015	7	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2015	8	1	0	1	1	1	0	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
2015	9	0	0	1	1	0	0	Near normal	Near normal	Moderately wet	Moderately wet	Near normal	Near normal
2015	10	-2	0	0	0	0	-1	Extremely dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2015	11	0	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2015	12	0	-2	0	0	0	-1	Near normal	Extremely dry	Near normal	Near normal	Near normal	Moderately dry
2016	1	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2016	2	0	0	-1	0	0	-1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
2016	3	1	0	-1	0	0	-1	Moderately wet	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
2016	4	-1	-1	-1	0	0	-1	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2016	5	0	0	0	-1	0	-1	Near normal	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
2016	6	-2	-1	-1	-2	-1	-1	Extremely dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
2016	7	0	-1	-1	-1	0	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2016	8	-1	-1	-1	-1	-2	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry
2016	9	1	0	-1	-1	-1	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2016	10	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2016	11	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2016	12	1	1	0	0	0	0	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2017	1	0	0	0	0	-1	0	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
2017	2	0	0	1	0	-1	0	Near normal	Near normal	Moderately wet	Near normal	Moderately dry	Near normal
2017	3	2	2	1	0	0	0	Extremely wet	Extremely wet	Moderately wet	Near normal	Near normal	Near normal
2017	4	2	2	2	1	0	0	Extremely wet	Extremely wet	Extremely wet	Moderately wet	Near normal	Near normal
2017	5	0	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2017	6	-1	0	0	0	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal

2017	7	-1	-2	-1	-1	-1	-1	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2017	8	2	0	0	0	1	-1	Extremely wet	Near normal	Near normal	Near normal	Moderately wet	Moderately dry
2017	9	-1	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2017	10	0	1	-1	0	0	-1	Near normal	Moderately wet	Moderately dry	Near normal	Near normal	Moderately dry
2017	11	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2017	12	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2018	1	0	-1	0	-1	0	-1	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
2018	2	0	-1	-1	-1	0	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2018	3	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2018	4	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2018	5	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2018	6	-2	-1	-1	-1	-1	-1	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2018	7	-2	-2	-2	-2	-1	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry
2018	8	-1	-2	-2	-2	-2	-1	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2018	9	-1	-2	-2	-2	-2	-2	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2018	10	-1	-2	-3	-2	-2	-2	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2018	11	0	-1	-2	-2	-2	-2	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2018	12	1	-1	-2	-2	-2	-2	Moderately wet	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2019	1	0	0	-2	-3	-3	-2	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2019	2	1	1	-1	-3	-3	-2	Moderately wet	Moderately wet	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2019	3	-1	0	-1	-2	-3	-2	Moderately dry	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2019	4	1	1	1	-1	-2	-2	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Extremely dry	Extremely dry
2019	5	0	0	0	-1	-2	-2	Near normal	Near normal	Near normal	Moderately dry	Extremely dry	Extremely dry
2019	6	0	0	0	0	-2	-2	Near normal	Near normal	Near normal	Near normal	Extremely dry	Extremely dry
2019	7	1	1	1	1	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
2019	8	0	1	1	1	0	-2	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Extremely dry
2019	9	1	1	1	1	1	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Extremely dry

2019	10	0	1	1	1	1	-1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately dry
2019	11	0	1	1	1	1	-1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately dry
2019	12	0	0	1	1	1	-1	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately dry
2020	1	0	-1	1	1	1	-1	Near normal	Moderately dry	Moderately wet	Moderately wet	Moderately wet	Moderately dry
2020	2	0	0	1	1	1	-1	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately dry
2020	3	1	0	0	1	1	-1	Moderately wet	Near normal	Near normal	Moderately wet	Moderately wet	Moderately dry
2020	4	1	1	0	1	1	-1	Moderately wet	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately dry
2020	5	2	2	2	2	1	0	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet	Near normal
2020	6	1	2	2	1	2	0	Moderately wet	Extremely wet	Extremely wet	Moderately wet	Extremely wet	Near normal
2020	7	1	2	2	2	2	1	Moderately wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2020	8	0	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
2020	9	2	2	2	2	2	2	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
2020	10	0	1	2	2	2	2	Near normal	Moderately wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
2020	11	0	2	2	2	2	2	Near normal	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
2020	12	0	0	2	2	2	2	Near normal	Near normal	Extremely wet	Extremely wet	Extremely wet	Extremely wet
2021	1	0	-1	1	2	2	2	Near normal	Moderately dry	Moderately wet	Extremely wet	Extremely wet	Extremely wet
2021	2	0	-1	2	1	2	2	Near normal	Moderately dry	Extremely wet	Moderately wet	Extremely wet	Extremely wet
2021	3	-1	-1	-1	1	2	2	Moderately dry	Moderately dry	Moderately dry	Moderately wet	Extremely wet	Extremely wet
2021	4	-1	-1	-2	1	2	2	Moderately dry	Moderately dry	Extremely dry	Moderately wet	Extremely wet	Extremely wet
2021	5	1	0	0	2	1	2	Moderately wet	Near normal	Near normal	Extremely wet	Moderately wet	Extremely wet
2021	6	-2	-2	-2	-2	1	1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately wet	Moderately wet
2021	7	-2	-4	-4	-4	-1	1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately wet
2021	8	-2	-2	-4	-4	-2	0	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Near normal
2021	9	-2	-2	-5	-5	-5	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	10	-2	-2	-5	-5	-5	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	11	0	-2	-2	-5	-5	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	12	0	-2	-2	-5	-5	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry

Ishwardi _SPI_Classification (1960-2021)

Year	Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24	SPI_1_Class	SPI_3_Class	SPI_6_Class	SPI_9_Class	SPI_12_Class	SPI_24_Class
1960	1	-0.1624						Near normal					
1960	2	-0.5059						Near normal					
1960	3	1.5673	1					Very wet	Moderately wet				
1960	4	-1.2529	0					Moderately dry	Near normal				
1960	5	0.8811	1					Near normal	Moderately wet				
1960	6	-0.4315	0	0				Near normal	Near normal	Near normal			
1960	7	1.4464	1	1				Moderately wet	Moderately wet	Moderately wet			
1960	8	-0.1437	1	1				Near normal	Moderately wet	Moderately wet			
1960	9	0.2578	1	0	1			Near normal	Moderately wet	Near normal	Moderately wet		
1960	10	0.067	0	1	1			Near normal	Near normal	Moderately wet	Moderately wet		
1960	11	0.3671	0	0	1			Near normal	Near normal	Near normal	Moderately wet		
1960	12	0.0809	0	1	0	0		Near normal	Near normal	Moderately wet	Near normal	Near normal	
1961	1	1.1674	0	-2.3851	1	0.5683		Moderately wet	Near normal	Extremely dry	Moderately wet	Near normal	
1961	2	1.3241	1	0.3258	1	0.6893		Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal	
1961	3	-0.8649	1	6.5794	1	0.462		Near normal	Moderately wet	Extremely wet	Moderately wet	Near normal	
1961	4	-0.8097	-1	-0.4984	0	0.4906		Near normal	Moderately dry	Near normal	Near normal	Near normal	
1961	5	0.0334	-1	-0.3166	0	0.2542		Near normal	Moderately dry	Near normal	Near normal	Near normal	
1961	6	0.4006	0	2.1117	0	0.5602		Near normal	Near normal	Extremely wet	Near normal	Near normal	
1961	7	-1.2651	-1	-0.7016	-1	-0.7001		Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal	
1961	8	0.9777	0	-0.3485	0	-0.209		Near normal	Near normal	Near normal	Near normal	Near normal	
1961	9	-1.082	-1	-0.6046	-1	-0.576		Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal	
1961	10	0.4106	0	-0.3594	0	-0.4848		Near normal	Near normal	Near normal	Near normal	Near normal	
1961	11	0.4224	-1	-0.3464	-1	-0.482		Near normal	Moderately dry	Near normal	Moderately dry	Near normal	
1961	12	0.0809	0	-0.5758	-1	-0.4818	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
1962	1	1.0729	0	0.1461	0	-0.4745	5.2493	Moderately wet	Near normal	Near normal	Near normal	Near normal	Extremely wet

1962	2	-0.5059	0	-0.7514	0	-0.6221	5.3528	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely wet
1962	3	-0.8649	-1	-4.113	-1	-0.6162	-0.1172	Near normal	Moderately dry	Extremely dry	Moderately dry	Near normal	Near normal
1962	4	0.4812	0	-0.1599	0	-0.4017	4.0538	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely wet
1962	5	0.7454	0	0.378	0	-0.1821	1.0282	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately wet
1962	6	-0.0398	0	0.1777	0	-0.4016	9.3702	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely wet
1962	7	-0.4219	0	-0.1757	0	-0.1374	-0.5355	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1962	8	-1.597	-1	-0.6665	-1	-0.9873	-0.8158	Severely dry	Moderately dry	Near normal	Moderately dry	Near normal	Near normal
1962	9	-0.5824	-1	-0.7443	-1	-0.7352	-0.9971	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
1962	10	-0.2554	-2	-0.9165	-1	-0.9395	-1.0159	Near normal	Extremely dry	Near normal	Moderately dry	Near normal	Moderately dry
1962	11	-0.3723	-1	-1.2545	-1	-0.9764	-1.0426	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
1962	12	0.4943	0	-1.3981	-1	-0.9559	-1.0281	Near normal	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
1963	1	-0.0192	-1	-1.7307	-1	-1.0373	-1.0837	Near normal	Moderately dry	Severely dry	Moderately dry	Moderately dry	Moderately dry
1963	2	-0.3349	-1	-1.1633	-1	-1.0491	-1.1848	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1963	3	-0.237	-1	-0.9955	-2	-0.9959	-1.1503	Near normal	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
1963	4	1.0249	1	0.2399	-1	-0.8322	-0.8908	Moderately wet	Moderately wet	Near normal	Moderately dry	Near normal	Near normal
1963	5	0.2618	1	0.3459	0	-1.0084	-0.8785	Near normal	Moderately wet	Near normal	Near normal	Moderately dry	Near normal
1963	6	0.8525	1	0.7485	0	-0.6034	-0.7029	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1963	7	-0.6017	0	0.2973	0	-0.7588	-0.5698	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1963	8	-0.0326	0	0.2526	0	-0.2689	-0.8579	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1963	9	-0.2887	-1	0.1243	0	-0.1458	-0.6774	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1963	10	-0.0707	0	-0.147	0	-0.1166	-0.7479	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1963	11	0.5877	0	-0.1724	0	-7.0988	-0.7378	Near normal	Near normal	Near normal	Near normal	Extremely dry	Near normal
1963	12	0.0809	0	-0.6521	0	-8.7798	-0.7314	Near normal	Near normal	Near normal	Near normal	Extremely dry	Near normal
1964	1	-0.0192	0	-0.4331	0	-4.278	-0.7644	Near normal	Near normal	Near normal	Near normal	Extremely dry	Near normal
1964	2	0.1019	-1	-0.5494	0	-2.6115	-0.7499	Near normal	Moderately dry	Near normal	Near normal	Extremely dry	Near normal
1964	3	-0.8649	-1	-0.603	-1	-6.1075	-0.7468	Near normal	Moderately dry	Near normal	Moderately dry	Extremely dry	Near normal
1964	4	0.2066	0	-0.4592	-1	-0.258	-0.7873	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal

1964	5	0.634	0	9.7769	0	-0.1419	-0.8481	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
1964	6	2.0711	2	1.5699	1	0.5748	-1.925	Extremely wet	Extremely wet	Very wet	Moderately wet	Near normal	Severely dry
1964	7	1.173	2	1.8019	2	1.418	0.463	Moderately wet	Extremely wet	Very wet	Extremely wet	Moderately wet	Near normal
1964	8	-1.05	2	1.4189	1	1.0816	0.5485	Moderately dry	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1964	9	-1.8687	0	0.9027	1	0.674	0.3462	Severely dry	Near normal	Near normal	Moderately wet	Near normal	Near normal
1964	10	2.1588	0	1.5952	1	1.4184	0.9219	Extremely wet	Near normal	Very wet	Moderately wet	Moderately wet	Near normal
1964	11	-0.1471	1	1.4741	1	1.3324	0.9054	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1964	12	0.0809	2	0.5708	1	1.2688	0.8773	Near normal	Extremely wet	Near normal	Moderately wet	Moderately wet	Near normal
1965	1	-0.1624	-1	3.0633	2	1.4177	0.9679	Near normal	Moderately dry	Extremely wet	Extremely wet	Moderately wet	Near normal
1965	2	0.4645	0	0.7218	2	1.4553	1.001	Near normal	Near normal	Near normal	Extremely wet	Moderately wet	Moderately wet
1965	3	0.7021	0	2.1765	1	1.5574	1.0554	Near normal	Near normal	Extremely wet	Moderately wet	Very wet	Moderately wet
1965	4	0.0347	0	-0.1727	0	1.5236	0.914	Near normal	Near normal	Near normal	Near normal	Very wet	Near normal
1965	5	-1.2702	-1	-0.8154	0	1.1827	0.7281	Moderately dry	Moderately dry	Near normal	Near normal	Moderately wet	Near normal
1965	6	-0.2165	-1	-0.7322	1	9.4126	0.4163	Near normal	Moderately dry	Near normal	Moderately wet	Extremely wet	Near normal
1965	7	0.9142	0	-3.0236	0	-6.1718	0.8362	Near normal	Near normal	Extremely dry	Near normal	Extremely dry	Near normal
1965	8	0.3537	0	7.2664	0	0.3518	0.9318	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
1965	9	0.8828	1	0.315	0	1.0101	1.163	Near normal	Moderately wet	Near normal	Near normal	Moderately wet	Moderately wet
1965	10	-1.0716	0	9.1818	0	1.4151	1.002	Moderately dry	Near normal	Extremely wet	Near normal	Moderately wet	Moderately wet
1965	11	-0.3723	0	0.3406	0	-1.9167	0.9485	Near normal	Near normal	Near normal	Near normal	Severely dry	Near normal
1965	12	0.6793	-1	0.508	0	-8.391	0.9276	Near normal	Moderately dry	Near normal	Near normal	Extremely dry	Near normal
1966	1	-0.1624	-1	0.1708	0	4.2827	1.021	Near normal	Moderately dry	Near normal	Near normal	Extremely wet	Moderately wet
1966	2	-0.5059	-1	-8.9181	0	-6.4438	1.013	Near normal	Moderately dry	Extremely dry	Near normal	Extremely dry	Moderately wet
1966	3	-0.8649	-2	-2.3366	0	-0.1292	1.0142	Near normal	Extremely dry	Extremely dry	Near normal	Near normal	Moderately wet
1966	4	0.8306	0	-0.1472	0	4.194	1.0959	Near normal	Near normal	Near normal	Near normal	Extremely wet	Moderately wet
1966	5	-4.264	-1	-1.4894	-1	-0.139	0.7299	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
1966	6	-0.3972	-1	-1.2834	-2	-0.2272	-0.1207	Near normal	Moderately dry	Moderately dry	Extremely dry	Near normal	Near normal
1966	7	-0.3745	-1	-1.2064	-1	-0.9638	-0.6394	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal

1966	8	-0.1174	-1	-1.1252	-1	-1.0866	-0.4727	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1966	9	-1.211	-1	-1.346	-2	-1.7751	-0.3741	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Severely dry	Near normal
1966	10	-0.0591	-1	-1.5727	-1	-1.5486	-1.025	Near normal	Moderately dry	Severely dry	Moderately dry	Severely dry	Moderately dry
1966	11	0.5212	-1	-1.0067	-1	-1.4671	-0.9912	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1966	12	0.5771	0	-0.9094	-1	-1.4389	-0.9757	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Near normal
1967	1	1.4246	1	-0.817	-2	-1.399	-0.9239	Moderately wet	Moderately wet	Near normal	Extremely dry	Moderately dry	Near normal
1967	2	-0.3349	0	-1.0868	-1	-1.4159	-0.9616	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
1967	3	1.1297	1	0.31	-1	-1.1823	-0.9154	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry	Near normal
1967	4	0.094	0	0.4592	-1	-1.3735	-0.9057	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Near normal
1967	5	-0.1815	0	9.0792	-1	-0.9132	-0.7832	Near normal	Near normal	Extremely wet	Moderately dry	Near normal	Near normal
1967	6	-0.5703	-1	-0.3568	0	-1.0366	-0.8589	Near normal	Moderately dry	Near normal	Near normal	Moderately dry	Near normal
1967	7	0.1229	0	-0.3496	0	-0.9058	-1.1709	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1967	8	0.0592	0	-0.3044	0	-0.7809	-1.2754	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1967	9	-0.3672	0	-0.5621	0	-0.4614	-1.6086	Near normal	Near normal	Near normal	Near normal	Near normal	Severely dry
1967	10	-0.5232	-1	-0.7071	-1	-0.5763	-1.4766	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
1967	11	-0.3723	-1	-0.6916	-1	-0.63	-1.4744	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
1967	12	0.4943	-1	-0.4861	-1	-0.6274	-1.4598	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
1968	1	-0.0192	-1	-0.7363	-1	-0.7087	-1.4927	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Moderately dry
1968	2	-0.3349	-1	-1.1387	-1	-0.722	-1.4974	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Severely dry
1968	3	0.012	-1	-1.1936	-1	-0.8569	-1.4461	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
1968	4	-0.1209	0	-0.8814	-1	-0.8931	-1.6037	Near normal	Near normal	Near normal	Moderately dry	Near normal	Severely dry
1968	5	-1.2056	-1	-1.2625	-2	-1.1275	-1.4995	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Severely dry
1968	6	1.3624	0	0.3562	0	-0.206	-0.844	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1968	7	1.2154	1	0.9185	1	0.3678	-0.326	Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal	Near normal
1968	8	0.2441	1	0.9252	1	0.4035	-0.2517	Near normal	Moderately wet	Near normal	Moderately wet	Near normal	Near normal
1968	9	-0.9082	0	0.5567	0	0.2386	-0.1994	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1968	10	0.2632	0	0.6115	0	0.3936	-0.1382	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal

1968	11	0.6491	-1	0.905	0	0.4316	-0.1361	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1968	12	0.5771	0	0.3522	0	0.402	-0.1417	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1969	1	-0.1624	0	-0.3959	1	0.4828	-0.16	Near normal	Near normal	Near normal	Moderately wet	Near normal	Near normal
1969	2	-0.237	-1	-0.7931	1	0.4913	-0.1577	Near normal	Moderately dry	Near normal	Moderately wet	Near normal	Near normal
1969	3	0.198	0	3.0058	0	0.5092	-0.2312	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
1969	4	0.4555	0	9.0569	0	0.603	-0.1816	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
1969	5	-0.9617	0	-0.67	-1	0.6442	-0.3092	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
1969	6	0.0069	0	-0.4915	0	1.0136	-0.164	Near normal	Near normal	Near normal	Near normal	Moderately wet	Near normal
1969	7	0.1431	0	-0.3259	0	-0.623	-0.1673	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1969	8	1.3878	1	0.3092	0	-8.3405	0.1842	Moderately wet	Moderately wet	Near normal	Near normal	Extremely dry	Near normal
1969	9	0.9596	1	0.5979	1	0.524	0.4984	Near normal	Moderately wet	Near normal	Moderately wet	Near normal	Near normal
1969	10	-1.8486	1	0.2101	0	0.1844	0.3621	Severely dry	Moderately wet	Near normal	Near normal	Near normal	Near normal
1969	11	0.8963	0	0.5151	0	0.2041	0.4162	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1969	12	1.1762	-1	0.6903	0	0.2521	0.4515	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	1	2.6033	2	1.3269	1	0.5126	0.6494	Extremely wet	Extremely wet	Moderately wet	Moderately wet	Near normal	Near normal
1970	2	0.7556	2	0.8182	1	0.574	0.6955	Near normal	Extremely wet	Near normal	Moderately wet	Near normal	Near normal
1970	3	0.5285	2	0.2487	1	0.6069	0.7278	Near normal	Extremely wet	Near normal	Moderately wet	Near normal	Near normal
1970	4	-1.8147	-1	0.6965	1	0.368	0.6308	Severely dry	Moderately dry	Near normal	Moderately wet	Near normal	Near normal
1970	5	-0.4968	-1	-5.6951	0	0.4543	0.7239	Near normal	Moderately dry	Extremely dry	Near normal	Near normal	Near normal
1970	6	-0.1537	-1	-0.3585	-1	0.3999	0.2421	Near normal	Moderately dry	Near normal	Moderately dry	Near normal	Near normal
1970	7	-0.2893	-1	-0.7752	0	0.2504	-0.2432	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	8	1.1691	0	-0.2383	0	0.1341	3.578	Moderately wet	Near normal	Near normal	Near normal	Near normal	Extremely wet
1970	9	0.731	1	7.5503	0	3.6769	0.3575	Near normal	Moderately wet	Extremely wet	Near normal	Extremely wet	Near normal
1970	10	1.863	2	0.8522	1	0.9362	0.7505	Very wet	Extremely wet	Near normal	Moderately wet	Near normal	Near normal
1970	11	-0.3723	2	0.9703	1	0.8149	0.6931	Near normal	Extremely wet	Near normal	Moderately wet	Near normal	Near normal
1970	12	0.0809	1	1.1502	1	0.6989	0.6675	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------

--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
2010	1	-0.1624	-1	0.3071	-0.6255	-0.6839	-1.0469	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2010	2	-0.2606	-1	5.573	-0.5813	-0.7	-1.051	Near normal	Moderately dry	Extremely wet	Near normal	Near normal	Moderately dry
2010	3	-0.8649	-1	-1.4964	1.2582	-0.9205	-1.0737	Near normal	Moderately dry	Moderately dry	Moderately wet	Near normal	Moderately dry
2010	4	-0.2739	-1	-1.5016	-6.9604	-0.8194	-1.0475	Near normal	Moderately dry	Severely dry	Extremely dry	Near normal	Moderately dry
2010	5	-0.7241	-1	-1.2739	-0.6759	-0.9328	-1.1893	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2010	6	-0.803	-1	-1.4368	-1.6791	-0.6937	-1.2671	Near normal	Moderately dry	Moderately dry	Severely dry	Near normal	Moderately dry
2010	7	-1.0689	-2	-1.7322	-1.8885	-1.2445	-1.5765	Moderately dry	Extremely dry	Severely dry	Severely dry	Moderately dry	Severely dry
2010	8	-1.0881	-2	-2.0095	-2.1107	-1.7337	-1.8088	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Severely dry	Severely dry
2010	9	-1.4481	-2	-2.2102	-2.381	-2.4752	-2.1139	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	10	0.0315	-2	-2.0718	-2.2149	-2.3233	-2.0344	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	11	0.011	-1	-1.946	-2.2045	-2.2755	-2.0203	Near normal	Moderately dry	Severely dry	Extremely dry	Extremely dry	Extremely dry
2010	12	1.46	0	-1.4817	-1.833	-1.9736	-1.843	Moderately wet	Near normal	Moderately dry	Severely dry	Severely dry	Severely dry
2011	1	0.2568	1	-1.3041	-1.9226	-2.0595	-1.8894	Near normal	Moderately wet	Moderately dry	Severely dry	Extremely dry	Severely dry
2011	2	-0.4155	1	-0.9823	-1.8494	-2.1017	-1.9086	Near normal	Moderately wet	Near normal	Severely dry	Extremely dry	Severely dry
2011	3	0.3086	0	0.2518	-1.6457	-1.9729	-2.0041	Near normal	Near normal	Near normal	Severely dry	Severely dry	Extremely dry
2011	4	0.5065	0	0.6059	-1.1776	-1.7699	-1.806	Near normal	Near normal	Near normal	Moderately dry	Severely dry	Severely dry
2011	5	-0.0214	0	0.3844	-0.6759	-1.5748	-1.8186	Near normal	Near normal	Near normal	Near normal	Severely dry	Severely dry
2011	6	-0.025	0	-0.1057	1.5125	-1.3226	-1.3666	Near normal	Near normal	Near normal	Very wet	Moderately dry	Moderately dry
2011	7	-0.1179	0	-0.1948	-4.2646	-1.0385	-1.4218	Near normal	Near normal	Near normal	Extremely dry	Moderately dry	Moderately dry
2011	8	2.6613	1	1.1112	1.211	0.6374	-0.6244	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2011	9	0.1512	1	0.9914	0.9344	0.947	-0.7958	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal

2011	10	-1.3626	1	0.6571	0.6323	0.7303	-0.8625	Moderately dry	Moderately wet	Near normal	Near normal	Near normal	Near normal
2011	11	-0.3723	-1	0.6731	0.6078	0.6946	-0.8655	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2011	12	0.0809	-2	0.7834	0.5579	0.508	-0.8566	Near normal	Extremely dry	Near normal	Near normal	Near normal	Near normal
2012	1	0.7512	0	1.3612	0.6526	0.6197	-0.8336	Near normal	Near normal	Moderately wet	Near normal	Near normal	Near normal
2012	2	-0.5059	0	-0.9124	0.706	0.6243	-0.8448	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2012	3	-0.6413	-1	-2.3047	0.8139	0.5634	-0.831	Near normal	Moderately dry	Extremely dry	Near normal	Near normal	Near normal
2012	4	-0.1764	-1	-1.0812	1.0261	0.4438	-0.8189	Near normal	Moderately dry	Moderately dry	Moderately wet	Near normal	Near normal
2012	5	-1.2506	-1	-1.4153	-1.6169	0.2202	-0.92	Moderately dry	Moderately dry	Moderately dry	Severely dry	Near normal	Near normal
2012	6	-0.6569	-1	-1.4155	-1.9751	-4.4517	-0.8725	Near normal	Moderately dry	Moderately dry	Severely dry	Extremely dry	Near normal
2012	7	-0.7041	-1	-1.5649	-1.6521	-0.2575	-0.8084	Near normal	Moderately dry	Severely dry	Severely dry	Near normal	Near normal
2012	8	-1.4876	-2	-1.9893	-2.045	-2.2439	-0.8933	Moderately dry	Extremely dry	Severely dry	Extremely dry	Extremely dry	Near normal
2012	9	-0.6032	-1	-1.9131	-2.0214	-2.3278	-0.7216	Near normal	Moderately dry	Severely dry	Extremely dry	Extremely dry	Near normal
2012	10	0.534	-1	-1.6073	-1.7414	-1.7989	-0.5909	Near normal	Moderately dry	Severely dry	Severely dry	Severely dry	Near normal
2012	11	1.4697	0	-1.032	-1.4309	-1.4705	-0.4337	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
2012	12	0.9538	1	-0.7689	-1.2952	-1.3862	-0.5251	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry	Near normal
2013	1	-0.0192	2	-0.5351	-1.3444	-1.4814	-0.5154	Near normal	Extremely wet	Near normal	Moderately dry	Moderately dry	Near normal
2013	2	0.3393	0	0.2611	-1.0583	-1.4563	-0.4917	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Near normal
2013	3	-0.8649	-1	0.8165	-0.9477	-1.4663	-0.55	Near normal	Moderately dry	Near normal	Near normal	Moderately dry	Near normal
2013	4	0.1307	0	0.4892	-0.7233	-1.3946	-0.6045	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
2013	5	0.2618	0	-8.145	4.9934	-1.015	-0.5745	Near normal	Near normal	Extremely dry	Extremely wet	Moderately dry	Near normal
2013	6	0.0553	0	-0.15	0.3299	-0.782	-0.5428	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2013	7	-1.5196	-1	-0.8767	-0.5655	-1.1982	-0.8996	Severely dry	Moderately dry	Near normal	Near normal	Moderately dry	Near normal
2013	8	-0.0889	-1	-0.8807	-0.8677	-0.6985	-1.9284	Near normal	Moderately dry	Near normal	Near normal	Near normal	Severely dry
2013	9	-1.2782	-2	-1.1425	-1.2586	-0.7876	-2.2173	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Near normal	Extremely dry
2013	10	0.2891	-1	-1.053	-1.1177	-0.8828	-1.8636	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Severely dry
2013	11	-0.3723	-1	-1.2054	-1.1654	-1.1479	-1.8581	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Severely dry
2013	12	0.0809	0	-1.4027	-1.0735	-1.1713	-1.8293	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Severely dry

2014	1	0.1753	-1	-0.9055	-1.1504	-1.2039	-1.9063	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Severely dry
2014	2	1.0038	0	-0.9647	-1.2181	-1.1601	-1.8387	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Severely dry
2014	3	0.3661	1	0.1767	-1.395	-1.0455	-1.7699	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry	Severely dry
2014	4	-0.9709	0	-0.7383	-1.0703	-1.2077	-1.8418	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Severely dry
2014	5	-0.3276	-1	-0.6045	-1.283	-1.3984	-1.7602	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Severely dry
2014	6	1.5268	1	0.7804	0.6429	-0.581	-0.9413	Very wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2014	7	-1.0023	0	0.1601	6.432	-0.4725	-1.0382	Moderately dry	Near normal	Near normal	Extremely wet	Near normal	Moderately dry
2014	8	0.1923	0	0.1058	0.1273	-0.3418	-0.724	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2014	9	-0.5928	-1	-0.1538	-0.1077	-0.1319	-0.7027	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2014	10	-0.1545	0	-7.9878	-0.1842	-0.2588	-0.8153	Near normal	Near normal	Extremely dry	Near normal	Near normal	Near normal
2014	11	-0.3723	-1	-6.9023	-0.2887	-0.2665	-0.9953	Near normal	Moderately dry	Extremely dry	Near normal	Near normal	Moderately dry
2014	12	0.0809	0	-0.9669	-0.319	-0.2738	-1.0144	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2015	1	-0.1624	-1	-0.6336	-0.1472	-0.2519	-1.0275	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2015	2	0.0488	-1	-1.0626	-3.8854	-0.3317	-1.0467	Near normal	Moderately dry	Moderately dry	Extremely dry	Near normal	Moderately dry
2015	3	0.5285	0	-0.5022	-1.0285	-0.3088	-0.9611	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2015	4	0.6866	1	0.196	-0.4197	-4.4323	-0.8696	Near normal	Moderately wet	Near normal	Near normal	Extremely dry	Near normal
2015	5	-0.1117	0	8.3801	-0.6416	8.1862	-0.9816	Near normal	Near normal	Extremely wet	Near normal	Extremely wet	Near normal
2015	6	0.5074	0	0.3431	7.7383	-0.597	-0.8191	Near normal	Near normal	Near normal	Extremely wet	Near normal	Near normal
2015	7	0.5718	0	0.5378	0.4407	4.557	-0.2865	Near normal	Near normal	Near normal	Near normal	Extremely wet	Near normal
2015	8	0.2355	1	0.5507	0.4819	5.7327	-0.2201	Near normal	Moderately wet	Near normal	Near normal	Extremely wet	Near normal
2015	9	-0.2609	0	0.3346	0.3101	0.1526	-3.5969	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely dry
2015	10	-0.2425	0	0.1172	0.1995	0.1211	-0.1293	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2015	11	0.011	-1	0.1509	0.1694	0.1132	-0.133	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2015	12	0.5771	0	-4.1778	0.1169	9.751	-0.135	Near normal	Near normal	Extremely dry	Near normal	Extremely wet	Near normal
2016	1	1.4811	0	-0.2571	0.1596	0.2373	-4.6	Moderately wet	Near normal	Near normal	Near normal	Near normal	Extremely dry
2016	2	0.2493	1	-0.5103	0.2421	0.2494	-8.6307	Near normal	Moderately wet	Near normal	Near normal	Near normal	Extremely dry
2016	3	1.9056	2	0.5597	0.3785	0.4494	6.9905	Very wet	Extremely wet	Near normal	Near normal	Near normal	Extremely wet

2016	4	-0.1577	1	0.7363	7.286	0.2913	0.1314	Near normal	Moderately wet	Near normal	Extremely wet	Near normal	Near normal
2016	5	0.2116	1	0.6069	-4.5437	0.3754	0.2202	Near normal	Moderately wet	Near normal	Extremely dry	Near normal	Near normal
2016	6	-1.0804	-1	-0.2048	-0.4428	-0.188	-0.5531	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
2016	7	-0.4943	-1	-0.5747	-0.5531	-0.7516	-0.4488	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2016	8	-1.0248	-1	-0.9367	-0.8677	-1.126	-0.7109	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry	Near normal
2016	9	0.9974	0	-0.6773	-0.3465	-0.48	-0.2773	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	10	-0.8656	0	-0.8395	-0.6273	-0.6101	-0.3608	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	11	-0.057	0	-0.9494	-0.6648	-0.6133	-0.3642	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	12	0.0809	-1	-0.5796	-0.9247	-0.6142	-0.3653	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2017	1	-0.0192	-1	-0.3996	-0.9283	-0.6994	-0.3388	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2017	2	-0.5059	-1	9.624	-1.0814	-0.7504	-0.3564	Near normal	Moderately dry	Extremely wet	Moderately dry	Near normal	Near normal
2017	3	0.0235	-1	-1.5767	-0.7043	-1.0389	-0.3878	Near normal	Moderately dry	Severely dry	Near normal	Moderately dry	Near normal
2017	4	0.7653	0	2.4363	-0.302	-0.8194	-0.3735	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
2017	5	-0.5654	0	-0.3113	-8.1021	-1.0382	-0.4678	Near normal	Near normal	Near normal	Extremely dry	Moderately dry	Near normal
2017	6	-0.8333	-1	-0.7965	-1.2205	-1.0206	-0.8212	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Near normal
2017	7	0.9251	0	-4.004	-0.1405	-0.3659	-0.7096	Near normal	Near normal	Extremely dry	Near normal	Near normal	Near normal
2017	8	0.4032	0	0.1157	2.1901	9.6308	-0.6827	Near normal	Near normal	Near normal	Extremely wet	Extremely wet	Near normal
2017	9	0.2849	1	0.179	8.76	-0.1848	-0.5296	Near normal	Moderately wet	Near normal	Extremely wet	Near normal	Near normal
2017	10	1.647	1	0.6003	0.6078	0.5418	-4.8627	Very wet	Moderately wet	Near normal	Near normal	Near normal	Extremely dry
2017	11	0.544	1	0.7799	0.6319	0.5584	-2.8936	Near normal	Moderately wet	Near normal	Near normal	Near normal	Extremely dry
2017	12	1.2562	1	1.2585	0.6926	0.6123	2.9978	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Extremely wet
2018	1	-0.1624	1	1.3414	0.7163	0.7095	1.9043	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Very wet
2018	2	0.1019	1	1.4881	0.9203	0.7407	1.4097	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately wet
2018	3	0.749	0	1.8951	1.4665	0.8081	-0.1091	Near normal	Near normal	Very wet	Moderately wet	Near normal	Near normal
2018	4	1.6806	2	1.6958	1.8312	1.0498	0.2104	Very wet	Extremely wet	Very wet	Very wet	Moderately wet	Near normal
2018	5	0.3403	1	1.2627	1.8366	1.246	0.2336	Near normal	Moderately wet	Moderately wet	Very wet	Moderately wet	Near normal
2018	6	-0.9374	0	0.25	1.0793	1.2605	0.2521	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Near normal

2018	7	0.7582	0	0.5741	0.6698	1.3142	0.6008	Near normal	Near normal	Near normal	Near normal	Moderately wet	Near normal
2018	8	-1.5834	-1	5.9353	0.1208	0.7393	0.5314	Severely dry	Moderately dry	Extremely wet	Near normal	Near normal	Near normal
2018	9	-2.0564	-1	-0.5784	-0.5602	0.15	-7.5093	Extremely dry	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
2018	10	-0.0942	-2	-1.1332	-0.5854	-0.5005	2.0262	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Extremely wet
2018	11	0.0676	-2	-1.3079	-0.6083	-0.5463	1.3439	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Moderately wet
2018	12	1.0182	0	-0.9381	-0.6191	-0.6	3.8951	Moderately wet	Near normal	Near normal	Near normal	Near normal	Extremely wet
2019	1	-0.1624	0	-2.326	-1.1612	-0.595	8.3609	Near normal	Near normal	Extremely dry	Moderately dry	Near normal	Extremely wet
2019	2	1.5131	1	-1.3737	-1.1826	-0.4721	0.1852	Very wet	Moderately wet	Moderately dry	Moderately dry	Near normal	Near normal
2019	3	-0.4973	0	-2.0598	-0.9299	-0.5853	0.1628	Near normal	Near normal	Extremely dry	Near normal	Near normal	Near normal
2019	4	0.3215	0	0.2938	-1.9297	-1.0201	9.3614	Near normal	Near normal	Near normal	Severely dry	Moderately dry	Extremely wet
2019	5	-0.3656	0	-3.0224	-1.3358	-1.2412	0.1175	Near normal	Near normal	Extremely dry	Moderately dry	Moderately dry	Near normal
2019	6	0.2093	0	-2.8175	-0.1466	-0.8383	0.3532	Near normal	Near normal	Extremely dry	Near normal	Near normal	Near normal
2019	7	-0.0389	0	-7.7345	-0.1026	-1.425	5.2884	Near normal	Near normal	Extremely dry	Near normal	Moderately dry	Extremely wet
2019	8	-0.8293	0	-0.5459	-0.3849	-1.1188	-0.2036	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
2019	9	-0.5928	-1	-0.6674	-0.631	-0.659	-0.4005	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2019	10	1.0168	0	-0.3594	-0.2827	-0.3012	-0.5909	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2019	11	0.86	0	-0.1724	-0.3421	-0.2197	-0.5626	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2019	12	0.7506	1	-0.2445	-0.289	-0.2632	-0.6237	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	1	1.2319	1	-0.1084	-0.2356	-0.1663	-0.5663	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	2	-0.5059	0	0.3444	-0.1485	-0.3258	-0.5878	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2020	3	0.0235	0	1.0615	-0.2418	-0.2824	-0.6385	Near normal	Near normal	Moderately wet	Near normal	Near normal	Near normal
2020	4	-0.6672	-1	-0.3183	-0.4821	-0.4374	-1.041	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2020	5	1.7822	1	1.0247	0.9295	0.2822	-0.6675	Very wet	Moderately wet	Moderately wet	Near normal	Near normal	Near normal
2020	6	-0.146	1	0.5734	0.93	0.14	-0.4751	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	7	0.8202	1	0.7771	0.8928	0.5724	-0.4674	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2020	8	-0.7241	0	0.5046	0.5003	0.5594	-0.3382	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2020	9	0.1752	0	0.4808	0.4497	0.7203	4.564	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely wet
2020	10	0.6014	0	0.7007	0.4838	0.5715	0.1692	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal

2020	11	-0.3723	0	9.8777	0.4634	0.4586	0.1502	Near normal	Near normal	Extremely wet	Near normal	Near normal	Near normal
2020	12	0.6342	0	0.2137	0.4464	0.4186	0.1104	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2021	1	-0.1624	-1	-0.2302	0.6739	0.4442	0.1608	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2021	2	-0.5059	-1	0.1364	5.9408	0.4487	6.1967	Near normal	Moderately dry	Near normal	Extremely wet	Near normal	Extremely wet
2021	3	-0.8319	-2	-0.1142	0.1116	0.3996	5.0822	Near normal	Extremely dry	Near normal	Near normal	Near normal	Extremely wet
2021	4	-0.3783	-1	-1.6049	-0.647	0.4282	-2.8539	Near normal	Moderately dry	Severely dry	Near normal	Near normal	Extremely dry
2021	5	0.2318	0	-0.5347	-0.1997	-0.1161	6.6716	Near normal	Near normal	Near normal	Near normal	Near normal	Extremely wet
2021	6	0.8801	1	0.259	0.3182	0.3206	0.2728	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2021	7	0.6251	1	0.5046	0.4169	0.2431	0.4668	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
2021	8	1.3326	1	0.9844	0.9032	0.9151	0.95	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2021	9	1.0902	1	1.2843	1.1445	1.1368	1.2893	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
2021	10	2.0553	2	1.9545	1.6983	1.6442	1.5206	Extremely wet	Extremely wet	Very wet	Very wet	Very wet	Very wet
2021	11	3.3716	3	2.7368	2.4407	2.3738	2.0426	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet
2021	12	2.8714	4	3.4631	3.0735	2.9607	2.5504	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet

Rajshahi_SPI_Classification (1960-2021)

Year	Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24	SPI_1_Class	SPI_3_Class	SPI_6_Class	SPI_9_Class	SPI_12_Class	SPI_24_Class
1960	1	-0.416						Near normal					
1960	2	-0.7001						Near normal					
1960	3	1.0083	0					Moderately wet	Near normal				
1960	4	-1.5593	-1					Severely dry	Moderately dry				
1960	5	1.1674	1					Moderately wet	Moderately wet				
1960	6	0.0828	0	0				Near normal	Near normal	Near normal			
1960	7	0.8046	1	1				Near normal	Moderately wet	Moderately wet			
1960	8	-0.2383	0	0				Near normal	Near normal	Near normal			
1960	9	1.4405	1	1	1			Moderately wet	Moderately wet	Moderately wet	Moderately wet		
1960	10	-0.4587	1	1	1			Near normal	Moderately wet	Moderately wet	Moderately wet		

1960	11	0.2165	1	1	1			Near normal	Moderately wet	Moderately wet	Moderately wet		
1960	12	0.2869	-1	1	1	1		Near normal	Moderately dry	Moderately wet	Moderately wet	Moderately wet	
1961	1	0.656	0	1	1	1		Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	
1961	2	1.135	1	1	1	1		Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	
1961	3	-0.388	0	-1	1	1		Near normal	Near normal	Moderately dry	Moderately wet	Moderately wet	
1961	4	0.0246	0	0	1	1		Near normal	Near normal	Near normal	Moderately wet	Moderately wet	
1961	5	1.0037	0	1	1	1		Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet	
1961	6	1.0707	1	1	1	1		Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	
1961	7	-0.7776	1	0	0	1		Near normal	Moderately wet	Near normal	Near normal	Moderately wet	
1961	8	0.6502	0	1	1	1		Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	
1961	9	-0.9527	-1	0	0	0		Near normal	Moderately dry	Near normal	Near normal	Near normal	
1961	10	1.6054	1	1	1	1		Very wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	
1961	11	0.1523	0	0	1	1		Near normal	Near normal	Near normal	Moderately wet	Moderately wet	
1961	12	0.6728	2	0	1	1	1	Near normal	Extremely wet	Near normal	Moderately wet	Moderately wet	
1962	1	0.7075	0	1	1	1	1	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1962	2	0.1062	0	0	0	1	1	Near normal	Near normal	Near normal	Near normal	Moderately wet	Moderately wet
1962	3	-0.8717	0	1	0	1	1	Near normal	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet
1962	4	0.2026	0	0	0	1	1	Near normal	Near normal	Near normal	Near normal	Moderately wet	Moderately wet
1962	5	1.6007	1	1	1	1	1	Very wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1962	6	-0.1056	1	0	1	0	1	Near normal	Moderately wet	Near normal	Moderately wet	Near normal	Moderately wet
1962	7	-0.2487	0	0	0	0	1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately wet
1962	8	-0.7766	-1	0	0	0	1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately wet
1962	9	-0.9987	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
1962	10	-0.5588	-2	-1	-1	-1	0	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1962	11	-0.3293	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1962	12	0.5207	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1963	1	-0.2491	-1	-2	-1	-1	0	Near normal	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Near normal

1963	2	-0.5989	-1	-2	-1	-1	0	Near normal	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Near normal
1963	3	-0.0169	-1	-1	-2	-1	0	Near normal	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Near normal
1963	4	0.885	0	0	-2	-1	0	Near normal	Near normal	Near normal	Extremely dry	Moderately dry	Near normal
1963	5	0.7614	1	1	-1	-1	0	Near normal	Moderately wet	Moderately wet	Moderately dry	Moderately dry	Near normal
1963	6	1.1015	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1963	7	0.3399	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1963	8	-0.1784	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1963	9	-0.3585	0	1	0	0	0	Near normal	Near normal	Moderately wet	Near normal	Near normal	Near normal
1963	10	0.7076	0	1	1	1	0	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
1963	11	0.8277	0	0	1	1	0	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Near normal
1963	12	0.5207	1	0	1	1	0	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
1964	1	-0.416	0	0	1	1	0	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Near normal
1964	2	-0.7001	-1	0	0	1	0	Near normal	Moderately dry	Near normal	Near normal	Moderately wet	Near normal
1964	3	-0.9892	-2	0	0	1	0	Near normal	Extremely dry	Near normal	Near normal	Moderately wet	Near normal
1964	4	1.3293	1	1	0	1	0	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal
1964	5	-0.2722	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1964	6	1.2519	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1964	7	0.3112	1	1	1	1	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1964	8	-0.7169	1	1	0	0	0	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Near normal
1964	9	0.0935	0	1	0	1	1	Near normal	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet
1964	10	1.6524	1	1	1	1	1	Very wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1964	11	-0.3293	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1964	12	0.2869	2	0	1	1	1	Near normal	Extremely wet	Near normal	Moderately wet	Moderately wet	Moderately wet
1965	1	-0.416	-1	0	1	1	1	Near normal	Moderately dry	Near normal	Moderately wet	Moderately wet	Moderately wet
1965	2	0.789	0	1	1	1	1	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1965	3	1.3087	1	2	1	1	1	Moderately wet	Moderately wet	Extremely wet	Moderately wet	Moderately wet	Moderately wet
1965	4	-0.5735	0	0	0	1	1	Near normal	Near normal	Near normal	Near normal	Moderately wet	Moderately wet

1965	5	-0.9521	-1	-1	0	1	1	Near normal	Moderately dry	Moderately dry	Near normal	Moderately wet	Moderately wet
1965	6	0.48	0	0	1	0	1	Near normal	Near normal	Near normal	Moderately wet	Near normal	Moderately wet
1965	7	0.7081	0	0	0	0	1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately wet
1965	8	-0.1003	0	0	0	1	1	Near normal	Near normal	Near normal	Near normal	Moderately wet	Moderately wet
1965	9	-0.5298	0	0	0	0	1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately wet
1965	10	-0.3483	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	11	0.7969	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
1965	12	0.2869	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1966	1	1.5625	1	-1	0	0	0	Very wet	Moderately wet	Moderately dry	Near normal	Near normal	Near normal
1966	2	-0.7001	1	-1	0	0	0	Near normal	Moderately wet	Moderately dry	Near normal	Near normal	Near normal
1966	3	-0.8717	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
1966	4	-0.7944	-2	-1	-1	0	0	Near normal	Extremely dry	Moderately dry	Moderately dry	Near normal	Near normal
1966	5	-0.4088	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
1966	6	0.4505	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1966	7	1.3521	1	1	1	0	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1966	8	1.132	1	1	1	1	1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1966	9	0.2701	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1966	10	-0.1312	1	1	1	1	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1966	11	0.6284	0	1	1	1	0	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
1966	12	0.5207	0	1	1	1	0	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
1967	1	0.7573	0	1	1	1	0	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
1967	2	-0.4925	0	0	1	1	0	Near normal	Near normal	Near normal	Moderately wet	Moderately wet	Near normal
1967	3	1.0766	1	0	1	1	0	Moderately wet	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
1967	4	0.8336	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1967	5	-1.1321	0	0	0	1	1	Moderately dry	Near normal	Near normal	Near normal	Moderately wet	Moderately wet
1967	6	-0.9705	-1	-1	-1	1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately wet	Near normal
1967	7	0.0032	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal

1967	8	-0.2687	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1967	9	-0.3036	0	-1	-1	-1	0	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
1967	10	-0.5934	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1967	11	-0.3293	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1967	12	0.5207	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1968	1	-0.416	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1968	2	-0.5989	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
1968	3	0.3724	0	-1	-1	-1	0	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal
1968	4	-1.1302	-1	-2	-1	-2	0	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Extremely dry	Near normal
1968	5	-1.5135	-2	-2	-2	-2	0	Severely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Near normal
1968	6	1.4248	0	0	0	-1	0	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Near normal
1968	7	0.9298	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1968	8	0.2908	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1968	9	-1.2898	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	10	0.2662	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1968	11	0.1523	-1	1	0	0	-1	Near normal	Moderately dry	Moderately wet	Near normal	Near normal	Moderately dry
1968	12	0.2869	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	1	-0.1291	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
1969	2	-0.7001	-1	-1	1	0	-1	Near normal	Moderately dry	Moderately dry	Moderately wet	Near normal	Moderately dry
1969	3	-0.2138	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1969	4	0.4285	0	0	-1	0	-1	Near normal	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
1969	5	-1.5135	-1	-1	-2	0	-1	Severely dry	Moderately dry	Moderately dry	Extremely dry	Near normal	Moderately dry
1969	6	0.5881	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1969	7	0.9421	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1969	8	1.5	1	1	1	0	0	Very wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
1969	9	0.7857	2	1	1	1	1	Near normal	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1969	10	-1.0256	1	1	1	1	1	Moderately dry	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet

1969	11	1.2185	0	1	1	1	1	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1969	12	0.2869	-1	1	1	1	1	Near normal	Moderately dry	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1970	1	1.5936	1	1	1	1	1	Very wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1970	2	0.3657	1	0	1	1	1	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet
1970	3	0.2668	1	0	1	1	1	Near normal	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet
1970	4	-1.7556	-1	0	1	1	1	Severely dry	Moderately dry	Near normal	Moderately wet	Moderately wet	Moderately wet
1970	5	-0.19	-1	-1	0	1	1	Near normal	Moderately dry	Moderately dry	Near normal	Moderately wet	Moderately wet
1970	6	1.002	0	0	0	1	1	Moderately wet	Near normal	Near normal	Near normal	Moderately wet	Moderately wet
1970	7	1.0273	1	1	1	1	1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1970	8	0.384	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1970	9	0.3438	1	1	1	1	1	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
1970	10	1.659	1	2	1	1	2	Very wet	Moderately wet	Extremely wet	Moderately wet	Moderately wet	Extremely wet
1970	11	0.2747	1	2	1	1	2	Near normal	Moderately wet	Extremely wet	Moderately wet	Moderately wet	Extremely wet
1970	12	0.2869	2	1	1	1	2	Near normal	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Extremely wet
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
2010	1	-0.416	-1	0	-1	-2	-1	Near normal	Moderately dry	Near normal	Moderately dry	Extremely dry	Moderately dry
2010	2	-0.4925	-1	0	-1	-2	-1	Near normal	Moderately dry	Near normal	Moderately dry	Extremely dry	Moderately dry
2010	3	-0.7704	-2	-2	-1	-2	-1	Near normal	Extremely dry	Extremely dry	Moderately dry	Extremely dry	Moderately dry
2010	4	-0.1541	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2010	5	-1.018	-1	-2	-1	-2	-2	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Extremely dry	Extremely dry

2010	6	-0.2228	-1	-1	-2	-2	-2	Near normal	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2010	7	-2.3577	-2	-2	-3	-2	-3	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	8	-1.6682	-2	-3	-3	-3	-3	Severely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	9	-1.3152	-3	-3	-3	-3	-3	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	10	0.3221	-2	-3	-3	-3	-3	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	11	0.08	-1	-2	-3	-3	-3	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2010	12	1.5971	1	-2	-3	-3	-3	Very wet	Moderately wet	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2011	1	0.2249	1	-2	-2	-3	-3	Near normal	Moderately wet	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2011	2	-0.7001	1	-1	-2	-3	-3	Near normal	Moderately wet	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2011	3	-0.2138	-1	0	-3	-3	-3	Near normal	Moderately dry	Near normal	Extremely dry	Extremely dry	Extremely dry
2011	4	0.8205	0	1	-2	-2	-3	Near normal	Near normal	Moderately wet	Extremely dry	Extremely dry	Extremely dry
2011	5	0.7494	1	1	0	-2	-3	Near normal	Moderately wet	Moderately wet	Near normal	Extremely dry	Extremely dry
2011	6	0.7878	1	1	1	-1	-2	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Extremely dry
2011	7	-1.5948	0	0	0	-1	-2	Severely dry	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
2011	8	1.6118	1	1	1	0	-1	Very wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
2011	9	-0.2321	0	1	0	1	-2	Near normal	Near normal	Moderately wet	Near normal	Moderately wet	Extremely dry
2011	10	-1.0932	0	0	0	0	-2	Moderately dry	Near normal	Near normal	Near normal	Near normal	Extremely dry
2011	11	-0.1125	-1	0	0	0	-2	Near normal	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
2011	12	0.2869	-1	0	0	0	-2	Near normal	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
2012	1	0.2249	-1	0	0	0	-2	Near normal	Moderately dry	Near normal	Near normal	Near normal	Extremely dry
2012	2	-0.7001	-1	-1	0	0	-2	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Extremely dry
2012	3	-0.4532	-1	-2	-1	0	-2	Near normal	Moderately dry	Extremely dry	Moderately dry	Near normal	Extremely dry
2012	4	1.169	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2012	5	-3.0621	-1	-1	-2	0	-2	Extremely dry	Moderately dry	Moderately dry	Extremely dry	Near normal	Extremely dry
2012	6	-1.0074	-1	-1	-2	-1	-2	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Extremely dry
2012	7	0.073	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	8	-0.6013	-1	-1	-1	-2	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry

2012	9	-0.4619	-1	-1	-1	-2	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry
2012	10	0.0268	-1	-2	-1	-1	-1	Near normal	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2012	11	2.3152	0	-1	-1	-1	-1	Extremely wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	12	0.5207	1	0	-1	-1	-1	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	1	-0.416	2	0	-1	-1	-1	Near normal	Extremely wet	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	2	0.8357	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	3	-0.1113	0	1	0	-1	-1	Near normal	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry
2013	4	0.1455	0	1	0	-1	-1	Near normal	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry
2013	5	0.7614	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2013	6	-0.5444	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2013	7	-2.2354	-1	-1	-1	-1	-1	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	8	0.1505	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2013	9	0.0617	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2013	10	1.0489	0	-1	-1	0	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
2013	11	-0.3293	1	-1	-1	-1	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	12	0.2869	1	-1	-1	-1	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	1	-0.416	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
2014	2	1.0538	0	0	-1	-1	-1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2014	3	-0.1113	0	1	-1	-1	-1	Near normal	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry
2014	4	0.1455	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2014	5	0.2872	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2014	6	-0.443	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2014	7	-0.5298	-1	-1	-1	0	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2014	8	0.985	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	9	-0.7123	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2014	10	-1.813	-1	-1	-1	-1	-1	Severely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	11	-0.3293	-2	-1	-1	-1	-1	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry

2014	12	0.2869	-2	-1	-1	-1	-1	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	1	0.7075	0	-1	-1	-1	-1	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	2	0.4245	0	-2	-1	-1	-1	Near normal	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2015	3	0.8129	1	-2	-1	-1	-1	Near normal	Moderately wet	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2015	4	1.3904	1	1	0	0	-1	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2015	5	0.6274	1	1	0	0	-1	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2015	6	0.3909	1	1	0	0	-1	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2015	7	0.3613	1	1	1	0	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2015	8	-1.2626	0	0	0	-1	0	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Near normal
2015	9	0.1869	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2015	10	-1.781	-1	0	0	0	-1	Severely dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2015	11	0.2747	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2015	12	0.5207	-2	-1	0	0	-1	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Moderately dry
2016	1	1.7429	1	-1	0	0	-1	Very wet	Moderately wet	Moderately dry	Near normal	Near normal	Moderately dry
2016	2	-0.3911	1	-1	-1	0	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Near normal	Moderately dry
2016	3	0.4059	1	-1	-1	0	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Near normal	Moderately dry
2016	4	1.6839	1	2	-1	0	0	Very wet	Moderately wet	Extremely wet	Moderately dry	Near normal	Near normal
2016	5	1.0371	2	2	1	0	0	Moderately wet	Extremely wet	Extremely wet	Moderately wet	Near normal	Near normal
2016	6	-1.3833	0	0	0	-1	0	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Near normal
2016	7	0.5215	0	0	1	0	0	Near normal	Near normal	Near normal	Moderately wet	Near normal	Near normal
2016	8	-0.7288	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2016	9	-0.5396	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2016	10	-0.0638	-1	-1	0	0	0	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
2016	11	-0.3293	-1	-1	0	0	0	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
2016	12	0.2869	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2017	1	-0.1291	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
2017	2	-0.7001	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal

2017	3	0.9614	0	0	-1	0	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2017	4	0.6277	1	0	-1	-1	0	Near normal	Moderately wet	Near normal	Moderately dry	Moderately dry	Near normal
2017	5	0.8206	1	1	0	-1	0	Near normal	Moderately wet	Moderately wet	Near normal	Moderately dry	Near normal
2017	6	-0.9583	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2017	7	0.6359	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2017	8	-0.1784	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2017	9	-0.9414	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2017	10	1.3071	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2017	11	0.2165	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2017	12	1.2319	1	0	0	0	0	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
2018	1	-0.416	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2018	2	0.3046	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2018	3	-0.2688	-1	1	0	0	0	Near normal	Moderately dry	Moderately wet	Near normal	Near normal	Near normal
2018	4	0.5537	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2018	5	0.6149	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2018	6	-0.9827	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2018	7	-0.5667	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2018	8	-1.976	-2	-2	-1	-1	-1	Severely dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2018	9	-1.0928	-2	-2	-2	-1	-1	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry
2018	10	-0.1727	-2	-2	-2	-2	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2018	11	-0.3293	-1	-2	-2	-2	-1	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2018	12	1.1604	0	-2	-2	-2	-1	Moderately wet	Near normal	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2019	1	-0.416	0	-2	-2	-2	-1	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2019	2	1.7279	1	-1	-2	-2	-1	Very wet	Moderately wet	Moderately dry	Extremely dry	Extremely dry	Moderately dry
2019	3	1.4252	2	0	-1	-1	-1	Moderately wet	Extremely wet	Near normal	Moderately dry	Moderately dry	Moderately dry
2019	4	1.0669	2	1	-1	-1	-1	Moderately wet	Extremely wet	Moderately wet	Moderately dry	Moderately dry	Moderately dry
2019	5	0.2315	1	1	0	-1	-1	Near normal	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry
2019	6	-1.2147	0	0	0	-2	-1	Moderately dry	Near normal	Near normal	Near normal	Extremely dry	Moderately dry

2019	7	-0.3514	-1	0	0	-2	-2	Near normal	Moderately dry	Near normal	Near normal	Extremely dry	Extremely dry
2019	8	-1.4571	-2	-1	-1	-1	-2	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2019	9	-0.377	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2019	10	0.7905	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2019	11	0.08	0	-1	-1	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2019	12	0.2869	1	-1	-1	-1	-2	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2020	1	0.8055	0	-1	-1.2301	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2020	2	-0.5989	0	0	-1.3054	-1	-2	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
2020	3	0.4709	0	1	-0.8732	-1	-2	Near normal	Near normal	Moderately wet	Near normal	Moderately dry	Extremely dry
2020	4	-0.279	0	-1	-1.0237	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
2020	5	0.7494	0	0	0.0093	-1	-2	Near normal	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
2020	6	0.3758	0	0	0.5356	-1	-2	Near normal	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
2020	7	0.7599	1	1	0.6552	0	-1	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2020	8	-1.055	0	0	0.1379	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2020	9	-0.1451	0	0	0.0157	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2020	10	-0.0245	-1	0	-0.0808	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
2020	11	-0.3293	0	0	-0.083	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2020	12	0.2869	0	0	-0.1172	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2021	1	-0.416	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2021	2	-0.7001	-2	-1	0	0	-1	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Moderately dry
2021	3	-0.9892	-2	-1	-1	0	-1	Near normal	Extremely dry	Moderately dry	Moderately dry	Near normal	Moderately dry
2021	4	-0.8361	-2	-3	-2	0	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Near normal	Moderately dry
2021	5	0.1315	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2021	6	0.2208	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2021	7	0.1567	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2021	8	2.1216	1	1	1	0	0	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal
2021	9	-2.1412	0	0	0	0	0	Extremely dry	Near normal	Near normal	Near normal	Near normal	Near normal

2021	10	-1.8486	0	0	0	-1	-1	Severely dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2021	11	-0.3293	-2	0	0	-1	-1	Near normal	Extremely dry	Near normal	Near normal	Moderately dry	Moderately dry
2021	12	0.2869	-2	0	0	-1	-1	Near normal	Extremely dry	Near normal	Near normal	Moderately dry	Moderately dry

Rangpur_SPI_classification (1960-2021)

Year	Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24	SPI_1_Class	SPI_3_Class	SPI_6_Class	SPI_9_Class	SPI_12_Class	SPI_24_Class
1960	1	0						Near normal					
1960	2	-1						Moderately dry					
1960	3	1	1					Moderately wet	Moderately wet				
1960	4	-2	-1					Extremely dry	Moderately dry				
1960	5	0	-1					Near normal	Moderately dry				
1960	6	0	-1	-1				Near normal	Moderately dry	Moderately dry			
1960	7	0	0	0				Near normal	Near normal	Near normal			
1960	8	-1	-1	-1				Moderately dry	Moderately dry	Moderately dry			
1960	9	1	0	0	0			Moderately wet	Near normal	Near normal	Near normal		
1960	10	0	0	0	0			Near normal	Near normal	Near normal	Near normal		
1960	11	0	0	0	0			Near normal	Near normal	Near normal	Near normal		
1960	12	0	0	0	-1	-1		Near normal	Near normal	Near normal	Moderately dry	Moderately dry	
1961	1	0	-1	-1	0	-1		Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	
1961	2	1	0	0	0	-1		Moderately wet	Near normal	Near normal	Near normal	Moderately dry	
1961	3	0	0	0	0	-1		Near normal	Near normal	Near normal	Near normal	Moderately dry	
1961	4	0	0	-1	-1	-1		Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	
1961	5	0	0	0	0	0		Near normal	Near normal	Near normal	Near normal	Near normal	
1961	6	0	0	0	0	0		Near normal	Near normal	Near normal	Near normal	Near normal	
1961	7	-1	0	-1	-1	-1		Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry	
1961	8	-1	-1	-1	-1	-1		Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	
1961	9	-1	-2	-1	-1	-1		Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	

1961	10	1	-1	-1	-1	-1		Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry	
1961	11	0	0	-1	-1	-1		Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	
1961	12	1	1	-1	-1	-1	-1	Moderately wet	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1962	1	1	0	-1	-1	-1	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1962	2	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
1962	3	0	-1	1	-1	-1	-1	Near normal	Moderately dry	Moderately wet	Moderately dry	Moderately dry	Moderately dry
1962	4	-2	-2	-2	-1	-1	-1	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
1962	5	1	0	0	0	-1	-1	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1962	6	0	0	0	1	-1	-1	Near normal	Near normal	Near normal	Moderately wet	Moderately dry	Moderately dry
1962	7	-1	0	0	-1	-1	-1	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
1962	8	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1962	9	-1	-1	0	0	0	-1	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1962	10	-1	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1962	11	0	-2	-1	0	0	-1	Near normal	Extremely dry	Moderately dry	Near normal	Near normal	Moderately dry
1962	12	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
1963	1	0	-1	0	0	-1	-1	Near normal	Moderately dry	Near normal	Near normal	Moderately dry	Moderately dry
1963	2	-1	-1	-2	-1	-1	-1	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
1963	3	1	1	0	-1	0	-1	Moderately wet	Moderately wet	Near normal	Moderately dry	Near normal	Moderately dry
1963	4	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	5	-1	-1	-1	-2	-1	-1	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
1963	6	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
1963	7	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	8	0	0	0	0	-1	0	Near normal	Near normal	Near normal	Near normal	Moderately dry	Near normal
1963	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1963	10	0	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1963	11	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1963	12	0	-1	0	0	0	-1	Near normal	Moderately dry	Near normal	Near normal	Near normal	Moderately dry

1964	1	0	0	-1	0	0	-1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
1964	2	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
1964	3	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
1964	4	0	-1	-1	-1	0	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
1964	5	0	0	-1	-1	0	-1	Near normal	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
1964	6	1	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1964	7	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1964	8	-1	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	9	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1964	10	1	-1	0	0	0	-1	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Moderately dry
1964	11	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1964	12	0	1	-1	0	0	-1	Near normal	Moderately wet	Moderately dry	Near normal	Near normal	Moderately dry
1965	1	0	-1	-1	0	-1	-1	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry
1965	2	0	-1	-1	0	-1	-1	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Moderately dry
1965	3	1	0	0	-1	0	-1	Moderately wet	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
1965	4	0	0	-1	-1	0	-1	Near normal	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry
1965	5	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1965	6	-1	0	0	0	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
1965	7	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1965	8	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
1965	9	-1	-1	-1	-1	0	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Moderately dry
1965	10	-1	0	-1	-1	-1	-1	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1965	11	1	-2	-1	-1	-1	-1	Moderately wet	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1965	12	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
1966	1	1	1	0	-1	-1	-1	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry
1966	2	-1	-1	-2	-1	-1	-1	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
1966	3	-1	-1	-2	-1	-1	-1	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
1966	4	-2	-2	-2	-1	-1	-1	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Moderately	Moderately dry

												dry	
1966	5	0	-1	-1	-2	-1	-1	Near normal	Moderately dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry
1966	6	-2	-2	-2	-2	-2	-2	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	7	-1	-2	-2	-2	-2	-2	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	8	0	-1	-2	-2	-2	-2	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	9	-2	-1	-2	-2	-2	-2	Extremely dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	10	-1	-1	-2	-2	-2	-2	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	11	1	-2	-2	-2	-2	-2	Moderately wet	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1966	12	0	-1	-1	-2	-2	-2	Near normal	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry
1967	1	0	1	-1	-2	-2	-2	Near normal	Moderately wet	Moderately dry	Extremely dry	Extremely dry	Extremely dry
1967	2	-1	-1	-2	-2	-2	-2	Moderately dry	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
1967	3	2	2	0	-1	-2	-2	Extremely wet	Extremely wet	Near normal	Moderately dry	Extremely dry	Extremely dry
1967	4	1	1	2	-1	-2	-2	Moderately wet	Moderately wet	Extremely wet	Moderately dry	Extremely dry	Extremely dry
1967	5	-3	0	0	-2	-2	-2	Extremely dry	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry
1967	6	-1	-2	-1	-1	-2	-2	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Extremely dry	Extremely dry
1967	7	0	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1967	8	-1	-1	-1	-1	-2	-3	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry	Extremely dry
1967	9	0	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1967	10	0	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1967	11	0	0	-1	-1	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1967	12	0	0	-1	-1	-1	-2	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1968	1	0	-1	-1	-1	-1	-2	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Extremely dry
1968	2	1	0	0	-1	-1	-2	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
1968	3	0	0	0	-1	-1	-2	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Extremely dry
1968	4	1	1	0	-1	-1	-2	Moderately wet	Moderately wet	Near normal	Moderately dry	Moderately dry	Extremely dry
1968	5	-1	0	0	0	-1	-2	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
1968	6	0	0	0	0	-1	-2	Near normal	Near normal	Near normal	Near normal	Moderately dry	Extremely dry
1968	7	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately	Moderately dry

												dry	
1968	8	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	9	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
1968	10	1	1	0	0	0	0	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Near normal
1968	11	1	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
1968	12	0	1	1	0	0	-1	Near normal	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
1969	1	1	0	1	0	0	-1	Moderately wet	Near normal	Moderately wet	Near normal	Near normal	Moderately dry
1969	2	0	0	1	0	0	-1	Near normal	Near normal	Moderately wet	Near normal	Near normal	Moderately dry
1969	3	1	1	1	1	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
1969	4	0	0	0	1	0	-1	Near normal	Near normal	Near normal	Moderately wet	Near normal	Moderately dry
1969	5	0	0	0	1	0	0	Near normal	Near normal	Near normal	Moderately wet	Near normal	Near normal
1969	6	0	0	0	1	0	0	Near normal	Near normal	Near normal	Moderately wet	Near normal	Near normal
1969	7	1	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1969	8	1	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1969	9	0	1	1	1	1	0	Near normal	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
1969	10	-1	0	0	0	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal
1969	11	2	0	0	0	0	0	Extremely wet	Near normal	Near normal	Near normal	Near normal	Near normal
1969	12	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	1	2	2	0	0	0	0	Extremely wet	Extremely wet	Near normal	Near normal	Near normal	Near normal
1970	2	0	1	0	0	0	0	Near normal	Moderately wet	Near normal	Near normal	Near normal	Near normal
1970	3	-1	0	-1	0	0	0	Moderately dry	Near normal	Moderately dry	Near normal	Near normal	Near normal
1970	4	-1	-1	0	0	0	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	5	-1	-2	-2	-1	0	0	Moderately dry	Extremely dry	Extremely dry	Moderately dry	Near normal	Near normal
1970	6	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
1970	7	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	8	1	1	0	0	0	1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately wet
1970	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
1970	10	-1	0	0	0	0	0	Moderately dry	Near normal	Near normal	Near normal	Near normal	Near normal

1970	11	1	-1	0	0	0	0	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Near normal
1970	12	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
--------	------	---------	---------	--------	--------	---------	--------	------------	----------------	-----------	-----------	-----------	-------------
-------	-------	---------	---------	---------	---------	---------	---------	-------------	---------------	----------	----------	-----------	-------------
2010	1	0	-1	1	0	0	0	Near normal	Moderately dry	Moderately wet	Near normal	Near normal	Near normal
2010	2	-1	-1	-1	0	0	0	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
2010	3	-2	-2	0	0	0	0	Extremely dry	Extremely dry	Near normal	Near normal	Near normal	Near normal
2010	4	1	0	0	1	0	0	Moderately wet	Near normal	Near normal	Moderately wet	Near normal	Near normal
2010	5	0	0	0	-1	0	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2010	6	1	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2010	7	0	0	0	0	1	0	Near normal	Near normal	Near normal	Near normal	Moderately wet	Near normal
2010	8	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	9	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2010	10	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2010	11	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2010	12	0	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2011	1	0	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2011	2	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2011	3	0	0	0	-1	0	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2011	4	-1	-1	-1	-1	0	0	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal
2011	5	0	-1	-1	-1	0	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal

2011	6	-1	-1	-1	-1	-1	0	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2011	7	0	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2011	8	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2011	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2011	10	-2	0	0	0	0	0	Extremely dry	Near normal	Near normal	Near normal	Near normal	Near normal
2011	11	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2011	12	0	-2	0	0	0	0	Near normal	Extremely dry	Near normal	Near normal	Near normal	Near normal
2012	1	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2012	2	0	-1	-1	0	-1	0	Near normal	Moderately dry	Moderately dry	Near normal	Moderately dry	Near normal
2012	3	-1	-1	-3	0	-1	0	Moderately dry	Moderately dry	Extremely dry	Near normal	Moderately dry	Near normal
2012	4	1	1	1	0	0	0	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Near normal
2012	5	-1	0	0	-1	0	0	Moderately dry	Near normal	Near normal	Moderately dry	Near normal	Near normal
2012	6	0	0	0	-1	0	-1	Near normal	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
2012	7	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2012	8	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2012	9	0	0	0	0	-1	-1	Near normal	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2012	10	-1	-1	-1	0	0	-1	Moderately dry	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2012	11	0	0	-1	0	0	-1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
2012	12	0	-1	-1	0	0	-1	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Moderately dry
2013	1	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	2	1	0	0	-1	-1	-1	Moderately wet	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	3	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	4	0	0	0	-1	-1	-1	Near normal	Near normal	Near normal	Moderately dry	Moderately dry	Moderately dry
2013	5	1	1	1	0	0	0	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Near normal
2013	6	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2013	7	-1	0	0	0	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2013	8	0	-1	-1	-1	-1	-1	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2013	9	-1	-1	-1	-1	-1	-1	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately	Moderately dry

												dry	
2013	10	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2013	11	0	0	-1	0	0	-1	Near normal	Near normal	Moderately dry	Near normal	Near normal	Moderately dry
2013	12	0	1	-1	0	0	-1	Near normal	Moderately wet	Moderately dry	Near normal	Near normal	Moderately dry
2014	1	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry
2014	2	1	0	0	-1	0	-1	Moderately wet	Near normal	Near normal	Moderately dry	Near normal	Moderately dry
2014	3	-1	0	1	-1	0	-1	Moderately dry	Near normal	Moderately wet	Moderately dry	Near normal	Moderately dry
2014	4	-2	-1	-2	-1	-1	-1	Extremely dry	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2014	5	-1	-2	-1	-1	-1	-1	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	6	-1	-2	-2	-1	-1	-1	Moderately dry	Extremely dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry
2014	7	-2	-2	-2	-2	-2	-2	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry
2014	8	0	-2	-2	-2	-2	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2014	9	1	0	-1	-1	-1	-1	Moderately wet	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	10	-2	1	-1	-1	-1	-1	Extremely dry	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	11	0	1	-1	-1	-1	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2014	12	0	-2	-1	-1	-1	-1	Near normal	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	1	1	0	1	-1	-1	-1	Moderately wet	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry
2015	2	1	1	1	-1	-1	-1	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Moderately dry	Moderately dry
2015	3	0	1	-1	-1	-1	-1	Near normal	Moderately wet	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2015	4	0	0	0	1	-1	-1	Near normal	Near normal	Near normal	Moderately wet	Moderately dry	Moderately dry
2015	5	0	0	0	1	-1	-1	Near normal	Near normal	Near normal	Moderately wet	Moderately dry	Moderately dry
2015	6	1	1	1	0	0	-1	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2015	7	-1	0	0	0	0	-1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately dry
2015	8	2	1	1	1	1	0	Extremely wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2015	9	1	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2015	10	-2	1	1	1	1	0	Extremely dry	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2015	11	0	0	1	1	1	0	Near normal	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal

2015	12	0	-2	0	1	1	0	Near normal	Extremely dry	Near normal	Moderately wet	Moderately wet	Near normal
2016	1	1	0	1	1	1	0	Moderately wet	Near normal	Moderately wet	Moderately wet	Moderately wet	Near normal
2016	2	-1	0	0	0	1	0	Moderately dry	Near normal	Near normal	Near normal	Moderately wet	Near normal
2016	3	2	2	0	1	1	0	Extremely wet	Extremely wet	Near normal	Moderately wet	Moderately wet	Near normal
2016	4	-1	1	0	1	1	0	Moderately dry	Moderately wet	Near normal	Moderately wet	Moderately wet	Near normal
2016	5	0	1	1	0	1	0	Near normal	Moderately wet	Moderately wet	Near normal	Moderately wet	Near normal
2016	6	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	7	1	1	1	1	1	1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet
2016	8	-1	0	0	0	0	1	Moderately dry	Near normal	Near normal	Near normal	Near normal	Moderately wet
2016	9	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	10	0	-1	0	0	0	0	Near normal	Moderately dry	Near normal	Near normal	Near normal	Near normal
2016	11	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2016	12	1	0	0	0	0	0	Moderately wet	Near normal	Near normal	Near normal	Near normal	Near normal
2017	1	0	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2017	2	-1	-1	0	0	0	0	Moderately dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
2017	3	2	2	0	0	0	0	Extremely wet	Extremely wet	Near normal	Near normal	Near normal	Near normal
2017	4	1	1	1	-1	0	1	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Near normal	Moderately wet
2017	5	1	2	2	0	0	1	Moderately wet	Extremely wet	Extremely wet	Near normal	Near normal	Moderately wet
2017	6	-2	-1	0	0	0	0	Extremely dry	Moderately dry	Near normal	Near normal	Near normal	Near normal
2017	7	0	-1	-1	-1	-1	0	Near normal	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2017	8	1	-1	0	0	0	0	Moderately wet	Moderately dry	Near normal	Near normal	Near normal	Near normal
2017	9	-2	0	-1	0	-1	-1	Extremely dry	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry
2017	10	0	0	-1	0	0	0	Near normal	Near normal	Moderately dry	Near normal	Near normal	Near normal
2017	11	0	-1	-1	0	0	0	Near normal	Moderately dry	Moderately dry	Near normal	Near normal	Near normal
2017	12	0	0	0	-1	0	0	Near normal	Near normal	Near normal	Moderately dry	Near normal	Near normal
2018	1	0	-1	0	-1	-1	0	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Near normal
2018	2	-1	-1	-1	-1	-1	0	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Near normal
2018	3	0	-1	0	-1	-1	-1	Near normal	Moderately dry	Near normal	Moderately dry	Moderately dry	Moderately dry

2018	4	1	0	0	0	-1	0	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Near normal
2018	5	1	1	1	-1	-1	0	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Moderately dry	Near normal
2018	6	0	0	0	0	0	0	Near normal	Near normal	Near normal	Near normal	Near normal	Near normal
2018	7	-2	-1	-1	-1	-1	-1	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2018	8	-1	-2	-1	-1	-1	-1	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2018	9	-1	-2	-1	-1	-1	-1	Moderately dry	Extremely dry	Moderately dry	Moderately dry	Moderately dry	Moderately dry
2018	10	-1	-2	-2	-2	-2	-1	Moderately dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2018	11	0	-2	-2	-1	-2	-1	Near normal	Extremely dry	Extremely dry	Moderately dry	Extremely dry	Moderately dry
2018	12	1	-1	-2	-1	-2	-1	Moderately wet	Moderately dry	Extremely dry	Moderately dry	Extremely dry	Moderately dry
2019	1	0	0	-2	-2	-2	-1	Near normal	Near normal	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2019	2	1	1	-2	-2	-2	-1	Moderately wet	Moderately wet	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2019	3	-1	0	-1	-3	-2	-2	Moderately dry	Near normal	Moderately dry	Extremely dry	Extremely dry	Extremely dry
2019	4	1	1	0	-2	-2	-2	Moderately wet	Moderately wet	Near normal	Extremely dry	Extremely dry	Extremely dry
2019	5	1	1	1	-1	-2	-2	Moderately wet	Moderately wet	Moderately wet	Moderately dry	Extremely dry	Extremely dry
2019	6	-1	0	0	0	-2	-1	Moderately dry	Near normal	Near normal	Near normal	Extremely dry	Moderately dry
2019	7	1	0	0	0	-1	-1	Moderately wet	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2019	8	-1	0	0	0	-1	-1	Moderately dry	Near normal	Near normal	Near normal	Moderately dry	Moderately dry
2019	9	1	1	0	0	0	-1	Moderately wet	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2019	10	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2019	11	0	1	0	0	0	-1	Near normal	Moderately wet	Near normal	Near normal	Near normal	Moderately dry
2019	12	0	0	1	0	0	-1	Near normal	Near normal	Moderately wet	Near normal	Near normal	Moderately dry
2020	1	0	0	0	0	0	-1	Near normal	Near normal	Near normal	Near normal	Near normal	Moderately dry
2020	2	0	-1	1	0	0	-1	Near normal	Moderately dry	Moderately wet	Near normal	Near normal	Moderately dry
2020	3	1	0	0	0	0	-1	Moderately wet	Near normal	Near normal	Near normal	Near normal	Moderately dry
2020	4	1	1	1	0	0	-1	Moderately wet	Moderately wet	Moderately wet	Near normal	Near normal	Moderately dry
2020	5	1	1	1	1	0	-1	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal	Moderately dry
2020	6	0	1	1	0	1	-1	Near normal	Moderately wet	Moderately wet	Near normal	Moderately wet	Moderately dry

2020	7	1	1	1	1	1	0	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2020	8	-1	1	1	1	1	0	Moderately dry	Moderately wet	Moderately wet	Moderately wet	Moderately wet	Near normal
2020	9	3	2	2	2	2	1	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2020	10	0	2	2	2	2	1	Near normal	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2020	11	0	2	2	2	2	1	Near normal	Extremely wet	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2020	12	0	0	2	2	2	1	Near normal	Near normal	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2021	1	0	-1	2	2	2	1	Near normal	Moderately dry	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2021	2	-1	-1	2	2	2	1	Moderately dry	Moderately dry	Extremely wet	Extremely wet	Extremely wet	Moderately wet
2021	3	-1	-2	-1	2	2	1	Moderately dry	Extremely dry	Moderately dry	Extremely wet	Extremely wet	Moderately wet
2021	4	-1	-2	-2	1	2	1	Moderately dry	Extremely dry	Extremely dry	Moderately wet	Extremely wet	Moderately wet
2021	5	1	0	0	2	1	1	Moderately wet	Near normal	Near normal	Extremely wet	Moderately wet	Moderately wet
2021	6	-2	-2	-2	-2	1	1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately wet	Moderately wet
2021	7	-2	-4	-4	-4	-1	0	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Near normal
2021	8	-2	-2	-5	-5	-1	0	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry	Near normal
2021	9	-2	-2	-6	-6	-5	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	10	-2	-2	-6	-6	-6	-1	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	11	0	-2	-2	-6	-6	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry
2021	12	0	-2	-2	-6	-6	-1	Near normal	Extremely dry	Extremely dry	Extremely dry	Extremely dry	Moderately dry

***The details SPI classifications of five stations (Rajshahi, Rangpur, Dinajpur, Ishwardi and Rangpur) are listed in the CD Rom for the time period 1960-2021.

Questionnaire

Date:

Questionnaire for PhD Research Program on title "**Drought Characterization and Agricultural Adaptation in Northwest Bangladesh"**. The information, collected from the questionnaire survey, is used only for research purpose. There is no scope of harm by this questionnaire.

Section-1: Personal Profile of the Respondents

1) Name :

2) Father's name :

3) District :

4) Upazila :

5) Union :

6) Village :

7) Gender : a) Male b) Female

8) Marital Status : a) Married b) Unmarried c) Widow d) Divorce

Section-2: Socio-Economic Condition of the Respondents (Farmer)

9) Age: …………………….

10) Years of Schooling (Education): ………………………

11) Average household income (BDT): ……………………….

12) Annual household income (BDT): ……………………….

13) Household Size (number): ……………………….

14) Family member involved in earning:

15) How many years do you involve in farming? ………………………….

16) Livestock Ownership: a**)** Own b) Hire

17) Land Ownership: a) Own b) Hire c) Joint venture

18) House type: a) Paka b) Semi Paka c) Half Paka d) Kancha

19) Farm Size (Decimal) : …………………………

Section-3: Climate Condition on the Study Area

20) Do you observe any change in temperature (since 1991 or last 30 years)?

a) Yes b) No c) Unknown

21) If yes, then what is your opinion on temperature change?	Increasing temperature	(1)
	Decreasing temperature	(2)
	Numbers of warm days have increased	(3)
	Number of warm days have decreased	(4)
	Numbers of cold days have increased	(5)
	Numbers of cold days have decreased	(6)

22) Do you know the reasons behind increasing/decreasing temperature? a) Yes b) No

23) If yes, then what are the causes behind this?	Decreasing rainfall in summer	(1)
	Decreasing rainfall in winter	(2)
	Increasing rainfall in summer	(3)
	Increasing rainfall in winter	(4)
	Man- made reason (Deforestation, Urbanization, Industrialization)	(5)
	Others	(6)

24) Do you observe any change in rainfall (since 1991 or last 30 years)?

a) Yes b) No c) Unknown

25) If yes, then what is your opinion on change in long term rainfall over the last 30 years in your locality?	Increasing rainfall	(1)
	Decreasing rainfall	(2)
	Timing of rainfall has changed in different seasons	(3)
	Numbers of rainy day have decreased	(4)
	Numbers of rainy days have increased	(5)

26) Do you know the reasons behind increasing/decreasing rainfall? a) Yes b) No

27) If yes, then what are the causes behind this?	Decreasing temperature in summer	(1)
	Decreasing temperature in winter	(2)
	Increasing temperature in summer	(3)
	Increasing temperature in winter	(4)
	Man- made reason (Deforestation, Urbanization, Industrialization	(5)
	Others	(6)

28) Do you hear the term climate change (Awareness)? a) Yes b) No

29) From where/ whom you got access of information about climate variability and change?	Tv (1) Radio (2) Newspaper (3) Internet (4) NGO activities (5) Government activities (6) Agriculture extension officer (7) Through friends and relatives (8)

Section-4: Farmer's Perception on Drought and Agricultural Adaptation

30) What Types of drought occur in your locality?

a) Occasional b) Mild c) Moderate d) Severe e) Extreme

31) Knowledge about drought management strategies: a) Low b) Medium c) High

32) Please rate the following farmer's perception on drought in drought prone area.

	Strongly disagree	**Disagree**	**No idea**	**Agree**	**Strongly Agree**
i. Dry seasons are longer					
ii. Drying up steams/ rivers/ ponds/ kharis					
iii. Low rainfall in rainy season					
iv. Delayed onset of rainfall					

33) Which season of crop calendar do your crops and fruits get affected during drought?

a) Pre-*Kharif* b) *Kharif* c) *Rabi*

34) In which month your cultivation is affected by drought?

Bangla Month	*Boishakh*	*Joishtho*	*Ashar*	*Srabon*	*Vadro*	*Asshin*
English Month	April-May	May-June	June-July	July-August	August-Sept.	Sept.-Oct.
Bangla Month	*Kartick*	*Agrohayan*	*Poush*	*Magh*	*Falgun*	*Chaitro*
English Month	Oct.-Nov.	Nov.-Dec.	Dec.-Jan.	Jan.-Feb.	Feb.-March	March-April

35) What are the main impacts of drought in your locality? Please mention your valuable opinion

Impacts	**Very High**	**High**	**Medium**	**Less**	**Very less**
Scarcity of soil water					
Unemployment					
Crop failures					
Losses of livestock					
Increased cost of production					
Health impacts					
Decline in groundwater levels					
Water quality deterioration					
Food scarcity					
Malnutrition					
Lower income					

36) What is the significant drought hazard occur in your locality?	Cause fatalities	(1)
	Health injuries	(2)
	Property damage	(3)
	Infrastructure damage	(4)
	Agricultural loss	(5)
	Damage to the environment	(6)
	Scarcity of drinking water	(7)
	Interruption of business	(8)
	Other types of harm or loss	(9)

37) Who are the most vulnerable in your locality? a) Male b) Female

38) Is literacy rate high in your locality? a) Yes b) No

39) Who are more literate in your village? a) Male b) Female

40) Are people dependent on agriculture? a) Yes b) No

41) Access to climate information: a) Low access b) Medium Access c) High access

42) Access to electricity: a) low b) moderate c) High

43) Access to credit: a) Yes b) No

44) Access to agricultural extension service: a) Yes b) No

45) Training Experiences: a) No training b) Training received

46) Organizational Participation: a) Yes b) No

47) Social Mobility: a) Low b) Medium c) high

48) Farmer's to farmer extension: a) Yes b) No

49) Irrigation sources: a) Canal/Pond b) Deep tube well c) Rain fed d) River

50) Land Preparation: a) Use tractor b) Bullocks c) Soil cutter or spade

Section-4: Knowledge of drought Adaptation Strategy and Mitigation

51) Please rate your opinion of current adaptation strategy used in your locality?

Adaptation Practice	Very High	High	Medium	Low	Very low
Drought tolerant rice varieties					
Agronomic management (manure and composting, seedbed method, ail lifting, tillage and shedding)					
Re excavation of traditional ponds/khals					
Increase amount of surface water					
Rain water harvesting					
Irrigation facility (Deep tube well, motorized and manual pumps, shallow tube-wells)					
Crop intensification (Diversified crops, cropping pattern)					
Alternative enterprise of land use change (mango cultivation, homestead gardening, jujube cultivation, fodder cultivation)					
Crop rotation and changing planting date					
Extra income generating activities					
Adoption of new technologies					

52) Which adaptation strategies do you take most to mitigate drought affect? ……………….

53) For drought mitigation chose more than one effect	1) Drought tolerant rice varieties
	2) Agronomic management (manure and composting, seedbed method, ail lifting, tillage and shedding)
	3) Re excavation of traditional ponds/khals
	4) Increase amount of surface water
	5) Rain water harvesting
	6) Irrigation facility (Deep tube well, motorized and manual pumps, shallow tube-wells)
	7) Crop intensification (Diversified crops, cropping pattern)
	8) Alternative enterprise of land use change (mango cultivation, homestead gardening, jujube cultivation, fodder cultivation)
	9) Crop rotation and changing planting date
	10) Extra income generating activities
	11) Adoption of new technologies

54) If you do not take any adaptation actions then what are the reasons behind that?

a) Insufficient information b) Poor financial condition c) Poor training facilities

d) Insufficient GO/NGO aid e) Others

55) Do you observe any change in crop production after taking above adaptation measures?

a) Production has increased b) Production has decreased c) No change d) Unknown

56) Do you observe any change in production cost?

a) Production cost has increased b) Production cost has decreased c) No change

57) Do you observe any change in price of crops?

a) Price has increased b) Price has decreased c) No change

58) Do you have any crop insurance in drought year a) Yes b) No

59) Are you satisfied with government crop insurance scheme?

a) Yes b) No c) Unknown

60) Do you able to get any any loan subsidies from GO / NGO/ Bank?

a) Yes b) No

61) Do you observe any improvement in socio-economic condition after taking above adaptation actions?

a) Yes b) No c) Unknown

62) If yes, then what are the improvements you have observed?	Income, savings, and purchasing capacity have increased (1) Availability of proper food (2) Availability of sufficient dresses (3) Good opportunity of education for children (4) Increase communication system (5) Expansion of tread and commerce (6) Opportunity for self-employment (7) Increase property (8) Others (9)
62) What are the future adaptation actions taken by the farmer to mitigate drought impacts?	Adjustment of seeding/planting timing (1) Introduction of new varieties (2) Provide supplemental irrigation (3) Use increased amount of chemical, organic fertilizer and insecticide (4) Minimize family expenditure and save money (5) Store crop harvest (6) Selecting less water consuming crops (7) Taking credit from rich people (8) Selling household properties and cattle (9) Seek alternative source of income (10)

63) Does lack of information and knowledge works as a barrier to climate change adaptation?

a) Yes b) No

64) Does Government/ NGO/ others support influences adopting strategies?

a) Yes b) No

Recent Trends of Meteorological Variables and Impacts on Agriculture in Northwest Bangladesh

5

J. M. Adeeb Salman Chowdhury,
Md. Abdul Khalek, and Md. Kamruzzaman

Abstract

The study focused on two meteorological variables (rainfall and temperature) and their trend variations from 1960 to 2021. The recorded data was extracted from five regional weather stations in northwest area under Bangladesh Meteorological Department (BMD). By trend analysis, Rajshahi station found the lowest annual average rainfall (1460 mm) and the highest annual average temperature (25.30 °C). The precipitation concentration index (PCI) in the study area described that most of the stations carried varying precipitation concentration (16–20) except Dinajpur station. Linear trend analysis, the nonparametric Mann–Kendall (MK) test, Kendall's tau, Sen's slope estimator, and Spearman's rho (SR) test were used to define whether there were any trend fluctuations and calculate the magnitude of changes at the selected stations. Further, the Sequential Mann–Kendall test was executed to distinguish trend differences and abrupt deviations over time. During the study, Rajshahi station showed the highest significant decreasing trend with the degree of change assessed by Sen's slope estimator which was − 5.50 mm/year. Through cropping seasonal rainfall analysis, it had been observed that only the *Rabi* season (80%) found a declining trend across all stations. According to temperature trend analysis, except for Dinajpur station, all stations showed increasing trends in the annual and seasonal analysis by MK test and SR test. On the other hand, only Bogura and Syedpur stations were found significant at 5% level of significance. The magnitude of change discovered by the Sen's slope estimates varied from − 0.003 to 0.017 °C/year. The *Kharif* season temperature was significantly observed with a positive trend in all stations; however, the *Rabi* and pre-*Kharif* seasons temperature continued to show both increasing and decreasing trends. Furthermore, we checked the time series properties of meteorological data and constructed an appropriate model to forecast next five years based on the previous 60 years' recorded data. The research outcomes will be valuable for the sustainable agronomic growth of the country and reduce agricultural crop vulnerability during drought in the northwest region.

J. M. Adeeb Salman Chowdhury ·
Md.Kamruzzaman (✉)
Institute of Bangladesh Studies,
University of Rajshahi, Rajshahi, Bangladesh
e-mail: mkzaman@ru.ac.bd

J. M. Adeeb Salman Chowdhury
e-mail: asc_2010@cou.ac.bd

Md.Abdul Khalek
Department of Statistics, University of Rajshahi,
Rajshahi, Bangladesh
e-mail: mak.stat09@gmail.com

J. Das and S. Halder (eds.), *Advancement of GI-Science and Sustainable Agriculture*,
GIScience and Geo-environmental Modelling, https://doi.org/10.1007/978-3-031-36825-7_5

Keywords

Trend analysis · Mann–Kendall test · Spearman's rho test · Sen's slope estimator · Sequential Mann–Kendall test · ARIMA model · Bangladesh

5.1 Introduction

Climate change has been recognized as a worldwide issue in recent years. Now the global environment is possessed by unpredictable weather conditions resulting in the climate variability and change (Alam et al. 2023). Despite the fact that climate change is a global phenomenon, its effects will not be equally distributed (Shahid and Khairulmaini 2009; Shaw et al. 2013; Karim et al. 2020). According to research, underdeveloped countries are more at risk from the effects of climate change than developed ones. This is mostly due to a poor and constrained capacity to adapt to climate change (Basak et al. 2022; Das et al. 2020a, b, c; Rahman and Lateh 2017). As a developing nation, Bangladesh is particularly in danger due to high climate inconsistency, extreme temperature, huge population density, extreme poverty, unorganized infrastructure, insufficient money supply, and weak educational system (Kamruzzaman et al. 2018). The Intergovernmental Panel on Climate Change (IPCC) report found that precipitation and temperature were identified worldwide significantly, but with varying magnitudes. Every year the nation experiences some sort of disaster, such as floods, droughts, river bank erosion, and cyclones threatening country's development efforts and resulting poor livelihood and huge agricultural loss (Adams et al. 1998). According to the IPCC (2014), globally the average temperature is increased by 0.85 °C between the year 1880 and 2012, and it will increase 0.3–4.8 °C by 2100 (Karim et al. 2020; Mullick et al. 2019). It is observed that Bangladesh has experienced with a significant amount of precipitation in the monsoon season and less rainfall in other seasons of the year, which also affects the food security and economic growth of the country (Akter and Rahman 2012; Mondol et al. 2018; Rahman et al. 2017; Rahman et al. 2016b; Salam et al. 2020).

Agriculture is heavily relying on country's economy, but the water constraint (shortage) hinders agricultural production. In our country, agriculture is the most prevalent occupation in rural areas, with approximately 51.88% of people actively involved in agricultural (BBS 2019b). It is a crucial sector contributing 13.82% to the country's GDP (BBS 2019a). The rural population, roughly 70% of the total, is extremely in danger due to natural disasters (Islam et al. 2019a). Bangladesh is the fourth-largest rice producer in the world, with an annual production of over 34.7 million metric tons. Nearly 80% of all cultivated land (11.7 million hectares) is planted with rice (Mainuddin et al. 2022). Rice is used to make 91% of all food grains and 60% of overall agricultural products (Rahman et al. 2016a, b; Yu et al. 2010).

Despite advancements in technology, such as better crop varieties, irrigation practices, and other sustainable adaptation strategies have established food security, climate conditions still contribute unpredictability to agricultural productivity of the country (Mainuddin and Kirby 2015; Kirby et al. 2015). As a result, rainfall and temperature trend analysis and future prediction have become important subjects of research in Bangladesh, as accurate trend detection directly effects on establishment of long-term food security, an agro-based economy, and infrastructural development. Environmental researchers conduct various types of research to understand the rainfall and temperature patterns of Bangladesh. A number of studies exhibited significant rising or falling trends of temperature and rainfall on a large scale using the MK test, Sen's slope estimator, and Kendall's tau (Shahid and Khairulmaini 2009; Zhang et al. 2009; Shahid 2010; Rahman and Lateh 2016; Rahman et al. 2017; Kamruzzaman et al. 2018; Das et al. 2021a, b). Shahid (2010) demonstrated a significant upward trend in annual and pre-season rainfall at 17 rain gauge stations in Bangladesh by using the MK test and Sen's slope estimator between 1958 and 2007. Similarly, Hossain et al. (2014) perceived rising tendencies in seasonal rainfall variability in the southwest coastal area of

Bangladesh during the years 1948–2007. Rahman and Lateh, (2016) constructed a regression model for trend detection from 1971 to 2010 and forecasting ten-year period of rainfall by the ARIMA method from 34 meteorological stations in Bangladesh. Their findings showed that annual rainfall was forecasted to decline by 153 mm between 2011 and 2020. As a result, almost dry conditions would continue during pre- and post-monsoon season in Bangladesh's northwestern, western, and southwestern regions. Rahman et al. (2017) used 60 years of monthly rainfall data to estimate rainfall trends of selected stations by applying the Mann–Kendall test. Additionally, they found unnoticeable trends in precipitation rather than rising trends for Khulna, Satkhira, Cox's Bazar stations, but they discovered falling trends for Srimongal stations by using the ARIMA approach. Similar types of research were found in hydro-climatic research based on global climate problem (Islam et al. 2021; Kamruzzaman et al. 2018, 2022; Yu et al. 2017).

Although the northwest zone produces huge amount of crops, the agriculture mostly relies on rainwater. In addition, inadequate rainfall, extreme temperature, surface water scarcity, and groundwater depletion for irrigation purposes are common problems in this region (Salam et al. 2020; Karim et al. 2020; Uddin et al. 2020a, 2020b). To address this problem, several studies have been done locally and country-wide to determine future trends. Kamruzzaman et al. (2018) identified the changing rainfall and temperature patterns in different cropping seasons in the NW Bangladesh. Almost identical results were found in different studies on the NW region of Bangladesh (Bariet al. 2016; Rahman et al. 2016a, b). It is traditionally accepted that drought is the outcome of decreasing trends of rainfall and increasing trends of extreme temperature. However, many environmental researchers do not agree with the above statement. To address the issue, many previous studies were conducted based on zone-wise or country-wise methods. However, some limitations have been found in the local and regional studies. The present chapter aims to identifying annual and seasonal trend fluctuations of climatic variables of five meteorological stations (*i.e.*, Bogura, Syedpur, Dinajpur, Rajshahi, and Ishwardi) during 1961–2021 and predicts monthly behavioral change to obtain approximate results. Furthermore, the study looks into the development of agro-economic activities and infrastructure that will strengthen the ability of farmers, policymakers, and researchers to deal with meteorological change.

5.2 Materials and Methods

5.2.1 Area of Study

Sixteen administrative districts, consisting 34,359 km^2 and residing 38 million people, from north and northwest Bangladesh are considered as study area of this research (Uddin et al. 2020a, BBS 2019a). According to Banglapedia (2003), the country belongs to a sub-tropical climate region with hot, humid, and erratic rainfall occurring throughout the year, mostly influenced by monsoon weather as well as pre- and post-monsoon exchanges. The country undergoes three climatic seasons such as (1) the month of November to February known as dry winter season, (2) the month of March to May known as pre-monsoon hot summer season, and (3) lastly the month of June to October regarded as rainy monsoon season (Rashid 1991). In winter season, the mean temperature lies between 18.5 and 21.0 °C, and hot summer season mean temperature ranges from 27.8 to 29.0 °C. The overall annual average rainfall from the northwest to the northeast region is 1329–4338 mm, which indicates that northwest region of Bangladesh receives less amount of rainfall (Shahid and Behrawan 2008; Shahid and Khairulmaini 2009).

During the month of April–May, the average temperature was experienced between 27 and 31 °C in the east and south and west-central portion of the country. However, the western regions of Bangladesh become very hot with a maximum of 40 °C temperature (Shahid 2010; Shahid et al. 2012; Khan et al. 2019). It is experienced that the average maximum temperature of northwest zone goes up to 24 °C in January and 34 °C in June. Meanwhile, the average temperature does not go beyond 27 °C from November to February but exceeds 32 °C from April to October (Bhuyan et al. 2018). The district-wise meteorological stations location is presented in (Fig. 5.1). According to Banglapedia (2003), in our country the agricultural calendar is based on three cropping seasons: *Rabi*, pre-*Kharif*, and *Kharif*. The *Rabi* period, which spans from early November to the end of February, is characterized by a dry climate. The pre-*Kharif* period starts in early March and lasts until the end of June, whereas the *Kharif* begins in the month July and ends in the month October when there is enough moisture from rainfall to support rain-fed or non-irrigated crops (Banglapedia 2003; Kamruzzaman et al. 2018; Shahid and Behrawan 2008).

5.2.2 Data

In this study, Bangladesh Meteorological Department (BMD), Dhaka, has provided rainfall and temperature data from 1960 to 2021. Besides, required and relevant records are retrieved from World Meteorological Organization (WMO), Bangladesh Water Development Board, and online resources from different websites.

5.2.3 Estimation of Missing Data

During study, every station has a number of missing values. Due to the global nature of missing daily temperature and rainfall records, many climatological algorithms have encountered difficulties. There are three broad categories of missing data estimation methods, such as: (a) within-stations, (b) between station, and (c) regression-based (Allen and DeGaetano 2001). The within-stations approach forecasts missing temperatures based on the previous and subsequent days' data. For example, to calculate the missing minimum temperature on *October 1*, the minimum temperatures between *September 30* and *October 2* could be averaged (Oliver 1980).The within-station method is utilized to calculate the daily readings that are lost for a maximum of three days temperature. When more than three days of data are unavailable, regression-based methods should be used. This method uses data from nearby stations. Regression-based approaches are also appropriate, when monthly data is lost, because both monthly and daily data are constructed from this method (Eiseheid et al. 1995). According to Kemp et al. (1983), several regression techniques tend to provide more accurate results compared to other missing data estimation procedures. Multiple imputation techniques are utilized to both daily (Recha et al. 2012) and monthly (Ingsrisawang and Potawee 2012) data for missing rainfall records because the standard error is correctly adjusted for missing data estimation (Enders 2010).

5.2.4 Rainfall Climatological Features

5.2.4.1 Coefficient of Rainfall Variability

The coefficient of rainfall variability CV (%) is determined using the following formula:

$$\mathrm{CV}(\%) = \frac{\sigma}{\mu} \times 100 \tag{5.1}$$

where CV is the coefficient of variation in percentage, μ is the annual average precipitation, and σ is the standard deviation.

5.2.4.2 Precipitation Concentration Index (PCI)

The concentration of rainfall (as major form of precipitation, in the selected study area) variability has been computed by applying the following formula of precipitation concentration index (Oliver 1980; Michiels et al. 1992):

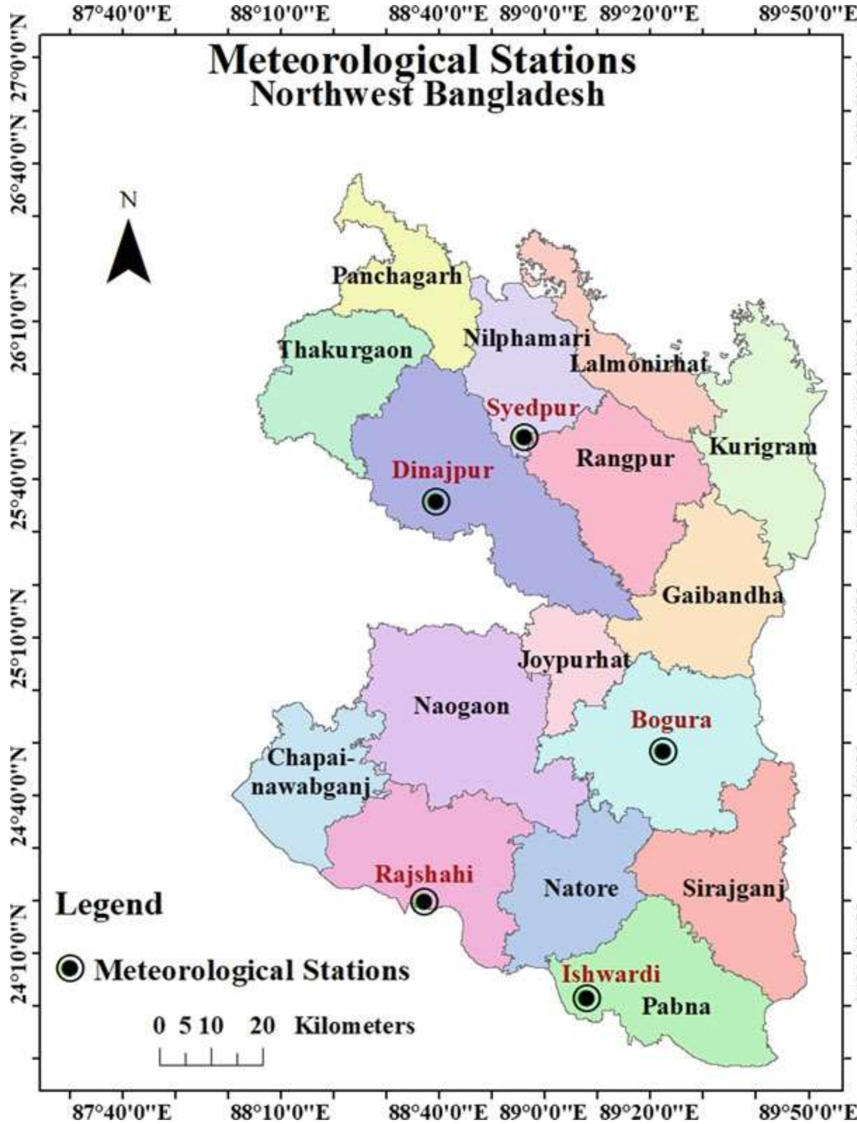


Fig. 5.1 Meteorological stations map in the nothwest region

$$\mathrm{PCI}_{\mathrm{annual}} = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \tag{5.2}$$

PCI represents the monthly precipitation concentration index, and p_i is the monthly precipitation in the month i. It is observed that when PCI values are < 10%, the precipitation concentration should be identical or low precipitation; if PCI value range is 11–15%, it indicates moderate concentration of precipitation; if it ranges 16–20%, then precipitation continues irregularly (Oliver 1980). If a PCI value > 20%, it means that the concentration of precipitation is either high or strongly irregular.

5.2.5 Rainfall and Temperature Trend Analysis

Different statistical techniques and trend detection formula have been implemented for the required study. Mainly descriptive statistical analysis (maximum, minimum, mean/average, standard deviation, and coefficient of variation) has been executed to present the general characteristic of temperature and rainfall time series data.

5.2.5.1 Linear Regression

A popular parametric technique for finding linear trends in time series data is linear regression. It is used to determine the slope of time-dependent meteorological variables (Tabari and Talaee 2011). Positive slope specifies increasing trend and vice versa. The linear monotonic change can be calculated as the following form:

$$y = ax + b \tag{5.3}$$

Here, $a = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2}$ and

$$b = \bar{y} - a\bar{x} \tag{5.4}$$

where y is the dependent variable such as (temperature, rainfall, and humidity) and x is the independent variable (year); a and b are the coefficient of slope and intercept term of the trend line; $\bar{x}$ and $\bar{y}$ are sample means (Rahman and Lateh 2016).

5.2.5.2 Mann–Kendall (MK) Test

The rank-based nonparametric MK (Mann 1945) test is applied as the primary method of trend detection. It is often used to check whether a time series data exhibits a monotonic rising and falling trend. (Das et al. 2021a; Kamruzzaman et al. 2018, 2022; Sa'adi et al. 2019; Rahman et al. 2017). The test statistic *(S)* is identified using the following formula:

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \tag{5.5}$$

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} +1, & if \quad (x_j - x_k) > 0 \\ 0, & if \quad (x_j - x_k) = 0 \\ -1, & if \quad (x_j - x_k) > 0 \end{cases} \tag{5.6}$$

Here, S means the trend detection. A rising trend is indicated by a positive value of S and vice versa. When sample size is greater than 10, then the test statistics $\boldsymbol{S}$ is normally distributed, with the following variance (Das et al. 2019):

$$\operatorname{Var}(S) = \frac{[(n(n-1)(2n+5)] - \sum_{i=1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \tag{5.7}$$

where m represents the total number of tied groups and t_i denotes the size of the *ith* group. The **Z** statistic is calculated using the following equation:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}}, & \text{for } S > 0 \\ 0, & \text{for } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}}, & \text{for } S < 0 \end{cases} \tag{5.8}$$

In general, the positive and negative Z values represent the rising and falling trends, respectively. According to the null hypothesis, there is no trend in records (either accepted or rejected) if the estimated Z value is smaller or greater than the critical value (Das et al. 2021b).

5.2.5.3 Kendall's Tau

Tau (Kendall 1948) assesses the intensity of x and y's monotonic relationship. The Kendall's tau correlation formula is given by,

$$\tau = \frac{S}{n(n-1)/2} \tag{5.9}$$

5.2.5.4 Sen's Slope Estimator

Sen's slope estimator (Sen 1968), which provides the robust estimation of time series, is used to evaluate the degree of change (slope Q) (Das and Bhattacharya 2018; Das et al. 2020b). The estimation slope can be attained from N pairs of data as:

$$Q_i = \frac{x_k - x_j}{k - j}, \qquad i = 1, 2, 3 \ldots N, \quad k > j \tag{5.10}$$

where x_k and x_j represent values of data at k and j times and Q_i is the median slope, respectively.

5.2.5.5 Spearman's Rho (SR) Test

The Spearman's rho (SR) test (Spearman 2010) is another technique that uniformly detects tends and clearly indicates the lack of trends (Das et al. 2020b; Shadmani et al. 2012; Tonkaz et al. 2007; Yue et al. 2002a). According to Yue et al. (2002b), maximum trend test has same strength for long-term data when it comes to detecting monotonic hydrological time series trends. The test statistic D and standardized test statistic Z_{SR} are defined by:

$$D = 1 - \frac{6\sum_{1}^{n}[R(X_i - 1]^2}{n(n^2 - 1)} \quad (5.11)$$

$$Z_{SR} = D\sqrt{\frac{(n-2)}{(1-D^2)}} \quad (5.12)$$

where R is the ith observation rank order in X_i time series and n is the sample size. The positive values Z_{SR} suggest rising trends and vice versa.

5.2.5.6 Sequential Mann–Kendall (SMK) Test

At the end of any period, it is well known that trend identification using the MK approach does not produce an accurate trend image for entire series. By using the sequential test for each distinct time series, it is possible to identify any fluctuations in the trend during the course of the inquiry (Sneyers 1990). This test establishes 2 series: [i] a progressive series $u(t_i)$ and [ii] a backward series $u'(t_i)$. . There is a statistically noteworthy change point that exists if they cross each other and diverge over predetermined definite threshold value (95% confidence limit). Their intersection point provides an approximate idea of the trend beginning year (Mosmann et al. 2004).

The SMK test is calibrated using rank values. The actual values in the series $(x_1, x_2, x_3 \ldots x_n)$ with the rank value y_i and the magnitudes of y_i $(i = 1, 2, 3 \ldots\ldots n)$ are compared with y_j $(j = 1, 2, 3 \ldots i - 1)$. The cases $y_i > y_j$ are enumerated and indicated for each comparison by $n_{i.}$ Here, t_i is test statistic of SMK test by applying the following formula:

$$t_i = \sum_{j}^{i} n_i$$

The distribution of test statistic t_i has a mean $E(t_i) = \frac{i(i-1)}{4}$ and variance $\mathrm{Var}(t_i) = \frac{i(i-1)(2i+5)}{72}$; then the following formula is employed to obtain the forward sequential results: (Sneyers 1990).

$$u(t_i) = \frac{[t_i - E(t_i)]}{\sqrt{\mathrm{Var}(t_i)}} \quad (5.13)$$

Similar approaches are used to find the backward sequential statistics $u'(t_i)$, which starts at the end of the sequence. Occasionally, the positive and negative trends are canceled by each other in SMK analysis but do not provide a substantial trend turning point (Nalley et al. 2013). This technique was widely used by many researchers to identify trends from the beginning point (Esteban-Parra et al. 1995; Makokha and Shisanya 2010) rather than whole trend detection. Nalley et al. (2013) applied this technique in order to determine the periodicities in the temperature time series.

5.2.5.7 Spatial Distribution Analysis

The Inverse Distance Weighing (IDW) method was employed to evaluate the spatial pattern of trend magnitude (MK test and Sen's slope estimates). This procedure is popular and simple for spatial interpolation (Shahid and Behrawan 2008; Rahman et al. 2017; Kamruzzaman et al. 2018; Islam et al. 2019a, b), and it is very reliable for displaying the spatial analysis of hydro-meteorological records (Praveen et al. 2020). Compared to other interpolation techniques, the IDW method is more effective (Islam et al. 2021). We have used the ArcGIS 10.0 software for performing the IDW method in this study.

5.2.5.8 ARIMA Modeling and Prediction

The ARIMA approach is recognized as a sophisticated and broadly used data analysis technique for forecasting time series (Box and Jenkins 1976). In hydrological research, the ARIMA models are utilized to discover complexity in data series and forecast upcoming scenarios (Dimri et al. 2020; Rahman et al. 2017). Typically, ARIMA model consists of three components: AR is the autoregressive component, MA is the moving average component, and the differencing order (D) integrated with the model both AR and MA. The ARIMA model ($p.d.q$) includes p = autoregressive term, d = trend term, and q = moving average term. After attaining data stationary, ARIMA method usually proceeds via four major steps: model identification, parameter estimates, model adequacy diagnostics, and forecasting. For the seasonal ARIMA model, notation is like ARIMA $(p, d, q) \times (P, D, Q)S$ where p = non-seasonal autoregressive (AR) order, d = non-seasonal differencing, q = non-seasonal moving average (MA) order, P = seasonal AR order, D = seasonal differencing, Q = seasonal MA order, and S = time span of repeating seasonal pattern. The fitted model performance is based on model selection criteria like log-likelihood, Akaike Information Criteria (AIC), and Bayesian Information Criteria (BIC). For this study, the Box Jenkins technique is implemented to forecast monthly rainfall and temperature data for the following five years based on 1960–2021.

5.3 Results and Discussion

5.3.1 Annual Rainfall Features

Rainfall is not constant across the country. Historically, in our country the northwest region received the least amount of rainfall as compared to the northeast. Around 75% of rainfall happens during the monsoon season (Alamgir et al. 2015). The results in Table 5.1 indicated that the mean annual rainfall ranges from 2171 to 1460 mm with mean value of 1767.80 mm. In 2010, Rajshahi station received the lowest amount of annual rainfall, 792 mm. Meanwhile, Syedpur station received the highest amount of annual precipitation 3748 mm in 1984. Moreover, Syedpur station received a maximum average annual rainfall amount of 2171 mm, whereas the other stations received less than 2000 mm amount of annual rainfall. During study period, the rainfall data was found positively skewed. The coefficient of variation is low in Rajshahi station (19.93%) and high in Ishwardi station (26.12%) which means maximum rainfall variability happened in Ishwardi station. The standard deviation of annual rainfall is high in Syedpur station, with 463.87 mm, and low in Rajshahi station, with 291 mm (Fig. 5.2 a). From the statistical analysis, about 80% stations in the research area were covered by irregular precipitation concentration index (PCI = 16–20), except Dinajpur station that carried a high precipitation concentration, which was more than 20%. Finally, all the stations were found to be positively skewed. The study area's annual rainfall statistics are provided in the following tables (Table 5.1).

5.3.2 Trend Analysis of Annual Rainfall

The MK test result revealed that 40% stations exhibit a positive trend, while the rest of the stations showed negative trend. Moreover, in annual rainfall trend analysis, a positive slope specified increasing amount of rainfall, while a negative slope designated decreasing trends (Table 5.2). According to MK test result *(Z),* Rajshahi station showed the highest amount of significant decreasing trend (− 2.654) at 5% level of significance, followed by Bogura (− 0.176) and Ishwardi (− 0.808), but they were found statistically insignificant. The magnitude of change in annual average rainfall was estimated at the rates of − 5.50, − 0.59, and − 1.71 mm/year at Rajshahi, Bogura, and Ishwardi stations, respectively, but only Rajshahi station showed statistically significant. In contrast, Syedpur and Dinajpur stations found insignificant positive trend, and the degree of

Table 5.1 Descriptive statistics of annual rainfall in the study area (1960–2021)

Stations	Annual rainfall (mm)							
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis	PCI_{Annual}
Bogura	1081	2601	1719	21.92	376.77	0.307	− 0.635	19.47
Dinajpur	920	3179	1906	23.77	453.08	0.395	0.525	20.58
Ishwardi	893	3021	1583	26.12	413.42	1.30	2.530	17.80
Rajshahi	792	2241	1460	19.93	291.00	0.069	0.114	18.16
Syedpur	1231	3748	2171	21.37	463.87	0.905	1.510	19.63

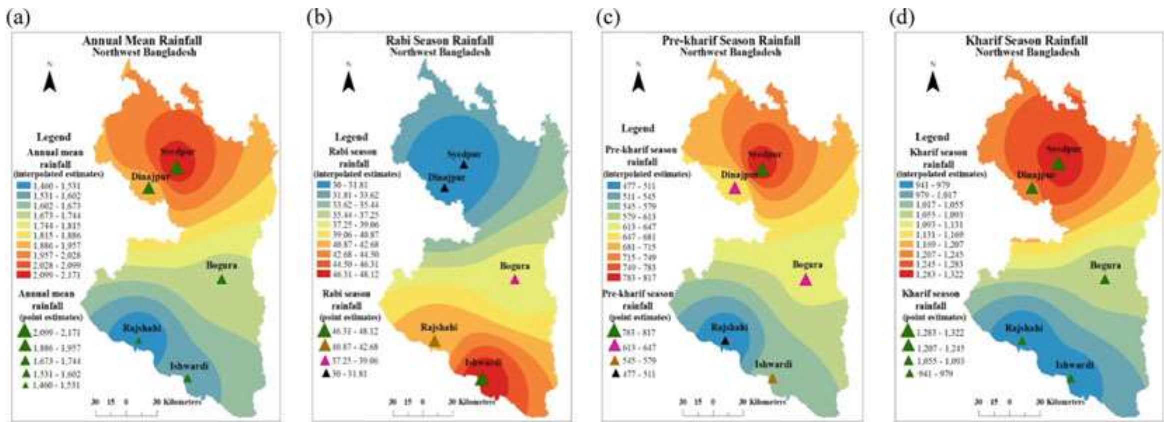


Fig. 5.2 Distribution of **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

change of these two stations was 3.68 and 2.59 mm/year, respectively. Besides, Kendall's tau revealed a monotonic trend of weak relationships in all stations. The linear regression trends of annual precipitation graph are shown in (Fig. 5.5). The MK test results (Z statistic) and the Sen's estimator of different stations are presented by the spatial distribution analysis (Fig. 5.3a). It is observed that annual average rainfall decreases at the Rajshahi division (Rajshahi, Bogura, and Ishwardi) but increases at the Rangpur division (Dinajpur and Syedpur).

5.3.3 Trend Analysis of Seasonal Rainfall

5.3.3.1 Rabi Season

During the *Rabi* season, the northwest zone received 37.8 mm of annual rainfall, which was significantly less than other parts of Bangladesh. In the study domain, annual average rainfall ranged from 30 mm to less than 50 mm in all stations. According to the regional distribution (Fig. 5.2b) of the *Rabi* season analysis, Dinajpur station found the lowest quantity of annual

Table 5.2 Long-term annual rainfall trend test results

Stations	MK test	Sen's slope	Kendall's tau	SR test
Bogura	− 0.176	− 0.59	− 0.016	− 0.195
Dinajpur	0.692	2.59	0.061	0.501
Ishwardi	− 0.808	− 1.71	− 0.071	− 0.830
Rajshahi	− 2.654*	− 5.50*	− 0.232*	− 2.813*
Syedpur	1.178	3.68	0.103	1.063

* Significant trends at 5% significance level, Sen's slope unit is in mm per year

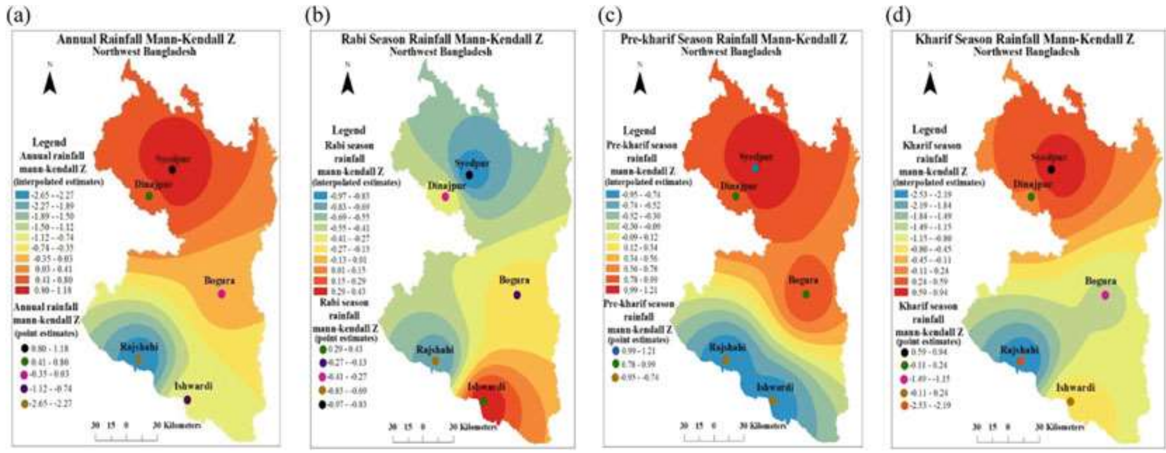


Fig. 5.3 Distribution of Z statistics estimates **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

rainfall (30 mm), whereas Ishwardi station received the highest quantity of rainfall, 48 mm. The standard deviation was high in Rajshahi station (38 mm) and low in Dinajpur station (25.85 mm). Moreover, the coefficient of variation revealed that 95.22% variation occurred in Bogura station, whereas Ishwardi station found low amount of rainfall variation (78.37%). The results of the MK test (Z statistics) exhibited that almost all stations shown an insignificant downward trends ranged from − 0.176 to − 0.966 at 95% confidence interval. Analysis of Sen's slope estimations revealed declining trends of 0.029, − 0.034, − 0.167, and − 0.136 mm/year in Bogura, Dinajpur, Rajshahi, and Syedpur, respectively, except Ishwardi station observed at a rate of change 0.107 mm/year (Table 5.3). Spearman rho's test also showed similar trend in all the station that ranged from 0.537 to − 1008. The distribution map of Z statistics and Sen's slope estimates of the *Rabi* season rainfall is depicted in (Fig. 5.3b and 5.4b). The findings of the study exhibited that the northwest region experienced a declining amount of rainfall in the Rabi season, which is particularly harmful for Boro rice production.

5.3.3.2 Pre-Kharif Season

The annual (mean or average) rainfall at different stations, in Bangladesh, in the pre-*Kharif* period was 623 mm, and the standard deviation varied from 153 to 240 mm. The pre-Kharif season rainfall analyses of spatial distribution (Fig. 5.2c) clearly showed that Syedpur station received significant rainfall with 1667 mm. Meanwhile, Rajshahi station found only 96 mm of rainfall in the study period (1960–2021). The northwest region had experienced both rising and falling trends in pre-*Kharif* season. The result derived from different trend analysis test (MK test, Sen's slope, and SR test) points out that 60% of stations showed increasing trend and 40% found insignificant decreasing trend. The MK test outcomes *(Z)* revealed that rainfall varied from − 0.905 (Ishwardi) to 1.208 (Syedpur). The Sen's slope estimates of Bogura, Dinajpur, and Syedpur stations identified insignificant rising trends at a rate of changes 1.73, 1.59, and 1.54 mm/year, respectively, while stations like Ishwardi and Rajshahi achieved insignificant falling trends at a magnitude of change − 0.905 and − 0.954 mm/year, respectively (Table 5.3). Spearman's rank correlation test (SR test) observed the same increasing and decreasing trends for the all stations. The spatial analysis of Z statistics and Sen's slope estimates is displayed in Figs. 5.3c and 5.4c. From above discussion, it is clear that the pre-*Kharif* season rainfall in Bangladesh shows downward trend in the northwest but strongly predicts upward trend in the north.

Table 5.3 Long-term seasonal rainfall trend test results

Stations	Rabi season			Pre-Kharif season			Kharif season		
	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test
Bogura	− 0.176	− 0.029	− 0.147	0.966	1.73	1.008	− 1.227	− 2.18	− 1.432
Dinajpur	− 0.255	− 0.034	− 0.031	0.947	1.59	0.995	0.20	0.50	− 0.007
Ishwardi	0.431	0.107	0.537	− 0.905	− 1.105	− 0.838	− 0.486	− 1.24	− 0.421
Rajshahi	− 0.838	− 0.167	− 0.886	− 0.954	− 1.00	− 0.903	− 2.53*	− 3.80*	− 2.711*
Syedpur	− 0.966	− 0.136	− 1.008	1.208	1.54	1.330	0.94	2.53	0.717

* Significant trends at 5% level, Sen's slope unit is in mm/year

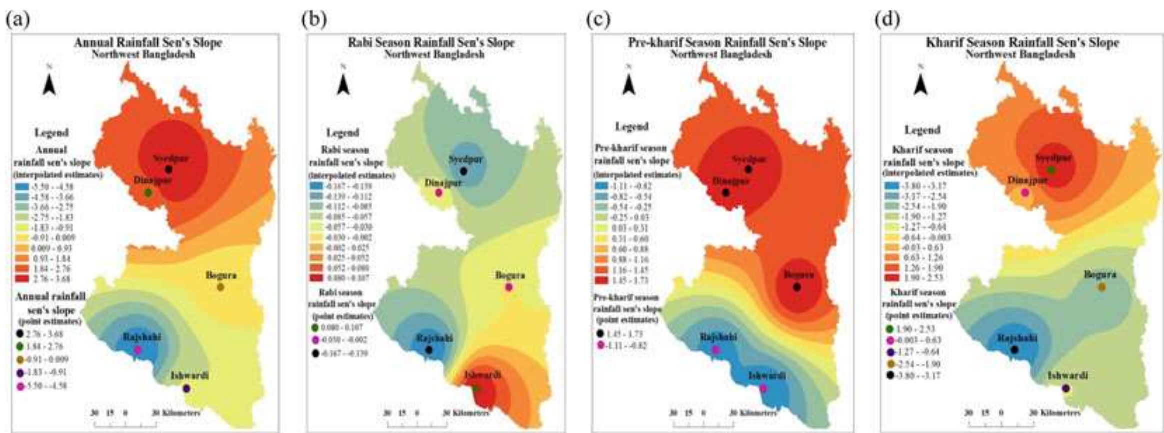


Fig. 5.4 Distribution of Sen's slope estimates **a** Annual average rainfall **b** *Rabi* rainfall **c** Pre-*Kharif* rainfall **d** *Kharif* rainfall

5.3.3.3 Kharif Season

The *Kharif* rainfall is very important for Aman rice production because rice is the main staple food in our country. The average annual rainfall during this season was 1104.8 mm. In this season, Rajshahi station received the least amount of maximum rainfall (1583 mm), and Syedpur station found maximum rainfall (2440 mm). The coefficient of variation is high (29.87%) at Dinajpur station and low (24.98%) at Rajshahi station (Fig. 5.2d). During the month of July to October is considered as the *Kharif* season in our country. In the present study, long-term *Kharif* season was dominated by a mixed rainfall trends in all stations. The MK test and SR test results were detected with same trend directions in the northwest region. From trend analysis, Rajshahi station showed the most significant decreasing trend with − 2.53 at 5% level of significance; on the contrary, Bogura and Ishwardi stations also observed decreasing trend in all trend analysis test, but they were not statistically significant. Moreover, the degree of change obtained by Sen's slope results was − 3.80, − 2.18, and − 1.24 mm/year at Rajshahi, Bogura, and Ishwardi stations, respectively. Dinajpur and Syedpur stations exhibited insignificant positive trends of 0.20 and 0.935 in accordance with the MK test statistic (*Z*), and the magnitude of change assessed by Sen's slope estimates of these two stations was 0.50 and 2.53 mm/year, respectively. According to the SR test results, all stations found a downward trend varied from − 2.711 to 0.717 (Table 5.3). The spatial distribution of MK *(Z)* statistic and Sen's slope estimates of the *Kharif* rainfall trends is shown in (Figs. 5.3d and 5.4d).

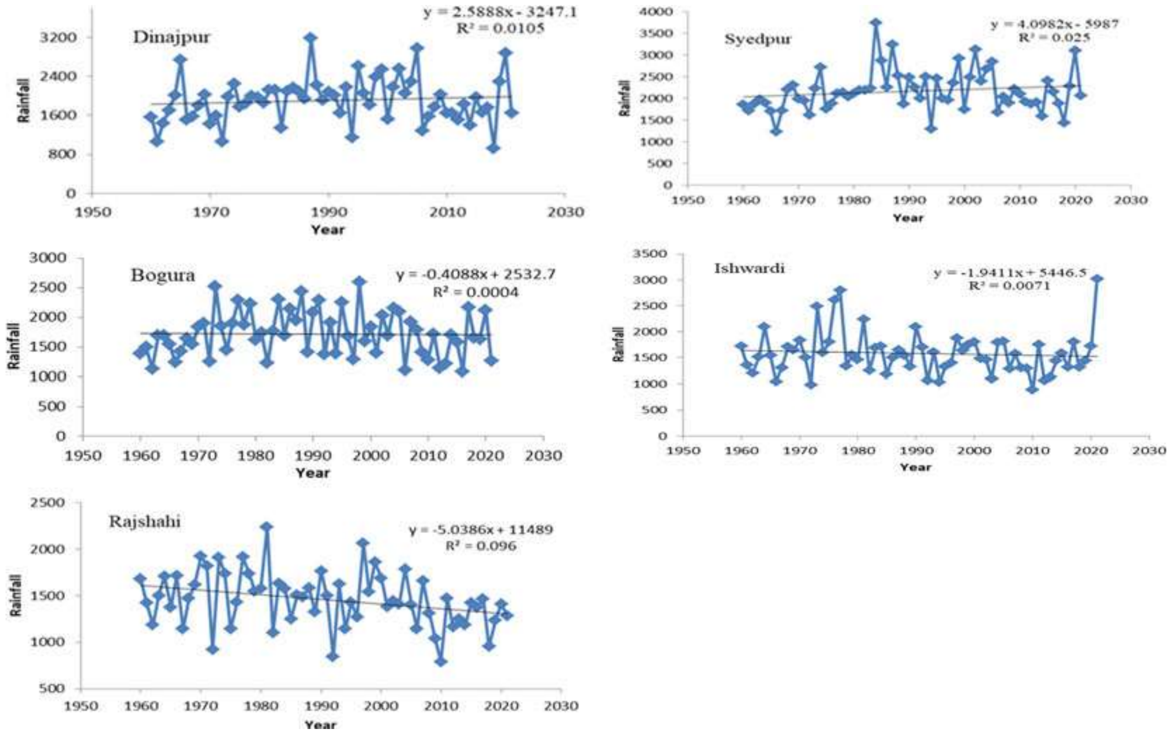


Fig. 5.5 Linear regression trends of annual average rainfall in northwest Bangladesh at five stations during 1960–2021

The linear trend line of yearly rainfall in the northwest region during 1960–2021 is displayed in (Fig. 5.5). The graph indicates that the trend line is decreasing at Bogura, Ishwardi, and Rajshahi stations, while an increasing annual average rainfall at Syedpur and Dinajpur stations.

5.3.4 Annual Temperature Features

The long-term annual mean temperature in the northwest recorded stations was 24.96 °C, and the temperature ranged from 24.30 °C (Syedpur) to 25.30 °C (Rajshahi). Based on historical temperature data, the warmer average extreme temperature varied from 26.57 °C to 25.35 °C, and the cooler average minimum temperature lied between 20.64 °C and 24.67 °C. It was evident that (Table 5.4) along with other descriptive analysis of annual temperature, the standard deviation was high (0.75 °C) at Syedpur station and low (0.31 °C) at Bogura station. The coefficient of variation of temperature data varied from 1.24% to 3.07% at different stations. It means Syedpur station observed maximum temperature variation. The long-term annual mean temperature is shown in (Fig. 5.6a) by spatial distribution analysis. The temperature dataset

Table 5.4 Descriptive statistics of the annual mean temperature of Bangladesh (1960–2021)

Stations	Annual temperature (°C)						
	Min	Max	Mean	CV (%)	SD	Skewness	Kurtosis
Bogura	24.67	26.08	25.24	1.24	0.31	0.613	0.204
Dinajpur	24.10	26.03	24.90	1.75	0.43	0.835	0.521
Ishwardi	24.12	26.26	25.08	1.52	0.38	0.242	1.369
Rajshahi	24.43	26.57	25.30	1.84	0.47	0.856	0.369
Syedpur	20.64	25.35	24.30	3.07	0.75	− 2.504	9.380

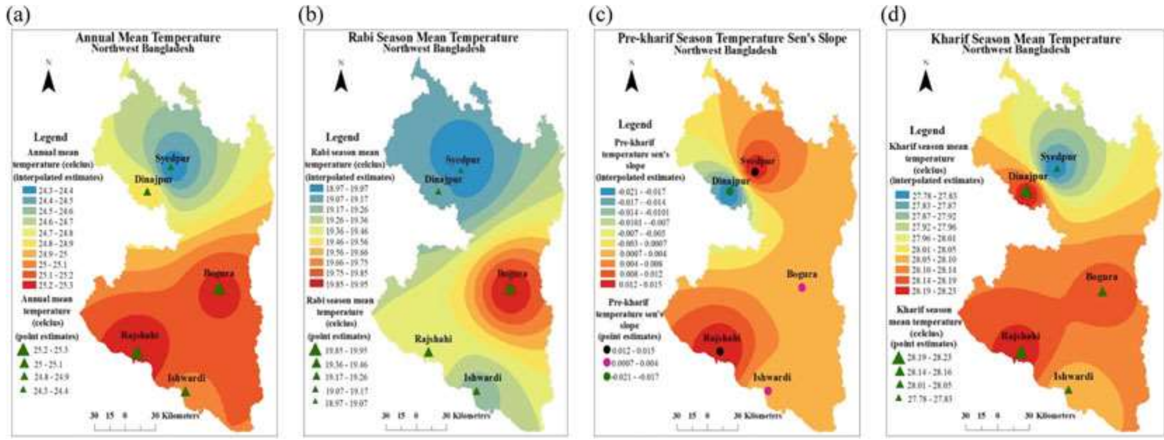


Fig. 5.6 Distributions of **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

was positively skewed in four stations, except Syedpur stations which found negative skewness. Similar results were identified for kurtosis. From the analysis, it is clearly said that the datasets are leptokurtic not mesokurtic.

5.3.5 Trend Analysis of Annual Temperature

The annual mean temperature observed that 80% of the stations displayed an increasing trend, except Dinajpur station which found decreasing trend (Table 5.5). During 60 year period, the highest significant rising trend was found at Bogura and Syedpur stations by the MK test statistic (*Z*) and SR test, and the magnitude of changes discovered by the Sen's slope estimates were 0.0095 °C/year and 0.017 °C/year, respectively. Ishwardi and Rajshahi stations also presented rising tendencies in annual temperature analysis, but not statistically significant. Apart from that, only Dinajpur station was shown falling trend with the MK test (− 1.014) and SR test (− 1.655), and the rate of change assessed by the Sen's estimates was − 0.003 °C/year. Meanwhile, Kendall's tau received positive relationships over time. The spatial distribution of average annual temperature is displayed in (Figs. 5.7a and 5.8a). Over the years, upward trend of temperature is dominating in this part of the country which will create more dry years and extreme temperature in the future. Linear trend analyses of the long-term annual temperature are shown in (Fig. 5.9).

5.3.6 Trend Analysis of Seasonal Temperature

5.3.6.1 Rabi Season

This season is characterized by the coldest temperature in Bangladesh, generally referred to as winter. The average temperature during *Rabi*

Table 5.5 Long-term annual temperature trend test results

Stations	MK test	Sen's slope	Kendall's tau	SR test
Bogura	4.514*	0.0095*	0.395*	5.040
Dinajpur	− 1.014	− 0.003	− 0.089	− 1.655
Ishwardi	1.451	0.004	0.130	1.390
Rajshahi	1.233	0.004	0.109	1.044
Syedpur	5.674*	0.017*	0.495*	7.259*

* Significant trends at 5% level, Sen's slope unit is in mm per year

season fluctuates from 18.97 to 19.95 °C with an average value 19.32 °C. In this season, the minimum temperature at different stations varied from 16.91 °C (Syedpur) to 18.78 °C (Bogura), and the maximum temperature ranged from 20.60 °C (Syedpur) to 21.52 °C (Rajshahi) (Fig. 5.6b). The coefficient of variation of temperature data varied from 2.51 to 4.16%; i.e., low-temperature variability was found at Bogura station, and high-temperature variability was described at Dinajpur station. The MK and SR test findings indicated that the trend fluctuations were identified by both positive and negative directions. According to the 60 years of historical data, 60% stations (Dinajpur, Ishwardi, and Rajshahi) showed a decreasing trend and 40% stations (Syedpur and Dinajpur) experienced a rising trend with the MK test results or SR test analysis (Table 5.6). The values of MK test statistic (Z) ranged from − 0.83 to 2.81. The degree of change evaluated by Sen's slope estimates was − 0.09, − 0.004, and − 0.01 °C/year at Dinajpur, Ishwardi, and Rajshahi stations, respectively, but statistically insignificant (Table 5.6). From the study, only Syedpur station revealed a significant rate of change with 0.014 °C/year. The spatial distribution of MK test statistic (Z) and Sen's slope estimates is displayed in (Figs. 5.7b and 5.8b).

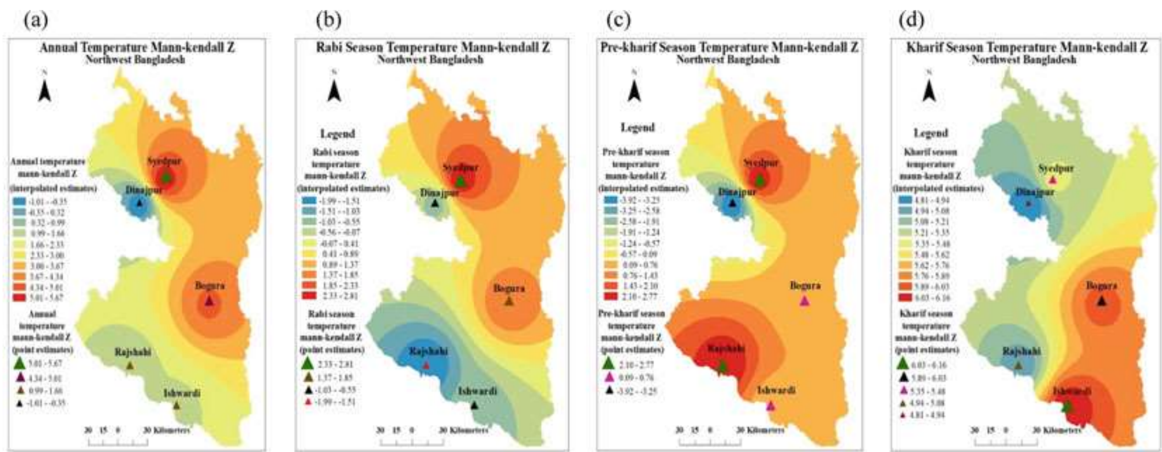


Fig. 5.7 Distributions of Z statistics estimates **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

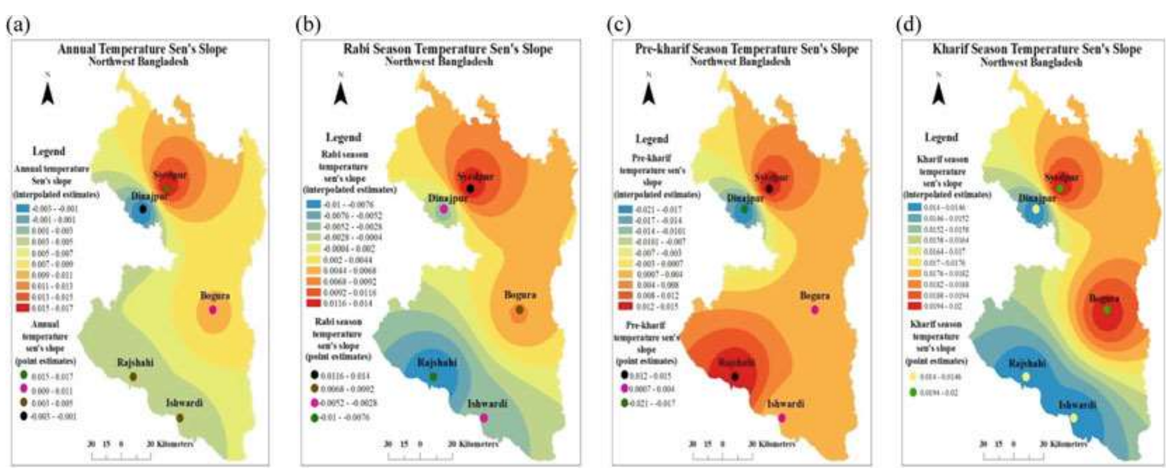


Fig. 5.8 Distribution of Sen's slope estimates **a** Annual average temperature **b** *Rabi* temperature **c** Pre-*Kharif* temperature **d** *Kharif* temperature

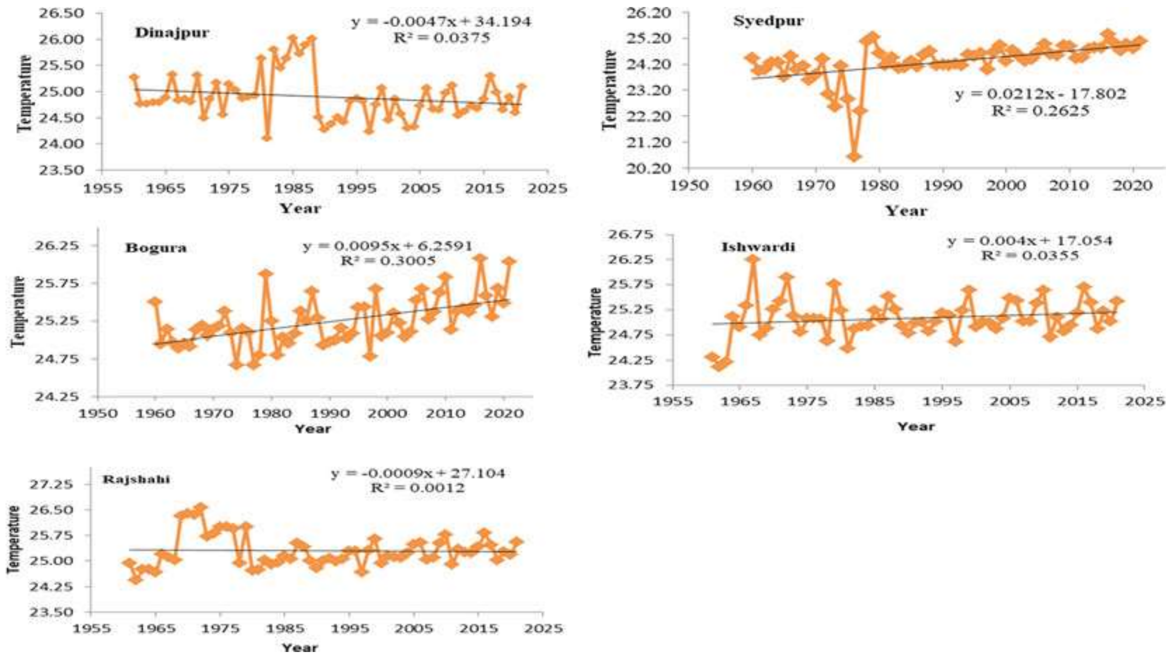


Fig. 5.9 Linear regression trends of annual average temperature during 1960–2021

5.3.6.2 Pre-Kharif Season

During the pre-*Kharif* season temperature analysis, Rajshahi station found average maximum temperature of 30.66 °C, while Syedpur station received 20.68 °C minimum average temperature. The overall average temperature ranged from 26.14 °C to 28.25 °C with a mean value of 27.47 °C. The standard deviation of pre-*Kharif* season temperature varied from 0.63 °C to 1.27 °C, and the CV showed 2.27% at Bogura station and high 4.85% at Syedpur station (Fig. 5.6c). In the study area, 80% of stations observed a strongly positive trend, while 20% station showed negative trend. From trend analysis, Dinajpur, Rajshahi, and Syedpur were statistically significant, but other two stations (Bagura, Ishwardi) were insignificant with increasing trends. Both the MK test and SR test revealed identical result, but only the Rajshahi station showed decreasing trend of − 0.744 in the SR test (Table 5.6). The proportion of change assessed by the Sen's slope estimates ranged from − 0.02 to 0.02 °C/year. However, a station like Dinajpur showed only a significant downward trend at 95% confidence interval, and the magnitude of change was –0.02 °C/year (Table 5.6). The areal dissemination of different stations indicates that in the future temperature trend is more increasing in the northwest region (Figs. 5.7c and 5.8c).

Table 5.6 Long-term seasonal temperature trend test results

Stations	Rabi season			Pre-Kharif season			Kharif season		
	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test	MK test	Sen's slope	SR test
Bogura	1.85	0.007	1.875	0.48	0.003	0.512	5.95*	0.02*	7.542*
Dinajpur	− 0.890	− 0.09	− 1.130	− 3.92*	− 0.02*	− 4.9*	4.81*	0.01*	5.529*
Ishwardi	− 0.834	− 0.004	− 0.799	0.24	0.001	0.227	6.16*	0.01*	8.016*
Rajshahi	− 1.99	− 0.01	− 1.671	2.77*	0.015*	− 0.744	4.96*	0.01*	6.118*
Syedpur	2.81*	0.014*	2.956*	2.77*	0.02*	2.753*	5.41*	0.02*	6.216*

* Significant trends at 5% level, Sen's slope unit is in mm per yer

5.3.6.3 *Kharif* Season

The *Kharif* season, which runs from July through October, is primarily referred to as a rainy season of Bangladesh. The annual average temperature during this time varied from 27.28 °C (Syedpur) to 28.23 °C (Dinajpur), with a mean value of 28.08 °C. The maximum average temperature ranged from 29.33 °C to 29.03 °C, and the minimum average temperature varied from 21.78 °C to 26.70 °C (Fig. 5.6d). The standard deviation of *Kharif* season temperature was low (0.35 °C) at Ishwardi station and comparatively high (1.13 °C) at Syedpur station. Among all the stations, the coefficient of variation was maximum at Syedpur station with 4.08%. Trend analysis of different stations revealed that significant rising trends were found at all five stations, which means the temperature was increased rapidly in the *Kharif* season. The MK test result showed that Ishwardi station experienced the highest positive trend (6.16), while Dinajpur station found the least positive trend (4.81) at 95% confidence interval. Almost similar result was predicted by the SR test analysis. Sen's slope analysis points out that the degree of change varied from 0.01 to 0.02 °C/year with an average 0.014 °C/year (Table 5.6). The spatial map of MK test and Sen's slope estimates is displayed in (Figs. 5.7d and 5.8d) which indicates that significant rising trend continues in the northwest region.

The linear trend analysis during 1960–2021 is displayed in (Fig. 5.9). The graphical analysis indicates that annual average temperature trend lines are decreasing at Dinajpur and Rajshahi stations and increasing at Syedpur, Bogura, and Iswardi stations.

5.3.7 Sequential Mann–Kendall (SMK) Analysis for Annual Rainfall and Temperature

5.3.7.1 Annual Rainfall

The SMK test determines the approximate year where the trend begins at 95% confidence limit. Results from the SMK test revealed that considering $u(t)$ statistics had almost similar to the MK test with decreasing trend at Bogura, Rajshahi, and Ishwardi stations. Here, no,-significant change of points is depicted in Bogura and Ishwardi station, but some abrupt change in annual rainfall was found 15 years ago at Rajshahi station approximately with a significant change point. The rest of the stations (Dinajpur and Syedpur) showed rising trend that starts early year of 1960 to 1965 but noticeable decreasing changes also display after 2004–2005. The SMK plot of different stations in the northwest zone is displayed in (Fig. 5.10).

5.3.7.2 Annual Temperature

The annual temperature analysis of the SMK test exhibited an upward tendency in almost all stations except Dinajpur. From trend analysis, more than one non-significant trend turning points was described at Dinajpur, Ishwardi, and Rajshahi stations, but only Dinajpur station discovered decreasing trend which starts from 1988 to 1990 and it continued till 2020. On the other hand, Rajshahi and Ishwardi stations also found periodic fluctuations between the late 1990s and 2020. A periodic significant upward trend was detected at Bogura and Syedpur stations defining only a trend turning point in the year 2003–2004, and the increment continued. It means that the temperature trend analysis method is dominant after 2003–2004 for Bogura and Syedpur stations. The following Fig. 5.11 represents SMK test analysis trend of annual temperature of different station.

5.3.8 Forecast from ARIMA Models

According to different trend analysis methods, the northwest zone experiences high temperatures and less rainfall throughout the year. The country's economy mostly depends on agricultural production, and about 80% of the population, directly and indirectly, depends on primary economic activities (Kamruzzaman et al. 2018). In our country, the summer monsoon receives the most precipitation, which directly affects our agricultural productivity. Adequate information on total rainfall and temperature characteristics helps our

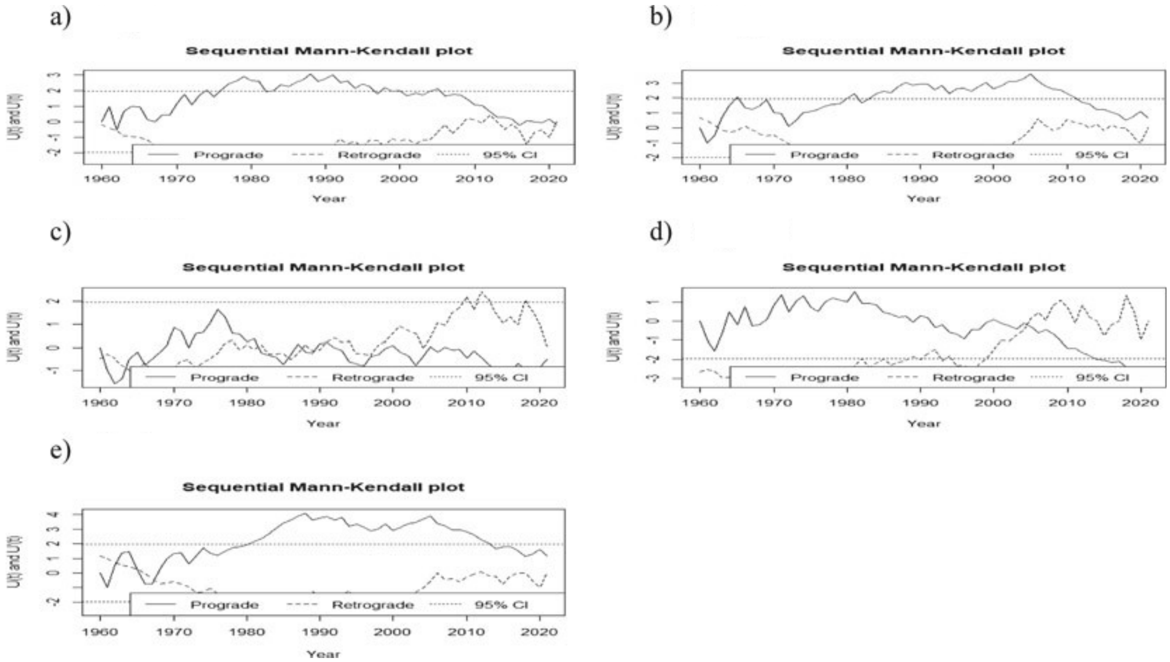


Fig. 5.10 Detection of annual rainfall trends **a** Bogura **b** Dinajpur **c** Ishwardi **d** Rajshahi **e** Syedpur by sequential MK analysis

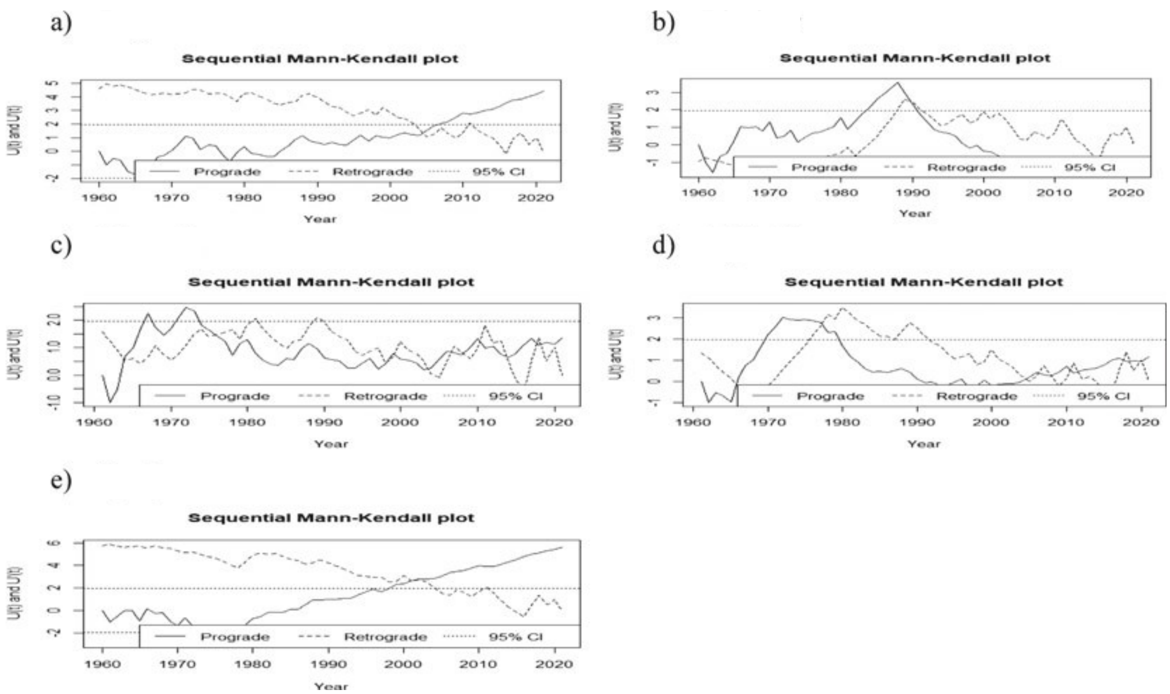


Fig. 5.11 Detection of annual temperature trends **a** Bogura **b** Dinajpur **c** Ishwardi **d** Rajshahi **e** Syedpur by sequential MK analysis

farmers and policymakers to draw a comprehensive picture of the monsoon and dry seasons. Early climate prediction lessens significant crop damage from drought, flood, and other climatic calamities. Moreover, if the total annual rainfall is normal, the intra-seasonal variability, such as early monsoon onset or usual monsoon throughout the year, may cause unavoidable disruption of agricultural activities, hydro-electric power supply, groundwater depletion, or even drinking water supply. The ARIMA technique is applied here to forecast monthly rainfall and temperature data for future five years (60 months) based on sixty years data. Previous years' data is cast-off to articulate the seasonal ARIMA model in determining model parameters.

5.3.8.1 Monthly Rainfall Forecast

Sixty years of monthly rainfall data is analyzed and used to predict future rainfall scenarios. The following table provides the estimated parameters for the ARIMA model of monthly rainfall (Table 5.7).

The station-wise forecasting values of the next five years monthly rainfall of different stations are displayed in (Fig. 5.12). In our study, monthly rainfall varied one station to another due to the diverse geographical locations.

5.3.8.2 Monthly Temperature Forecast

The monthly temperature predictions of all stations are detailed below (Table 5.8). The expected parameters of the ARIMA model for the next five years are based on the previous sixty years data.

It has been detected that the monthly predicting temperature not only fluctuates in one station with a small margin (Fig. 5.13) but also fluctuates from one station to another. Moreover, the temperature has been rising over the years in the northwest zone, and gradually it will increase in the near future also.

5.4 Conclusion

The present chapter elaborates on the latest trends in rainfall variability and temperature during 1960–2021 at five distinguished weather stations in the northwest Bangladesh. The MK test and SR test are equally effective in assessing rainfall and temperature trends. Sen's estimation also gives excellent results, and it is almost identical to the MK test statistic and SR test results. From the recent research work, it is established that the average annual rainfall is 1768 mm and temperature is 24.96 °C. Whereas Syedpur station shows the highest amount of annual average rainfall, Rajshahi station receives the maximum average temperature in the northwest zone. The study findings discover that only Rajshahi station shows maximum significant downward trend of annual rainfall (− 5.50 mm/year), as well as the *Kharif* season (− 3.80 mm/year) also by Sen's estimation. However, other stations represent increasing/decreasing trend by the MK test, SR test, and Sen's slope estimator, but they are not statistically significant. The total rainfall statistic exhibits a substantial change during the research period. These kinds of changes in most of the

Table 5.7 ARIMA models of monthly rainfall data

Station	Month January 1960–December 2021				
	Model	Sigma^2 estimated	Log-likelihood	AIC	BIC
Bogura	ARIMA(0,0,1)(1,1,0)[12]	14,253	− 4540.04	9086.09	9099.87
Dinajpur	ARIMA(0,0,3)(2,1,0)[12]	17,660	− 4618.73	9249.45	9277.0
Ishwardi	ARIMA(1,0,0)(1,1,0)[12]	13,235	− 4513.08	9032.16	9045.95
Rajshahi	ARIMA(1,0,0)(1,1,0)[12] with drift	9365	− 4386.2	8780.4	8798.78
Syedpur	ARIMA(1,0,0)(1,1,0)[12] with drift	21,813	− 4695.41	9398.83	9417.21

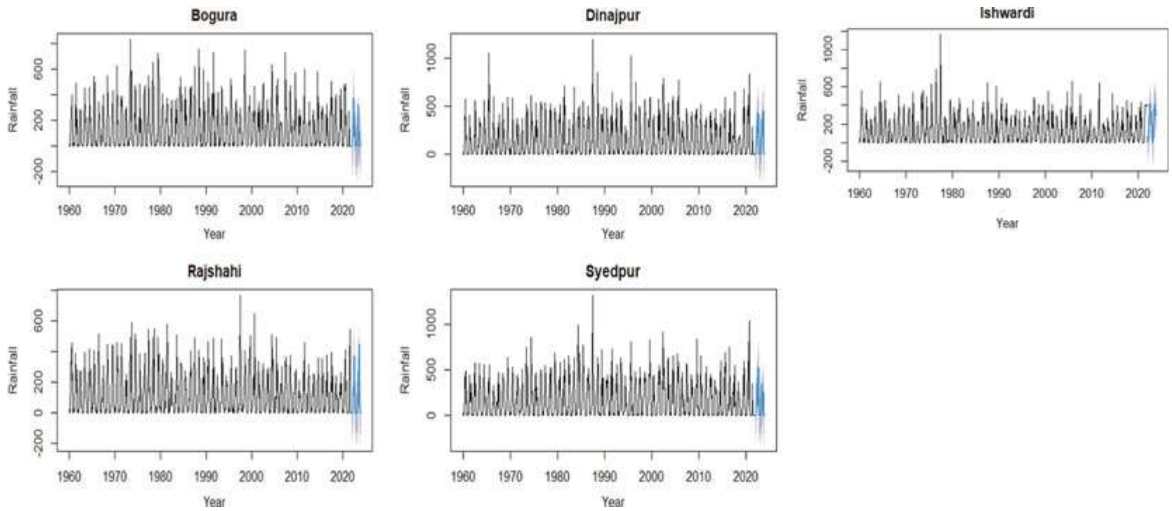


Fig. 5.12 Forecasting monthly rainfall of different stations

Table 5.8 ARIMA models of monthly temperature data

Station	Month January 1960–December 2021				
	Model	Sigma^2 estimated	Log-likelihood	AIC	BIC
Bogura	ARIMA(2,0,2)(2,1,0)[12] with drift	1.103	− 1073.5	2163	2199.76
Dinajpur	ARIMA(0,0,3)(2,1,2)[12]	0.9458	− 1023.63	2063.27	2100.03
Ishwardi	ARIMA(2,0,2)(2,1,2)[12]	0.6953	− 897.94	1813.89	1855.1
Rajshahi	ARIMA(0,0,2)(0,1,1)[12] with drift	0.8151	− 954.94	1919.88	1942.78
Syedpur	ARIMA(0,0,1)(0,1,1)[12] with drift	1.317	− 1146.91	2301.82	2320.2

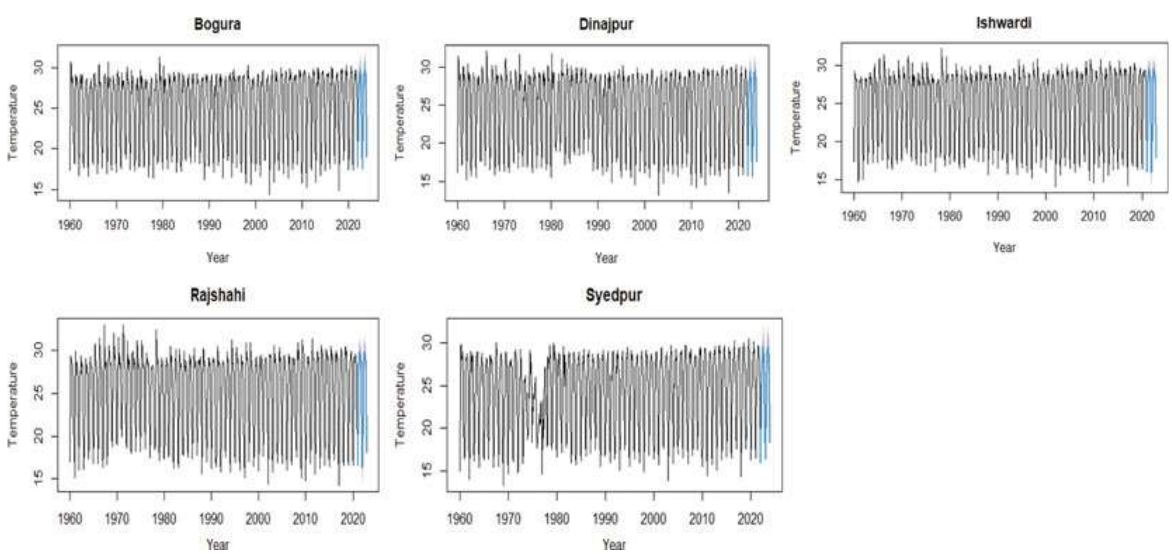


Fig. 5.13 Forecasting monthly temperature of different stations

stations placed the northwest region in danger and increased drought frequency. However, climate variable like temperature also observed an increasing trend 80% of stations, but Dinajpur station reveals a falling trend with a magnitude of change − 0.003 °C/year. From cropping season temperature trend analysis, both upward and downward trends are found during the *Rabi* and pre-*Kharif* seasons. But *Kharif* season shows noteworthy trend of increment at 5% significance level. The degree of change is assessed by Sen's slope estimates which differ from 0.01 to 0.02 °C per year with an average value of 0.014 °C per year. Additionally, SMK analysis has illustrated the starting and turning points of the annual trends. In this chapter, the ARIMA models are used for long-term monthly rainfall and temperature data to forecast future trend in the northwest region. Based on the findings, the information is gathered consistently with the previous studies and will be supportive for farmers, policymakers and researchers on local-scale scheduling on climate change scenarios of the country. Therefore, sustainable adaptation practices are mandatory for agricultural development in the northwest area.

References

Adams RM, Hurd BH, Lenhart S et al (1998) Effects of global climate change on agriculture: an interpretative review. Climate Res 11(1):19–30

Akter KS, Rahman M (2012) Spatio-temporal quantification and characterization of drought patterns in Bangladesh. J Water Environ Technol 10(3):277–288. https://doi.org/10.2965/jwet.2012.277

Alam J, Saha P, Mitra R, Das J (2023) Investigation of spatio-temporal variability of meteorological drought in the Luni River Basin, Rajasthan, India. Arab J Geosci 16(3):201. https://doi.org/10.1007/s12517-023-11290-8

Alamgir M, Shahid S, Hazarika MK, Nashrrullah S, Harurn SB, Shamsudin S et al (2015) Analysis of meteorological drought pattern during different climatic and cropping seasons in Bangladesh. JAWRA J Am Water Resour Assoc 51(3):794–806. https://doi.org/10.1111/jawr.12276

Allen RJ, DeGaetano AT (2001) Estimating missing daily temperature extremes using an optimized regression approach. Int J Climatol 21(11):1305–1319. https://doi.org/10.1002/joc.679

Banglapedia (2003) Bangladesh Asiatic Society, Dhaka

Bari SH, Rahman MTU, Hoque MA et al (2016) Analysis of seasonal and annual rainfall trends in the northern region of Bangladesh. Atmos Res 176–177. https://doi.org/10.1016/j.atmosres.2016.02.008

Basak A, Rahman ATMS, Das J, Hosonod T, Kisi O (2022) Drought forecasting using the Prophet Model in semi-arid climate region of western India. Hydrol Sci J 67(9):1397–1417. https://doi.org/10.1080/02626667.2022.2082876

BBS (2019a) Statistical Yearbook of Bangladesh 2018. Bangladesh Bureau of Statistics. Government of The People's Republic of Bangladesh, Dhaka

BBS (2019b) Report on Agriculture and Rural Statistics 2018. Bangladesh Bureau of Statistics. Government of The People's Republic of Bangladesh, Dhaka

Bhuyan Md DI, Islam M, Bhuiyan K et al (2018) A trend analysis of temperature and rainfall to predict climate change for Northwestern region of Bangladesh. Am J Clim Change 07(02):115–134. https://doi.org/10.4236/ajcc.2018.72009

Box EP, Jenkins GM (1976) Time series analysis: forecasting and control (Revised edition). San Francisco, Holden Day

Das J, Bhattacharya SK (2018) Trend analysis of long-term climatic parameters in Dinhata of Koch Bihar district, West Bengal. Spatial Inf Res 26(3):271–280. https://doi.org/10.1007/s41324-018-0173-3

Das J, Mandal T, Saha P (2019) Spatio-temporal trend and change point detection of winter temperature of North Bengal, India. Spatial Inf Res 27(4):411–424. https://doi.org/10.1007/s41324-019-00241-9

Das J, Gayen A, Saha P, Bhattacharya SK (2020a) Meteorological drought analysis using Standardized Precipitation Index over Luni River Basin in Rajasthan, India. SN Appl Sci 2(9):1–17. https://doi.org/10.1007/s42452-020-03321-w

Das J, Rahman AS, Mandal T, Saha P (2020b) Challenges of sustainable groundwater management for large scale irrigation under changing climate in Lower Ganga River basin in India. Groundw Sustain Dev 11(1–11):100449. https://doi.org/10.1016/j.gsd.2020.100449

Das J, Mandal T, Saha P, Bhattacharya SK (2020b) Variability and trends of rainfall using non-parametric approaches: a case study of semi-arid area. MAUSAM 71(1):33–44. https://doi.org/10.54302/mausam.v71i1.4

Das J, Mandal T, Rahman S et al (2021a) Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches. Theoret Appl Climatol 143(3–4):1557–1579. https://doi.org/10.1007/s00704-020-03508-6

Das J, Rahman AS, Mandal T, Saha P (2021b) Exploring driving forces of large-scale unsustainable groundwater development for irrigation in lower Ganga River basin in India. Environ Dev Sustain 23(5):7289–7309. https://doi.org/10.1007/s10668-020-00917-5

Dimri T, Ahmad S, Sharif M et al (2020) Time series analysis of climate variables using seasonal ARIMA approach. J Earth Syst Sci 129(1):149. https://doi.org/10.1007/s12040-020-01408-x

Eischeid JK, Baker CB, Karl TR et al (1995) The quality control of long-term climatological data using objective data analysis. J Appl Meteorol 34:2787–2795

Enders CK (2010) Applied missing data analysis. The Guilford Press, New York. http://books.google.co.ke/. ISBN: 978-1 60623-639-0 Assessed 20 Nov 2022

Esteban-Parra MJ, Rodrigo FS, Castro-Díez Y et al (1995) Temperature trends and change points in the northern Spanish Plateau during the last 100 years. Int J Climatol 15(9):1031–1042. https://doi.org/10.1002/joc.3370150909

Hossain M, Roy K, Datta D et al (2014) Spatial and temporal variability of rainfall over the South-West Coast of Bangladesh. Climate 2(2):28–46. https://doi.org/10.3390/cli2020028

Ingsrisawang L, Potawee D (2012) Multiple imputations for missing data in repeated measurements using MCMC and copulas. In: Proceedings of the international multi conference of engineers and computer scientist 2012. Assessed 20 July 2013

IPCC (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (eds)]. IPCC, Geneva, Switzerland, p 151

Islam M, Hossain M, Sikder M et al (2019a) Farmers' adaptation strategies to drought and their determinants in Barind tract, Bangladesh. SAARC J Agric 17 (1):161–174. https://doi.org/10.3329/sja.v17i1.42769

Islam MS, Hossain MZ, Sikder MB et al (2019b) Drought adaptation measures and their effectiveness at Barind Tract in northwest Bangladesh: a perception study. Nat Hazards 97(3):1253–1276. https://doi.org/10.1007/s11069-019-03704-2

Islam T, Karim MR, Mondol AH et al (2021) Appraising trends and forecasting of hydroclimatic variables in the north and northeast regions of Bangladesh. Theor Appl Climatol 143(1–2):33–50. https://doi.org/10.1007/s00704-020-03411-0

Kamruzzaman M, Rahman MS, Ahmed MS et al (2018) Spatio-temporal analysis of climatic variables in the western part of Bangladesh. Environ Dev Sustain 20 (1):89–108. https://doi.org/10.1007/s10668-016-9872-x

Kamruzzaman M, Rahman MS, Basak A et al (2022) Assessment and adaptation strategies of climate change through the prism of farmers' perception: a case study. Int J Environ Sci Technol. https://doi.org/10.1007/s13762-022-04254-0

Karim F, Mainuddin M, Hasan M et al (2020) Assessing the potential impacts of climate changes on rainfall and evapotranspiration in the Northwest Region of Bangladesh. Climate 8(8):94. https://doi.org/10.3390/cli8080094

Kemp WP, Burnell DG, Everson DO, Thomson AJ et al (1983) Estimating missing daily maximum and minimum temperatures. J App Meteorol Climatol 22 (9):1587–1593

Kendall MG (1948) Rank correlation methods. 4th edition. Charles Griffin, London

Khan HR, Rahman A, Luo C, Kumar S et al (2019) Detection of changes and trends in climatic variables in Bangladesh during 1988–2017. Heliyon 5(3):e01268. https://doi.org/10.1016/j.heliyon.2019.e01268

Kirby JM, Ahmad MD, Mainuddin M et al (2015) The impact of irrigation development on regional groundwater resources in Bangladesh. Agric Water Manag 159: 264–276. https://doi.org/10.1016/j.agwat.2015.05.026

Mainuddin M, Kirby M (2015) National food security in Bangladesh to 2050. Food Secur 7(3):633–646. https://doi.org/10.1007/s12571-015-0465-6

Mainuddin M, Peña-Arancibia JL, Karim F et al (2022) Long-term spatio-temporal variability and trends in rainfall and temperature extremes and their potential risk to rice production in Bangladesh. PLOS Climate 1 (3):e0000009. https://doi.org/10.1371/journal.pclm.0000009

Makokha GL, Shisanya CA (2010) Trends in mean annual minimum and maximum near surface temperature in Nairobi City, Kenya. Adv Meteorol 2010:1–6. https://doi.org/10.1155/2010/676041

Mann HB (1945) Nonparametric tests against trend. Econometrica 13(3):245. https://doi.org/10.2307/1907187

Michiels P, Gabriels D, Hartmann R et al (1992) Using the seasonal and temporal Precipitation concentration index for characterizing the monthly rainfall distribution in Spain. CATENA19(1):43–58. https://doi.org/10.1016/0341-8162(92)90016-5

Mondol AH, Al-Mamun, Iqbal Metal (2018) Precipitation concentration in Bangladesh over different temporal periods. Adv Meteorol 2018:1–18. https://doi.org/10.1155/2018/1849050

Mosmann V, Castro A, Fraile R (2004) Detection of statistically significant trends in the summer precipitation of mainland Spain. Atmos Res 70(1):43–53. https://doi.org/10.1016/j.atmosres.2003.11.002

Mullick MRA, Nur RM, Alam MJ et al (2019) Observed trends in temperature and rainfall in Bangladesh using pre-whitening approach. Global Planet Change 172:104–113. https://doi.org/10.1016/j.gloplacha.2018.10.001

Nalley D, Adamowski J, Khalil B et al (2013) Trend detection in surface air temperature in Ontario and Quebec, Canada during 1967–2006 using the discrete wavelet transform. Atmos Res 375–398. https://doi.org/10.1016/j.atmosres.2013.06.011

Oliver JE (1980) Monthly precipitation distribution: a comparative index. Prof Geogr 32(3):300–309. https://doi.org/10.1111/j.0033-0124.1980.00300.x

Praveen B, Talukdar S, Shahfahad et al (2020) Analyzing trend and forecasting of rainfall changes in India using non-parametrical and machine learning approaches. Sci Rep 10(1):10342. https://doi.org/10.1038/s41598-020-67228-7

Rahman MR, Lateh H (2016) Spatio-temporal analysis of warming in Bangladesh using recent observed temperature data and GIS. Clim Dyn 46(9–10):2943–2960. https://doi.org/10.1007/s00382-015-2742-7

Rahman MR, Lateh H (2017) Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model. Theoret Appl Climatol 128 (1–2):27–41. https://doi.org/10.1007/s00704-015-1688-3

Rahman AS, Kamruzzama Md, Jahan CS et al (2016a) Long-term trend analysis of water table using 'MAKESENS' model and sustainability of groundwater resources in drought prone Barind area, NW Bangladesh. J Geol Soc India 87(2):179–193. https://doi.org/10.1007/s12594-016-0386-9

Rahman MS, Kamruzzaman M, Jahan CS et al (2016b) Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics. Sustain Water Resour Manag 2(3):297–312. https://doi.org/10.1007/s40899-016-0057-4

Rahman MA, Yunsheng L, Sultana N et al (2017) Analysis and prediction of rainfall trends over Bangladesh using Mann-Kendall, Spearman's rho tests and ARIMA model. Meteorol Atmos Phys 129(4):409–424. https://doi.org/10.1007/s00703-016-0479-4

Rashid HE (1991) Geography of Bangladesh. University Press Ltd., Dhaka (Bangladesh)

Recha CW, Makokha GL, Traore PS et al (2012) Determination of seasonal rainfall variability, onset and cessation in semi-arid Tharaka district, Kenya. Theor Appl Climatol 108(3–4):479–494. https://doi.org/10.1007/s00704-011-0544-3

Sa'adi Z, Shahid S, Ismail T, Chung E-S et al (2019) Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann-Kendall test. Meteorol Atmos Phys 131(3):263–277. https://doi.org/10.1007/s00703-017-0564-3

Salam R, Towfiqul AR, Islam S et al (2020) Spatiotemporal distribution and prediction of groundwater level linked to ENSO teleconnection indices in the northwestern region of Bangladesh. Environ Dev Sustain 22(5):4509–4535. https://doi.org/10.1007/s10668-019-00395-4

Sen PK (1968) Estimates of the regression coefficient based on Kendall's Tau. J Am Stat Assoc 63 (324):1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Shadmani M, Marofi S, Roknian M et al (2012) Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho tests in Arid Regions of Iran. Water Resour Manage 26(1):211–224. https://doi.org/10.1007/s11269-011-9913-z

Shahid S (2010) Rainfall variability and the trends of wet and dry periods in Bangladesh. Int J Climatol 30 (15):2299–2313. https://doi.org/10.1002/joc.2053

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

Shahid S, Khairulmaini OS (2009) Spatio-Temporal variability of rainfall over Bangladesh during the time period 1969–2003. Asia-Pac J Atmos Sci 45(3):375–389

Shahid S, Harun SB, Katimon A et al (2012) Changes in diurnal temperature range in Bangladesh during the time period 1961–2008. Atmos Res 118:260–270. https://doi.org/10.1016/j.atmosres.2012.07.008

Shaw R, Mallick F, Islam, A (eds) (2013) Climate change adaptation actions in Bangladesh. Springer, Japan. https://doi.org/10.1007/978-4-431-54249-0

Sneyers R (1990) On the statistical analysis of series of observations. Secr. of the World Meteorological Organization. World Meteorological Organization, ISBN 978-92-63-10415-1

Spearman C (2010) The proof and measurement of association between two things. Int J Epidemiol 39 (5):1137–1150. https://doi.org/10.1093/ije/dyq191

Tabari H, Talaee PH (2011) Temporal variability of precipitation over Iran: 1966–2005. J Hydrol 396(3–4):313–320. https://doi.org/10.1016/j.jhydrol.2010.11.034

Tonkaz T, Çetin M, Tülücü K et al (2007) The impact of water resources development projects on water vapor pressure trends in a semi-arid region, Turkey. Clim Change 82(1–2):195–209. https://doi.org/10.1007/s10584-006-9160-0

Uddin MA, Kamal AM, Shahid S et al (2020a) Volatility in rainfall and predictability of droughts in Northwest Bangladesh. Sustainability 12(23):9810. https://doi.org/10.3390/su12239810

Uddin MJ, Hu J, Islam MT et al (2020b) A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. Arab J Geosci 13(9):323. https://doi.org/10.1007/s12517-020-05302-0

Yu WH, Alam M, Hassan A et al (2010) Climate change risks and food security in Bangladesh. Earthscan London, Washington, DC

Yu Z, Lei G, Jiang Z, Liu F et al (2017) ARIMA modeling and forecasting of water level in the middle reach of the Yangtze River. In: 2017 4th International Conference on Transportation Information and Safety (ICTIS), pp 172–177. https://doi.org/10.1109/ICTIS.2017.8047762

Yue S, Pilon P, Cavadias G (2002a) Power of the Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J Hydrol 259(1–4):254–271. https://doi.org/10.1016/S0022-1694(01)00594-7

Yue S, Pilon P, Phinney B et al (2002b) The influence of autocorrelation on the ability to detect trend in hydrological series. Hydrol Process 16(9):1807–1829. https://doi.org/10.1002/hyp.1095

Zhang Q, Xu C-Y, Zhang Z (2009) Observed changes of drought/wetness episodes in the Pearl River basin, China, using the standardized precipitation index and aridity index. Theoret Appl Climatol 98(1–2):89–99. https://doi.org/10.1007/s00704-008-0095-4

Md. Kamruzzaman <mkzaman@ru.ac.bd>

Acceptance letter

3 messages

Dr. Jayanta Das <jayanta.daas@gmail.com> Wed, Jan 17, 2024 at 6:22 PM
To: "Md. Kamruzzaman" <mkzaman@ru.ac.bd>

Dear Md. Kamruzzaman,
Corresponding Author
I am pleased to inform you that your research paper entitled **"Determinants of Local Farmers' Adaptation Strategies to Drought Vulnerability: Evidence from Northwest Bangladesh"** authored by J. M. Adeeb Salman Chowdhury, Md. Abdul Khalek, Jayanta Das, Md. Kamruzzaman has been accepted for publication in the Special Issue of the Indian Journal of Spatial Science scheduled for February 2024. This decision was reached after a thorough review process and careful consideration of the quality and relevance of your research.

Your paper will make a valuable contribution to our journal, and we believe it will be of great interest to our readers. We appreciate the effort and dedication you and your co-authors have put into conducting this research and preparing the manuscript.

Once again, congratulations on the acceptance of your paper, and we look forward to publishing your work in the Indian Journal of Spatial Science. Your contribution will undoubtedly enrich our journal and benefit the academic community.

Thank you for choosing our journal as the platform to disseminate your research findings.

Sincerely,

Dr. Jayanta Das
Guest Editor
Indian Journal of Spatial Science

--
Regards
Dr. Jayanta Das
HOD, Assistant Professor
Department of Geography
Rampurhat College
Affiliated to The University of Burdwan
Rampurhat, Birbhum, West Bengal, India, Pin 731224
Mobile- (+91) 9735333399

Md. Kamruzzaman <mkzaman@ru.ac.bd> Wed, Jan 17, 2024 at 6:34 PM
To: adeeb_cu@yahoo.com

[Quoted text hidden]

Md. Kamruzzaman <mkzaman@ru.ac.bd> Wed, Jan 17, 2024 at 6:36 PM
To: adeeb_cu@yahoo.com

Thank you so much for your nice cooperation.
[Quoted text hidden]

Determinants of Local Farmers' Adaptation Strategies to Drought Vulnerability: Evidence from Northwest Bangladesh

J. M. Adeeb Salman Chowdhury[1 4], Md. Abdul Khalek[2], Jayanta Das[3], Md. Kamruzzaman[4*]
[1] (Department of Statistics, Comilla University, Cumilla)
[2] (Department of Statistics, University of Rajshahi, Bangladesh)
[3]Department of Geography, Rampurhat College, Rampurhat, West Bengal, India
[4] (Institute of Bangladesh Studies, University of Rajshahi, Bangladesh)
*Correspondence should be addressed to Md. Kamruzzaman, Email: mkzaman@ru.ac.bd

Abstract

The northwest part of Bangladesh is primarily experiencing droughts with lower precipitation levels in comparison to other parts of the nation. For this reason, the study aims to assess local famers' present adaptation strategies with their different demographic, socio-economic and firm characteristics foctors. Field level primary data was collected through questionnaire from 4 upazials (sub-district) under the district of Rajshahi, Chapainawabganj, Naogaon, Dinajpur in northwest Bangladesh. A total of 375 respondents were selected by PPS (Probability Proportionate to Size) sampling from each upazila. During study, drought mainly effects increased cost of crop production, declining ground water level, crop failures, scarcity of soil water and food security rather than unemployment and water quality deterioration. The Chi-square and Cramer's V test, was applied to find out the degree of association and magnitude of the relationship between the factors and adaptation measures. The study found that local farmers implemented irrigation facility, drought tolerant rice verities, agronomic management and alternative land use change as their most popular adaptation strategies compared to re-excavation of traditional ponds, increase amount of surface water, crop intensification, extra income etc. The association of adaptation measures and the corresponding factors indicated that the monthly household income, loan subsidy, firm size, access to climate information, earning member and firm level experience played vital role to execute affordable adaptation strategies. Furthermore, this study helping the policy makers to implement better adaptation strategies and increasing crop production.

Keywords: Drought; Adaptation; Determinants; Chi-square; Cramer's V.

1. Introduction

Bangladesh is usually familiar with destructive effects of climate change and gradual environmental challenges (Thomas et al., 2013; IPCC, 2014; Islam et al., 2018). As the whole area of the country is not highly affected by drought, the North and Northwestern areas are specifically climate stress zone due to geographical nature and manmade reason (Uddin et al., 2020b). In this area, drought is a regular phenomenon that are not only depends on high rainfall variability and extreme temperatures, but also groundwater depletion, re-excavation of rivers and ponds, deforestation, etc., increasing the severity of drought (Habiba, 2012; Salam et al., 2019, Uddin et al., 2020b). Over the last three decades the average temperature increases sharply and annual rainfall varies significantly across the different hydrological regions of the country, with lower rainfall ranging from 791-2,241 mm in the dry north-western *Barind* region to high rainfall (2,586-5,944 mm) in the north-eastern region (Roy et al., 2017). Bangladesh is an agricultural country that includes 147570 km^2 with a population of 165.65 million, which is more than doubled when the first census conducted during 1974 (BBS, 2022a). In rural areas, about 68.49% of people are highly marginalized and face different types of natural disasters (Islam et al., 2019, BBS 2022a) because, agriculture is the most common occupation and about 51.88% of people are directly engaged in agricultural activities (BBS, 2019b). That's why, agricultural is a vital sector in our country's economy, which contributes 13.82% to country's GDP (BBS, 2019a). In our country, climate variables like rainfall and temperature influence the agricultural crop production (Kamruzzaman et al., 2018).

Recently, the climate model of Bangladesh prevails that the northwest region will face extreme temperature, warmer nights, and increased frequency of droughts as a result of rainfall variations (Selvaraju & Bass, 2007). Moreover, complicated geographic nature, groundwater is not sufficient for irrigation in northwest Bangladesh. As a result, shortage of water creates soil moisture deficiency which impacts the agricultural crop production and daily livlihood (Rahman et al., 2017a). Basically, in South Asia groundwater-based irrigation is practiced for irrigation purpose to produce high yielding rice in dry season. This region includes India and Bangladesh are ranked as the second and fourth major rice-producing countries around the globe (Scott & Sharma, 2009; IRRI, 2010). Bangladesh reported declining trends in groundwater level, especially northwest region creates the worst scenario across the country, which designates unsustainable groundwater extraction for irrigation (Jahan et al., 2010; Rahman et al., 2016a). In the *Kharif* [1]season different types of drought cause on average annual damages of 2.32 million hectares of cultivable *T.aman* (rice variety) and also damages 1.2 million hectares of *Rabi* crops in the *Rabi* season (Karim et al., 2012, CEGIS, 2012). Even in extreme drought conditions yield reduction varies 45 to 60% T.*aman* rice and also reduces production 50 to 70% *Rabi* crops (Climate Change Cell of Bangladesh, 2009). Rahman et al. (2007) found that the Aman crop yield in the northwest area of Bangladesh was significantly reduced by 25-30% due to the drought in 2006. The said phenomenon (drought) had triggered the damage of millions of hectares of cultivated land that causes loss of crop production, which negatively impacted the livelihood of poor farmers who depend primarily on agriculture. Thus, the rural livelihood faces significant challenge due to decrease staple food-crop production, abnormal price hike of basic foods, reducing job opportunity, low accessibility of safe drinking water, and losses of cattle rearing and poultry farming (Habiba et al., 2014). According to Bangladesh Delta Plan-2100 (BDP), there is a projected negative impact on the aggregate rice production, with an estimated decline of 17% by 2050, which might impede the achievement of food and nutrition security (NAP, 2023).

In our country, farmers with small land holding, are directly depends on several types of agricultural work and to survive against extreme climate conditions but lack of capitals makes life of farmers more difficult to access safe food and health security (McDowell & Hess, 2012). They are the primary stakeholder of an underdeveloped country like Bangladesh. The farming community of northwest region faces challenge of frequent droughts, because it adversely affects their livelihood patterns by reducing crop harvest, livestock, and fisheries (Habiba et al., 2014). In the cropping season, surface water bodies like ponds, and rivers dry up due to lack of rainfall and extreme temperature. Extensive ground water depletion has hampered the total farming system and caused serious jeopardy to crop production and income generating activities (Dey et al., 2012; Alam, 2015). In these circumstances, most of the countries have implemented green agriculture technology, which offers sustainable adaptation strategies, to combat the risk and consequences of global warming (Ikram et al., 2021). Adaptation in agriculture is the process through the respondent's perception about climate change that are integrated into agricultural systems for decision-making (Bryant et al., 2020; Ali et al., 2021). Climate change adaptation refers to the adjustment of human or natural systems in response to current or anticipated climate-related stimuli or their effects (IPCC, 2007). This process aims to reduce harm and take advantage of beneficial situations. To address climate variability and drought severity, a significant number of researchers around the world emphasis that farmers' practice variety of adaptation measures (Hassan & Nhemachena 2008; Deressa et al., 2009; Shankar et al., 2013; Belay et al., 2017; Alam et al., 2017; Fadina & Barjolle, 2018; Rymbai & Sheikh, 2018; Mamun et al., 2021; Ibrahim & Menash, 2022; Redda et al., 2022; Sohail, 2022); which are generally recognized and valid their own research areas. In Bangladesh, small number of studies have been conducted on farmers' perceptions, drought and adaptive strategies (Habiba et al., 2012; 2014; Alauddin & Sarker, 2014; Alam, 2015; Hossain et al., 2016; Ara, 2018; Mardy et al., 2018; Islam et al., 2019). However very few of them find out actual influential factors against adaptation measures. So, it is really difficult to draw a complete scenario on drought adaptation because no single strategy or solution fit for all regions or country. The ability of farmers to make decisions towards implementing adaptation measures through personal efforts is influenced by numerous factors known as determinants. The primary function of the determinants is to influence farmers' decision-making process with respect to the multiple types of adaptation options according to their planning and perceptions. Anik et al. (2021) identified six common adaptation strategies which influence education, subsistence pressure, income from livestock and poultry, extension service, organizations participations, and apply ICT for agricultural. These factors were significantly and positively related to the selected adaptation strategies but increasing women's participation in farming activities was inversely related in drought prone areas Bangladesh. Nevertheless, there are still huge gap to take appropriate

[1] In Bangladesh, there are three distinct agricultural seasons referred to as Pre-Kharif (mid-March to June), Kharif (July to mid-October), and Rabi (mid-October to mid-March). Of the three, the Rabi season is entirely reliant on irrigation, while the other two primarily rely on rainfall for crop cultivation.

adaptation measures mainly in the northwest area. A related investigation has been conducted on Rajshahi division of Bangladesh that the factors influence the implementation of adaptation measures particularly in the Barind tract (Islam et al., 2019) but in this study cover whole northwest region and get better association with factors as well as finding the main effects of drought and other related issues such as socioeconomic, demographic, and agricultural characteristics.

However, in our country, farmers normally apply multiple adaptation strategies for their agricultural plan simultaneously without any idea of the present meteorological trend and other climate related factors. The result of the study could help the public and other private organizations to increase farmers' ability putting various strategies into practice to reduce the adverse effects of drought.

2. Materials and Methods

2.1 Study Area

The northwest part of Bangladesh, agricultural production faces critical situation due to the changes in weather and unpredictable climate conditions (Karim et al., 2020). Geographically, the study area has mainly covered by $34{,}359 km^2$ under Rajshahi and Rangpur division with 16 administrative districts (Figure 1) (Uddin et al., 2020a; BBS 2019a). Inadequate rainfall and extreme temperature are very common indices over the last few decades; therefore, drought occurs recurrently in the northwest region. Rainfall in the said country is highly seasonal and most of it falls during the summer monsoon season, almost 80% of the annual precipitation happens during the monsoon summer season (Islam et al., 2020). The climate of the area is semi-arid, with little rainfall and high temperatures.

2.2 Sampling Design and Sample Size Determination

Data collection was conducted using a cross-sectional survey of different households in respective upazilas (sub-district or part of district). The survey primarily focused on farmers who had experienced drought and cultivated variety of crops on their own or rented farms and took minimum one adaptation strategy by themselves. At first, four districts were chosen based on the drought intensity and severity of the prone area, which was determined by geographical location, historical data, literature review of different journals, reports from the media, online sources, and consultations with local farmers. Because for long time the agricultural productions of the selected districts were always at risk by prolonged drought condition and scarcity of groundwater. Then the survey was conducted on four upazilas (sub-districts or parts of district) under the selected districts by SRS without replacement method using random number table. Then, considering villages as strata under each union and choose one village in each stratum by SRS, where each household was taken as sampling unit of this study. Finally, the required samples were determined at 5% level of significance through PPS (Population Proportional to Size) sampling scheme. The questionnaire mainly focused on gathering information about adaptation strategies used by the farmers to ensure sustainable agriculture and livelihood patterns. The questionnaire mainly included with personal profile of the respondent, socio-demographic characteristics of farmer, farmers' perceptions in response to drought and agricultural adaptation and knowledge about drought adaptation strategies and mitigation. Each question was organized chronologically to understand the relationship among different variables. Respondents data was collected by using closed-end (with multiple response options) and open-end (without multiple response options) structured questions. Household head was particularly the main respondent (farmer) of the data set because they usually took the decision-making power for farming and adaption policy. The key members of households were selected by PPS scheme using the list of farming households collected the Department of Agricultural Extension (DAE) Office of each upazila. The total number of respondents were 2725 *(N).* The estimated sample size was 375, by PPS scheme (i.e*;* 92 farmers from Narayanpur village of Bhadair union in Tanore upazila of Rajshahi district, 93 from Azaiyr village of Kasba Union in Nachole upazila of Chapainawabganj district, 90 for Horipur village of Tilna union in Shapahar upazila of Naogaon district, 100 for Suroil village of Vihial union in Chiribandar upazila of Dinajpur district, Figure 1) using equation (2).

Then the required sample size for this study was calculated by using R.A. Fisher equation for known population.

$$n = \frac{Z^2.p.q.N}{e^2(N-1)+Z^2.p.q} \tag{1}$$

Here,

N = Total number of households
Z = 95% Confidence level = 1.96
p = Estimated population proportion (0.5 as it maximizes the sample size)
q = 1-p
e = Error limit (5% = 0.05)
n = Sample size

Here the size of the study population N = 2725 is known. The given formula calculated the sample household for each village (n_i)

$$n_i = \frac{N_i}{N} \times n \qquad (2)$$

N_i is the number of households in each selected village. All respondents (farmers) of the selected households (sampling unit) using SRS (without replacement) technique with random number table

Table 1: Sampling Design in the study area

District	Upazila	Union	Selected Village
Rajshahi	Tanore	Bhadair	Narayanpur
Chapainawabganj	Nachole	Kasba	Azaiyr
Naogaon	Shapahar	Tilna	Horipur
Dinajpur	Chirirbandar	Vihial	Suroil

Reserve Sample

Household members may be missing during field surveys because of migration and other demographic factors. In some cases, the respondents are ineligible to response and it is difficult to predict the non-response rate[2]

So, researcher consider 20% of the total sample (375) as reserve sample. i.e. $n_s = n \times \frac{20}{100}$

= 375× 20/100

= 74

Finally, survey was conducted on (total sample + reserve sample) = (375+74) = 449 respondents.

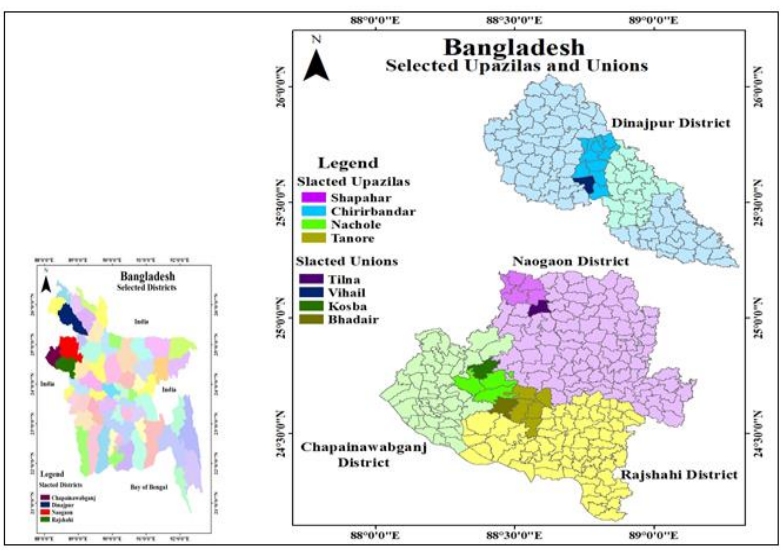


Figure 1: Location map of the study area
(*Developed by the researcher using ArcGIS 10.2.2*)

---

[2] Organization for Economic Co-operation and Development. (2013). Technical report of the survey of adult skills (PIAAC).

2.3 Data Collection and Analysis

Data was collected through household survey, focus group discussions (FGD) and direct field observations. A questionnaire survey was conducted by using qualitative and quantitative data during the month of March to April in 2022. Skilled interviewers worked under the supervision of the researcher to conduct interviews, either at participants' homes or at agreed-upon locations. Additionally, in four upazilas (sub-districts or parts of district), four FGDs (each group consisting of 7 to 8 participants) were conducted including both male and female expertized farmers using FGD guideline. The FGD Participants were purposively chosen with the assistance of a Sub-Assistant Agriculture Officer from the four upazilas and some respondents were chosen based on their willingness, availability and their farming experience. Collecting data and information regarding participants' perceptions about climate change over time, their farming operations, drought impacts on agricultural cultivation, and indigenous adaptation practices in response to drought. The researcher also relied on a non-structured questionnaire to gather information in accordance with appropriate guidelines. Furthermore, the researcher participated in field observation as part of the primary data collection process.

Firstly, Pearson's Chi–Square test was conducted to evaluate the association between the implementation of adaptation strategies by the farmers and their influencing factors. This association of categorical variables, are identified by using this test whether independent or correlated and considering two hypotheses. The null hypothesis claims that there is no association, whereas the alternative hypothesis supports an association between the variables. If the computed p-value is greater than level of significance α (=0.05), then the null hypothesis will be accepted, while the p-value less than equal to α allows the acceptance of alternative hypothesis. Secondly, Cramer's *V* (Cramer, 1946) test was applied in this research to find out the magnitude of the correlations between the variables. The value of the *V* lies between 0 to 1. If the *V* values near to zero shows a weak association between the variables, whereas the value closer to 1 indicates a strong association. In addition, demographic, socio economic and farm characteristics were described by the percentage of the total frequency of the selected village of four upazila. A five-point rating scale was established to identify the perceived effects of drought in four drought-prone villages under four upazilas (sub-districts or parts of district). The statistical analyses were conducted using SPSS-27 Software and MS excel.

3. Demographic Information and Firm Characteristics

The socio-economic characteristics of the respondents were collected from four villages (namely Narayanpur, Azaiyr, Suroil and Haripur) under four selected unions of four upazilas (sub-districts or parts of districts). Table 2 included respondent age category, years of education, average monthly income, family size, firm size, firming experience, and others farm characteristics of the respondents. The socio-economic characteristics are dominated by the age level 30 to 50 years of respondents. In the study villages, about 55% to 60% of farmers had completed primary and secondary school, while 28% to 42% farmers were still illiterate. During the survey, 62% of farmers of Narayanpur village in Tanore upazila earned very low amount less than 12000 tk, while 68.9% of farmers earned more than 25000 tk in a month in Haripur village of Shapahar upazila. In the study area, on average 54% family size were small (<4) and 31.9% family size were middle (4-6) whereas large family (>6) ranged from 8.9% to 18.5%. During study Narayanpur, Azaiyr and Suroil village had 38% to 39% landless farmers, while maximum farmers of Haripur village of Shapahar upazila had in total 84.4% small, medium and large firm rather than landless and marginal (Table 6.1). Less than 20% of farmers in Suroil and Haripur village were more than (>25 years) experience in farming and 42% of farmers of Azaiyr village of Nachole upazila had low farming experience and 50% of farmers had medium experience of farming in Narayanpur village of Tanore upazila. Climate information is the primary objective for farming and adaptation policy. That's why, in survey study 'access to climate information' almost observed similar result in all selected villages under the respective upazila. In other words, on average more than 80% climate accessibility found in the research area. Among all the villages, Suroil village of Chirirbandar upazila under Dinajpur district found better electric accessibility (80%) than other sample villages. Social interaction in a community developed our knowledge and decision-making capability, in this current work high social mobility varied from 66.7% to 83.7%. Another important characteristic of farming activity was 'farmer to farmer extension' service. On an average 59% of farmers were highly engaged with farmer to farmer extension. More than 80% of respondents took loan subsidies in Narayanpur and Haripur village under Tanore and Shaparar upazila but 91.4% of farmers in Azaiyr village of Nachole upazila did not take any loan whereas the farmers of Suroil village were likely to take.

Table 2: Socio-economic and farm characteristics of the respondents

Category	Selected Villages Respondents			
	Narayanpur (%)	**Azaiyr (%)**	**Suroil (%)**	**Haripur (%)**
Age (Year)				
Less than 30	7.6	7.5	14	23.3
30-40	28.3	38.7	26	44.4
40-50	35.9	28	27	22.2
>50	28.3	25.8	33	10
Education (Years)				
Illiterate	28.3	38.7	42	28.9
Primary	37	33.3	24	20
Secondary	23.9	21.5	17	34.4
Higher Secondary or Graduate	10.9	6.5	17	16.7
Income ('000' BDT)				
Low Income (<12000)	62	45.2	46	5.6
Middle (12000-25000)	38	49.5	51	25.6
High Income (>25000)	0	5.4	3	68.9
Family size				
Small (less than 4)	48.9	54.8	66	55.6
Middle (4-6)	32.6	31.2	24	35.6
Large (more than 6)	18.5	14	10	8.9
Firm size (ha)				
Landless (0)	39.1	38.7	39	13.3
Marginal (0.0-0.20)	19.6	16.1	21	3.3
Small (0.20-0.40)	31.5	30.1	27	21.1
Medium (0.40-0.60)	8.7	8.6	12	30
Large (> 0.60)	1.1	6.5	1	32.2
Firming experience (years)				
Low (less than 15)	26.1	41.9	39	41.1
Medium (15-25)	50	22.6	42	44.4
High (> 25)	23.9	35.5	19	14.4
Climate accessibility				
High	77.2	94.6	75	82.2
Low	22.8	5.4	25	17.8
Access to electricity				
High	68.5	60.2	80	68.9
Low	31.5	39.8	20	31.1
Social mobility				
High	83.7	66.7	76	70
Low	16.3	33.3	24	30
Farmer to farmer extension				
High	65.2	53.8	67	50
Low	18.5	40.9	27	35.6
No	16.3	5.4	6	14.4
Loan subsidies				
Yes	82.6	8.6	40	86.7
No	17.4	91.4	60	13.3

4. Main Effects of Drought

The farmers were given the opportunity to rank the main effects of drought on agricultural output using a scale of very high, high, medium, low, and very low with corresponding score 4, 3, 2, 1 and 0 respectively. The statements were ranked in order to give highest priority to the remarks that described situations in which the effects of the drought are extreme. To compute the main effects of drought it is possible to formulate a weighted average index (WAI) for finding out the ranking of main effects.

$$WAI = \frac{F_{vh}\times 4+F_h\times 3+F_m\times 2+F_l\times 1+F_{vl}\times 0}{N} \tag{1}$$

Where, $WAI =$ weighted average index, $F_{vh} =$ Very high effect response frequency, $F_h =$ High effect response frequency, $F_m =$ Medium effect response frequency, $F_l =$ Low effect response frequency, $F_{vl} =$ Very low effect response frequency, N = Total number of respondents.

The rank order of perceived impacts of drought is shown in (Table 2). In all four upazilas (sub-districts or parts of district) a statement list of possible effects of drought were interviewed to the respondents of the respective village under each upazila to collect preliminary data and WAI method used for computing drought effect as mention in the equation (1). Overall farmers identified that increased cost of production as having the highest effect by drought with WAI 3.68. Most of the farmers cultivated their land using traditional instruments and different types of crop seeds, sharing irrigation water during the dry spells, but the global price hike of all the products heated up the agricultural sector, although governmental subsidies were given to each upazila. The second main effects were the declining ground water level with WAI 3.63, almost all the farmers relied on ground water for their rice cultivation, so the ground water shortage during the crop growing season might have an impact on agricultural output.

The third most effect observed by the researcher was crop failures with WAI 3.45. Most of the farmers in the study region were illiterate and few of them completed only primary or elementary level of education, meanwhile a big margin of the respondents was landless. Therefore, they had no idea about crop cultivation and mitigation the effect of crop failures. But according to Mardy et al. (2018), farmers reported crop failures were the least severe drought consequences in the northwest, which really differs above statements.

Table 3: Overall main effects of drought by rank order of farmers

Statements	Very High	High	Medium	Low	Very low	WAI	Rank
Increased cost of production	290	62	11	11	1	3.68	1
Declining ground water levels	289	45	33	4	4	3.63	2
Crop failures	250	69	37	13	6	3.45	3
Scarcity of soil water	203	124	34	14	0	3.38	4
Lower income	176	78	78	32	11	3.00	5
Food scarcity	166	29	123	44	13	2.78	6
Health impacts	111	45	162	46	11	2.53	7
Malnutrition	36	129	86	71	53	2.06	8
Loss of livestock	59	31	181	75	29	2.04	9
Water quality deterioration	45	68	142	65	55	1.95	10
Unemployment	41	49	105	159	21	1.81	11

Very high = 4, High = 3, Medium = 2, Low = 1, Very Low = 0

The farmers identified that soil water scarcity is the fourth most major perceived effect during study with a WAI of 3.38. Due to the soil water scarcity in the peak cropping season rice and mango cultivation were badly affected in most areas of Nacole and Shapahar upazila. Farmers also identified effects like lower income, food scarcity, health impacts, malnutrition, and losses of livestock with a rank order of WAI. During the study, water quality deterioration and unemployment reported least severe effects with WAI value 1.95 and 1.81. The above findings might differ to other research studies depending on time, spatial distribution and archeological environment.

5. Adaptation Strategy Adopted by the Farmers

Farmers are asked about their current adaptation strategy in response to drought. Based on the questionnaire survey, focused group discussions and direct field observations farmers from different villages under selected upazila in the northwest region have been employing various strategies to lessen the impact of drought. The bulk of the respondents who are engaged in agricultural activities are male and maximum farmers are over 30 years of age. In the study area, it is clearly demonstrated that the overall percentage of different upazila adopted by the farmers' is shown in (Figure 1). Maximum number of respondents in different villages agreed that irrigation facility is their primary adaptation strategy (34%), because huge amounts of groundwater irrigation is required in this region for rice cultivation during drought period. Moreover, some farmers in Naogaon District also used another adaptation option like agronomic management (16%) as their second highest adaptation strategy, because instead of rice cultivation they cultivate mango for more profit and less water consume. In the study area, there are also used traditional types of adaptation strategies like drought tolerant rice varieties (15%), alternative enterprise of land use change (10%) for their rice farming, in order to survive with the shortage of groundwater and maximum benefit during the dry spells. adopting new technologies (8%) is another adaptation technique in the study area, during survey young farmers are highly motivated with new technology-based irrigation system and digital monitoring of weather forecasting. But respondents are not habituated with popular adaptation option like re-excavation of traditional ponds (1%), rainwater harvesting (3%), crop rotation and changing planting date (3%), crop intensification (3%). In order to reduce this difficulty, numerous farmers embraced 'Extra income generating activities (6%)' in parallel with other adaptation measures for their extra benefit (Figure 2). It is absolutely visible that earning from other source of income helps to increase their living standard during extreme climate variability. The popular alternative economic sources are business, rickshaw puller, day worker, etc. In the study area numerous adaptations measures available in respective upazilas (sub-districts or parts of district), but farmers are mostly familiar with their cost-effective adaptation for sustainable farming.

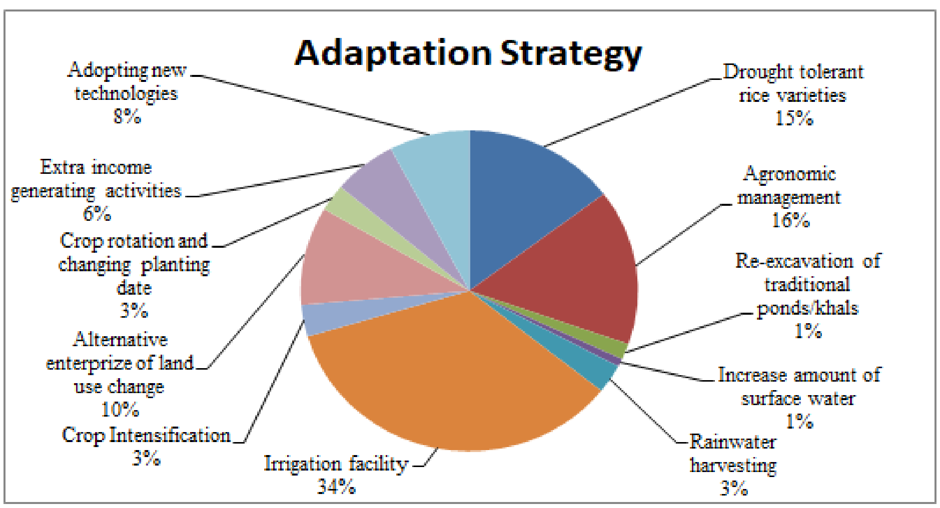


Figure 2: Distribution of proportion of adaptation strategy adopted by the farmers' in the study area

6. Factor Influence the Choice of Adaptation Options

In the northwest region of Bangladesh farmers used different adaptation strategy based on their indigenous knowledge and local perception on climate change. Mainly, the region produced almost 70-80% rice and other crops to meet up our food habit. But now a day's food insecurity is a primary concern due extreme climate variability and burden of huge population. So, it is urgent need to improve a present adaptation options on regional cropping zone. Farmer's choice to take appropriate adaptation options due to drought depends on various factors including demographic, social and farm characteristics. The following Table 4 displays the elements or factors that have been examined to assess their correlation with the execution of various adaptation strategies by Chi-Square statistics and Cramer's V. The statistical significance of the association has been established by evaluating corresponding p-values. As earlier, farmers mainly depend on various adaptation measures to survive against climate change and produce maximum crop to ensure food security for the nation. The findings show that there are lots of demographic factors which are significantly associated with adaptation options. Analysis has demonstrated that income has a substantial influence on every factor and plays an essential role in enhancing farmers' ability implementing strategies. They need to acquire and/or acquire an irrigation pump, fertilizer, seeds, and other necessary items, which are entirely contingent on the availability of resources. Farmers can't take adaptive steps on their own if they don't have enough capital, even if they've met other requirements. Loan Subsidy is the second highest firm characteristics associated with the maximum number of adaptation strategies. Small farmer is very poor to survive with the primary earning source that's why they need credit/loan facility from government bodies and other NGO's learning about suitable adaptation options to increase agricultural production. Credit facility with low interest rate not only enrich agricultural development but also change farmers livelihood patterns. Climate accessibility and firm size i.e agricultural land are the third highest important factors that associated with eight adaptation measures out of eleven. They are significantly correlated with eight number of adaptation strategies after income and loan subsidy factors. Access to climate now a days helps farmer as well as agricultural officer to know about early climate scenario of the study area. When drought period occurs farmers usually used drought tolerant rice varieties, irrigation facility, agronomic management, crop intensification, extra income activities, adopting new technologies etc. Another factor firm size is the bigger dimension of the farm enables farmers to effortlessly implement adaptation methods, such as crop diversification, land use change, crop rotation intercropping etc. These techniques require sufficient area for execution. Moreover, farmers who own larger land parcels have the capability to undertake the challenge of applying new strategies and are also equipped to handle immediate stress if any strategy does not yield anticipated results. Another two important determinants are firm level experience and earning member of family. These two factors have significant correlations with precisely six specific measures. Any kind of farming experience is so important increasing food security and well prediction about the climate change. Earning member size is significantly increase the farmers adaptation ability, source of income, upgrade the livelihood pattern, good schooling and proper food affordability. Age, family size and land ownership are not significantly correlated all the adaptation options during the survey period in the northwest area. It is very interesting that farmers age and land ownership have significantly association only with four adaptation strategies. Although respondent has own land but they don't used appropriate adaptation options due to lacking knowledge and proper training facility. The least affect association among the factors are education and farmer to farmer extension. Education is the backbone of a nation but in the study area education are not influence adaptation strategy because they are used to their traditional and indigenous adaptation strategies.

The Cramer's V test results, which indicate the strength of the estimated correlations between the factors that influence the adaption measures, are displayed in Table 4. The findings indicated that nearly all of the correlations exhibit a moderate level of strength, as the V values are less than 0.5. Nevertheless, the main focus of the V test is not to accept or reject any association but moderately to offer a quantitative measure of strength of the relationships. It is evident that drought tolerant rice varieties, irrigation facilities, crop intensification, extra income generating activities, land use change are the most effective adaptation measures associated with the above mentionable factors (Table 4). Agroeconomic management, crop rotation & changing planting date and rainwater harvesting are almost significant with below 50% of the associated factors. During survey, least possible adaptation strategies are re-excavation of traditional ponds and increase amount of surface water which correlated with lowest number of factors.

Table 4: Chi-square test statistics and Cramer's V- Statistics between factors and Adaptation Strategy

Determinant	Adaptation Strategies																					
	Drought tolerant rice verities		Agronomic management		Re-excavation of traditional pond		Increase amount of surface water		Rainwater harvesting		Irrigation facility		Crop intensification		Land use change		Crop rotation and changing planting Time		Extra income generating activities		Adopting new technologies	
	P-value (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*	*P-value* (λ^2)	*V*
Age	**0.001**	**0.16**	0.070	0.13	**0.004**	**0.15**	0.613	0.10	0.157	0.12	**0.002**	**0.16**	0.133	0.12	0.111	0.12	0.600	0.10	**0.011**	**0.15**	0.421	0.11
Education	**0.013**	**0.14**	0.801	0.09	0.128	0.12	0.204	0.12	0.219	0.11	0.128	0.12	0.831	0.08	0.488	0.10	0.291	0.11	0.213	0.12	0.559	0.10
Income	**0.00**	**0.26**	**0.012**	**0.14**	**0.001**	**0.16**	**0.00**	**0.22**	**0.00**	**0.21**	**0.00**	**0.34**	**0.002**	**0.16**	**0.00**	**0.20**	**0.00**	**0.21**	**0.00**	**0.27**	**0.087**	**0.13**
Family Size	0.199	0.12	0.440	0.10	0.955	0.06	0.534	0.10	0.049	0.14	**0.036**	**0.14**	**0.036**	**0.15**	0.371	0.10	**0.035**	**0.15**	0.327	0.11	0.076	0.14
Earning Member	**0.00**	**0.26**	0.112	0.14	0.670	0.07	0.217	0.12	**0.05**	**0.16**	**0.007**	**0.20**	**0.002**	**0.21**	**0.001**	**0.23**	0.651	0.08	**0.008**	**0.19**	0.069	0.15
Firm Level Experience	**0.00**	**0.23**	**0.00**	**0.21**	**0.001**	**0.19**	0.328	0.11	0.168	0.13	**0.042**	**0.13**	**0.001**	**0.19**	0.159	0.13	0.194	0.12	**0.00**	**0.24**	0.542	0.09
Firm Size	**0.00**	**0.20**	0.683	0.09	0.192	0.12	**0.00**	**0.18**	**0.00**	**0.20**	**0.00**	**0.25**	**0.018**	**0.14**	**0.002**	**0.16**	**0.000**	**0.20**	**0.000**	**0.21**	0.216	0.12
Land Ownership	0.175	0.12	0.877	0.07	0.441	0.10	0.067	0.14	0.101	0.13	**0.00**	**0.21**	0.117	0.13	**0.030**	**0.15**	**0.007**	**0.17**	**0.008**	**0.17**	0.095	0.13
Access to Climate	**0.042**	**0.14**	**0.005**	**0.17**	0.480	0.10	0.410	0.11	**0.033**	**0.15**	**0.229**	**0.12**	**0.002**	**0.18**	**0.000**	**0.20**	0.657	0.09	**0.000**	**0.21**	**0.000**	**0.21**
Social Mobility	**0.001**	**0.18**	**0.005**	**0.17**	0.397	0.11	0.090	0.14	0.627	0.09	0.094	0.13	**0.007**	**0.17**	**0.05**	**0.14**	0.191	0.12	**0.001**	**0.18**	0.056	0.14
Farmer to farmer Extension	0.142	0.13	**0.007**	**0.17**	0.739	0.08	**0.043**	**0.15**	0.402	0.11	0.064	0.14	0.205	0.12	0.313	0.11	0.157	0.13	0.445	0.10	0.873	0.07
Loan Subsidy	**0.00**	**0.32**	**0.00**	**0.31**	0.691	0.08	**0.00**	**0.28**	0.078	0.15	**0.00**	**0.38**	**0.00**	**0.41**	**0.00**	**0.39**	**0.03**	**0.17**	**0.00**	**0.36**	**0.00**	**0.27**

Note: *P* value of Chi-square test; Statistically Significant at $\alpha = 0.05$ (*Bold Number*); Cramer's *V* Statistically significant according to their corresponding *P* value

7. Conclusion

In response to the imminent danger of global warming, Bangladesh has been extensively deliberating and implementing many adaptation techniques to mitigate the adverse effects of drought in the northwest region. In the study area, there has no doubt that the adoption of local adaptation practice varied by individual and demographic factors of the farmers such as age, education, income, loan subsidy, access to climate etc. The statistical result indicates that every adaptation strategy is influenced by one or more determinants, and conversely, each determinant or factor has an influence on one or more adaptation procedures i.e. there is strong association with some influential factors and adaptation strategies. In addition, the study reveals several other significant findings that should be considered when developing policies in the future. From survey analysis, it is observed that, most of the farmers haven't used popular adaptation strategies like re-excavation of traditional ponds, increase amount of surface water, rainwater harvesting and crop rotation etc; which are the most substantial approach to alleviate irrigation scarcity and groundwater depletion. This situation has revealed actual limitations of the farmers' in implementing a successful adaption approach. According to the WAI index, drought mainly effects cost of crop production, declining groundwater levels, food security and scarcity of soil water. The results of the V test indicate that factors actually influence the decision-making process of implementing adaptation measures. However, farmers still retain some degree of choice in selecting an adaptation strategy. Furthermore, it is necessary to formulate and execute an appropriate strategy that will provide guidance to farmers in choosing the effective adaptation measure according to their socioeconomic and agricultural attributes. Finally, the study facilitates the government and non-government organizations in categorizing various adaptation measures that can be adopted by individual farmers by examining their demographic information and firm characteristics, thereby identifying the factors that influence these measures.

References

[1] Alam, G. M. M., Alam, K. and Mushtaq, S. (2017). Climate change perceptions and local adaptation strategies of hazard-prone rural households in Bangladesh. Climate Risk Management, 17, 52–63.

[2] Alam, K. (2015). Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh. Agricultural Water Management, 148, 196–206.

[3] Alauddin, M. and Sarker, M. A. R. (2014). Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh an empirical investigation. Ecological Economics, 106, 204-213.

[4] Ali, S., Ghosh, B. C., Osmani, A. G., Hossain, E. and Fogarassy, C. (2021). Farmers' climate change adaptation strategies for reducing the risk of rice production: Evidence from Rajshahi district in Bangladesh. Agronomy, 11(3), 600.

[5] Anik, A. R., Rahman, S., Sarker, J. R. and Al Hasan, M. (2021). Farmers' adaptation strategies to combat climate change in drought prone areas in Bangladesh. International Journal of Disaster Risk Reduction, 65, 102562.

[6] Ara, I. (2018). Perceptions and responses to climate change: Understanding adaptation strategies and multilevel capacities in Northern Bangladesh using livelihood resources. Regional Problems, 3(1), 124–131.

[7] BBS (2019a). Statistical Yearbook of Bangladesh 2018. Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

[8] BBS (2019b). Report on Agriculture and Rural Statistics 2018. Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh

[9] BBS (2022a). Population and Housing Census 2022. Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

[10] BBS (2022b). Structure of Agricultural Holdings and Livestock & Fisheries. Agricultural Census 2019. Bangladesh Bureau of Statistics. Dhaka: Government of the People's Republic of Bangladesh.

[11] Belay, A., Recha, J. W., Woldeamanuel, T. and Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. Agriculture & Food Security, 6(1), 24.

[12] Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chiotti, Q. and Singh, B. (2000). Adaptation in Canadian agriculture to climatic variability and change. Societal adaptation to climate variability and change, 181-201.

[13] CEGIS (2012). Center for Environment and Geographic Information Service. CEGIS, Dhaka, Bangladesh.

[14] Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T. and Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change, 19(2), 248–255.

[15] Dey, N., Alam, M., Sajjan, A., Bhuiyan, M., Ghose, L., Ibaraki, Y. and Karim, F. (2012). Assessing environmental and health impact of drought in the northwest Bangladesh. Journal of Environmental Science and Natural Resources, 4(2), 89–97.

[16] Fadina, A. M. R. and Barjolle, D. (2018). Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. Environments, 5(1), 15.

[17] Habiba, U., Shaw, R. and Takeuchi, Y. (2012). Farmer's perception and adaptation practices to cope with drought: Perspectives from Northwestern Bangladesh. International Journal of Disaster Risk Reduction, 1, 72-84.

[18] Habiba, U., Shaw, R. and Takeuchi, Y. (2014). Farmers' adaptive practices for drought risk reduction in the northwest region of Bangladesh. Natural hazards, 72(2), 337-359.

[19] Hassan, R. M. and Nhemachena, C. (2008). Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. African Journal of Agricultural and Resource Economics 2(311-2016-5521), 83-104.

[20] Hossain, M. N., Chowdhury, S. and Paul, S. K. (2016). Farmer-level adaptation to climate change and agricultural drought: Empirical evidences from the Barind region of Bangladesh. Natural Hazards, 83,1007–1026.

[21] Ibrahim, B. and Mensah, H. (2022). Rethinking climate migration in sub-Saharan Africa from the perspective of tripartite drivers of climate change. SN Social Sciences, 2(6), 87.https://doi.org/10.1007/s43545-022-00383-y

[22] Ikram, M., Ferasso, M., Sroufe, R. and Zhang, Q. (2021). Assessing green technology indicators for cleaner production and sustainable investments in a developing country context. Journal of Cleaner Production, 322, 129090.

[23] IPCC (2007). Climate change 2007: impacts, adaptation and vulnerability. In: Contribution of working group II to the fourth assessment report of Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[24] IPCC (2014 c). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (eds)]. IPCC, Geneva, Switzerland, p 151.

[25] IRRI (2010). World Rice Statistics (WRS), Philippines. International Rice Research Institute, Manila.

Islam, M. S., Hossain, M. Z. and Sikder, M. B. (2019). Farmers' adaptation strategies to drought and their determinants in barind tract, Bangladesh. SAARC Journal of Agriculture, 17(1), 161-174.

[26] Islam, M. S., Hossain, Md. Z. and Sikder, M. B. (2019). Drought adaptation measures and their effectiveness at Barind Tract in northwest Bangladesh: A perception study. Natural Hazards, 97(3), 1253–1276.

[27] Islam, M. T., Shen, S., and Yang, S. (2018). Predicting design water requirement of winter paddy under climate change condition using frequency analysis in Bangladesh. Agricultural Water Management,195(C), 58–70.

[28] Kamruzzaman, M., Rahman, A. T. M., Ahmed, M., Kabir, M., Mazumder, Q. H., Rahman, M. S., and Jahan, C. S. (2018). Spatio-temporal analysis of climatic variables in the western part of Bangladesh. Environment, Development and Sustainability, 20(1), 89-108.

[29] Karim, M. R., Ishikawa, M., Ikeda, M., and Islam, M. (2012). Climate change model predicts 33% rice yield decrease in 2100 in Bangladesh. Agronomy for Sustainable Development, 32(4), 821-830.

[30] Karim, F., Mainuddin, M., Hasan, M., & Kirby, M. (2020). Assessing the potential impacts of climate changes on rainfall and evapotranspiration in the northwest region of Bangladesh. *Climate*, *8*(8), 94.

[31] Mamun, A. A., Roy, S., Islam, M. T., Alam, G. M. M., Alam, E., Chandra Pal, S., Sattar, Md. A., and Mallick, J. (2021). Smallholder farmers' perceived climate-related risk, impact, and their choices of sustainable adaptation strategies. Sustainability, 13(21), 11922.

[32] Mardy, T., Uddin, M., Sarker, Md., Roy, D. and Dunn, E. (2018). Assessing coping strategies in response to drought: a micro level study in the north-west region of Bangladesh. Climate, 6(2), 23.

[33] McDowell, J. Z. and Hess, J. J. (2012). Accessing adaptation: Multiple stressors on livelihoods in the Bolivian highlands under a changing climate. Global Environmental Change, 22, 342–352.

[34] NAP (2023). National Adaptation Plan Bangladesh (2023-2050). Ministry of Environment, Forest and Climate Change, Bangladesh.

[35] Rahman, A. A., Alam, M., Alam, S. S., Uzzaman, M. R., Rashid, M. and Rabbani, G. (2007). Risks, vulnerability and adaptation in Bangladesh. Human Development Report, 8.

[36] Rahman, A. S., Jahan, C. S., Mazumder, Q. H., Kamruzzaman, M. and Hosono, T. (2017a). Drought analysis and its implication in sustainable water resource management in Barind area, Bangladesh. Journal of the Geological Society of India, 89, 47-56.

[37] Rahman, A. S., Kamruzzaman, M., Jahan, C. S., Mazumder, Q. H. and Hossain, A. (2016a). Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics. Sustainable Water Resources Management, 2, 297-312.

[38] Redda, A., Tana, T., Alemayehu, Y., Hadgu, G., Elias, B. and Girma, A. (2022). Maize farmers' perceptions of climate change and determinants of adaptation decisions in northern Ethiopia. Sustainable Agriculture Research, 11(3), 38-53.

[39] Roy, K., Gain, A. K., Mallick, B. and Vogt, J. (2017). Social, hydro-ecological and climatic change in the southwest coastal region of Bangladesh. Regional Environmental Change, 17, 1895-1906.

[40] Rymbai, D. and Sheikh, F. M. (2018). The insight of agricultural adaptation to climate change: a case of rice growers in Eastern Himalaya, India. International Journal of Biometeorology, 62(10), 1833-1845.

[41] Salam, R., Islam, A. R. M. T. and Islam, S. (2019). Spatiotemporal distribution and prediction of groundwater level linked to ENSO teleconnection indices in the northwestern region of Bangladesh. Environment, Development and Sustainability.

[42] Scott, C. A. and Sharma, B. (2009). Energy supply and the expansion of groundwater irrigation in the Indus-Ganges Basin. International Journal of River Basin Management, 7(2), 119-124.

[43] Selvaraju, R. and Baas, S. (2007). Climate variability and change: adaptation to drought in Bangladesh: a resource book and training guide (Vol. 9). Food & Agriculture Org.

[44] Shankar, K. R., Nagasree, K., Sankar, G. M., Prasad, M. S., Raju, B. M. K., Rao, A. S. and Venkateswarlu, B. (2013). Farmers' Perceptions and Adaptation Measures towards Changing Climate in South India and Role of Extension in Adaptation and Mitigation to Changing Climate. Central Research Institute for Dryland Agriculture, Hyderabad, India.

[45] Sohail, M. T. (2022). A PLS-SEM approach to determine farmers' awareness about climate change mitigation and adaptation strategies: pathway toward sustainable environment and agricultural productivity. Environmental Science and Pollution Research, 1-14.

[46] Thomas, T. S., Mainuddin, K., Chiang, C., Rahman, A., Haque, A., Islam, N., ... and Sun, Y. (2013). Agriculture and adaptation in Bangladesh: Current and projected impacts of climate change (Vol. 1281). Intl Food Policy Res Inst.

[47] Uddin, M. A., Kamal, A. M., Shahid, S. and Chung, E. S. (2020a). Volatility in rainfall and predictability of droughts in northwest Bangladesh. Sustainability, 12(23), 9810.

[48] Uddin, M. J., Hu, J., Islam, A. R. M. T., Eibek, K. U. and Nasrin, Z. M. (2020b). A comprehensive statistical assessment of drought indices to monitor drought status in Bangladesh. Arabian Journal of Geosciences, 13, 1-10.