Assessing and predicting drought vulnerability of Jessore district in Bangladesh with Markov Chain model

Abstract

The agricultural sector, which is crucial to the socioeconomic framework of Bangladesh, is particularly affected by drought. Agricultural drought primarily arises from insufficient rainfall. The Markov Chain model is employed to assess the probabilities of experiencing sequences of wet and dry days in this field. The long-term fluctuations in temperature and rainfall patterns contribute to local and regional drought conditions, leading to failures in productive sectors and a decline in socioeconomic status. This study focused on monitoring and predicting agriculture drought probability by decade of Jessore district from the south western part of Bangladesh. The daily rainfall data of Jessore district from January 1961 to December 2020 is considered for investigation. After cleaning the daily rainfall data set we calculated them into different time interval like 5, 7, 10 and 30 days by using Microsoft Excel then we use R program to analyze drought index under Markov Chain Model for threshold value 7 mm of rainfall and to predict the drought probability for the next decade 2021 to 2030 with monthly data. From the above discussion we found that the chronic drought prone period is observed for 5 day, 7 day and 10 series at first TPM whereas 30 days series showed occasional drought prone at this TPM but due to climate change these drought is convert to moderate, mild and occasional for most of the series at higher TPM in case of Jessore district and the maximum severity occurred around 7 months during 1961-1970. The forecasted drought probability showed that in Jessore district the next decade will be occasional drought at most of the time.

Keywords: Drought monitoring, rainfall, Drought index, Markon chain, Jessore district

1 Introduction

Due to the global warming, in South Asia most of the climate models project a decrease in precipitation during the dry season and increase during the monsoon season. This will cause a combination of more extreme droughts and floods in this region. Bangladesh, especially in western part, is one of the most disaster-prone countries in the world (Ali 1996) where drought is a regular phenomenon.

Drought is a temporary but complex feature of significant nature in climatic system which is usually caused by deficit in precipitation and also occurs in both high and low rainfall areas resulting imbalance between water supply and its demand (Gregory 1986). It has the greatest impact on environment and society and sometimes require relief efforts on a global scale (Ahmed 1995). Droughts are generally classified into four classes like meteorological, agricultural, hydrological and socioeconomic droughts. Instead of the difference in definitions, they are all water-deficit phenomena caused by the lack of rainfall (Liu, et al. 2016). To quantify the agricultural drought, scientists use precipitation shortages, evapotranspiration and available soil moisture (Wilhite and Glantz 1985; Banik et al. 2000) and Xianfeng et al. (2016) defined agricultural drought as the extent to which soil moisture is lower than the least requirement of plants during growth. It is necessary to understand the potential changes due to drought under future climate warming, to monitor and predict its occurrence at seasonal time scales and to evaluate climate model for projections. Bangladesh has suffered from nine droughts of major magnitude (Paul, 1998). Despite the recurrent and

devastating nature of droughts in Bangladesh, it has attracted far less scientific attention than floods or cyclones(Alexander, 1995). From November to May, most regions of Bangladesh have a long period of dry weather. During 1998-1999, some portions of the northwest, southwest, and central zones experienced nearly no rainfall (Hossain & Islam, 2000). Droughts occurred more frequently during the pre-monsoon, post-monsoon, and monsoon seasons of 1951, 1957, 1961, 1972, 1976, 1979, 1986, 1989, and 1997, affecting about half of the country's total population (Shahid, 2011).

Bangladesh, especially in western part, is one of the most disaster-prone countries in the world (Ali 1996) where drought is a regular phenomenon. A number of studies have been carried out on the impact of droughts on agriculture (Karim et al., 1996; Jabber, 1990; Jabber et al., 1982; Saleh et al., 2000; Mazid et al., 2005). However, studies on impact of drought and ecological effect have not received enough scientific attention (Brammer 1987) in the country. Few studies were done on drought impact using standard drought modeling in Bangladesh. Shahid and Behrawan (2008) studied the extent and impacts of drought in the western part of the country considering socioeconomic and physical indicators of drought vulnerability and prepared drought risk map, but failed to prepare accurate composite drought vulnerability map. Western region of Bangladesh will be at high risk of drought hazard under climate change conditions. In recent decades, Bangladesh has shown an increased drought frequency and intensity due to land use pattern changes. Rahman and Rahman (2021) investigated the threshold value for detecting drought in case of Pabna district. Besides these drought monitoring for different geographical regions with Markov chain model found (Rahman and Rahman 2020 (a,b), Rahman et. al (2021)). Concern among Bangladesh's scientists has increased regarding changes in precipitation, potential evapotranspiration (PET), and drought events. Thus, a better insight into drought frequency and intensity can help decision-making for agriculture allocation and adaptation to climate change, especially during the dry season in the paddy growing regions in Bangladesh. So, the aim of the paper is to monitor the drought index by decade and forecast the drought probability with Markov chain model in case of Jessore district of Bangladesh. This study will help policy makers to take necessary step to mitigate drought vulnerability which will ensure food security to achieve sustainable development goal (SDG) within 2030.

2. Study Area and Data

Jessore District, officially known Jashore District, is a district in southwestern Bangladesh. It is bordered by India to the west, Khulna and Satkhira districts to the south, Khulna and Narail to the east, and Jhenaidah and Magura districts to the north. Jessore is the capital of the district. Annual average temperature range from 15.4 to 34.6 °C (59.7 to 94.3 °F). The annual rainfall is 1,537 millimetres (60.5 in). The main occupations are agriculture 39.84%, agricultural labour 24.13%, other wage labour 2.68%, commerce 11.99%, service 8.66%, industry 1.41%, transport 3.11% and others 8.18% (Wikipedia, 2025) The map of Jessore district is given below in Map 1.

Map 1: Map of the Jessore district (Source: https://www.worldmap1.com/map/jessore-map)

2.1 Data Sources and Smoothing

The daily rainfall data of Jessore weather station around 60 i.e 6 decades from 1961 to 2020 is collected from Bangladesh meteorological department (BMD). There were some missing data over that range. Collecting the data from Jessore Station, there were two missing year (1971,1990) and about almost three missing months(March, April and May in 1980) which were not recorded. The missing value were random, however continuous missing data for one month to several months also evident in some stations. By using Microsoft Excel data, we have separated this time interval in 5, 7, 10 and 30 days series format then we estimate missing value by using SPSS, then it was finally ready to apply our methodology. After that we use R program to analyze under Markov chain model for threshold value 7mm of rainfall. For prediction the drought probability in these stations we use the monthly data i.e 30 days data only for the decade 2021-2030 with Markov chain model.

3 Methodology

3.1 Drought Index

Drought monitoring is vital for early warning and mitigation efforts. Over the years, numerous drought indices have been developed to evaluate drought severity and duration. The Standardized Precipitation Index (SPI), established by McKee et al. (1993), is one of the most extensively used indices for meteorological drought monitoring. SPI is useful since it can be calculated for several time scales, making it suitable for analyzing both short-term and long-term drought situations (Hayes et al., 1999). Another extensively used measure is the Palmer Drought Severity measure (PDSI), which integrates temperature and soil moisture data, making it effective for long-term drought evaluation (Palmer, 1965). However, PDSI

has been questioned for its complexity and susceptibility to regional climatic variables (Alley, 1984).

In addition to SPI and PDSI, the Rainfall Anomaly Index (RAI) and Z-Score Index (ZSI) have been employed to assess precipitation anomalies.

Drought indices are essential for monitoring and quantifying drought conditions. Various indices have been developed to assess meteorological, hydrological, and agricultural droughts. Among them, the Standardized Precipitation Index (SPI), Rainfall Anomaly Index (RAI), Palmer Drought Severity Index (PDSI), and Z-Score Index (ZSI) are widely used for drought analysis (Mishra and Singh, 2010). Kamaruzzaman et al. (2016) and Alam et al. (2013) used Markov chain based index for identifying drought for different stations. In our study we use Markov chain model to create drought index based on rainfall data.

3.2 Markov Chain Model

Markov chain probability model is based on the assumption that the state of any day depends only on the state of the preceding day. A two state Markov chain model involves the calculations of two conditional probabilities (1) α, the probability of a wet week following dry week and (2) $^{\beta}$, the probability of a dry week. The two state Markov chain for the conditional probabilities are as follows:

		Dry	**Wet**
Present state	Dry	1- α	α
	Wet	ß	1- ß

Let us consider the conditional probabilities

$P_0 = \Pr\{W/D\}$

$P_1 = \Pr\{W/W\}$

The above sequence is considering as is irreducible Markov chain with two argotic states.

Its stationary probability distribution has a probability of success

$P = p_{01}/(1 - (p_{11} - p_{01}))$.

3.3 Markov Chain Model of Order M

A Markov Chain is a Markov process where the state and parameter spaces are considered to be discrete and the dependence of the state is called Markovian dependence. The m order Markov chain is a sequence of trails of the outcome if each trail depends on the outcome of the directly preceding trails and depends only on that. According to the sequence of random variables $\{X_n\}$ forms a Markov chain of order m, if given a fixed m, for all possible values of the variables $X_n (n = 0,1,2, \dots)$ it is true that

$\Pr[X_n = j|X_0 = i_0, X_1 = i_1, \dots, X_{n-m}]$

$\Pr[X_n = j|X_{n-m} = i_{n-m}]$

3.4 Method of Markov Chain Model

Several authors have found that the sequences in daily rainfall occurrences can be described by a simple Markov chain model. Additional evidence to indicate the feasibility of using a Markov chain model has been presented by Rahman (1999 a&b), Banik et al. (2002), and Alam et al., (2011). The theory of Markov chain is described below:

Let $X_0, X_1, X_2, \dots, X_n$ be random variables distributed identically and taking only two values, namely 0 and 1, with probability one, i.e.

$$X_n = \begin{cases} 0 \text{ if the n-th week is dry} \\ 1 \text{ if the n-th week is wet} \end{cases}$$

Firstly, it may be assume that,

$$P(X_n + 1 = x_n + 1, X_n = x_n, X_n - 1 = x_n - 1, \dots, X_0 = x_0) = P(X_n + 1 = x_n + 1, X_n = x_n)$$

Where $X_0, X_1, \dots, X_n + 1 \in \{0,1\}$

In other words, it is assumed that probability of wetness of any week depends only on whether the previous week was wet or dry. Given the event on previous week, the probability of wetness is assumed independent of further preceding weeks. So, the stochastic process $\{X_n, n = 0, 1, 2\dots\dots\}$ is a Markov chain.

Considering the transition matrix as:

$P_{ij} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$

Where $P_{ij} = P(X_1 = j | X_0 = i) i, j = 0,1$ note that $P_{00} + P_{01} = 1$ and $P_{10} + P_{11} = 1$

For higher order transition probability matrix we have,

$$P_{ij}^{(m+1)} = \sum_r p_{ir} p_{rj}^{(m)}$$

Finally, we get the stable point at $T^i \cong T^{i+1}$

Where, i = 1, 2, 3, 4, ..., n

3.5 Index of Drought Proneness

P_{11} gives the probability of a week to be wet given that previous week was also wet. When P_{11} is large, the chance of wet weeks is also large. But only a small value of P_{11} may not indicate high drought proneness. In this case, large value of P_{01} implies a large number of short wet spells which can prevent occurrence of drought. Hence, an index of drought proneness may be defined as $DI = P_{11} * P_{01}$

The index of drought proneness is bounded by zero and one. Higher the value of DI, lower will be the degree of drought proneness. The extent of drought proneness is given in Table 1.

Table 1: The index of drought proneness

Criteria	Degree of drought proneness
0.000≤DI≤0.125	Chronic
0.125≤DI≤0.180	Severe
0.180≤DI≤0.235	Moderate
0.235≤DI≤0.310	Mild
0.310≤DI≤1.000	Occasional

Source: Banik, et al. 2000

4. Result And Discussion

Meteorological drought is a very common phenomenon in the southwestern part of Bangladesh (Shaid and Hazarika, 2010). This statement is also supported by the present study. Chronic to Occasional all classes of meteorological drought occurred during the period 1961-2020 in the study area. In the present study we convert the data into 5 days, 7 days, 10 days and 30 days and 7 mm rainfall considered as threshold value (Alam et al., 2013) and occurrence of agricultural drought has been calculated by decade wise in Jessore district. We

also calculated duration and Severity of drought by decade and predict drought probability for next decade 2021-2030.

4.1 Drought Index for Jessore District by decade

4.1.1 Decade 1961-1970

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 1961-1970 is given in Table 2.

Table 2: Analysis of drought index for the decade (1961-1970) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
1961-1970	5 days	0.0606	Chronic	0.2036	Moderate
	7 days	0.0549	Chronic	0.2684	Mild
	10 days	0.0426	Chronic	0.2701	Occasional
	30 days	0.1098	Chronic	0.4417	Occasional

From the above Table 2 we observed that the chronic drought prone periods are found for each period in case of 5 days, 7 days, 10 days and also for 30 days at 1st TPM and at higher TPM the Moderate, Mild, Occasional and Occasional drought prone periods are found in Jessore district. The Figure 1 showed that during the period 1961 to 1970 we found that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it showed that the drought is being stable at specific stage (14th, 22th, 27th and 42th) for 5, 7 and 10 days and it turns into Moderate, Mild, Occasional and Occasional drought prone at 5 days, 7 days, 10 days and 30 days respectively.

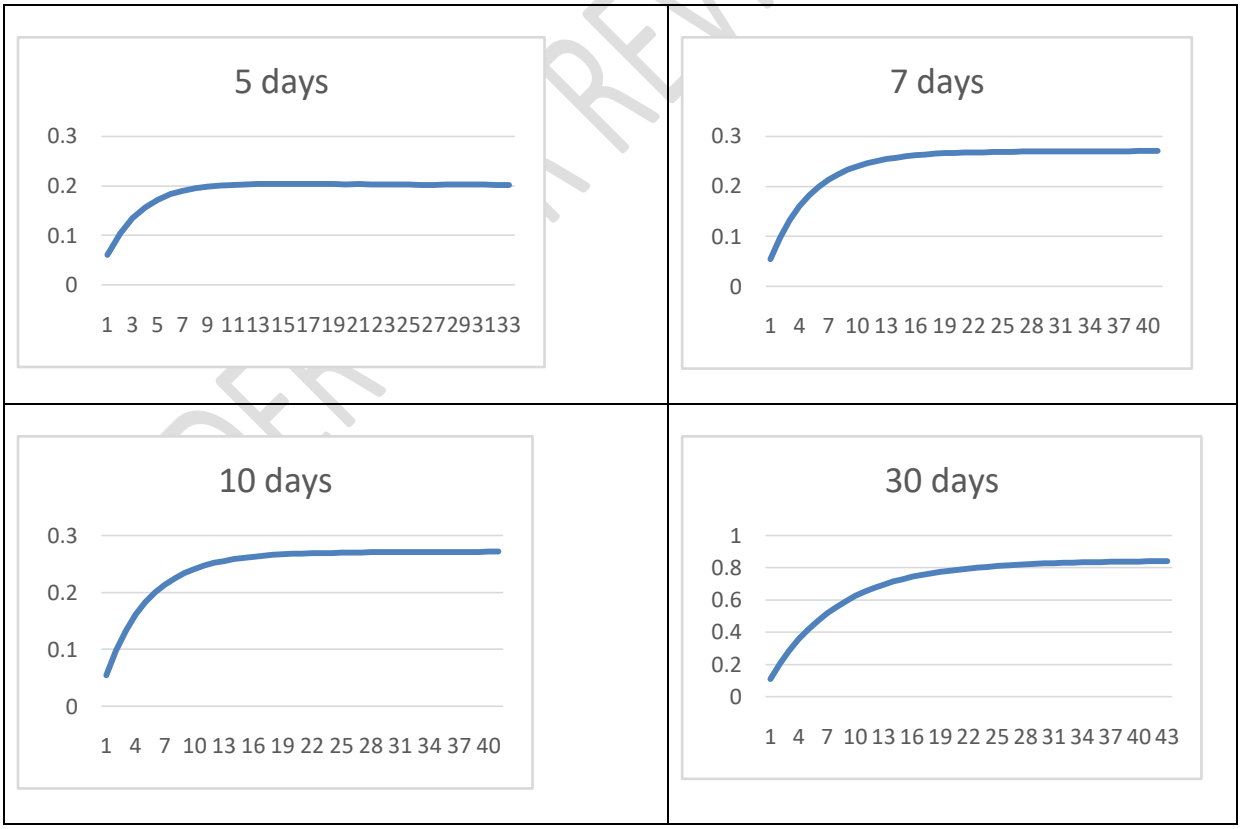

Figure 1: Drought scenario at different stage for Jessore district at decade 1961-1970

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 1961-1970 is given in Table 3.

Table 3: Duration and severity of drought of Jessore district for the decade 1961-1970

Duration	1	3	4	1	2	2	1	1
Severity	0.54309	1.78554	1.22794	0.54309	0.03758	0.02758	0.01879	0.01879
Duration	7							
Severity	3.01349							

4.1.2 Decade 1971-1980

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 1971-1980 is given in Table 4.

Table 4: Analysis of drought index for the decade (1971-1980) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
1971-1980	5 days	0.0600	Chronic	0.2042	Moderate
	7 days	0.0534	Chronic	0.2691	Mild
	10 days	0.0413	Chronic	0.3433	Occasional
	30 days	0.1067	Chronic	0.4117	Occasional

From the above Table 4 we observed that the chronic drought prone periods are found for each period in case of 5 days, 7 days 10 days and 30 days at 1st TPM and at higher TPM Moderate, Mild, Occasional and Occasional drought prone periods are found in Jessore district. The Figure 2 showed that during the period 1971 to 1980 we found that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it showed that the drought is being stable at specific stage (14th , 21th, 45th and 42th) for 5, 7, 10 and 30 days and it turns into Moderate, Mild, Occasional and Occasional drought prone are found in case of Jessore district.

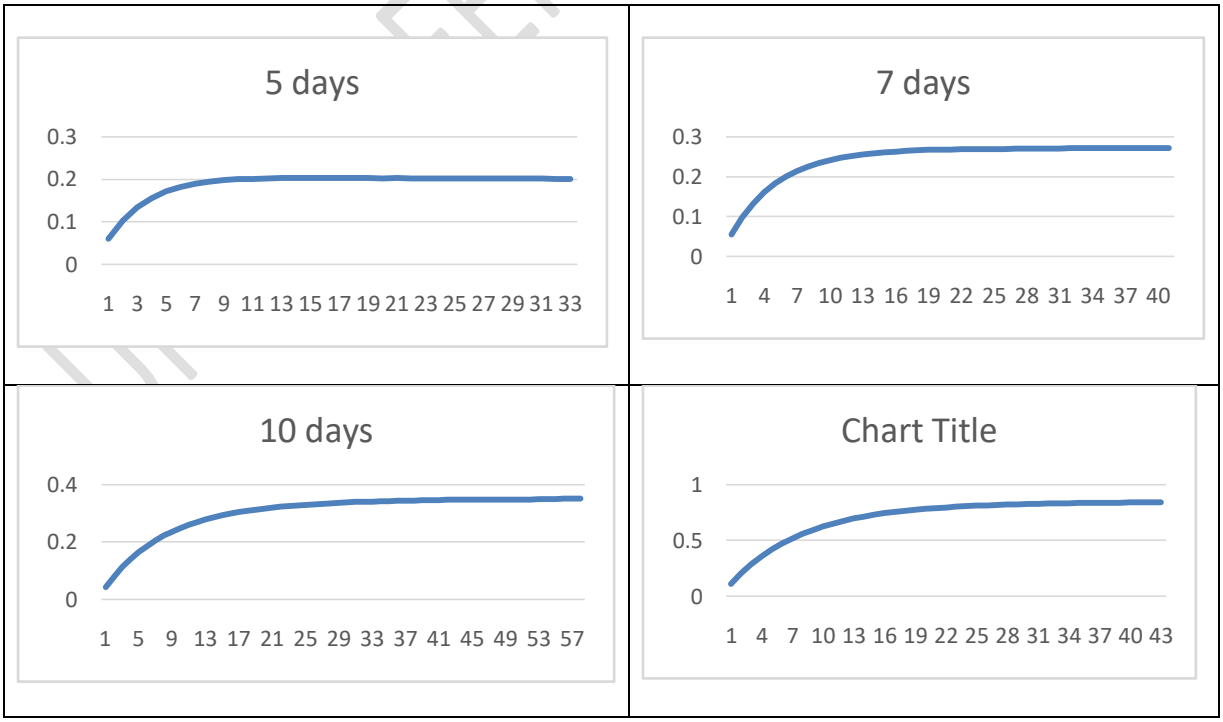

Figure 2: Drought scenario at different stage for Jessore district at decade 1971-1980

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 1971-1980 is given in Table 5.

Table 5: Duration and severity of drought of Jessore district for the decade 1971-1980

Duration	3	1	1	3	1	1	2	2
Severity	0.05638	0.01879	0.59518	1.20915	0.01879	0.54309	0.61397	0.56189
Duration	1	5	2					
Severity	0.59518	2.39951	0.61397					

4.1.3 Decade 1981-1990

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 1981-1990 is given in Table 6.

Table 6: Analysis of drought index for the decade (1981-1990) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
1981-1990	5 days	0.0593	Chronic	0.2184	Moderate
	7 days	0.0459	Chronic	0.2774	Mild
	10 days	0.0360	Chronic	0.3459	Occasional
	30 days	0.0301	Chronic	0.3461	Occasional

From the above Table 6 we observed that the chronic drought prone periods are found for each period at 1st TPM and at higher TPM the Moderate, Mild and Occasional drought prone periods are found in Jessore district for the series 5 days, 7 days and 10 days. The 30 days series we also shown chronic drought prone at first TPM and Occasional drought prone at higher TPM. Figure 3 during the period 1981 to 1990 we see that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it shows that the drought is being stable at specific stage (14th, 28th , and 50th) for 5, 7 and 10 days and it turns into Moderate, Mild and Occasional drought and 30 days series become stable at stage 56 and showed Occasional drought prone.

The daily Rainfall of decade period from 1991-2000 in Jessore district considering 5 days, 7 days and 10 days have been used for Table 4.3.6

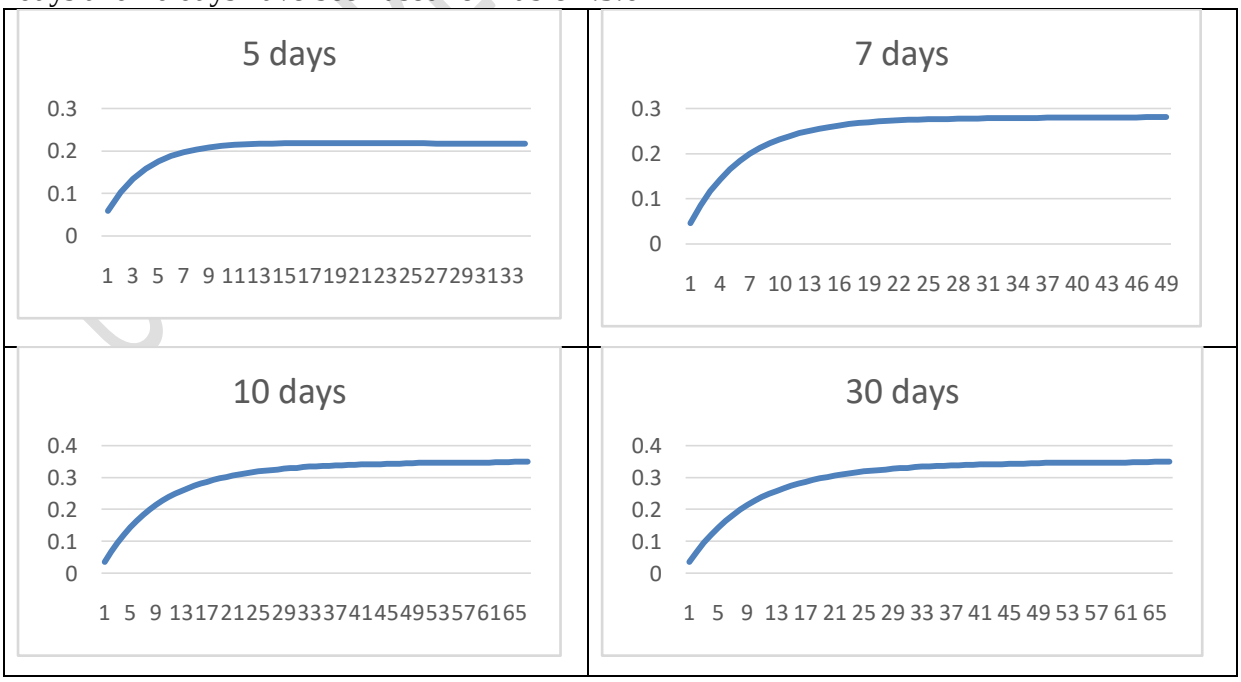

Figure 3: Drought scenario at different stage for Jessore district at decade 1981-1990

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 1981-1990 is given in Table 7.

Table 7: Duration and severity of drought of Jessore district for the decade 1981-1990

Duration	2	1	1	1	1	4	3	1
Severity	0.03758	0.59518	0.01879	0.01879	0.59518	2.27655	1.78554	0.01879
Duration	2	5	1					
Severity	0.03758	1.82313	0.10879					

4.1.4 Decade 1991-2000

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 1991-2000 is given in Table 8.

Table 8: Analysis of drought index for the decade (1991-2000) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
1991-2000	5 days	0.0663	Chronic	0.2278	Moderate
	7 days	0.0543	Chronic	0.2990	Mild
	10 days	0.0475	Chronic	0.3868	Occasional
	30 days	0.1098	Chronic	0.8417	Occasional

From the above Table 8 we found that the 5 days, 7 days, 10 days and also 30 days series showed Chronic drought prone at the first TPM and at higher TPM the Moderate, Mild, Occasional and Occasional drought prone periods are found in Jessore district for the series 5 days, 7 days, 10 days and 30 days respectively. Figure 4 during the period 1991 to 2000 we see that for 5 days, 7 days, 10 days and 30 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it shows that the drought is being stable at specific stage (22th, 34th, 56th and 44th) and become Moderate, Mild, Occasional and Occasional respectively.

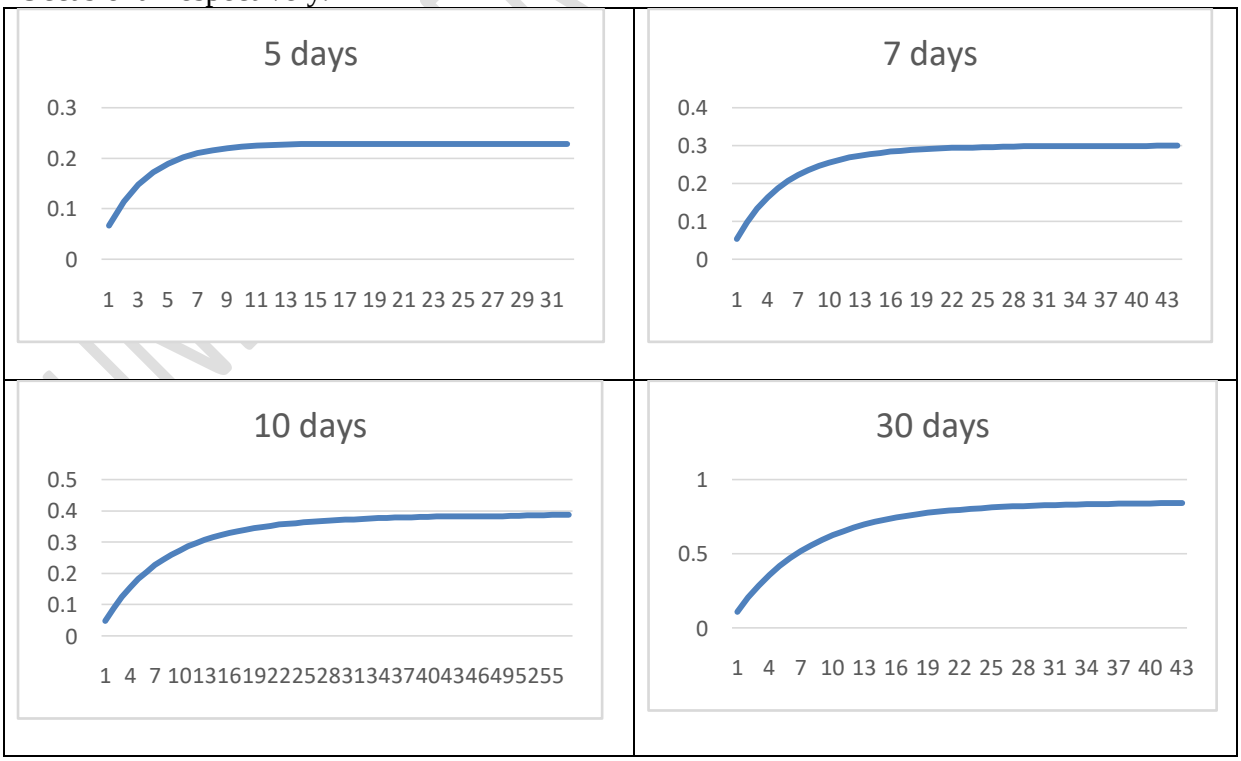

Figure 4: Drought scenario at different stage for Jessore district at decade 1991-2000

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 1991-2000 is given in Table 9.

Table 9: Duration and severity of drought of Jessore district for the decade 1991-2010

Duration	2	1	1	5	3	2	1	1
1Severity	1.13827	0.59518	0.01879	1.82313	1.15707	0.61397	0.01879	0.01879
Duration	1	2	1	2				
Severity	0.01879	0.61397	0.01879	1.19037				

4.1.5 Decade 2001-2010

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 2001-2010 is given in Table 10.

Table 10: Analysis of drought index for the decade (2001-2010) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
2001-2010	5 days	0.0619	Chronic	0.2236	Moderate
	7 days	0.0460	Chronic	0.2881	Mild
	10 days	0.0370	Chronic	0.3567	Occasional
	30 days	0.9012	Occasional	0.9331	Occasional

From the above Table 10 we found that the 5 days, 7 days, 10 days series showed Chronic drought prone at the first TPM and the 30 days series showed Occasional drought at first TPM and at higher TPM the Moderate, Mild, Occasional and Occasional drought prone periods are found in Jessore district for the series 5 days, 7 days, 10 days and 30 days respectively. Figure 5 during the period 2001 to 2010 we see that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it shows that the drought is being stable at specific stage (26th, 37th and 51th) for 5, 7 and 10 days and it turns into Moderate, Mild and Occasional. The 30 days series showed Occasional drought prone and become stable at only few stage 4.

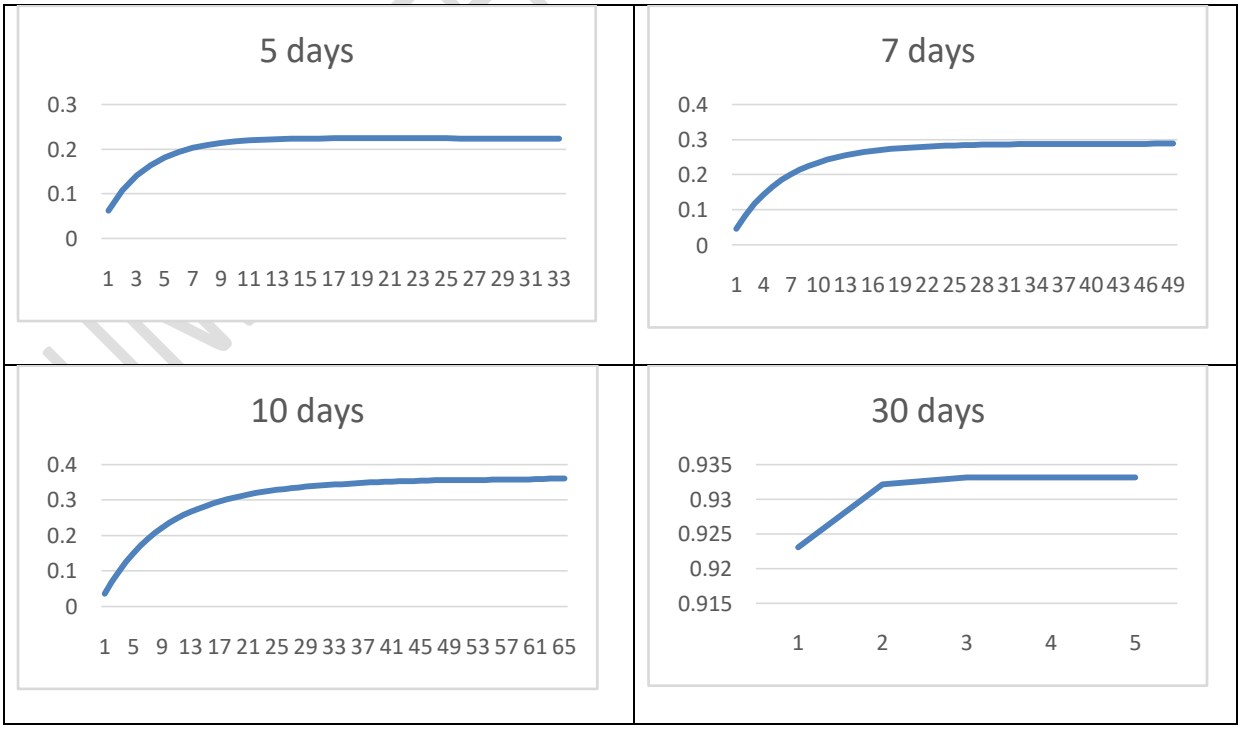

Figure 5: Drought scenario at different stage for Jessore district at decade 2001-2010

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 2001-2010 is given in Table 11.

Table 11: Duration and severity of drought of Jessore district for the decade 2001-2010

Duration	1	1	1	1	3	3	1	1
Severity	0.01879	0.01879	0.01879	0.59518	1.68137	1.78554	0.01879	0.59518
Duration	1	2	1	5	1			
Severity	0.01879	0.03758	0.01879	2.39951	0.01879			

4.1.6 Decade 2011-2020

The calculated DI (Drought Index) for 5 days, 7 days, 10 days and 30 days series with threshold value 7mm in case of Jessore for the decade 2011-2020 is given in Table 12.

Table 12: Analysis of drought index for the decade (2011-2020) in Jessore district

Year	Data	Frist TPM		Higher TPM	
		DI	Comment	DI	Comment
2011-2020	5 days	0.0607	Chronic	0.2056	Moderate
	7 days	0.0477	Chronic	0.2711	Mild
	10 days	0.0379	Chronic	0.3408	Occasional
	30 days	0.8190	Occasional	0.8658	Occasional

From the above Table 12 we found that the 5 days, 7 days and 10 days series showed Chronic drought prone at the first TPM and the 30 days series showed Occasional drought at first TPM and at higher TPM the Moderate, Mild, Occasional and Occasional drought prone periods are found in Jessore district for the series 5 days, 7 days, 10 days and 30 days respectively. Figure 6 during the period 2011 to 2020 we see that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 7 mm and finally due to climate change it shows that the drought is being stable at specific stage (28th, 33th and 52th) for 5, 7 and 10 days and it turns into Mild, Occasional and Occasional drought and 30 days series become stable at only few stage at 5.

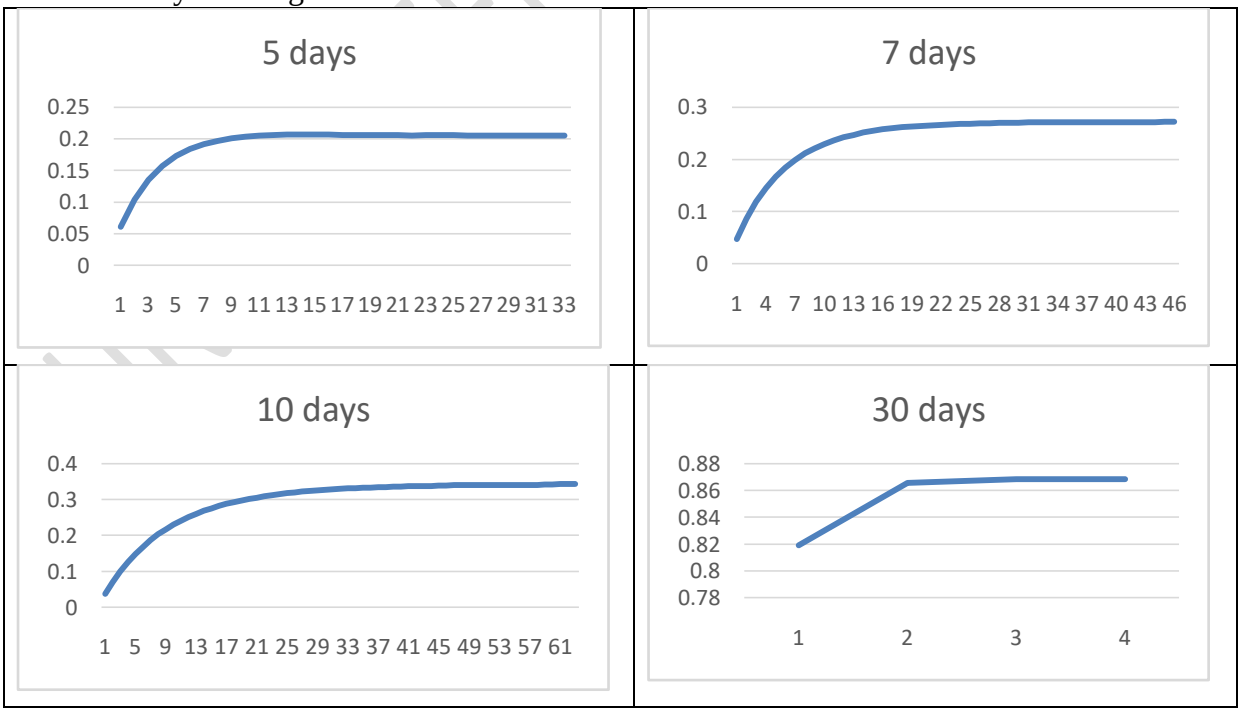

Figure 6: Drought scenario at different stage for Jessore district at decade 2011-2020

Duration and Severity

The duration and severity of drought in case of Jessore district for the decade 2011-2020 is given in Table 13.

Table 13: Duration and severity of drought of Jessore district for the decade 2011-2020

Duration	1	2	1	1	1	1	2	2
Severity	0.01879	1.19036	0.54309	0.01879	0.01879	0.01879	0.03758	1.13827
Duration	1	1	1	2	1	3	1	1
Severity	0.01879	0.59518	0.01879	0.61397	0.59518	1.78554	0.01879	0.01879

4.2 Predict Drought Probability for the Decade 2021-2030 in Jessore district

To forecast the drought conditions in Jessore district, the Markov Chain Model was applied to SPI index based on historical monthly rainfall data. Markov Chain forecasts drought by estimating transition probabilities between drought states, then simulating future states based on historical patterns, predicting drought severity probabilistically over time. Forecast probabilities (2021-2030) is given in table 14.

Table 14: Predicted drought probability of Jessore district for decade 2021-2030

Chronic	**Severe**	**Moderate**	**Mild**	**Occasional**
0.00948	0.04554	0.06641	0.11954	0.75901

Table 14 indicates the likelihood of drought conditions in the following 10 years from 2021 to 2030 using the SPI index in case of Jessore district. The table shows that Occasional drought have the highest probability i.e. in Jessore district the next decade will be occasional drought at most of the time. On the other hand, the "Mild Drought" has a significant probability (11.95%) and moderate drought conditions occur very regularly. Besides, we can see that "severe drought" is rare (4.5%), while "Chronic" is extremely rare (0.9%). Last of all, we can state that water resource management should focus on reducing mild and moderate drought effects, as they are more common in the long run.

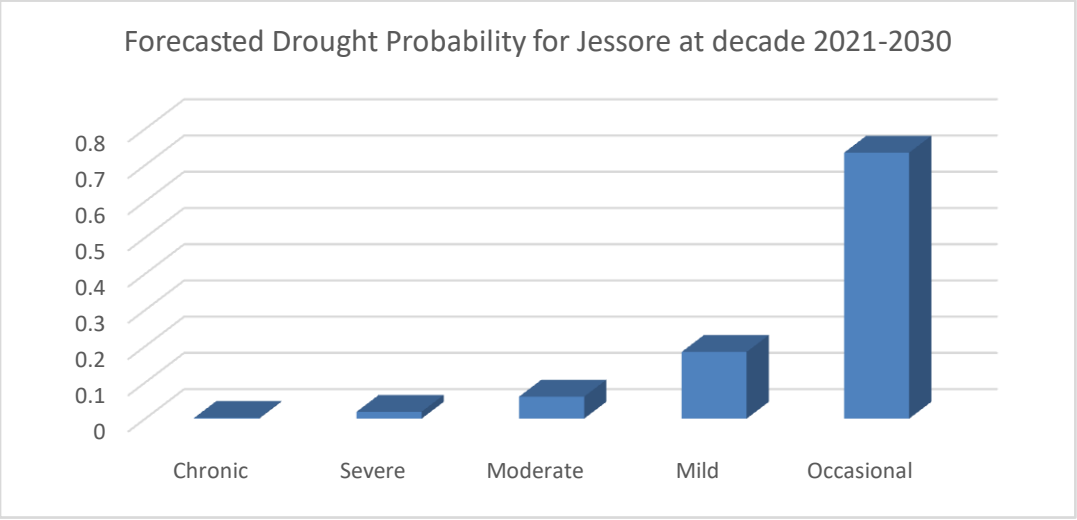

Figure 7: Bar diagram of forecasted drought probability for Jessore at 2021-2030

5 Conclusion and Recommendation

Agricultural drought primarily pertains to insufficient rainfall. The yield of crops in a given area is influenced by the fluctuations in rainfall during the monsoon season. Drought is a transient yet intricate aspect of the climate system. Markov Chain models have been employed to estimate the probabilities of experiencing sequences of wet and dry days in the region. The empirical result conclude the drought index by different decade with different time scale. These are summarized below:

(i) In 1961-1970 chronic (DI =0.0606, 0.0549, 0.0426 and 0.1098) drought is found at first TPM but at higher TPM moderate (DI = 0.2036) drought is found and for 5 days, mild (DI = 0.2684) drought is found and for 7 days and occasional (DI = 0.2701 and 0.8307) drought prone period is for 10 and 30 days. The maximum duration of severity is 7 at this decade.

(ii) In 1971-1980 chronic (DI =0.0600, 0.0534, 0.0413 and 0.1067) drought is found at first TPM but at higher TPM moderate (DI = 0.2042) drought is found and for 5 days, mild (DI = 0.2691) drought is found and for 7 days and occasional (DI = 0.3433 and 0.8270) drought prone period is for 10 and 30 days. The maximum duration of severity is 5 at this decade.

(iii) In 1981-1990 chronic (DI =0.0593, 0.0459, 0.0360 and 0.0301) drought is found at first TPM but at higher TPM moderate (DI = 0.2184) drought is found and for 5 days, mild (DI = 0.2774) drought is found and for 7 days and occasional (DI = 0.3459 and 0.3469) drought prone period is for 10 and 30 days. The maximum duration of severity is 5 at this decade.

(iv) In 1991-2000 chronic (DI =0.0663, 0.0543, 0.0475 and 0.1098) drought is found at first TPM but at higher TPM moderate (DI = 0.2278) drought is found and for 5 days, mild (DI = 0.2990) drought is found and for 7 days and occasional (DI = 0.3868 and 0.8417) drought is found and for 10 and 30 days. The maximum duration of severity is 3.

(v) In 2001-2010 chronic (DI =0.061, 0.048, 0.040 and 0.9012) drought is found at first TPM but at higher TPM moderate (DI = 0.2236) drought is found and for 5 days, mild (DI = 0.2881) drought is found and for 7 days and occasional (DI = 0.3565 and 0.9331) drought is found and for 10 and 30 days. The maximum duration of severity is 5.

(vi) In 2011-2020 chronic (DI =0.059, 0.046 and 0.039) drought is found for 5, 7 and 10 days and occasional drought prone period is found for 30 days at first TPM but at higher TPM moderate (DI = 0.2056) drought is found and for 5 days, mild (DI = 0.2711) drought is found and for 7 days and occasional (DI = 0.3408 and 0.8658) drought prone period is found for 10 and 30 days.

From the above discussion we found that the chronic drought prone period is observed for 5 day, 7 day and 10 series at first TPM whereas 30 days series showed occasion drought prone at this TPM but due to climate change these drought is convert to moderate, mild and occasional for most of the series at higher TPM in case of Jessore district and the maximum severity occurred around 7 months during 1961-1970. The forecasted drought probability for the next decade showed that in Jessore district the next decade will be occasional drought at most of the time.

The forecasted drought probability for the next decade showed that in Jessore district the next decade will be occasional drought at most of the times.
This study will contribute to policy formulation and strategic planning in the areas such as, agricultural practices and crop diversification, investments in irrigation development works and allocation of water to different uses.
The production of crops, especially Aman crop is heavily damaged every year due to inadequate soil moisture regime prevailing in drought affected areas. To struggle this situation government, agriculturist and farmers will adopt the following policies:

- Supplementary irrigation will be ensured in service and extremely severe drought affected areas of this northern part of Bangladesh.
- Proper strategy will be pursued for cultivating crops.

So the finding of the studies will help in proper implementation of agricultural policy to increase overall agricultural production in northwestern part of Bangladesh which is expected to bring about significant positive change in the country and also help the government and relevant organization to identify methods for reducing poverty and achieving sustainable development in agriculture and land use. This study would also help us to achieve sustainable development goals such as sustainable water and combat climate change.

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