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RESEARCH ARTICLE

ASSESSING AND PREDICTING DROUGHT VULNERABILITY OF JESSORE DISTRICT IN BANGLADESH WITH MARKOV CHAIN MODEL

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Abstract

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The agricultural sector, which is crucial to the socioeconomic framework of Bangladesh, is particularly exaggeratedwith different natural calamities such as drought, flood, cyclone etc.Drought primarily arises from insufficient rainfall. Markov Chain model is employed to assess the probability of suffering sequences of wet and dry days in this field.The long-term fluctuations in rainfall and temperature patterns contribute the 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 southwestern part of Bangladesh. The daily rainfall data of Jessore district from January 1961 to December 2020 is considered for investigation. Following the cleansing of the daily rainfall dataset, we computed the data into various time intervals of 5, 7, 10, and 30 days utilizing Microsoft Excel. Subsequently, we employed the R programming language to analyze the drought index using the Markov Chain Model, focusing on a threshold value of 7 mm of rainfall, and to forecast the drought probability for the upcoming decade from 2021 to 2030 based on monthly data. The empirical study showed 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 global climate change these drought 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.

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Introduction:-

As a result of global warming, most climate models in South Asia predict a reduction in rainfall during the dry season and an increase during the monsoon season. This shift is expected to lead to a heightened occurrence of both severe droughts and floods in the region. Bangladesh, particularly its western region, is recognized as one of the most disaster-prone nations globally, where droughts are a frequent occurrence (Ali 1996).

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Drought represents a temporary yet intricate phenomenon within the climatic system, primarily resulting from a lack of precipitation. It can manifest in both regions with high and low rainfall, leading to an imbalance between water supply and demand (Gregory 1986). The effects of drought are profound, impacting both the environment and society, and may necessitate global relief efforts (Ahmed 1995). Droughts are typically categorized into four types: meteorological, agricultural, hydrological, and socioeconomic. Despite variations in their definitions, all these categories represent water-deficit situations stemming from insufficient rainfall (Liu et al. 2016). To assess agricultural drought, researchers analyze factors such as precipitation deficits, evapotranspiration, and the moisture available in the soil (Wilhite and Glantz 1985; Banik et al. 2000). Xianfeng et al. (2016) further characterized agricultural drought as the degree to which soil moisture falls below the minimum requirements for plant growth. Understanding the potential impacts of drought in the context of future climate change is essential for monitoring and predicting its occurrence on a seasonal basis, as well as for evaluating climate models for future projections.

Bangladesh has experienced nine significant droughts (Paul, 1998). Although droughts in Bangladesh are recurrent and have severe consequences, they have received considerably less scientific focus compared to 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 in 1951, 1957, 1961, 1972, 1976, 1979, 1986, 1989, and 1997, affecting about half of the country's total population (Shahid, 2011).

Bangladesh, particularly in its western region, is recognized as one of the most disaster-prone nations globally (Ali 1996), where drought occurs frequently. Numerous studies have examined the effects of drought on agriculture (Karim et al., 1996; Jabber, 1990; Jabber et al., 1982; Saleh et al., 2000; Mazid et al., 2005). Nevertheless, research focusing on the ecological consequences of drought has not garnered sufficient scientific scrutiny (Brammer 1987) within the country. Limited studies have utilized standard drought modeling to assess the impact of drought in Bangladesh. Shahid and Behrawan (2008) investigated the extent and effects of drought in the western region, taking into account socioeconomic and physical indicators of drought vulnerability, and created a drought risk map; however, they did not succeed in developing an accurate composite drought vulnerability map. The Western part of Bangladesh will be at high risk of drought hazard. Recently, Bangladesh has found an increased number of drought frequency.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)). There is growing concern among scientists in Bangladesh about alterations in precipitation patterns, potential evapotranspiration (PET), and occurrences of drought. Therefore, gaining a deeper understanding of the frequency and intensity of droughts is essential for informed decision-making regarding agricultural distribution and adaptation strategies to climate change, particularly in the dry season within the paddy cultivation areas of Bangladesh.So, the aim of the paper is to monitor the drought vulnerability by decade and forecast the drought probability for next decade with most effective 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. Description of Study Area and Data

Jessore (Jashore) districtbelong to the southwestern part of Bangladesh. The area is adjacent to India on the west, the Khulna and Satkhira districts to the south, Khulna and Narail to the east, and the Jhenaidah and Magura districts to the north. Jessore is the capital of the district. The average yearly temperature varies between 15.4 and 34.6 °C (59.7 to 94.3 °F), with an annual total precipitation of 1,537 millimetres (60.5 inches).The primary occupations include agriculture (39.84%), agricultural labor (24.13%), other wage labor (2.68%), commerce (11.99%), services (8.66%), industry (1.41%), transport (3.11%), and various other activities at 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 Origin and Smoothing

The daily rainfall records from the Jessore weather station, spanning approximately 60 years from 1961 to 2020, were obtained from the Bangladesh Meteorological Department (BMD). During this period, some data were missing. Specifically, data from two years (1971 and 1990) and nearly three months were not recorded. The missing values appeared to be random; however, there were instances of continuous missing data for durations ranging from one month to several months. Utilizing Microsoft Excel, we organized the data into series formats of 5, 7, 10, and 30 days, and subsequently estimated the missing values using SPSS, preparing the dataset for our methodology. Following this, we employed the R programming language to conduct an analysis using the Markov chain model, focusing on a threshold rainfall value of 7mm. To predict drought probabilities at these stations, we utilized the monthly data, specifically the 30-day data, for the decade spanning 2021 to 2030, again applying the Markov chain model.

Methodology:-

3.1 Drought Index

Monitoring drought conditions is essential for proactive warning and mitigation strategies.Throughout the years, various drought indices have been created to assess the severity and duration of drought conditions.McKee et al. (1993) proposed theStandardized Precipitation Index (SPI)for meteorological drought monitoring. The Standardized Precipitation Index (SPI) is advantageous as it can be computed across various time scales, rendering it effective for the assessment of both short-term and long-term drought conditions (Hayes et al., 1999). Another extensively used measure is the Palmer Drought Severity Index (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 play a crucial role in the assessment and measurement of drought conditions. Numerous indices have been established to evaluate meteorological, hydrological, and agricultural droughts. Notably, the Standardized

Precipitation Index (SPI), Rainfall Anomaly Index (RAI), Palmer Drought Severity Index (PDSI), and Z-Score Index (ZSI) are commonly employed for drought analysis (Mishra and Singh, 2010). Kamaruzzaman et al. (2016) and Alam et al. (2013) utilized a Markov chain-based index to identify drought conditions across various stations. In our research, we apply a Markov chain model to develop a drought index derived from rainfall data.

3.2MarkovChainModel

The Markov chain probability model operates under the premise that the condition of any given day is influenced solely by the condition of the day prior. A two-state Markov chain model necessitates the computation of two conditional probabilities: (1) α, representing the likelihood of experiencing a wet week after a dry week, and (2) ß, denoting the probability of a dry week. The conditional probabilities for the two-state Markov chain are outlined as follows:

Presentstate		
	Dry	Wet
Dry	1-α	α
Wet	ß	1-ß

Letusconsidertheconditionalprobabilities$P_0 = \Pr\{W/D\}$and $P_1 = \Pr\{W/W\}$. The aforementioned sequence is regarded as an irreducible Markov chain consisting of two ergodic states.The stationary probability distribution indicates a likelihood of success,

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

3.3M Order MarkovChainModel

A Markov Chain is defined as a Markov process characterized by discrete state and parameter spaces, with the state dependency referred to as Markovian dependence. An m-order Markov chain consists of a series of outcomes where each outcome is contingent solely on the immediately preceding outcomes. The sequence of random variables $\{X_n\}$ constitutes a Markov chain of order m if, for a specified m, it holds true for all potential values of the variables X_n(n=0,1,2,…).

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

3.4Approach of the Markov Chain Model

Numerous researchers have demonstrated that the patterns of daily rainfall can be effectively modeled using a straightforward Markov chain approach. Further support for the applicability of this model has been provided by Rahman (1999 a&b), Banik et al. (2002), and Alam et al. (2011). The principles of the Markov chain are outlined as follows: Let $X_0, X_1, X_2, \dots, X_n$ represent random variables that are identically distributed and can only assume two values, specifically 0 and 1, with a probability of one i.e

$$X_n = \begin{cases} 0\text{ifthen-thweekisdry} \\ 1\text{ifthen-thweekiswet} \end{cases}$$

now,itmaybeassumedthat,

$$P\big(X_n+1 = x_n+1, X_n = x_{n,} X_n-1 = x_n-1, \dots, X_0 = x_0\big) = P(X_n+1 = x_n+1, X_n = x_n)$$

where $X_{0,}X_1, \dots, X_n+1 \in \{0,1\}$

In other terms, it is presumed that the likelihood of a week being wet is solely contingent upon whether the preceding week was wet or dry. Given the condition of the previous week, the probability of wetness is considered independent of any earlier weeks. Therefore, the stochastic process $\{X_n$, n = 0, 1, 2…….} constitutes a Markov chain.

Assuming 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 the transition probability matrix of a higher order, we have,$P_{ij}^{(m+1)} = \sum_r p_{ir} p_{rj}^{(m)}$

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

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

3.5DroughtPronenessIndex

P_{11} represents the likelihood of a week being wet, contingent upon the previous week also being wet. A high value of P_{11}indicates a greater probability of consecutive wet weeks. Conversely, a low P_{11}does not necessarily suggest a high susceptibility to drought. In such instances, a significant P_{01} value indicates a prevalence of brief wet periods, which can mitigate the risk of drought. Therefore, a drought proneness index can be formulated as DI=P_{11}*P_{01}. This index ranges from zero to one, where a higher DI value correlates with a reduced risk of drought. The degree of drought proneness is shown (Banik, etal.2000) detailed in Table 1.

Table 1:Theindexofdroughtproneness

Drought types	Values
Chronic	$0.000 \leq DI \leq 0.125$
Severe	$0.125 \leq DI \leq 0.180$
Moderate	$0.180 \leq DI \leq 0.235$
Mild	$0.235 \leq DI \leq 0.310$
Occasional	$0.310 \leq DI \leq 1.00$

4. Result and Discussion:-

Meteorological drought is a prevalent occurrence in the southwestern region of Bangladesh, as noted by Shaid and Hazarika (2010), a finding corroborated by the current research. Throughout the period from 1961 to 2020, various levels of meteorological drought, ranging from chronic to occasional, were observed in the study area. In this research, we have transformed the data into intervals of 5, 7, 10, and 30 days, using a threshold value of 7 mm of rainfall (Alam et al., 2013), and the incidence of agricultural drought has been assessed on a decadal basis in the 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

The analysis of Table 2 reveals that chronic drought-prone periods are identified for durations of 5 days, 7 days, 10 days, and 30 days at the first threshold of precipitation measurement (TPM). At higher TPM levels, varying degrees of drought—specifically Moderate, Mild, and Occasional—are observed in the Jessore district. Furthermore, Figure 1 illustrates that between 1961 and 1970, chronic drought conditions for 5, 7, and 10 days emerged at a threshold value of 7 mm. Ultimately, due to climate change, drought conditions have stabilized at specific intervals (14^{th}, 22^{th}, 27^{th}, and 42^{th} days) for the aforementioned durations, transitioning into Moderate, Mild, and Occasional drought classifications for 5 days, 7 days, 10 days, and 30 days, respectively.

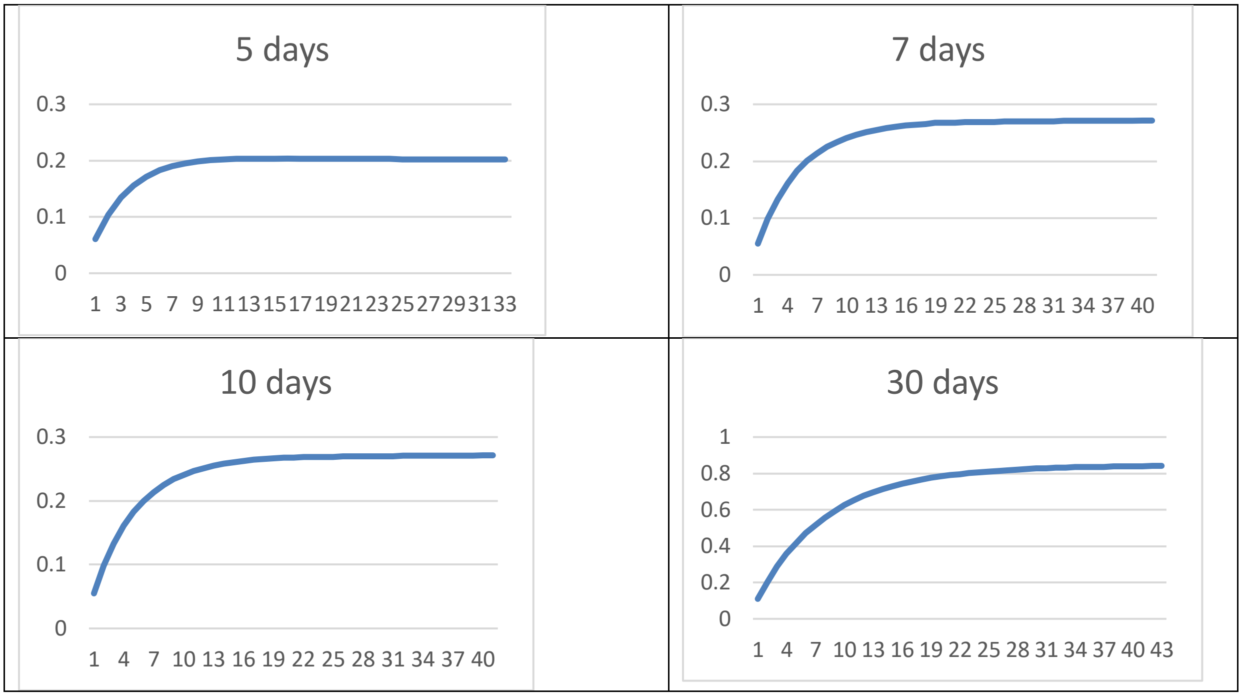

Figure 1:- Drought scenario at different stage for Jessore district at decade 1961-1970.

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

Table 4 indicates that chronic drought-prone periods are identified for each duration of 5 days, 7 days, 10 days, and 30 days at the first TPM. Additionally, at higher TPM levels, moderate, mild, and occasional drought-prone periods are observed in the 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 (14^{th}, 21^{th},45^{th} and 42^{th}) 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.

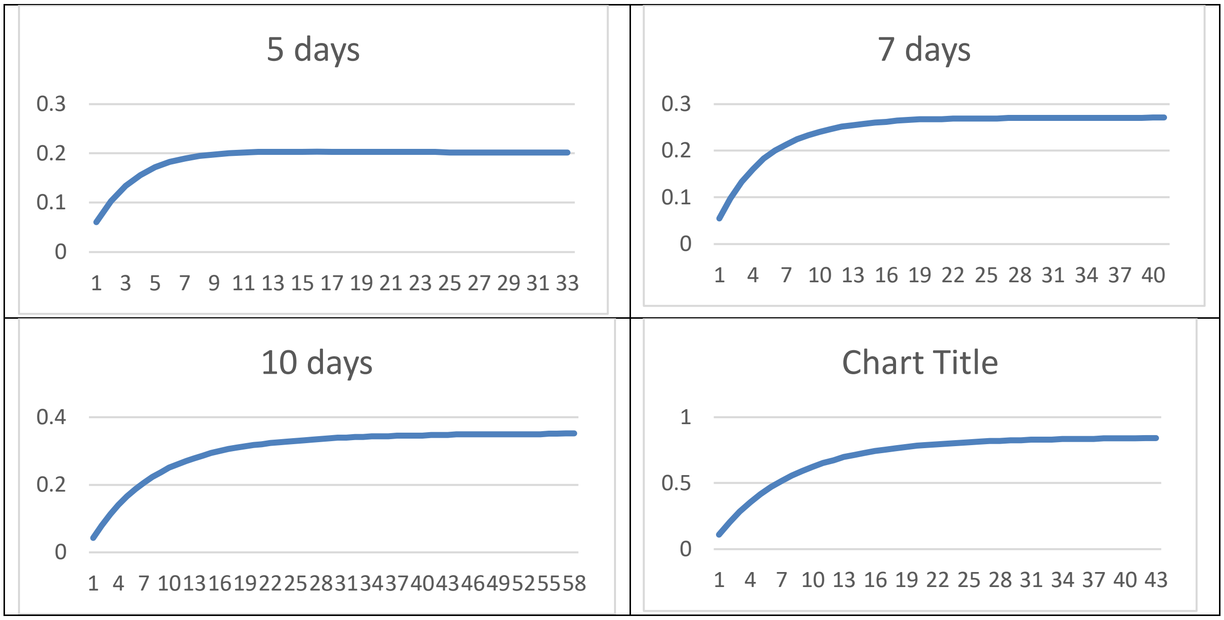

Figure 2:- Drought scenario at different stage for Jessore district at decade 1971-1980

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 6It has been noted that chronic drought-prone periods are identified for each interval at the 1st TPM, while at higher TPMs, Moderate, Mild, and Occasional drought-prone periods are observed in the Jessore district for the 5-day, 7-day, and 10-day series. The 30 days series we also shown chronic drought prone at first TPM and Occasional drought prone at higher TPM.In Figure 3, the data from 1981 to 1990 indicates that drought conditions lasting 5, 7, and 10 days were persistent at the initial threshold of 7 mm. Ultimately, as a result of climate change, the drought conditions stabilize at specific intervals (14th, 28th, and 50th days) for the 5, 7, and 10-day durations, transitioning into Moderate, Mild, and Occasional droughts. Furthermore, the 30-day series stabilizes at stage 56, indicating a tendency towards Occasional drought.

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

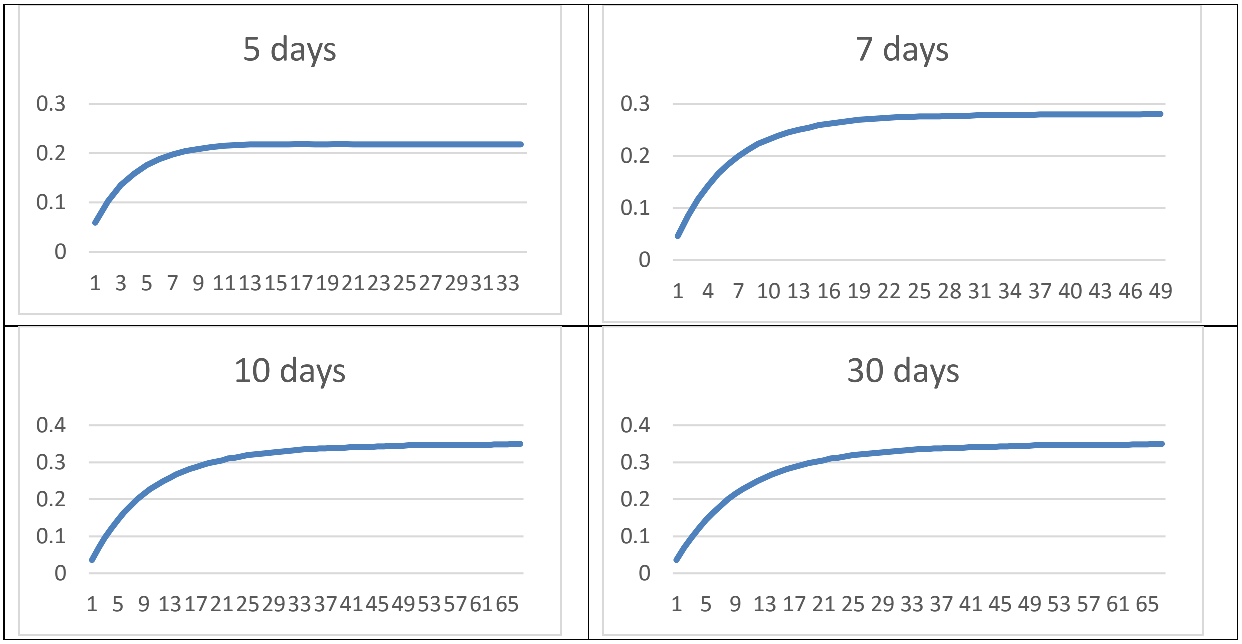

Figure 3:- Drought scenario at different stage forJessoredistrict at decade 1981-1990.

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 thresholdvalue 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

The result from Table 8we 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 (22^{th}, 34^{th},56^{th} and 44^{th}) and become Moderate, Mild, Occasional and Occasional respectively.

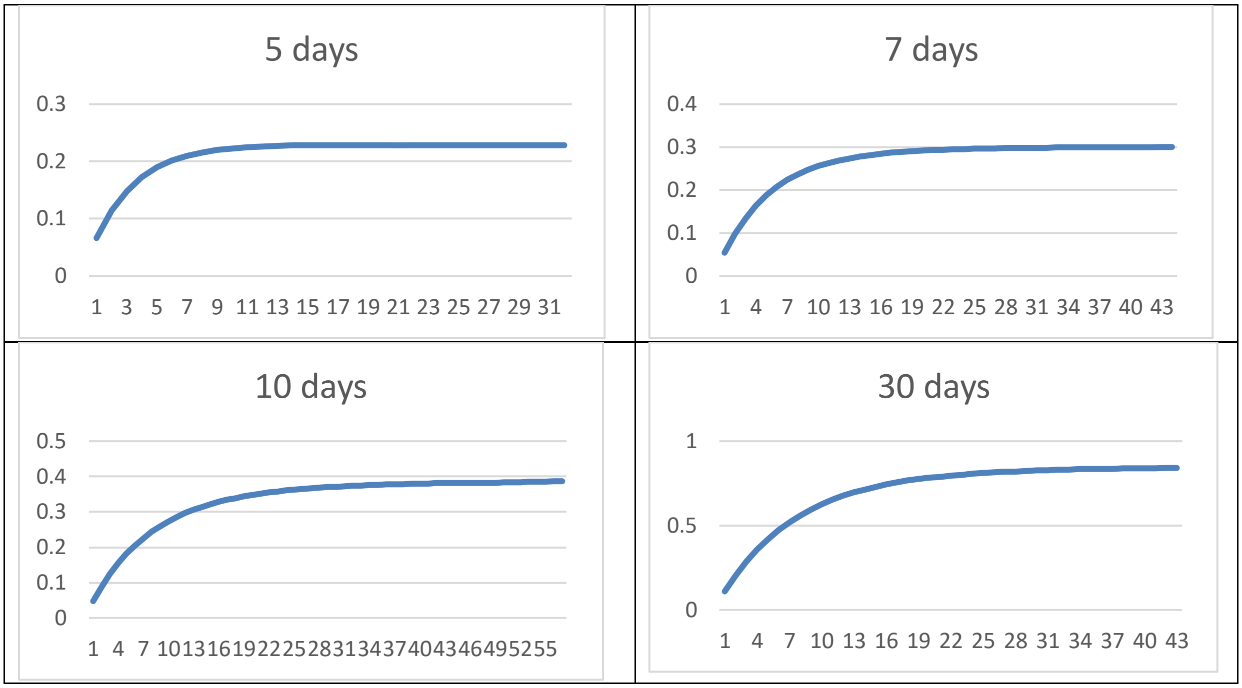

Figure 4:- Drought scenario at different stage for Jessore district at decade 1991-2000.

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 ofJessore 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

The Table 10showedthat the 5 days, 7 days, 10 days series present Chronic drought prone at the first TPM and the 30 days series present Occasional drought prone period 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 5showed that the 5, 7 and 10 days data series found out chronic drought prone period at first TPM at the time period 2001 to 2010 and the drought is being stable at specific stage (26^{th}, $37^{th}$and 51^{th}) for 5, 7 and 10 days and it turns into Moderate, Mild andOccasional. The 30 days series showed Occasional drought prone and became stable at only fewstage 4.

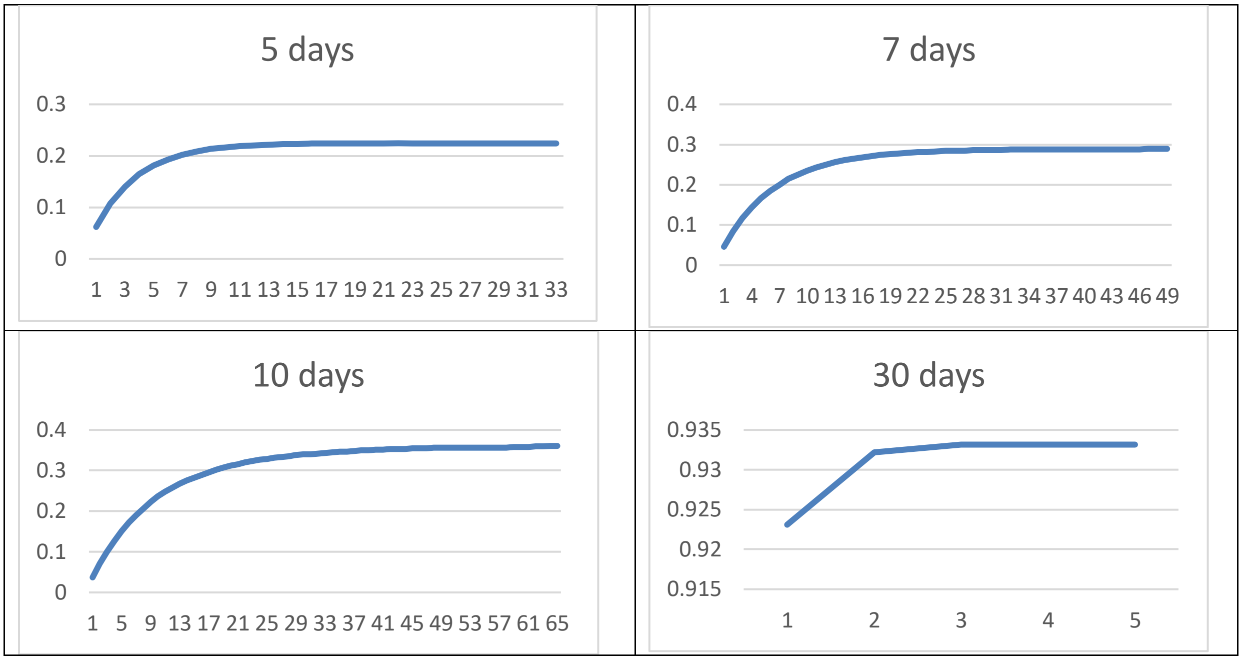

Figure 5:- Drought scenario at different stage for Jessore district at decade 2001-2010.

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

The analysis of Table 12 indicates that the 5-day, 7-day, and 10-day series exhibited chronic drought conditions at the initial threshold point (TPM), while the 30-day series demonstrated occasional drought at the first TPM. At higher TPMs, the 5-day, 7-day, 10-day, and 30-day series in Jessore district revealed moderate, mild, and occasional drought conditions, respectively. Furthermore, Figure 6 illustrates that from 2011 to 2020, the 5-day, 7-day, and 10-day series experienced chronic drought at the initial threshold value of 7 mm. Ultimately, due to climate change, the drought conditions have stabilized at specific stages (28^{th}, 33^{th}, and 52^{th}) for the 5-day, 7-day, and 10-day series, transitioning into mild and occasional droughts, while the 30-day series has stabilized at only a few stages at a threshold of 5.

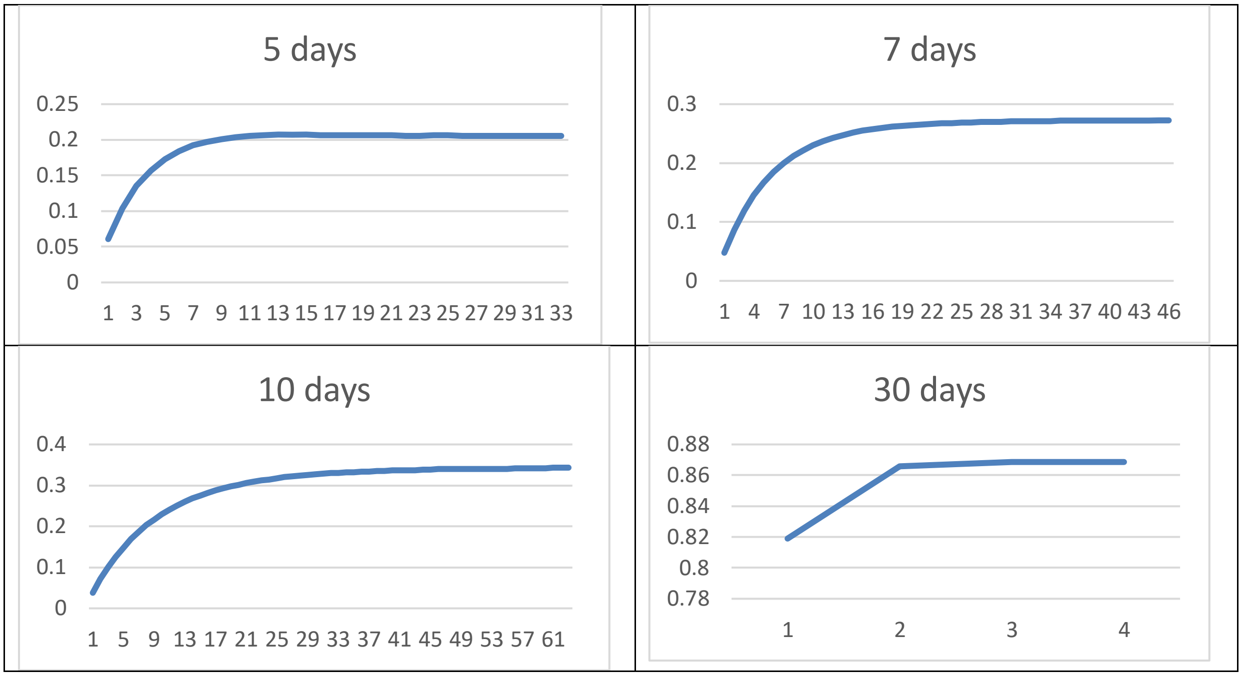

Figure 6:- Drought scenario at different stage for Jessore district at decade 2011-2020.

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.

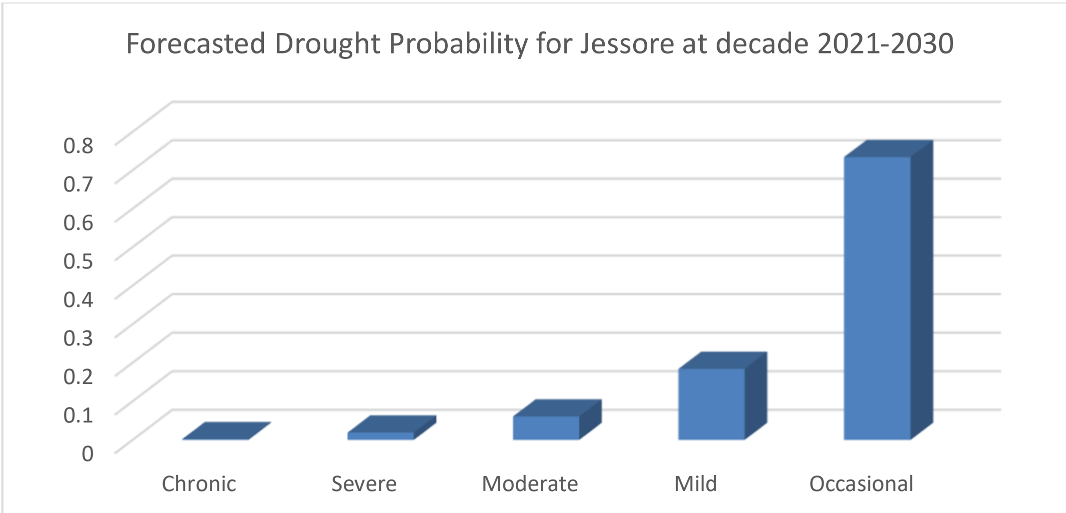

Figure 7:- Bar diagram of forecasted drought probability for Jessore at 2021-2030.

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 concludes 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 research will aid in the development of policies and strategic plans related to agricultural practices, crop diversification, investment in irrigation infrastructure, and the allocation of water resources. The cultivation of crops, particularly the Aman variety, suffers significant losses annually due to insufficient soil moisture in drought-prone regions. To address this issue, the government, agricultural experts, and farmers will implement the following strategies:
• Ensuring supplementary irrigation in severely drought-affected the Jessore district of Bangladesh.
• Developing effective strategies for crop cultivation.
Consequently, the outcomes of this research will facilitate the effective execution of agricultural policies aimed at enhancing overall agricultural productivity in northwestern Bangladesh, which is anticipated to lead to substantial positive changes in the country. Additionally, it will assist the government and relevant organizations in identifying strategies to alleviate poverty and achieve sustainable agricultural development and land use. This study will also contribute to the attainment of sustainable development goals, including sustainable water management and climate change mitigation.

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