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RESEARCH ARTICLE

MONITORING DROUGHT VULNERABILITY AT DIFFERENT TIME SCALES: A CASE STUDY FROM RAJSHAHI DISTRICT, BANGLADESH

Md. Mostafizur Rahman[1] and M. Sayedur Rahman[2]

1. Associate Professor, Data Mining Research Group, Department of Statistics, University of Rajshahi, Bangladesh.
2. Professor, Environmental Research Group, Department of Statistics, University of Rajshahi, Bangladesh.

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Abstract

Drought is a slow onset natural disaster which creates a threat to social and agro-ecological balance. The failure of rain and the occurrence of drought during any particular growing season may lead to severe food shortage and increase vulnerability. The purpose of this study is to estimate the Drought Index (DI) in multiple time scales for Rajshahi district of Bangladesh.The 52 years daily rainfall data during the period 1964-2015 used for analysis. **There were some missing data over that range.** We separated this time interval in 5, 7 and 10 days series format then we estimate missing value by using **imputtation method. Finally, we used** R code to analyze Markov Chain Model by considering threshold value 3mm. At first, we find out the Drought Index from the first transition probability matrix and then estimate with higher transition probability matrix. When the higher transition probability matrix became stable, then we estimate the DI. The empirical study showed that for 5, 7 and 10 days Drought Index (DI) followed extreme to moderate, mild to occasional, and extreme to occasionally drought respectively. But in first transition probability matrix it showed chronic drought and due to climate change after different stages chronic drought turned into severe, moderate, mild and occasional drought. In overall interpretation, we found mild for 5 days and occasional drought for 7 and 10 days respectively. By extracting information about drought characteristics that include its spatial extent, severity, and frequency are important for policy maker to take necessary steps in advance to mitigate the effect of drought for producing crops which will reduce the food insecurity and vulnerability for developing sustainable development.

Introduction:-

Drought is a natural incident that can inflict damage of disastrous proportion i.e. the reduction of crop production and distressing the general population over the lack of water. It is a frequent and worldwide incident bearing some characteristics that vary significantly from one region to another region. An extended lack of precipitation can propagate through the hydrological system and affect soil moisture, resulting in soil moisture drought, as well as groundwater and discharge, resulting in hydrological drought. Although its impact varies from one region to another

Corresponding Author:- Md. Mostafizur rahman
Address:- Associate Professor, Data Mining Research Group, Department of Statistics, University of Rajshahi, Bangladesh.

but the strategies and principles underlying the task of managing drought risk are similar except some specific situation of any countries. Natural droughts are recurring phenomena which generally affecting nearly all components of the water cycle that can be classified into meteorological, agricultural and hydrological droughts. Hydrological droughts, which include both stream flow and groundwater (GW) droughts, usually occur due to the deficiencies in surface and sub-surface water supplies. The GW drought is a very specific type of hydrological drought that occurs when groundwater recharge, heads or discharge deviate from normal.

Bangladesh is one of the most disaster-prone countries in the world. Almost every year, the country experiences disasters of one kind or another, such as tropical cyclones, storm surges, coastal erosion, floods, and droughts, causing heavy loss of life and property and jeopardizing the development activities (Ali, 1996). Every year, Bangladesh experiences a dry period for 6 months, from November to April, when rainfall is normally low. This country has already experienced an increased frequency of drought in recent years. It is a recurrent phenomenon in some parts of the country but Rajshahi district is one of the most vulnerable areas to drought (Shahid, 2011). There are number of studies available where researchers showed the impact of drought on agricultural (for example, Karim et al., 1990; Ashokraj, 1979; DeGaetano, 1999; Freidman, 1957; Gregory, 2000; Huq, 2001; Kayano and Sansígolo, 2008; Klemeš, 1987; Kripalini et al., 1996; Lloyd-Hughes and Saunders, 2002 ; Nicholson et al., 1998; Rahman, 2013; Rahman and Lateh , 2015; Ramsey et al., 2007; Yu et al., 2010; Wilhite and Glantz, 1985). Some author showed the impact of drought on food production (Ahmed and Bernard, 1989; Ericksen et al., 1993; Karim and Iqbal, 2001). Erickson et al (1993) and World Bank (2000) investigated the effect of drought on economy. Paul 1998 demonstrated the effect of drought on society in case of Bangladesh. The first agricultural drought risk map of Bangladesh was prepared by Karim et al., (1996) by considering the cumulative effect of dry days, higher temperatures during pre-monsoon period and soil moisture availability. WARPO-EGIC (1996) prepared maps of winter and pre-monsoon drought prone areas of Bangladesh using the agro ecological zones database and land resources inventory map at 1:1,000,000 scale. Karim and Iqbal (2001) reviewed the concept of WARPO-EGIC (1996) and produced three different drought risk maps for winter, pre-monsoon, and monsoon seasons. They defined drought risk classes as slight, moderate, severe, and very severe related to the yield losses of 15–20%, 20–35%, 35–45%, and 45–70%, respectively, for different crops. No standard drought index method has been used for the assessment of droughts in Bangladesh. Since its independence in 1971, 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. However, losses from drought are likely to be more severe than from floods in Bangladesh.

So, the aim of this study is to provide considerations for developing an index to measure the daily drought extent in multiple time scales for Rajshahi district Bangladesh. The rest of the paper is organized as follows: Section 2 presents the characteristics of study area, Section 3 present Methodology, Section 4 present the Results and Discussions and finally Conclusions is provided in Section 5.

Study Area:

Rajshahi District covers around 2407.01 sq km, located in between 24°07' and 24°43' north latitudes and in between 88°17' and 88°58' east longitudes. It is bounded by Naogaon district on the north, West Bengal state of India, Kushtia district and Ganges river on the south, Natore district on the east, Nawabganj on the west. Rajshahi's climate is classified as tropical where the summers are much rainier than the winters. The average annual temperature in Rajshahi is 25.8 °C. About 1419 mm of precipitation falls annually. Precipitation is the lowest in December, with an average of 2 mm. The greatest amount of precipitation occurs in July, with an average of 301 mm. The map of Rajshahi district is given in Figure 1.

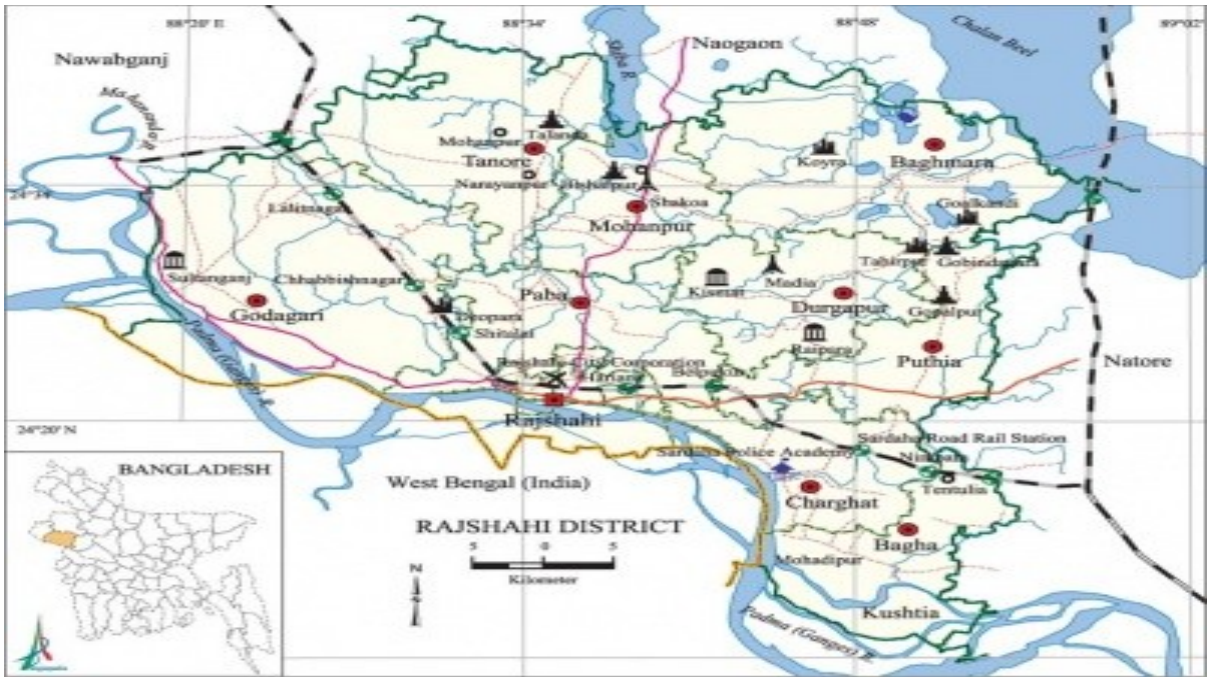

Figure 1:- Map of Rajshahi district (Source: Banglapedia).

Data Source & Smoothing:

The daily rainfall data of 52 years from 1964 to 2015 of Rajshahi station is collected from Bangladesh meteorological department. **There were some missing data over that range. Collecting the data from Rajshahi Station, there were two missing year (1969,1970) and about almost three missing months (March, April and May in 1971) 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 and 10 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 3mm of rainfall.

Methodology:-

Although it is difficult to monitor drought but different indexes have been used to detect the drought (Dracupet et. al, 1980; Wilhite and Glantz, 1985). Palmer Drought Severity Index (PDSI) widely used in the United States (Palmer, 1965). Heddinghaus and Sabol (1991) made some modifications to improve the PDSI. Standardized Precipitation Index (SPI) proposed by McKeeet et. al. (1993) measured meteorological flood and drought by using only precipitation. In our study we use Markov Chain model to detect drought.

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. The dependence relation-ship is commonly assumed as first order dependence in which the outcome of one trial is dependent only on the outcome of the previous trial such that these transition probabilities are constants. Thus the appropriate mathematical model for studying the effect of dependence on this conventional procedure is a two state discrete time Markov Chain. In recent years there have been made a few attempts to model such dependence by higher order discrete state Markov Chains. 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

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

Let us consider the conditional probabilities which are denoted by
$P_0 = Pr\{W/D\}$
$P_1 = Pr\{W/W\}$
This sequence is irreducible Markov chain with two argotic states. Its stationary probability distribution has a probability of success $P = p_{01}/(1 - (p_{11} - p_{01}))$.

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 (Medhi, 1981). A Markov chain of order m 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

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

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 (Anderson and Goodman, 1957). Additional evidence to indicate the feasibility of using a Markov chain model has been presented by Rahman (1999 a&b), Banik et al. (2002). 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.

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

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 $P_{00}+P_{01} = 1$ 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

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. (2002).

Result and Discussion:-

Markov Chain Model had been used to evaluate Drought Index using Higher Transition Probability Matrix. An index based on the parameters of this model has been suggested for agriculture drought measurement in Rajshahi district. For calculating Drought Index we consider threshold value 3 mm.

Drought Index at different decade from 1964 to 2015 for Rajshahi:

The drought index based on rainfall for the decade from 1964-1969 at 5 days, 7 days and 10 days were reported in Table 2 and Figure 2.

Table 2:- Drought index for wet and dry period for decade (1964-1969).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.058	0.929	0.053	Chronic	0.207	Moderate
7 days	0.045	0.957	0.043	Chronic	0.26	Mild
10 days	0.036	0.973	0.035	Chronic	0.332	Occasional

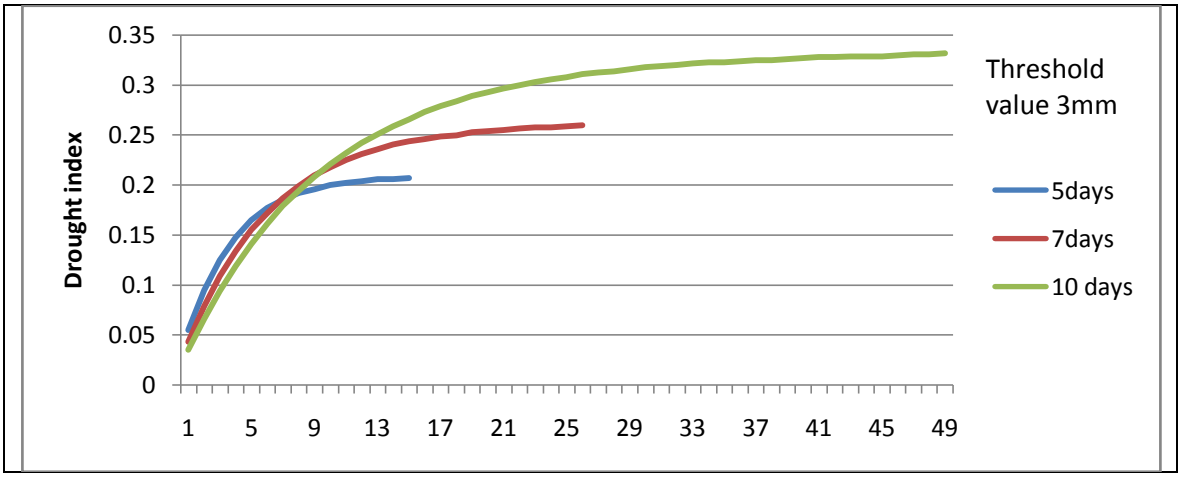

Figure 2:- Drought index scenario for the decade (1964-1969).

From the above Table 2 we observed that the chronic drought prone periods found for each period at 1st Transition Probability Matrix (TPM) and at higher TPM we found the moderate, mild and occasional drought for 5 days, 7 days and 10 days respectively. From the Figure 2 during the period 1964 to 1969 we found that for 5, 7 and 10 days drought were chronic in the initial stage for threshold value 3 mm and finally, due to climate change it showed that the drought was being stable at specific stage (16th, 27th and 50th) steps for 5, 7 and 10 days respectively and it turned into moderate, mild and occasional drought. The daily Rainfall for the decade from 1970-1979 for considering 5 days, 7 days and 10 days is given in Table 3 and Figure 3.

Table 3:- Drought index for wet and dry period for decade (1970-1979).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.066	0.935	0.061	Chronic	0.256	Mild
7 days	0.047	0.963	0.045	Chronic	0.315	Occasional
10 days	0.040	0.974	0.038	Chronic	0.380	Occasional

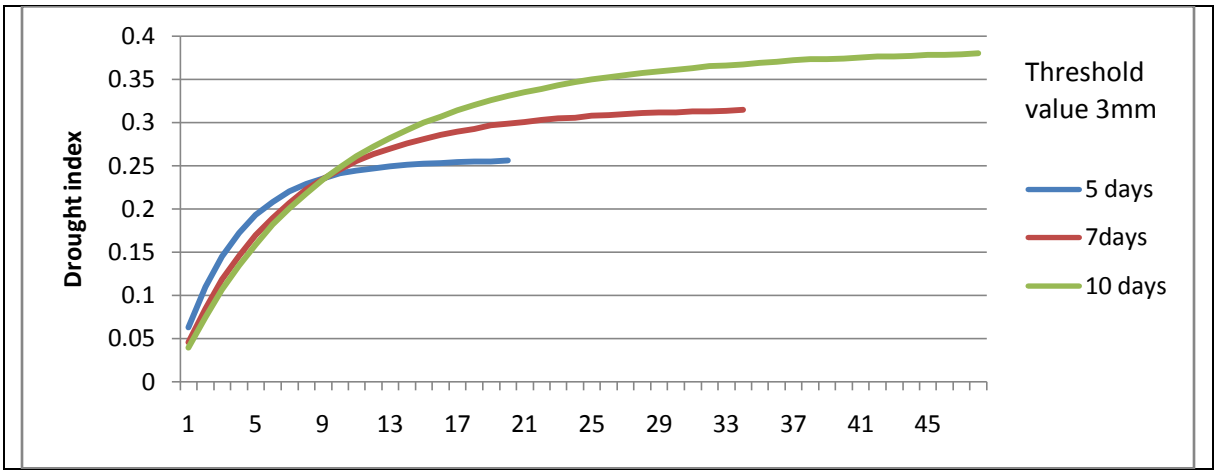

Figure 3:- Drought index scenario for the decade (1970-1979).

From the above Table 3 we observed that the chronic drought prone periods found for each period at 1st TPM and at higher TPM the drought converted in to mild and occasional. The Figure 3 showed that for 5, 7 and 10 days drought were chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (21th, 35th and 49th days) for 5, 7 and 10 days and it turned into mild and occasional drought respectively. The daily Rainfall for the decade from 1980-1989 for considering 5 days, 7 days and 10 days is given in Table 4 and Figure 4.

Table 4:- Drought index for wet and dry period for decade (1980-1989).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.072	0.930	0.066	Chronic	0.259	Mild
7 days	0.053	0.960	0.050	Chronic	0.326	Occasional
10 days	0.047	0.972	0.045	Chronic	0.397	Occasional

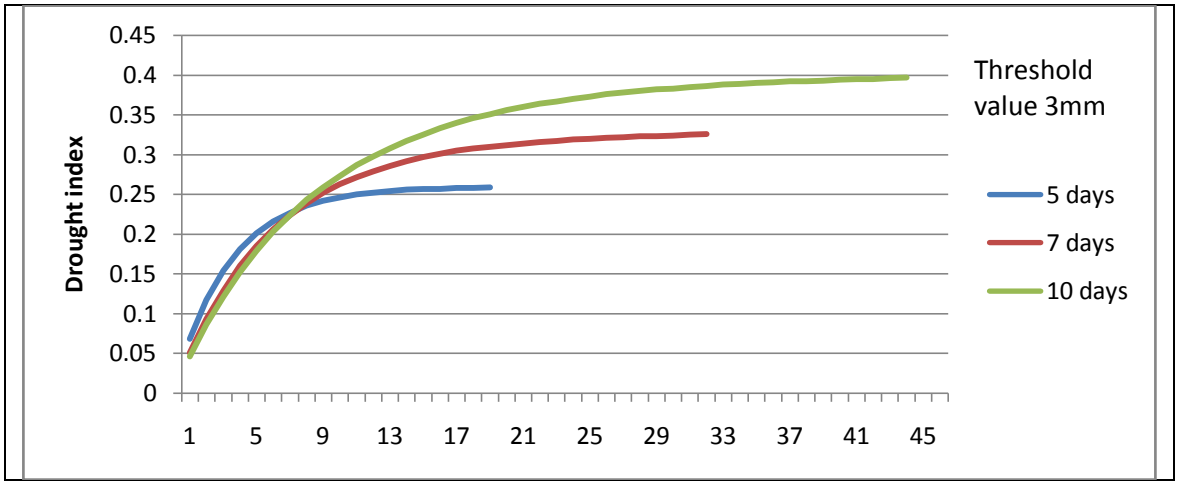

Figure 4:- Drought index scenario for the decade (1980-1989).

From the above Table 4 we observed that at the 1st TPM the drought prone was chronic drought prone for each periods but at higher TPM the mild and occasional drought prone were found in Rajshahi district. From the figure 4 during the period 1980 to 1989 we found that for 5, 7 and 10 days drought were chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (20th, 33th and 45th) for 5, 7 and 10 days and it turns into mild and occasional drought respectively. The daily Rainfall for the decade from 1990-1999 for considering 5 days, 7 days and 10 days is given in Table 5 and Figure 5.

Table 5:- Drought index for wet and dry period for decade (1990-1999).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.069	0.930	0.064	Chronic	0.248	Mild
7 days	0.053	0.958	0.050	Chronic	0.314	Occasional
10 days	0.048	0.971	0.046	Chronic	0.390	Occasional

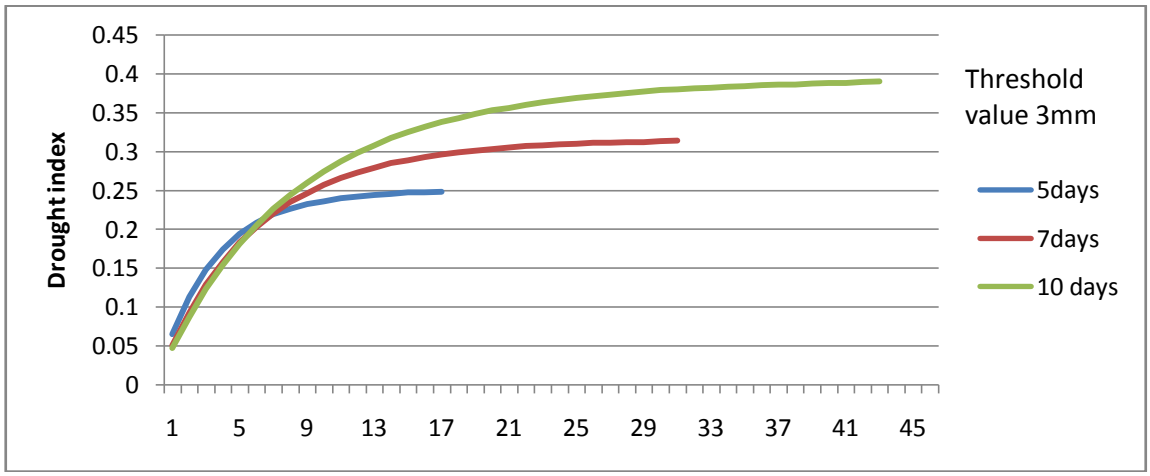

Figure 5:- Drought index scenario for the decade (1990-1999).

The chronic drought prone were found for each period at 1st TPM and at higher TPM the mild and occasional drought prone periods were found in Rajshahi district (Table 5). From the figure 5 during the period 1990 to 1999 we saw that for 5, 7 and 10 days drought were chronic in the preliminary stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (18th, 33th and 44th) for 5, 7 and 10 days and it turns into mild and occasional drought. The daily Rainfall for the decade from 2000-2009 for considering 5 days, 7 days and 10 days is given in Table 6 and Figure 6.

Table 6:- Drought index for wet and dry period for decade (2000-2009).

year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.071	0.925	0.065	Chronic	0.242	Mild
7 days	0.053	0.958	0.050	Chronic	0.311	Occasional
10 days	0.037	0.976	0.036	Chronic	0.382	Occasional

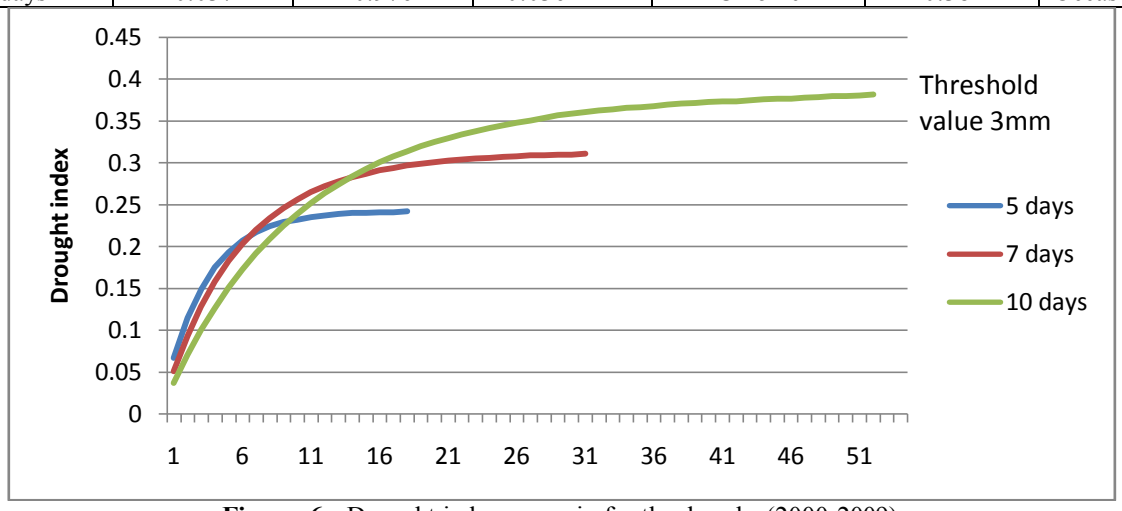

Figure 6:- Drought index scenario for the decade (2000-2009).

From Table 6 we observed that the chronic drought prone periods were found for each period at 1st TPM and at higher TPM the mild and occasional drought prone periods were found. Figure 3 indicated that for 5, 7 and 10 days drought were chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (19th, 32th and 53th) for 5, 7 and 10 days and it turned into mild and occasional drought respectively. The daily Rainfall for the decade from 2010-2015for considering 5 days, 7 days and 10 days is given in Table 7 and Figure 7.

Table 7:- Drought index for wet and dry period for decade (2010-2015).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.077	0.907	0.069	Chronic	0.209	Moderate
7 days	0.058	0.948	0.054	Chronic	0.282	Mild
10 days	0.042	0.972	0.040	Chronic	0.369	Occasional

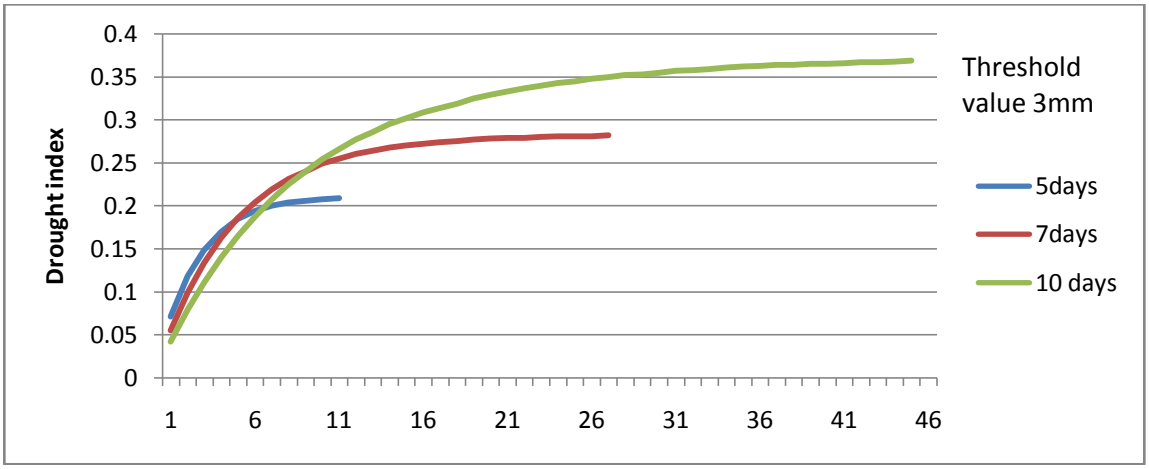

Figure 7:- Drought index scenario for the decade (2010-2015).

From Table 7, we observed that the chronic drought prone periods were found for each period at 1st TPM and at higher TPM the moderate, mild and occasional drought prone periods are found. From Figure 7 during the period 2010 to 2015 we saw that for 5, 7 and 10 days drought are chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (12th, 28th and 46th) for 5, 7 and 10 days and it turned into moderate, mild and occasional drought respectively.

Overall Drought index during the time periods 1964-2015 for Rajshahi:

The daily Rainfall for the decade from 1964-2015 for considering 5 days, 7 days and 10 days is given in Table 8 and Figure 8.

Table 8:- Drought index for wet and dry period for the whole range data (1964-2015).

Year	P_{01}	P_{11}	1st TPM		Higher TPM	
			DI	Comment	DI	Comment
5 days	0.0590	0.945	0.056	Chronic	0.270	Mild
7 days	0.0485	0.963	0.047	Chronic	0.323	Occasional
10 days	0.0412	0.975	0.040	Chronic	0.389	Occasional

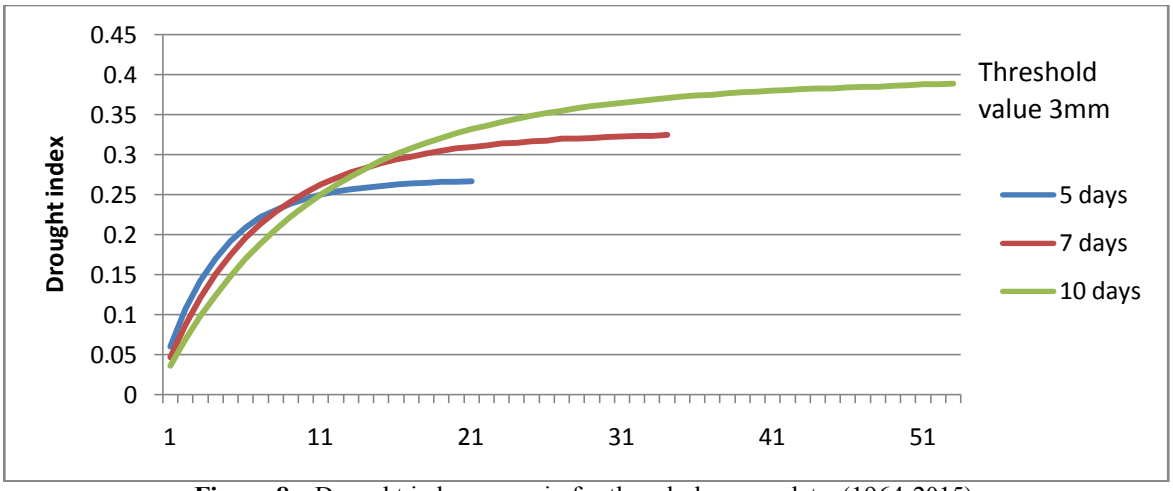

Figure 8:- Drought index scenario for the whole range data (1964-2015).

We observed from the Table 8 the first TPM of Rajshahi district for 5 days, 7 days and 10 days were chronic. But at higher TPM the drought were mild and occasional for the whole period 1964 to 2015. Figure 8 indicated that for 5, 7 and 10 days drought were chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (25th, 35th and 51th) for 5, 7 and 10 days and converted into mild, occasional and occasional respectively.

Conclusions:-

In this paper we observed the drought index in case of Rajshahi district at different time scale for the data range 1964 to 2015. We separated the data into different time periods 5 days, 7 days and 10 days for the different decade. We applied to analyze Drought Index using Markov Chain Model to the rainfall data in different time scales. At first, we find out the Drought Index from the first transition probability matrix. Then we estimate the higher transition probability matrix. When the higher transition probability matrix is became stable, and then we estimate the Drought index of that stable transition probability matrix.

We observed the following drought index in Rajshahi district at decade wise into different time period

1. In 1964-1969 chronic (DI = 0.053, 0.043 and 0.035) drought was found at first TPM. But at higher TPM moderate, mild and occasional drought was found at 5, 7 and 10 days respectively and their Drought index were 0.207, 0.26, and 0.332 respectively.
2. In 1970-1979 chronic (DI = 0.061, 0.045 and 0.038) drought was found at first TPM. But at higher TPM mild drought was found at 5 days (DI=0.256), and for 7 and 10 days Occasional drought is found and Drought index were 0.315 and 0.38 respectively.
3. In 1980-1989 chronic (DI = 0.066, 0.050 and 0.045) drought was observed at first TPM. But at higher TPM the drought index convereted into mild for 5 days (DI=0.259), and for 7 days (DI=0.326) and 10 days (0.397).
4. In 1990-1999 all of these three series presented chronic (DI = 0.064, 0.050 and 0.046) drought at first TPM. But at higher TPM mild drought was found at 5 days (DI=0.248), and for 7 and 10 days Occasional drought was found and Drought index were 0.314 and 0.39 respectively.
5. In 2000-2009 chronic (DI = 0.065, 0.050 and 0.036) drought was found at first TPM. But at higher TPM mild drought was observed at 5 days (DI=0.242), and for 7 and 10 days Occasional drought was observed and Drought index were 0.311 and 0.382 respectively.
6. In 2010-2015 chronic (DI = 0.069, 0.054 and 0.040) drought was found at first TPM. But at higher TPM moderate, mild occasional drought was found at 5, 7 and 10 days respectively and their Drought index were 0.209, 0.282, and 0.369 respectively.

The overall drought index for the whole data range 1964 to 2015 indicate that the drought were chronic in the starting stage for threshold value 3 mm and finally due to climate change it showed that the drought was being stable at specific stage (25th, 35th and 51th) for 5, 7 and 10 days and converted into mild, occasional and occasional respectively.From the above findings we observed that the decades of different time scale in Rajshahi was stable in different stages. Different decades of Rajshahi districts were similar due to the similar climatic change. 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, when the Irrigation is needed much in Rajshahi district. An agricultural development plan can be focused as a long term strategy for Rajshahi district. Supplementary irrigation will be ensured by the government in service in extremely drought season in this area.

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