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Predictive Analysis of Drought Management in Rajshahi and Dinajpur District of Bangladesh

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Abstract

The historical daily time series rainfall data for the period of 51 years (1964 to 2014) of Rajshahi and Dinajpur rainfall station were usually used to know 5 days,7 days, 10 days, monthly, seasonal, annual and decadal rainfall variability and probabilities at different threshold values for suitable crop planning. Rainfall agriculture in Bangladesh accounts for 95% of the local cercal production, impacting hundreds of millions people. Early warning of poor rainfall conditions is a critical indicator of food security. However, characterizing the remaining uncertainty in a season has largely been ignored by the food security community. For five days, seven days and ten days in Rajshahi and Dinajpur station, it was an erratic behaviour of rainfall pattern indicating drought proneness scenario fluctuate which form extreme to moderate, mild and occasionally drought process occurs respectively. Monthly frequency distribution of consecutive dry weeks in Rajshahi and Dinajpur found that four consecutive dry weeks was in month of January, February. In March, three consecutive dry weeks is 25 times approximately. In November, December three and four consecutive dry weeks are 22 times and 32 times and 29 times and 32 times respectively. Remaining month May, June, July, August, September and October plenty of rainfall occurs. So Rain water harvest can play a vital role to reduce the impact of agriculture drought. The probability matrix of consecutive dry weeks in Rajshahi and Dinajpur Station, the four consecutive dry weeks had been occurred in January, February and December following 51%, 25% and 63% and 65%, and 57% respectively. For Monthly average decade of dry weeks in Rajshahi found extreme drought (3 to 4 dry weeks) in January, February, November and December and no drought (0 to 1 dry weeks) in May, June, July, August and September.

This study helps decision makers a tool for understanding the likelihood of specific rainfall amounts provides additional time to enact and mobilize efforts to reduce the impact of agriculture drought, effective drought forecasting and warning techniques need to be considered. The study area is more drought prone and challenge for crop production due to the low values of drought index, probability getting at least 8,10 and 12 consecutive wet weeks are comparatively low, probability of at least 3 consecutive dry week is comparatively high. Decade at year wise analysis also indicate almost similar results.

Keywords: Predictive Analysis, Drought Management, Characterizing Rainfall, Drought Index.

AMS Classification: 62M10; 91B82.

1. Introduction

One of the widely used definitions for Drought is: a protracted period of deficient precipitation resulting in extensive damage of crops, resulting in loss of yield (NDMC, 2006). Paul BK et al. (1998), in his Manual Drought Management, described that Drought is difficult to provide a precise and universally accepted definition of drought due to its varying characteristics and impacts across different regions of the world, such as rainfall patterns, human response and resilience, and diverse academic perspectives. Drought is a temporary aberration unlike aridity, which is a permanent feature of climate. Seasonal aridity (i.e. a well-defined dry season) also needs to be distinguished from drought.

Sun et al. (2012) found their results will useful to Moreover, the frequency, intensity and duration of droughts are expected to increase due to global warming and rapid urbanization, which will negatively affect Chinese food security Therefore, the risk of agricultural drought must be assessed to improve drought preparedness and reduce the negative effects of drought on agriculture .Studies on the risk of agricultural drought have evaluated various elements of agricultural systems (A.T.M. Jahangir Alam et al, 2013, 2014).

Wilhite et al. 2000; Knutson et al. 1998; ATM Jahangir Alam et al, 2013 have reported that the risk of agricultural drought should be investigated at macroscopic levels, such as water resource planning, policy incentives and the establishment of early warning systems. Banik et al.,(2000) found their study will useful to agricultural planners and irrigation engineers to identifying the areas where agricultural development should be focused as a long term drought mitigation strategy (Md. Kamruzzaman et al, 2016). Also this study will contribute toward a better understanding of the climatology of drought in a major drought-prone region of the world.

Objectives of the study is to explore drought management using rainfall data for predict future climate scenarios, to reduce daily rainfall data in 5 days, 7 days and 10 days' time period using different threshold values, To analyze agriculture drought characteristics based on daily rainfall using Markov chain model.

2. Materials and Methods

2.1. Data Source

The rainfall stations consider for this study namely Rajshahi and Dinajpur data collected from Bangladesh Meteorological Department, Dhaka, Bangladesh over the range January, 1964 to December, 2014 (51 years). 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. Then, by using SPSS 16.0 the data were replaced with mean of the previous year. On the other hand, there were a huge data about eight missing years (1972 to 1980) which were not found from Dinajpur Station. By replacing rainfall data of the nearest station (named Rajshahi), It was recorded. After then it was finally ready to apply our methodology.

Let us, sequences conditional probabilities which are denoted by, P_{00}= Pr {D/D; dry after dry}; P_{01} = Pr {D/W; dry after wet}; P_{10}= Pr {W/D; wet after dry}; P_{11} =

Pr {W/W; wet after wet} (1)

Let, X_0 X_1 X_2..........................X_n be random variables distributed identically and talking only two values, namely 0 and 1, with probability one, i.e., Firstly we assume that,

$$P\ (X_{n+1}=X_{n+1}: X_n=x_n, x_{n-1}............................, X_0=x_0) = P\ (X_{n+1}=1|X_n=x_n)$$

Where X_0, X_1..x_n+1 ε {0, 1}.

In other word, it is assumed that probability of wetness of any week depend only one whether the previous week was wet of dry given the event on previous week.

The probability of wetness in assumed independent of further preceding weeks, So $\{X_{n\,;}\ n=0,1,2,.............\}$ is a Markov Chain (Medhi, 1981)

Consider the transition Probability matrix:

$$P_{ij} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \tag{2}$$

2.2. Measuring Drought Index

P_{11} gives the probability of a week to be wet given the previous week was wet also. 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:

$DI = P_{01} * P_{11}$ by Banik et. al., 2000.

This 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 below (Banik et. al., 2000).

Table 1: Index of Drought-proneness

Criteria	Degree of drought-proneness
$0.000 \leq DI \leq 0.125$	Chronic
$0.125 < DI \leq 0.180$	Severe
$0.180 < DI \leq 0.235$	Moderate
$0.235 < DI \leq 0.310$	Mild
$0.310 < DI \leq 1.00$	Occasional

From equation (2), we have calculated higher transition probability matrix, where $P_{ij}^{n} = P_{ij}^{n+1}$. In this condition using stable transition probability matrix finally the Drought Index calculated as, $DI = P_{01} * P_{11}$ by Banik et. al., 2000. Data analysis is done by R Program.

3. Results & Discussions

Markov chain model have been used to estimate probabilities of getting a sequence of dry-wet weeks for Rajshahi and Dinajpur station of transition probability matrix. Then we estimate the higher transition probability matrix. When the higher transition probability matrix is became stable, then we estimate the Drought index of that stable transition probability matrix. After all this we can make a comparison between this Drought Index. The Sensitivity of crop damage without rain depends on soil moisture holding capacity as well as duration of drought proneness particularly tolerance levels are 5 days, 7 days and 10 days.

It showed that the first step of Drought Index is 0.047 which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.085 which is also extreme drought. Similarly after 21 steps Transition Probability matrix is stable. Finally the Drought Index = 0.250, which indicate mild drought. The erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate. (Table-1 & Figure -1)

Figure-2 and Table-1 showed that the first step of Drought Index is 0.044 which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.079 which is also extreme drought. Similarly after 23 steps transition probability matrix is stable. Finally the Drought Index = 0.252, which indicate mild drought. Similarly, For five days and ten days in Rajshahi and Dinajpur station, it was an erratic behaviour of rainfall pattern indicating drought proneness scenario fluctuate which form extreme to moderate, mild and occasionally drought process occurs respectively.

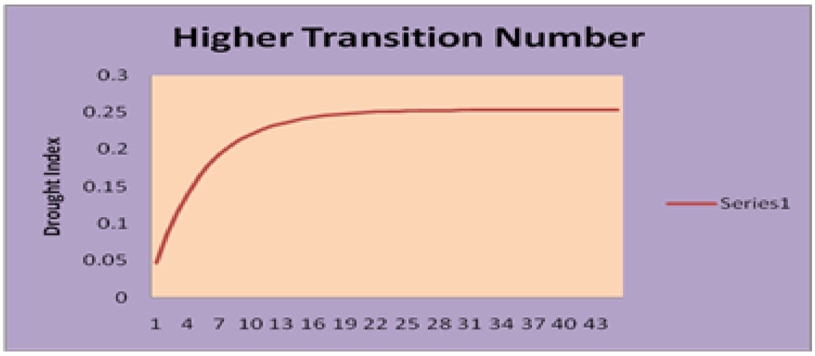

Figure 1: Higher Transition scenario of Drought Index for 7 days with 5mm threshold value in Rajshahi Station

Table 1: Scenario of Drought Index (DI) using higher transition Probability matrix with 5mm threshold value for 7 Days in Rajshahi Station and Dinajpur Station

Rajshahi				Dinajpur			
P_{01}	P_{11}	DI	Degree of drought proneness	P_{01}	P_{11}	DI	Degree of drought proneness
.049	.951	.047	Extreme drought	.046	.956	.044	Extreme drought
.094	.907	.085	Extreme drought	.087	.916	.079	Extreme drought
.134	.867	.116	Extreme drought	.125	.879	.109	Extreme drought
.170	.831	.141	Severe drought	.159	.845	.134	Severe drought
.203	.799	.162	Severe drought	.190	.815	.155	Severe drought
.232	.770	.179	Severe drought	.218	.787	.172	Severe drought
.259	.744	.193	Moderate drought	.244	.762	.186	Moderate drought
.260	.744	.204	Moderate drought	.268	.739	.198	Moderate drought
.305	.699	.213	Moderate drought	.289	.718	.208	Moderate drought
.324	.680	.220	Moderate drought	.309	.699	.216	Moderate drought
.342	.663	.227	Moderate drought	.327	.682	.223	Moderate drought
.358	.647	.232	Moderate drought	.343	.666	.228	Moderate drought
.372	.633	.235	Mild drought	.358	.652	.233	Moderate drought
.385	.620	.238	Mild drought	.371	.639	.237	Mild drought
.397	.609	.241	Mild drought	.383	.627	.240	Mild drought
.407	.599	.243	Mild drought	.394	.616	.243	Mild drought
.416	.590	.245	Mild drought	.404	.606	.244	Mild drought
.425	.582	.247	Mild drought	.413	.597	.246	Mild drought
.433	.574	.248	Mild drought	.421	.589	.247	Mild drought
.440	.567	.249	Mild drought	.429	.582	.249	Mild drought
.446	.561	.250	Mild drought	.436	.575	.250	Mild drought
.452	.555	.250	Mild drought	.442	.569	.251	Mild drought
				.448	.563	.252	Mild drought
				.453	.558	.252	Mild drought

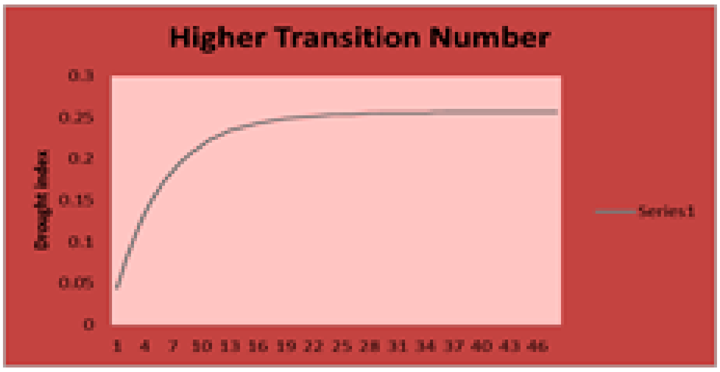

Figure 2: Higher Transition scenario of Drought Index for 7 days with 5mm threshold value in Dinajpur Station

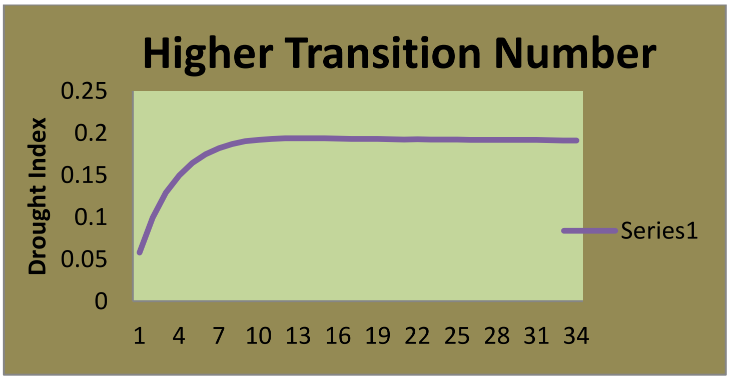

Figure 3: Higher Transition scenario of Drought Index for 5 days with 5mm threshold value in Rajshahi Station

Figure-3 showed that the first step of drought index, (DI) is 0.058 which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.099 which is also extreme drought. Similarly after 12 steps transition probability matrix is stable. Finally the Drought Index = 0.193, which indicates moderate drought. The erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate.

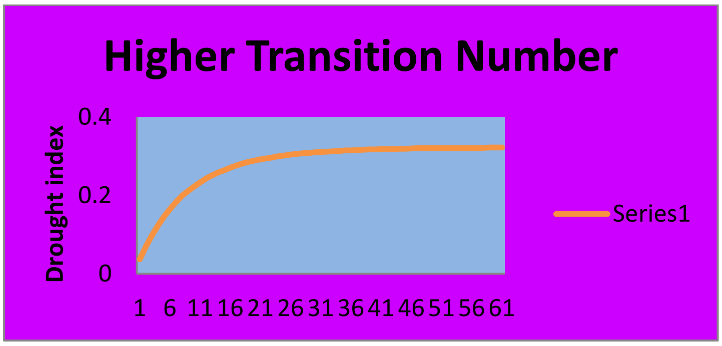

Figure 4: Higher Transition scenario of Drought Index for 10 days with 5mm threshold value in Rajshahi Station

Figure-4 showed that the first step of Drought Index, (DI) is 0.037, which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.069 which is also extreme drought. In 5^{th} step, The Drought Index was 0.146, which indicates severe drought. In 7^{th} step, it was 0.182, which follows moderate drought. In 12^{th} step, it reduced in mild drought from moderate drought, since drought index was 0.243.After 40 steps, this transition probability matrix is stable. Finally the Drought Index = 0.317, which indicates occasionally drought. The erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate.

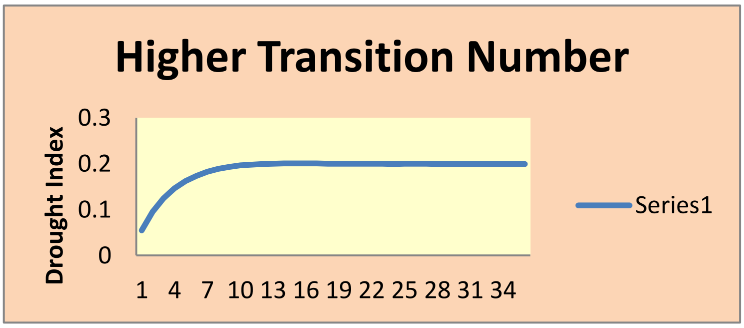

Figure 5: Higher Transition scenario of Drought Index for 5 days with 5mm threshold value in Dinajpur Station

Figure-5 showed that the first step of Drought Index, (DI) is 0.054 which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.095 which is also extreme drought. Similarly after 14 steps transition probability matrix is stable. Finally the Drought Index = 0.200, which indicate moderate drought. The erotic behaviour of rainfall pattern indicate drought proneness scenario fluctuate.

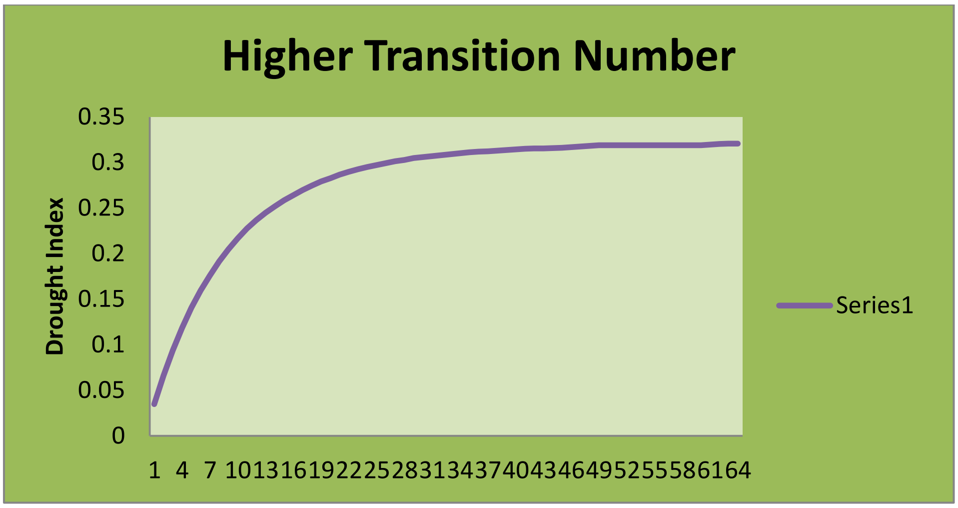

Figure 6: Higher Transition scenario of Drought Index for 10 days with 5mm threshold value in Dinajpur Station

Figure-6 showed that the first step of Drought Index is 0.034 which indicates extreme drought. Next higher transition probability matrix indicate, Drought Index = 0.066 which is also extreme drought. In 5th step, The Drought Index was 0.140, which indicates severe drought. After running 3 steps more it was 0.191 which follows moderate drought. In 12th step, it reduced in mild drought from moderate drought, since drought index was 0.236. Finally after 49 steps, the Drought Index = 0.320866, which indicates occasionally drought. The erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate.

Table 2: Probability matrix of consecutive dry weeks in Rajshahi

	No dry week	1 dry week	2 consecutive dry weeks	3 consecutive dry weeks	4 consecutive dry weeks
January	0	0.04	0.1	0.35	0.51
February	0.04	0.059	0.25	0.4	0.25
March	0.04	0.078	0.12	0.5	0.2
April	0.04	0.24	0.4	0.27	0.08
May	0.41	0.25	0.22	0.09	0.02
June	0.76	0.2	0.02	0	0.02

July	0.98	0.02	0	0	0
August	0.92	0.06	0	0	0.02
September	0.82	0.14	0.04	0	0
October	0.04	0.39	0.4	0.17	0.04
November	0	0	0.08	0.49	0.43
December	0	0	0.04	0.33	0.63

Table-2 showed the Probability matrix of consecutive dry weeks in Rajshahi. Therefore each and every month have some probability of dryness. In the given 51 years (1964-2014) 4 consecutive dry weeks had been occurred in January, February and December following 51%, 25%, 63% respectively. Consecutive 3 dry weeks were given in March and November following 50% and 49%. On the other hand, May, June, July, August, September occurred in no dry weeks following 41%, 76%, 98%, 92%, 82% respectively. Therefore rain water harvest can play a vital role to mitigate an agricultural drought at food security.

Table 3: Transition probability matrix of dry weeks in Dinajpur

January	0	0	0.12	0.24	0.65
February	0	0.02	0.16	0.37	0.45
March	0	0.02	0.18	0.49	0.31
April	0.02	0.27	0.43	0.18	0.1
May	0.41	0.43	0.12	0.02	0.02
June	0.75	0.25	0	0	0
July	0.88	0.1	0	0	0.02
August	0.84	0.14	0.02	0	0
September	0.65	0.31	0.04	0	0
October	0.12	0.18	0.43	0.24	0.04
November	0.02	0	0.06	0.35	0.57
December	0	0	0.04	0.24	0.73

Table-3 showed the Probability matrix of consecutive dry weeks in Dinajpur. Therefore each and every month have some probability of dryness. In the given 51 years (1964-2014) 4 consecutive dry weeks had been occurred in January, February, November and December following 65%, 45%, 57% and 73% respectively. Consecutive 3 dry weeks were given in March following 49%. On the other hand, May, June, July, August, September occurred in no dry weeks following 41%, 75%, 88%, 84%, 65% respectively. Therefore rain water harvest can play a vital role to mitigate an agricultural drought at food security.

Table 4: season-wise summary Statistics of total dry weeks in Rajshahi

Summary statistics	Pre-Kharif Season	Kharif Season	Rabi Season
Average	6	3	13
Maximum	12	5	16
Minimum	1	0	10

Table-4 was given the average total dry weeks, maximum and minimum total dry weeks by seasonally in Rajshahi among total 51 years total dry weeks. It showed that the maximum 12 dry weeks occurred in pre-kharif season in a year within the given years. Moreover, the minimum 1 dry week in a year and the average week was 6 from total dry weeks in those given 51 years. On this way in Kharif season of Rajshahi, we got the result of average is 3weeks, maximum is 5 weeks and minimum is 0 weeks. Moreover, for Rabi Season there are 13 average total dry weeks, 16 maximum total dry weeks and 10 minimum total dry weeks.

Table 5: Season-wise summary Statistics of total dry weeks in Dinajpur

Summary statistics	Pre-Kharif Season	Kharif Season	Rabi Season
Average	6	3	14
Maximum	10	7	16
Minimum	3	0	10

Table-5 was given the average total dry weeks, maximum and minimum total dry weeks by seasonally in Dinajpur among total 51 years total dry weeks. It showed that the maximum 10 dry weeks occurred in pre-kharif season in a year within the given years. Moreover, the minimum 3 dry weeks in a year and the average week was 6 from total dry weeks in those given 51 years. On this way in Kharif season of Dinajpur, we got the result of average is 3total dry weeks, maximum is 7 total dry weeks and minimum is 0 total dry weeks. Moreover, for Rabi Season there are 14 average total dry weeks, 16 maximum total dry weeks and 10 minimum total dry weeks. Monthly frequency distribution of consecutive dry weeks in Rajshahi and Dinajpur found that four consecutive dry weeks was in month of January, February. In March, three consecutive dry weeks is 25 times approximately. In November, December three and four consecutive dry weeks are 22 times and 32 times and 29 times and 32 times respectively. Remaining month May, June, July, August, September and October plenty of rainfall occurs. So Rain water harvest can play a vital role to reduce the impact of agriculture drought.

4. Conclusions

Agriculture is the backbone of the economy of the developing countries like Bangladesh with more than 70% of the working population involved directly or indirectly with this sector. So the failure of rain and the occurrence of drought during any particular growing season may lead to severe food shortage. Irrigation plan will not be implemented properly due to lack of water. The whole agro-economic system of a country is hampered due to this natural disaster.

For five days in Rajshahi station, we found the Drought Index followed extreme to moderate drought. The erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate year to year, seasons to seasons, region to region. For seven days, we also found an erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate which from extreme to mild drought and for ten days in Rajshahi station, Drought Index was extreme to occasionally drought process occurs.

For five days in Dinajpur station, we found the Drought Index followed extreme to moderate drought. The erratic behaviour of rainfall pattern indicates drought proneness scenario fluctuate in the similar pattern. For seven days, we also found an erratic behaviour of rainfall pattern indicate drought proneness scenario fluctuate which from extreme to mild drought and for ten days in Rajshahi station, Drought Index was extreme to occasionally drought process occurs.

Monthly frequency distribution of consecutive dry weeks in Rajshahi and Dinajpur found that four consecutive dry weeks was in month of January, February. In March, three consecutive dry weeks is 25 times approximately. In November, December three and four consecutive dry weeks are 22 times and 32 times and 29 times and 32 times respectively. Remaining month May, June, July, August, September and October plenty of rainfall occurs. So Rain water harvest can play a vital role to reduce the impact of agriculture drought.

The probability matrix of consecutive dry weeks in Rajshahi, in the given 51 years (1964-2014) 4 consecutive dry weeks had been occurred in January, February and

December following 51%, 25% and 63% respectively. On the other hand, May, June, July, August, September occurred in no dry weeks following 41%, 76%, 98%, 92%, 82% respectively. Therefore, rain water harvest can play a vital role to mitigate an agricultural drought and food security.

The probability matrix of consecutive dry weeks in Dinajpur, in the given 51 years (1964-2014) 4 consecutive dry weeks had been occurred in January, February, November and December following 65%, 45%, 57% and 73% respectively. On the other hand, May, June, July, August, September occurred in no dry weeks following 41%, 75%, 88%, 84%, 65% respectively. Therefore, rain water harvest can play a vital role to mitigate an agricultural drought and food security. This could be result in alleviation of poverty in all its forms, removing hunger, ensuring access to safe and nutritious food, ensure healthy lives and promote inclusive and sustainable economic growth and combat climate change and its impacts to assist the government strengthening the means of implementation and revitalize the global partnership for sustainable development to fulfil the goal no. 1, 2, 8 and 13 namely “No Poverty”, “Zero Hunger”, “Decent work and Economic Growth” and “Climatic Action” of Sustainable Development Goals (SDGs).

References

[1] A. T. M. Jahangir Alam, M Sayedur Rahman and A. H. M. Sadaat (2014). Markov chain analysis of weekly rainfall data for predicting agricultural drought at Barind, Bangladesh. Book Chapter, Edited by T Islam, PK Srivastava, M Gupta, X Zhu, S Mukherjee, Computational intelligence techniques in earth and environmental sciences, Chapter: 6, 109-128, Publisher: Springer.

[2] A.T.M. Jahangir Alam, M Sayedur Rahman and A.H.M. Sadaat Alam (2013). Spatio- Temporal Variations of Agricultural Drought at Barind Region, Bangladesh: An Application of Markov Chain Model. Irrigation and Drainage, DOI: 10.1002/ird.1800, John Wiley & Sons, Ltd.

[3] A. T. M. Jahangir Alam, M Sayedur Rahman and A. H. M. Saadat (2013). Monitoring meteorological and agricultural drought dynamics in Barind region Bangladesh using standard precipitation index and Markov chain model. 3 (3): International Journal of Geomatics and Geosciences, 511-524.

[4] Banik, P, A. Mandal and M. S. Rahman. (2000). Markov chain analysis of weekly rainfall data in determining drought-proneness. Discrete Dynamics in nature and society, 7: 231-239

[5] Md. Kamruzzaman, A. T. M. Sakiur Rahman, Md. Enamul Kabir, Chowdhury Sarwar Jahan, Quamrul Hasan Mazumder and M Sayedur Rahman, (2016). Modeling of Agricultural Drought Risk Pattern using Markov Chain and GIS in the Western Part of Bangladesh, J. of Environment, Development and Sustainability, pp1-20.

[6] Knutson C, Haigh T, Hayes, M. and Widhalm, M. (2011). Farmer perceptions of sustainable agriculture practices and drought risk reduction in Nebraska, USA. Renew Agric Food Syst 26:255–266.

[7] Knutson C, Hayes M. and Phillips T. (1998). How to reduce drought risk[R]. Western Drought Coordination Council, Wisconsin.

[8] National Drought Mitigation Center (2006). What is drought? Understanding and defining drought, http://www.drought.unl.edu/whatis/concept.htm. Cited 29 Oct 2007

[9] National Drought Mitigation Center (2006). What is drought? Understanding and defining drought, http://www.drought.unl.edu/whatis/concept.htm. Cited 29 Oct 2007

[10] Paul B. K. (1998). Coping mechanisms practiced by drought victims (1994/5). in North Bengal, Bangladesh. Appl Geogr 18(4):355–373

[11] Sun, L. Scott, W. and Davidson, A. (2012). Multiple drought indices for agricultural drought risk assessment on the Canadian prairies. Int J Climatol 32(11):1628–1639.

[12] Wilhite, D. A. and Glantz, M. H. (1985). Understanding the drought phenomenon: The role of definitions. Water International, 10(3), pp111–120.

[13] World Bank Bangladesh (1998). Water resource management in Bangladesh: steps towards a new national water plan, Report No. 17663-BD, The World Bank Bangladesh, Dhaka.