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Analysing the Variability of Rainfall Threshold Values for Drought Prognosis in Bangladesh

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Analysing the Variability of Rainfall Threshold Values for Drought Prognosis in Bangladesh

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Department of Statistics in Partial Fulfillment of the Requirements for the Degree of Master of Philosophy, University of Rajshahi.

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DECLARATION

I here by certify that the thesis entitled "**Analysing the Variability of Rainfall Threshold Values for Drought Prognosis in Bangladesh**" submitted to the university of Rajshahi, Bangladesh for the degree of Master of Philosophy is based on my research work carried under the supervisor Professor Dr. M. Sayedur Rahman and co-supervisor Professor Dr. Md. Ripter Hossain, Department of Statistics, university of Rajshahi. To the best of my knowledge, this work has not been submitted before as candidature for any other degree.

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Dedicated To

My Beloved Parents

CERTIFICATE

This is to certify that the thesis entitled **"Analysing the Variability of Rainfall Threshold Values for Drought Prognosis in Bangladesh**" submitted by Md. Mahbub Alam, Lecturer, Department of Statistics, Badalgachi Women's Degree College, Badalgachi, Naogaon, in partial fulfillment for the requirements of the degree of Master of Philosophy. It is also certified that the research work embodied in this thesis is original and carried out by him under our supervision and used in this thesis is genuine and original. No part of the work has not been submitted for any others degree.

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ABSTRACT

The Rainfall plays a significant role in the agriculture of country. Rainfall is the most important weather parameter affecting non-irrigate crop areas for Bogra, Jessore and Feni water deficits and excess water are the greatest constraints for rainfall rice yields in this region. The daily rainfall data for 30 years during the period 1981-2010 of the rainfall stations in Bogra, Jessore and Feni are considered in this study. The daily data were reduced in the weekly form and the drought index has been calculated using the probability of Markov chain model. Drought is temporary but complex feature of the climate system. Agricultural drought is mainly concerned with inadequacy of rainfall. Markov chain model have been used to evaluate probabilities of getting a sequence of wet-dry weeks over this region. An index based on the parameters of this model has been suggested for agricultural drought measurement in this region.

The results of our Bogra district annually rainfall data we observed the moderate drought, pre-kharif rainfall data we observed the mild occasional and moderate drought, kharif rainfall data we observed the occasional and rabi rainfall data we observed the chronic prone. As a result failure of rains and the occurrence of drought during any particular growing season lead to severe food shortages.

A Markov Chain model is established to fit daily rainfall data for the various aspects of rainfall occurrence patterns and could be mathematically derived from the Markov Chain by using maximum likelihood estimate and these were also established to fit the observed data. The rainfall probability was not found to very much during rabi (November- February) season. But much more

variation of rainfall probabilities was observed during both kharif (June-October) and pre-kharif (March- May) seasons. Obviously, one would presume conditions variation in these probabilities also yearly, seasonally and annually. Based on these findings and using chi-square test, it could be concluded that the model fit was good.

This study investigates the methods to obtain estimates of the conditional probabilities, the probability of success and its probability distribution to describe the yearly, seasonal and annual variability. The limited data set the results are quite good and the model is doing a reasonably good job of daily rainfall.

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The Author

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α = The probability of a wet week following a dry week

β = The probability of a dry week following a wet week

DI = Drought Index

Pr (W/D) = Probability of a wet week given dry on previous week

Pr (W/W) = Probability of a wet week given wet on previous dry week

P_j (W/D) = Probability of rainfall of wet day after dry in month j

P_j (W/W) = Probability of rainfall of wet day after wet day in month j

P = Probability of Success

P_{00} = Probability of a dry week given dry on previous week

P_{01} = Probability of a dry week given wet on previous week

P_{10} = Probability of a wet week given dry on previous week

P_{11} = Probability of a wet week given wet on previous week

CHAPTER-I

1. Introduction

It is important, however, to stress that because drought affects so many sectors in society, there is a need for different definitions (Wilhite & Glantz, 1985). The particular problem under study, the data availability and the climatic and regional characteristics are among the factors influencing the choice of event definition. Wilhite & Glantz (1985) found more than 150 published definitions of drought, which might be classified in a number of ways. Some of the most common drought definitions are summarized in Tate & Gustard (2000), Demuth & Bakenhus (1994) and Dracup *et al.* (1980).

The terms "drought *event* definition" and "drought index" are frequently being confused. A drought index is often a single number characterizing the general drought behaviors at a measurement site, where as a drought event definition is applied to select drought events in a time series including the beginning and end of the droughts.

In this report different classification systems are summarized. A separate chapter discusses at-site drought definitions. These include definitions applicable to quantify temporal and spatial variations in meteorological droughts in terms of lack of precipitation, as well as hydrological droughts in terms of stream flow and groundwater deficits. A separate section addresses water resources management aspects. Droughts are regional in nature and regional drought event definitions are discussed separately. The report is a contribution to the European Commission supported project "Assessment of the Regional Impact of Droughts in Europe" (ARIDE). The event definitions chosen within specific activities of the ARIDE project are therefore described separately, including a discussion of their suitability in general. Emphasis has been paid to restrict the number of definitions applied within the project. If the event definition requires subjective choices to be made, recommendations are given. Some concluding remarks are given at the end.

The rainfall characteristics of Bangladesh are few. The significance of rainfall analysis has been highlighted of hydrological and climatological studies because of its influence in all human activities such as agricultural, industrial and domestic. It is essential to know the average amount and variability of rainfall for the purpose of agriculture, hydrological planning, industrial and water management. (Rahman and Alam, 1997).

Drought studies have been suffering from the lack of consistent methods for drought analysis. The first step in a drought analysis would be to define the drought event. Scientists have only agreed on very general definitions of a drought, e.g. Beran & Rodier (1985): "The chief characteristic of a drought is a decrease of water availability in a particular period over a particular area". Yevjevich (1967) claims that the lack of general acceptance of a precise and objective definition of drought, has been one of the principle obstacles to the investigation of drought. It is important to be aware that different definitions might lead to different conclusions regarding the drought phenomenon. For instance, it is possible that rainfall statistics summarized over a calendar year indicate no drought, whereas the moisture supply in the growing season does.

Drought occurs when varies combinations of the physical factors of the environment produce in internal water stress in crop plants sufficient to reduce their productivity. Agricultural drought is mainly concerned with inadequacy of rainfall. The crop yield in the area will depend on variation of rainfall in monsoon season.

Drought is a temporary but complex feature of climate system of a given region with widespread significance (Olapido, 1985), which is usually caused by precipitation deficit (Gregory, 1986). Such natural disasters leave a long lasting effect on a social and economic fabric of a region where it strikes, sometimes requiring relief efforts on a global scale (Ahmad, 1995).Although we can recognize a drought when it hits a given region. There is no universal definition of this term. Various characteristics of drought, including definitions and their meteorological, hydrological and economic aspects were discussed by Landsberg (1982), Olapido (1985), Ahmad (1991) and reviewed extensively by Gregory (1986) and Nieuwolt (1986).

Statistical inference is an essential tool for concluding any research. The probability theory of Markov chain has been extensively developed. Where as statistical inference concerning Markov chain model has not been comparatively developed yet (Billingsley, 1961). There is a tendency for rainy days and dry days to cluster and form respective sequences. This reality of meteorological persistence can best be described a Markov chain model of proper order corresponding to the order of conditional dependence of the physical phenomena (Rahman, 1999 a,b). The significance of rainfall analysis has been highlighted by hydrological and climatological studies because of its influence in all human activities such as agricultural, industrial, and domestic (Rahman, 2000). Variability of rainfall is especially important because it has got effects on both hydrology and agriculture of the high Barind region (Rahman and Alam, 1997).

Inference problems, such as estimation and hypothesis testing, involving Markov chains were considered by several authors (Anderson and Goodman, 1957; Billingsley, 1961). These problems were studied not only for their theoretical interest but also for their applications in diverse areas.

Environment and Forest Ministry had taken priority action and organized an national awareness seminar on “Combating Land Degradation and Desertification” in 1998 with assistance from UNCCD. This has created opportunity of public awareness ensuring inter-sectoral discussion at public, private and civil society level on issues and consequences of land degradation, drought, aridity and desertification. As a follow-up of this event, Government, Universities and NGOs came up with action research programmes.

1.1 Objective of the study

The aims and objectives of my study are as follows:

- To estimate the Conditional Probability of wet-dry Transition Matrix Using Markov Chain Model for Weekly rainfall Threshold values 2.5 mm, 5 mm and 10 mm.
- To estimate the drought Index (DI) for weekly rainfall Threshold values 2.5 mm, 5 mm and 10 mm which indicate the variability of rainfall and its impacts on agriculture.
- To the test of significant of wet - dry rainfall week of the study area by using Chi-square test.

CHAPTER-II

2. Literature Review

2.1. Rainfall

Bangladesh has an average rainfall of about 2300 mm, ranging from 1250-5000 mm. Mean annual rainfall is lowest in the centre-west (1250 mm). It increases towards the north, east and south, reaching more than 2500 mm in the extreme north-west, near and within the northern and eastern hills, and near the coast, and exceeding 5000 mm in the extreme north- east. In all areas, about 85-90 percent of the annual total occurs between mid-April and end-September. Totals vary considerably between years. This is mainly because of the yearly variability in pre-monsoon rainfall and the irregular incidence of heavy rainfall events within the monsoon season. Winter rainfall, when it occurs may be either from local thunderstorms or from depressions crossing northern India. Pre-monsoon thunderstorms usually give rainfall of high intensity. Periods of heavy monsoon rainfall may give more than 100 mm in a day.

2.2 Climate Change

Bangladesh is one of the most vulnerable countries to climate change and sea level rise (United Nations Framework Convention to Climate Change (UNFCCC) in Rio de janeiro 1992 and ratified the Climate Convention in April 1994).A National Climate Committee was constituted in 1994 for policy guidance and to oversee the implementation of obligations under the UNFCCC process. The government of Bangladesh, Academic Institutes, and Research Organizations carried out these studies and most of them were carried out collectively. At present two noteworthy studies are going on in the country i.e. National Communication to UNFCCC and Reduce Vulnerability to climate change. The studies are implementing by the Department of Environment and CARE Bangladesh respectively (Rahman and Alam).

The Intergovernmental Panel on Climate Change's Second Assessment Report (1996) concluded, "the balance of evidence suggests that there is a discernible human influence on global climate," `important uncertainties remain. What changes in climate can we expect? What will the impacts be on, for example, agriculture, unmanaged, ecosystems, and sea level? Which regions of the world will be most affected? Accordingly, the climate modeling community needs the capability for multiple simulations using ever more detailed and accurate coupled models. Multiple simulations will be the basis for forecasting –tens to hundreds of years in the future- the likelihood and impact of climate variability and change over regions as small as river basins (Bell *et al*., 2000).The change in climate may bring about changes in population dynamics, growth and distribution of insect and pests. Regional weather changes may, therefore, influence the occurrence of particular species of aphids during the cropping season (Hundal and Prabhjyot Kaur, 2004).

Temperature of the earth has increased by 0.3 – 1 ^{0}C since the beginning of the 20th century as a consequence of increased CO_2 in the atmosphere. Computer simulation of global temperature change shows that if the CO_2 concentration of the atmosphere becomes doubled from its present-day value, then global temperature would increase 1.3^0-4^{0}C. In low and tropical latitudes the change would be very small (only 0.05^0-0.25^{0}C).On the other hand, temperature increase would be much higher in the middle and high latitude regions (5^0-9^{0}C).Moreover, there will be differential temperature increase in summer and winter- temperature increase i8n the winter season will be higher than in the summer. According to some analysis, the effects of increased temperature will have both destructive and beneficial consequences – destructive to some areas and beneficial to other areas. Global warming will cause the polar ice and Himalayan ice caps to melt at a slow pace. As a consequence, it is estimated that the sea level will rise 2-3 meters by the year 2050. in that case , all low coastal plains and delta areas around the world will be submerged- thereby the reducing the area of fertile agriculture lands and food production, and increasing food shortage, hunger, poverty and human misery on a global scale. If this prediction true, then a significant area of the southern half of Bangladesh will be submerged by the Bay of Bengal. However, there is another side to argument. Actually climatic changes on a global scale do not occur overnight; in fact, they occur only over a time scale of thousands of year (http://www.banglapedia.net/HT/C_0288.HTM).

2.3. Weather

Weather is a natural variability but seems to strive after effects of the global warming. Severe weather such as heavy rains causing flash flood is more frequent or at the least more frequently reported, while a prolonged sequence of dry cyclones (those passing without rains but with clouds) causing drought is more common than ever before (Kim, 2000).

The climate is controlled primarily by summer and winter winds, and partly by pre-monsoon and post-monsoon circulation. Monsoon originates over the Indian occean, and carries warm, moist, and unstable air. The easterly Trade Winds are also warm, but relatively drier. The Northeast Monsoon comes from the Siberian Desert, retaining most of its pristine cold, and blows over the country, usually in gusts during dry winter months (Rahman and Alam, 2003).

Some of the projections for how the climate may change in response to human activities are put forward with a focus on global temperature and changes in precipitation and hydrological cycle and, in particular, changes in extremes of rainfall, flooding and drought (Trenberth, 1997, 2000: Karl *et al*., 1995).

The model formulation of the weather generator is implemented by Wilks (1992). The model variables are 4 daily weather characteristics: total sun radiation (Srad), maximum temperature (Tmax), minimum temperature (Tmin) and amount of precipitation (rain). An occurrence of the precipitation is modeled by a non-stationary first order Markov chain, precipitation amount is modeled by gamma distribution, GAMMA (ALPHA, BETA). The remaining quantities or more exactly, the standardized deviations from their mean annual courses are modeled by a first-order autoregressive process (Dubrovsky, 1995).

The natural disaster is defined as "Strictly speaking, a natural disaster is the catastrophic consequence of a natural phenomenon or combination of phenomena resulting injury, loss of life and property on a relatively large scale, and severe disruption to human activities" (Reddy, 2004).He identified several natural disasters, namely (i) Weather disasters such as (a) tropical cyclones, hurricanes, typhoons; (b) other types of storms (extra-tropical cyclones, thunderstorms, tornadoes); (c) floods; (d) drought; and (e) climate change, etc. and (ii) non-weather disasters such as (a) fires (ecological hazard); (b) infestations (biological hazard); (c) earthquakes (geological hazard); (d) release of hazardous materials from industry, transport, volcanoes, etc (ecological hazard); Except earthquake, the intensity of the other three non-weather disasters are also related to weather conditions. Earthquakes and hazardous material may affect weather. The impact of natural disasters on population could be reduced through proper scientific assessment of the past and the present weather data. However, the success of this depends on how the implementing agencies react to these suggestions (Reddy, 2004).

2.4 Climate

Climate is the average condition of the atmosphere near the earth`s surface over a long period of time, taking into account temperature, precipitation, humidity, wind, cloud, etc. Bangladesh is located in the tropical monsoon region its climate is characterized by high temperature, heavy rainfall, often excessive humidity, and fairly marked seasonal variations. The most striking feature of its climate is the reversal of the wind circulation between summer and winter which is an integral part of the circulation system of the South Asian subcontinent. From the climatic point of view, three distinct seasons can be recognized in Bangladesh-the cool dry season from November to February, the pre-monsoon hot season from March to May, and the rainy monsoon season which lasts from June to October. The month of March may also be considered as the spring season, and the period from mid- October through mid-November may be called the autumn season. The rainy season, which coincides with the summer monsoon, is characterized by southerly or southwesterly winds, very high humidity, heavy rainfall, and long consecutive days of rainfall, which are separated byshort spells of dry days

(http://www.banglapedia.net/HT/C_0288.HTM).

The climate of Bangladesh is characterized high temperature, heavy rainfall, often excessive humidity, and fairly marked seasonal variations (Rahman and Alam 2003).

Since the beginning of the industrial age, the concentration of CO2 in the atmosphere has increased from 280 to 350 pars per million (Bazzaz and Fazer, 1992). The increase of CO2 and several other green house gases such as methane, nitrous oxide, chlorofluorocarbons (CFCs) could an increase global temperature of about 4.2^0C and possibly a change in precipitation patterns and amounts in some regions (Kimball *et al*., 1983).

The lacks of rainfall and high air temperature are the chief reasons for the desertification. Climate change occurs due to natural and anthropogenic disturbances in our environment. These anthropogenic factors may contribute to the observed climatic change and variations. The degree of climatic change is very important in assessing environmental impacts such as the increase of bacteria, virus and related diseases that have been reported. The global climate change is the sum of both local and regional departures in climate elements and variables (Munn, 1998).

Effect of climate variability on agriculture is very important. Several studies indicate that weather during cropping season strongly influences the crop growth. In all agricultural regions, the effects of natural climate variability will interact with human induced climate change to determine the magnitude of the impacts on agricultural production (Rahman, 2000)

2.5 Impact of Climate Change

The nature of climate changes in Bangladesh and to assess the physical, economic, environmental and social Impacts of the predicted climate change. Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agricultural productivity. Often the linkages between these key factors and production losses are obvious, but sometimes the linkages are less direct (Ahmed and Shibasaki, 2000). Bangladesh agricultural impacts of climate change could have profound effect in poor and developing countries in South Asia. The country has a humid tropical climate (BARK, 1991).

To estimate the impacts, we need: a model which relates weather and/or climate characteristics with the characteristics of the system being studied climatic and/or weather data for present-climate and changed-climate conditions for given location or for a region in a resolution required by the model used in an impact study (Dubrovsky, 1997).

The impacts of climate change on agricultural food production are global concerns, and they are very important for Bangladesh. Agriculture is the single most and the largest sector of Bangladesh's economy which accounts for about 35% of the GDP and about 70%of the labor force. Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food and from problems of agricultural land and water resources depletion (Ahmed and shibasaki, 2000). Estimation of quantitative impacts of potential climate change on environment and various aspects of human being requires high-resolution surface weather data (Dubrovsky, 1997).

It is generally assumed that the increasing concentration of greenhouse gases in the atmosphere will significantly contribute to the change of climate in near future. The potential subjects of the climate change impacts include, e.g. cycle and water resource management, agriculture, forestry, tourism and human health. The rising temperature and carbon dioxide and uncertainties in rainfall associated with global climate change may have serious direct and indirect consequences on crop production and hence food security (Sinha and Swaminathan 1991). It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on different crops contributing to our food security. The effect of changes in temperature, precipitation and CO_2 concentrations on crop productivity have been studies extensively using crop simulation model. The combined effects of climate change have been found to have implications for dry land and irrigated crop yields (Rosenzweig and Iglesias , as well as by the magnitude of warming, the direction and magnitude of precipitation change (Adams *et al*., 1998).

2.6 Drought

Drought is primarily an agricultural phenomenon that refers to conditions where plants are responsive to certain levels of moisture stress that affect both the vegetative growth and yield of crops. It occurs when supply of moisture stored in the soil is insufficient to meet the optimum need of a particular type of crop. As a consequence of usual hydro-meteorological variability, drought occurs in pre-monsoon season when the potential evapo-transpiration (PET) is higher than the available moisture due to uncertainty in rainfall while in post-monsoon season it is due to prolonged dry periods without appreciable rainfall (Karim *et al.*, 1990a). In both the seasons, due to sudden increases in temperature coupled with non-availability of rainfall causes a sharp rise in PET. One may relate to occurrence of drought with certain physical observations: (i) development of continually broken cracks on the dried up topsoil, (ii) burnt-out yellowish foliage in the vegetation cover (top yellow syndrome), particularly observed in betel nut trees and bamboo groves, and (iii) loosening of soil structure, ending up in the topsoil transforming into a dusty layer.

Pre-monsoon drought is called *Rabi* and Pre-*Kharif* drought since it affects both *Rabi* and Pre-*Kharif* crops. The commonly affected major crops include HYV *Boro*, *Aus*, wheat, pulses, sugarcane, and potatoes. Significant damages can occur where irrigation possibilities are limited. Post-monsoon drought is also known as *Kharif* drought as it affects *Kharif* crops. *Aman* is the most common *Kharif* crop that is affected by post-monsoon drought as its reproductive stage is severely constrained by shortage of available moisture.

Table-1 presents drought prone areas by cropping seasons.

Crop season	Area under various drought severity class (in million ha)					
	Very severe	**Severe**	**Moderate**	**Slight**	**Unaffected**	**Non-T. *Aman***
Pre-*Kharif*	0.403	1.15	4.76	4.09	2.09	-
Kharif (T. *Aman* only)	0.344	0.74	3.17	2.90	0.68	4.71
Rabi	0.446	1.71	2.95	4.21	3.17	-

Source: Iqbal and Ali, 2001.

It is prognosticated that, under climate change scenario evapo-transpiration will increase significantly, especially during the post-monsoon and pre-monsoon seasons, in the backdrop of diminishing rainfall in winter and already erratic rainfall variability over time and space (Karim *et al*., 1998). As a consequence, severity of moisture stress, particularly in the north-western districts mentioned in earlier sections, will increase leading to drought conditions. An earlier estimate suggests that the area severely affected by drought in Rabi season could increase from 4000 km^2 to 12000 km^2 under severe climate change scenario (Huq *et al.*, 1996).

High index of aridity in winter, especially in the western parts of the country may be compensated by increased withdrawal from the surface water sources. If that is the case, despite the minimum flow in the Ganges as provided by the Ganges Water Sharing Treaty (GOB-GOI, 1996) it would be extremely difficult to provide adequate freshwater flows in the downstream of the Ganges dependent areas, particularly during the dry season. The issue of drought has been reiterated in the Bangladesh NAPA document. It is reported earlier that, combating excessive aridity will require either augmented inflows of the Ganges from the upstream or increased ground water withdrawal in those areas (Halcrow *et al.*, 2001b).

The drought definitions and types into four categories: climatological, agricultural, hydrological and socioeconomic (American Meteorological Society, 1997). A prolonged as for example, of several months or years duration the meteorological drought. The atmospheric conditions resulting in the absence or reduction of precipitation-can developed quickly and end abruptly. A few weeks duration i.e., dryness in the surface layers (root zone), which occurs at a critical time during the following season, can result in an agricultural drought that several reduces crop yields.

In Bangladesh drought is defined as the period when moisture content of soil is less than the required amount for satisfactory crop-growth during the normal crop growing season. Droughts are common in the northwestern districts of Bangladesh. However, drought can also occur in areas that usually enjoy adequate rainfall and moisture levels. Due to drought severity, crop ranges between 20 and 60 percent or even may be more for transplanted aman and other rice verities. Depending on the intensity of drought, the estimated yield reduction of different crops varies from 10% to 70%. The yield loss may considerably be reduced through judicious and limited irrigation at the critical stages of crop growth (http;//www.banglapedia.net/HT/D- 0284.HTM).

Defined the drought in general terms as a prolonged absence or market deficiency of precipitation, ”a “deficiency of precipitation that results in water shortage for some activity or for some group “or a “period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a hydrological imbalance”(World Meteorological Organization 1992; American Meteorological Society, 1997).

Drought should be considered relative to some long-term average condition of balance between precipitation and evapotranspiration in a particular area, a condition often perceived as “normal”. It is also related to the timing (i.e., principal season of occurrence, delays in the start of the rainy season, occurrence rains in relation to principal crop growth stages) and the effectiveness (i.e., rainfall intensity, number of rainfall events) of the rains. Other climatic factors such as high temperature, high wind, and low relative humidity are often associated with it in many regions of the world and can significantly aggravate its severity (NDMC, 2006).

Drought is a temporary feature in the sense that, considered in the context of variability, it is experienced only when precipitation falls appreciably below normal. Aridity is, by definition, restricted to regions of low precipitation and usually of high temperature, whereas drought is possible in virtually any precipitation or temperature regime. The drought identification and evaluation procedures slowly evolved during the first half of the twentieth century from simplistic approaches that considered the phenomenon to be a rainfall deficiency, to problem-specific models of limited applicability. The stage was set for the development of a more sophisticated technique to quantitatively appraise what Steila (1987) termed the total environmental moisture status.

The effects of changing water demand on the severity of drought was illustrated by Frick *et al*. (1990) in a study of the impact of prolonged droughts on the water supply. Increased population and industrial development results in a greater demand for water, which implies an increasing vulnerability of present water resource systems to the occurrence of drought, and which suggests a broader, more severe impact of drought when it does occur.

Fernandez and Salas (1999a) subsequently pointed out that return period techniques utilized for floods and other high-flow events may not be applicable to drought events. They suggested that representing data dependence with a simple Markov chain be utilized in analyzing runs of independent and dependent events. They illustrated their technique in a companion paper (Fernandez and Salas, 1999b) by using annual precipitation, minimum stream flows and annual stream flows as drought indices. McKee *et al*. (1993) developed the Standardized Precipitation Index (SPI) as an alternative to the palmer Index for Colorado. Historical data are used to compute the probability distribution of the monthly and seasonal observed precipitation totals and then the probabilities are normalized using the inverse normal (Gaussion) function. Guttman (1999) determined that the person Type III distribution is the "best" universal model for computing the probability distribution. The SPI methodology allows expression of droughts in terms of precipitation deficit, percent of normal and probability of non-exceedance as well as the SPI.

2.7. Drought Index

The American Meteorological Society (1997) suggests that the time and space processes of supply and demand are the two basic processes that should be included in an objective definition of drought and derivation of a drought index. The world Meteorological Organization defined a drought index as an index, which is related to some of the cumulative effects of a prolonged and abnormal moisture deficiency (World Meteorological Organization, 1992). Friedman (1957) identified four basic criteria that may drought index should meet: 1) the timescale should be appropriate to the problem at hand; 2) the index should be a quantitative measure of large-scale, long-continuing drought conditions: 3) the index should be applicable to the problem being studiet; and 4) a long accurate past record of the index should be available or computable.

Many quantitative measures of drought have been developed based on the sector and location affected, the particular application, and the degree of understanding of the phenomena. The water balance model developed by Palmer (1965) was a turning point in the evolution of drought indices. While an improvement over simple early twentieth- century measures, the Palmer Index suffers from some inherent weaknesses (these weaknesses will be discussed later). Post-Palmer solutions include modern indices, such as the Surface Water Supply Index and the Standardized Precipitation Index, and the Drought Monitor.

Blumenstock (1942) applied probability theory to compute drought frequencies in a climate study. For his index, he used the length of the drought in days, where a drought was considered terminated by the occurrence of at least 2.54 mm (0.10 in.) of precipitation in 48 h or less.

Keetch and Byram (1968) developed an index of drought for use by fire control managers. Based on a 203- mm (8 in) soil moisture storage capacity, the Drought Index (DI) is expressed in hundredths of an inch of spoil moisture depletion, ranging from 0 (one moisture deficiency) to 800 (absolute drought). Computation of the DI is based on a daily water budgeting procedure where by the drought factor is balanced with precipitation and soil moisture. The Keetch-Byram drought Index (KBDI) has become widely used in wildfire monitoring and prediction.

2.8 Predicting and Planning Drought

Predicting drought depends on ability to for cast two fundamental meteorological surface parameters, precipitation and temperature. From the historical record we know that climate is inherently variable. We also know that anomalies of precipitation and temperature may last from several months to several decades.

Precipitation is the largest single determinant of drought. Temperature and other climate elements are also important. It is not uncommon for drought periods to be accompanied by higher summer temperatures. Drought planning involves preparing for not only average conditions, but also extremes. Thus, producers should know the extent of their current drought conditions and what the expectations are for the coming week, month and season (NDMC, 2006).

Drought is normal part of virtually every climate on the planet, even rainy ones. It is the most complex of all natural hazards, and it affects more people than any other hazard. The impacts of drought are greater than the impacts of any other natural hazard. The impacts of these droughts illustrate our continuing and perhaps increasing vulnerability to extended periods of water shortage (Wilhite and Glantz, 1987).

Although drought is a natural hazard, society can reduce its vulnerability and therefore lessen the risks associated with drought episodes. The impacts of drought, like those of other natural hazards, can be reduced through mitigation and preparedness In additional to drought planning at the state and national level. Planning has also become more prevalent at the regional and local levels. The output numeric values were analyzed in two steps: for rainfed land and for irrigated land. A high numeric value within each category was assumed to be indicative of a geographic area that is likely to be vulnerable to agricultural drought (NDMC, 2006).

CHAPTER–III

3. Materials and Methods

3.1 Site Selection and Data Collection

The data used in this study refer to the daily rainfall data of Bogra, Jessore and Feni district. Rainfall recording stations were available for 30 years and recorded by Bangladesh Water Development Board. The data used in this study refer to the daily rainfall data of Bogra, Jessore and Feni district. Rainfall recording stations were available for 30 years and recorded by Bangladesh Meteorological Department.

3.2.1 Markov Chain Model

A two-state Markov Chain method involves the calculation of two conditional probabilities: (1) α , the probability of a wet week following a dry week and (2) β , the probability of a wet week following a wet week. The two states Markov Chain for the combination of conditional probabilities is :

Present State	Future State		
		Dry	Wet
	Dry	$1-\alpha$	α
	Wet	β	$1-\beta$

Let us consider the conditional probabilities which are denoted by

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

$$P_1 = \Pr\{W / W\} \quad (1)$$

This sequence is irreducible Markove chain with two ergodic state. Its stationary probability distribution has probability of success

$$P = P_0 /(1-(p_1 - P_0)) \quad (2)$$

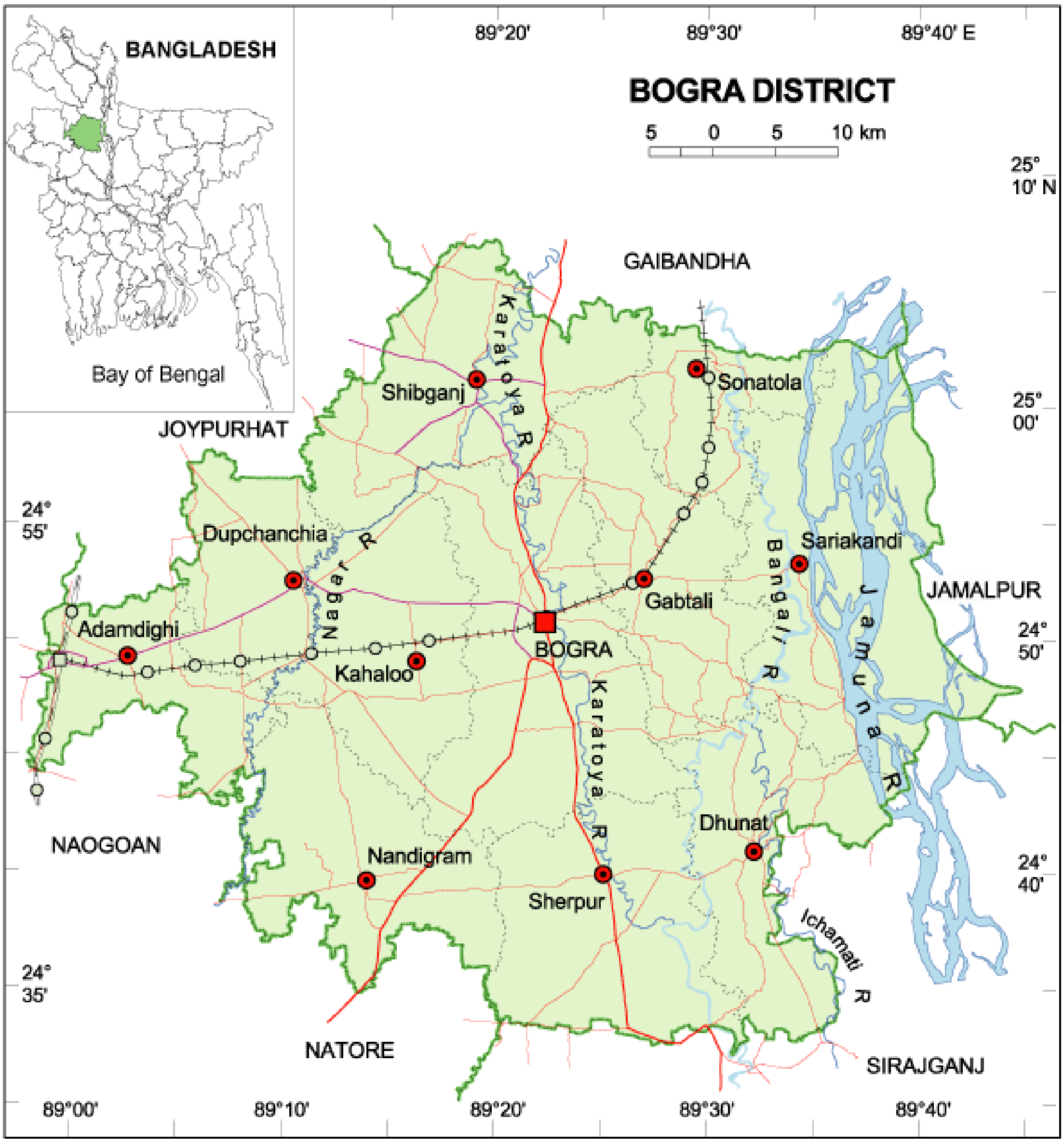

Chart-1: Shows Study Area of Bogra District

Chart-2: Shows Study Area of Jessore District

Chart-3: Shows Study Area of Feni District

3.2.2 Markov Chain

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 Katz (1974), Anderson and Goodman (1957), Todorovic and Woolhiser (1974) and Rahman (1999 a, b)

Let X_0, X_1, X_2,........................ , X_n , be random variables distributed identically and taking only two values, namely o and 1, with probability one,

i.e., $$X_0 = \begin{cases} 0 \text{ if the nth week is dry} \\ 1 \text{ if the nth week is wet} \end{cases} \qquad (3)$$

Firstly we assume that,

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

where, $X_0, X_1, ..., x_{n+1}$ € {o, 1}.

In other words it is assumed that probability of wetness of any week depends only one 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 ………} is a Markov chain (Medhi, 1981).

Consider the transition matrix, $P_{ij} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$ (4)

Where $P_{ij}=P(X_{1=j} / X_{0=i})$ i,j = 0, 1 . Note $P_{00} + P_{01} = 1$ and $P_{10} + P_{11} = 1$.

Let $P = P(X_0=1)$, Here P is the absolute probability of a week being wet during the monsoon period. Clearly, $P(X_0 = 0) = 1-p$.

For a stationary distribution

$$[1-p \quad p] \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} = [1-p \quad p] \qquad (5)$$

Which gives

$$p = \frac{p_{01}}{1-(p_{11}-p_{01})} \tag{6}$$

It is further assumed that P_{ij} 's remaining constant over the years. The maximum Likelihood estimates of p_{01} and p_{11} are appropriate relative functions.

Let Y be the random variable such that Y= number of wet weeks among a n weeks period i.e. $Y = X_0 + X_1 + \ldots\ldots\ldots + X_{n-1}$

For large n , Y follows normal distribution with

$$\text{Mean} = n \times p \tag{7}$$

$$\text{Variance} = n \times p \times (1-p) \times \frac{1+p_{11}-p_{01}}{1-p_{11}+p_{01}} \tag{8}$$

Where p is the stationary Probability of week being wet.

This is an asymptotic result which indicates neither the exact distribution for small n nor the rapidity of approach to normality (Feller, 1957).

3.2.3 Index of Drought Proneness

P_{11} gives the probability of a week to be wet given that previous week was w*et al*so. When P_{11} is large, that 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

$$DI = P_{11} \times P_{01} \tag{9}$$

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)

DI Calculated final stable transition probability matrix where

$$p_{ij}^{n} = p_{ij}^{n+1} \tag{10}$$

Table: 2 Index of drought- proneness

Criteria	Degree of drought proneness
$0.000 \le DI \le 0.125$	Chronic
$0.125 < DI \le 0.180$	Severe
$0.180 < DI \le 0.235$	Moderate
$0.235 < DI \le 0.310$	Mild
$0.310 < DI \le 1.000$	Occasional

3.2.4 Test of Hypothesis

On the basis of the asymptotic distribution theory discussed in the preceding section, we can derive certain methods of statistical inference. Here we shall assume that every $P_{ij} > 0$. First we consider testing the hypothesis that certain transition probabilities P_{ij} have specified values $P_{ij}{}^{0}$. We make use of the fact that under the null hypothesis the $(n)^{1/2}(\overline{P}_{ij} - P_{ij}{}^{0})$ have a limiting normal distribution with mean zero, and variances and covariances depending on $P_{ij}{}^{0}$ in the same way as observations for multinomial estimates. We can use standard asymptotic theory for multinomial or normal distributions to test a hypothesis about one or more Pij , or determine a confidence region for one or more Pij.

As a specific example consider testing the hypothesis that $P_{ij} = P_{ij}{}^{0}$. j = 1, 2, ------ , m for given I . Under the null hypothersis,

$$\sum_{j=1}^{m} n_i \frac{(\overline{P}_{ij} - P_{ij}{}^{0})^2}{P_{ij}{}^{0}} \qquad (11)$$

Has an asymptotic χ^2 – distributions with m-1 degree of freedom (according to the usual asymptotic theory for multinomial variables) Thus the critical region of first test of this hypothesis at significance level α consists of the set $\widetilde{P}_{ij}$ for which (11) is greater than the significance point of the χ^2 – distribution with m-1 degrees of freedom

In the stationary Markov chain, P_{ij} is the probability that an individual in state i at time t-1 moves to state j at t. A general alternative to this assumption is that the transition probability depends on t; Let us say it is $P_{ij}(t)$ .We test the null hypothesis H : $p_{ij}(t) = P_{ij}$ (t=1, 2, ------ T) Under the alternative hypothesis, the estimates of the transition probabilities for time t are

$$\widetilde{P}_{ij}(t) = \frac{n_{ij}(t)}{n_i(t-1)} \qquad (12)$$

The likelihood function maximized under the null hypothesis is

$$\prod_{i=1}^{T} \prod_{i,j} \widetilde{P}_{ij}^{\,n_{ij}(t)} \qquad (12)$$

The likelihood function maximized under the alternate is

$$\prod_{t} \prod_{ij} \widetilde{P}_{ij}^{\,n_{ij}(t)}(t) \qquad (13)$$

For a given I, the set $\widetilde{P}_{ij}(t)$ has the same asymptotic distribution as the estimates of multinomil probabilities $P_{ij}(t)$ for T independent samples. The asymptotic distribution of $-2\log\lambda_i$ is χ^2 (m-1) (T-1) degrees of freedom. The preceding remarks relating to the contingency table approach dealt with a given value I, Hence, the hypothesis can be tested separately for each value of i. Similarly the test criterion based on (13) can be written as

$$\sum_{i=1}^{m} -2\log\lambda_i = -2\log\lambda \qquad 14$$

CHAPTER-IV

4. Results and Discussions

4.1 Drought Index Calculated by using Rainfall 2.5 mm for Bogra Jessore and Feni District

The daily rainfall of 30 years during the period from 1981-2010 in Bogra Jessore and Feni District considering 52 standard weeks have been used for Table-4.1.1. The drought prone weeks are found in Bogra District which are drought index values DI= 0.30, 0.30, 0.31, 0.30. Jessore District which are drought index values DI= 0.29, 0.28, 0.27, 0.28. Feni District which are drought index values DI= 0.30, 0.29, 0.25, 0.28.

Table: 4.1.1. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Annual by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.54	0.56	0.55	28.60	13.37	0.30	Mild
	10 Years (1981-1990)	0.53	0.56	0.55	28.60	13.64	0.30	Mild
	10 Years (1991-2000)	0.55	0.56	0.49	29.12	13.07	0.31	Mild
	10 Years (2001-2010)	0.54	0.56	0.55	28.60	13.38	0.30	Mild
Jessore	30 Years (1981-2010)	0.53	0.55	0.55	28.60	13.37	0.29	Mild
	10 Years (1981-1990)	0.52	0.54	0.55	28.60	13.64	0.28	Mild
	10 Years (1991-2000)	0.51	0.56	0.49	29.12	13.07	0.27	Mild
	10 Years (2001-2010)	0.54	0.56	0.55	28.60	13.38	0.28	Mild
Feni	30 Years (1981-2010)	0.54	0.56	0.55	28.60	13.37	0.30	Mild
	10 Years (1981-1990)	0.53	0.55	0.55	28.60	13.64	0.29	Mild
	10 Years (1991-2000)	0.55	0.56	0.49	29.12	13.07	0.25	Mild
	10 Years (2001-2010)	0.54	0.56	0.55	28.60	13.38	0.28	Mild

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Bogra Jessore and Feni District considering 13 standard weeks have been used for Table– 4.1. 2 The Mild, occasional Moderate drought prone weeks are found in Bogra District which are drought index values DI=0.26, 0.34, 0.22, 0.21, Jessore District which are drought index values DI=0.25, 0.57, 0.21, 0.22, Feni District which are drought index values DI=0.29, 0.34, 0.22, 0.21.

Table: 4.1.2. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore , Feni District for Pre-Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.52	0.49	0.50	6.54	3.12	0.26	Mild
	10 Years (1981-1990)	0.62	0.55	0.58	7.54	2.76	0.34	Occasional
	10 Years (1991-2000)	0.47	0.47	0.47	6.11	3.34	0.22	Moderate
	10 Years (2001-2010)	0.46	0.46	0.46	5.98	3.23	0.21	Moderate
Jessore	30 Years (1981-2010)	0.55	0.56	0.49	29.12	13.07	0.25	Mild
	10 Years (1981-1990)	0.74	0.77	0.76	16.72	4.26	0.57	Occasional
	10 Years (1991-2000)	0.46	0.46	0.46	5.98	3.23	0.21	Moderate
	10 Years (2001-2010)	0.47	0.47	0.47	6.11	3.34	0.22	Moderate
Feni	30 Years (1981-2010)	0.53	0.55	0.55	28.60	13.37	0.29	Mild
	10 Years (1981-1990)	0.61	0.56	0.56	16.12	2.56	0.34	Occasional
	10 Years (1991-2000)	0.48	0.46	0.47	6.11	3.34	0.22	Moderate
	10 Years (2001-2010)	0.49	0.43	0.47	6.11	3.34	0.21	Moderate

The daily rainfall of Kharif season of 30 years(1981- 2010) during the period from June to October in Bogra, Jessore , Feni District considering 22 standard weeks have been used for Table-4.1.3.The occasionally drought prone weeks are found in Bogra District which are drought index values DI=0.64, 0.57, 0.59, 0.76. Jessore District which are drought index values DI=0.65, 0.57, 0.59, 0.76, Feni District which are drought index values DI=0.65, 0.57, 0.59, 0.76.

Table: 4.1.3. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.79	0.81	0.81	15.06	3.22	0.64	Occasional
	10 Years (1981-1990)	0.74	0.77	0.76	16.72	4.26	0.57	Occasional
	10 Years (1991-2000)	0.76	0.78	0.78	17.16	3.93	0.59	Occasional
	10 Years (2001-2010)	0.87	0.87	0.87	11.31	1.47	0.76	Occasional
Jessore	30 Years (1981-2010)	0.79	0.83	0.81	15.06	3.22	0.65	Occasional
	10 Years (1981-1990)	0.74	0.77	0.76	16.72	4.26	0.57	Occasional
	10 Years (1991-2000)	0.76	0.78	0.78	17.16	3.93	0.59	Occasional
	10 Years (2001-2010)	0.86	0.87	0.87	11.36	1.47	0.76	Occasional
Feni	30 Years (1981-2010)	0.78	0.84	0.81	15.06	3.22	0.65	Occasional
	10 Years (1981-1990)	0.74	0.77	0.76	16.72	4.26	0.57	Occasional
	10 Years (1991-2000)	0.76	0.78	0.78	17.16	3.93	0.59	Occasional
	10 Years (2001-2010)	0.87	0.87	0.87	11.31	1.47	0.76	Occasional

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Bogra, Jessore, Feni District considering 17 standard weeks have been used for Table -4.1.4.The chronic drought prone weeks are found in Bogra District which are drought index values DI = 0.02, 0.03, 0.03, 0.01, Jessore District which are drought index values DI = 0.02, 0.03, 0.04, 0.02, Feni District which are drought index values DI = 0.02, 0.03, 0.03, 0.01.

Table: 4.1.4 Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Rabi Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.16	0.16	0.16	2.72	2.16	0.02	Chronic
	10 Years (1981-1990)	0.18	0.18	0.18	3.06	2.51	0.03	Chronic
	10 Years (1991-2000)	0.19	0.19	0.19	3.23	2.62	0.03	Chronic
	10 Years (2001-2010)	0.11	0.11	0.11	1.87	1.66	0.01	Chronic
Jessore	30 Years (1981-2010)	0.16	0.16	0.17	2.89	2.16	0.02	Chronic
	10 Years (1981-1990)	0.18	0.18	0.18	3.06	2.67	0.03	Chronic
	10 Years (1991-2000)	0.20	0.20	0.20	3.40	2.71	0.04	Chronic
	10 Years (2001-2010)	0.14	0.16	0.14	2.38	2.63	0.02	Chronic
Feni	30 Years (1981-2010)	0.17	0.17	0.17	2.88	2.16	0.02	Chronic
	10 Years (1981-1990)	0.18	0.18	0.19	3.23	2.67	0.03	Chronic
	10 Years (1991-2000)	0.19	0.19	0.19	3.23	2.62	0.03	Chronic
	10 Years (2001-2010)	0.12	0.12	0.11	1.87	1.66	0.01	Chronic

4.2 Drought Index Calculated by using Rainfall 5 mm for Bogra Jessore and Feni District

The daily rainfall of 30 years during the period from 1981-2010 in Bogra, Jessore , Feni District considering 52 standard weeks have been used for Table -4.2.1.The mild drought prone weeks are found in Bogra District which are drought index values DI=0.27, 0.28, 0.28, 0.25 , Jessore District which are drought index values DI=0.25, 0.28, 0.26, 0.27, Feni District which are drought index values DI=0.25, 0.28, 0.27, 0.29 .

Table: 4.2.1 Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Annual by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.51	0.53	0.42	26.97	16.45	0.27	Mild
	10 Years (1981-1990)	0.51	0.54	0.23	27.34	22.35	0.28	Mild
	10 Years (1991-2000)	0.52	0.54	0.53	27.56	13.48	0.28	Mild
	10 Years (2001-2010)	0.49	0.51	0.50	26.00	13.53	0.25	Mild
Jessore	30 Years (1981-2010)	0.50	0.51	0.50	26.00	13.53	0.25	Mild
	10 Years (1981-1990)	0.51	0.54	0.23	27.34	22.35	0.28	Mild
	10 Years (1991-2000)	0.49	0.54	0.54	27.56	13.48	0.26	Mild
	10 Years (2001-2010)	0.52	0.53	0.53	27.56	13.48	0.27	Mild
Feni	30 Years (1981-2010)	0.50	0.51	0.50	26.00	13.53	0.25	Mild
	10 Years (1981-1990)	0.51	0.54	0.23	27.34	22.35	0.28	Mild
	10 Years (1991-2000)	0.52	0.53	0.53	27.56	13.48	0.27	Mild
	10 Years (2001-2010)	0.53	0.56	0.55	28.60	22.35	0.29	Mild

The daily rainfall of Pre-Kharif season of 30 years(1981-2010) during the period from March to May in Bogra, Jessore, Feni District considering 13 standard weeks have been used for Table-4.2.2.The Mild, occasional, Moderate, drought prone weeks are found in Bogra District which are drought index values DI= 0.26, 0.37, 0.21, 0.21, , Jessore District which are drought index values DI=0.24, 0.21, 0.16, 0.35, Feni District which are drought index values DI=0.24, 0.36, 0.28, 0.28.

Table: 4.2.2. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Pre-Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.50	0.50	0.50	6.54	3.22	0.26	Mild
	10 Years (1981-1990)	0.61	0.61	0.61	7.93	3.09	0.37	Occasional
	10 Years (1991-2000)	0.45	0.46	0.45	5.85	3.29	0.21	Moderate
	10 Years (2001-2010)	0.45	0.46	0.45	5.85	3.29	0.21	Moderate
Jessore	30 Years (1981-2010)	0.49	0.51	0.50	6.50	3.38	0.24	Mild
	10 Years (1981-1990)	0.45	0.46	0.45	5.85	3.29	0.21	Moderate
	10 Years (1991-2000)	0.40	0.40	0.40	5.20	3.12	0.16	Severe
	10 Years (2001-2010)	0.59	0.60	0.60	7.80	3.18	0.35	Occasional
Feni	30 Years (1981-2010)	0.49	0.49	0.49	6.37	3.22	0.24	Mild
	10 Years (1981-1990)	0.63	0.58	0.61	7.93	3.09	0.36	Occasional
	10 Years (1991-2000)	0.51	0.56	0.56	7.28	3.06	0.28	Mild
	10 Years (2001-2010)	0.51	0.54	0.53	6.89	3.43	0.28	Mild

The daily rainfall of Kharif season of 30 years(1981-2010) during the period from June to October in Bogra, Jessore , Feni District considering 22 standard weeks have been used for Table – 4.2.3. The occasionally drought prone weeks are found in Bogra District which are drought index values DI = 0.64, 0.67, 0.50, 0.76, Jessore District which are drought index values DI = 0.68, 0.65, 0.51, 0.73, Feni District which are drought index values DI = 0.73, 0.68, 0.54, 0.75.

Table4.2.3. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.82	0.82	0.82	17.60	4.16	0.64	Occasional
	10 Years (1981-1990)	0.82	0.82	0.82	18.04	3.25	0.67	Occasional
	10 Years (1991-2000)	0.71	0.71	0.71	15.62	6.38	0.50	Occasional
	10 Years (2001-2010)	0.87	0.87	0.87	19.14	2.86	0.76	Occasional
Jessore	30 Years (1981-2010)	0.83	0.82	0.80	17.60	4.16	0.68	Occasional
	10 Years (1981-1990)	0.81	0.81	0.81	17.82	3.25	0.65	Occasional
	10 Years (1991-2000)	0.72	0.72	0.72	15.84	6.38	0.51	Occasional
	10 Years (2001-2010)	0.84	0.87	0.87	19.14	2.86	0.73	Occasional
Feni	30 Years (1981-2010)	0.86	0.86	0.86	18.92	3.66	0.73	Occasional
	10 Years (1981-1990)	0.83	0.82	0.83	18.04	3.23	0.68	Occasional
	10 Years (1991-2000)	0.74	0.74	0.73	16.06	6.38	0.54	Occasional
	10 Years (2001-2010)	0.85	0.89	0.88	19.36	2.86	0.75	Occasional

The daily rainfall of Rabi season of 30 years(1981-2010) during the period from November to February in Bogra, Jessore , Feni District considering 17 standard weeks have been used for Table-4.2.4.The chronic drought prone weeks are found in Bogra District which are drought index values DI=0.02, 0.03, 0.02, 0.01, Jessore District which are drought index values DI=0.02, 0.02, 0.04, 0.01, Feni District which are drought index values DI=0.02, 0.03, 0.04, 0.02.

Table 4.2.4. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Rabi by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.14	0.15	0.14	2.44	1.32	0.02	Chronic
	10 Years (1981-1990)	0.18	0.19	0.18	3.06	0.25	0.03	Chronic
	10 Years (1991-2000)	0.14	0.14	0.14	2.38	2.05	0.02	Chronic
	10 Years (2001-2010)	0.11	0.11	0.11	1.87	1.66	0.01	Chronic
Jessore	30 Years (1981-2010)	0.15	0.16	0.15	2.55	1.31	0.02	Chronic
	10 Years (1981-1990)	0.14	0.15	0.14	2.44	1.32	0.02	Chronic
	10 Years (1991-2000)	0.20	0.22	0.22	3.74	2.73	0.04	Chronic
	10 Years (2001-2010)	0.13	0.12	0.12	1.56	1.66	0.01	Chronic
Feni	30 Years (1981-2010)	0.16	0.16	0.17	2.89	2.16	0.02	Chronic
	10 Years (1981-1990)	0.18	0.18	0.18	3.06	2.67	0.03	Chronic
	10 Years (1991-2000)	0.20	0.20	0.20	3.40	2.71	0.04	Chronic
	10 Years (2001-2010)	0.14	0.16	0.14	2.38	2.63	0.02	Chronic

4.3 Drought Index Calculated by using Rainfall 10 mm for Bogra Jessore and Feni District:

The daily rainfall of 30 years during the period from 1981-2010 in Bogra, Jessore, Feni District considering 52 standard weeks have been used for Table-4.3.1.The moderate drought prone weeks are found in Bogra District which are drought index values DI = 0.20, 0.21, 0.21, 0.18, Jessore District which are drought index values DI = 0.21, 0.21, 0.19, 0.24, Feni District which are drought index values DI = 0.21, 0.20, 0.21, 0.18.

Table 4.3.1. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Annual by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.44	0.45	0.44	22.88	13.06	0.20	Moderate
	10 Years (1981-1990)	0.45	0.46	0.45	23.40	13.13	0.21	Moderate
	10 Years (1991-2000)	0.45	0.46	0.45	23.40	13.13	0.21	Moderate
	10 Years (2001-2010)	0.42	0.43	0.42	21.80	12.93	0.18	Moderate
Jessore	30 Years (1981-2010)	0.45	0.47	0.46	23.92	13.43	0.21	Moderate
	10 Years (1981-1990)	0.44	0.47	0.45	23.40	13.64	0.21	Moderate
	10 Years (1991-2000)	0.43	0.45	0.44	22.88	13.33	0.19	Moderate
	10 Years (2001-2010)	0.48	0.50	0.49	25.48	13.51	0.24	Moderate
Feni	30 Years (1981-2010)	0.45	0.46	0.45	23.40	13.13	0.21	Moderate
	10 Years (1981-1990)	0.43	0.47	0.44	22.88	13.33	0.20	Moderate
	10 Years (1991-2000)	0.44	0.47	0.45	23.40	13.64	0.21	Moderate
	10 Years (2001-2010)	0.42	0.43	0.42	21.80	12.93	0.18	Moderate

The daily rainfall of Pre-Kharif season of 10 years (1991-2000) during the period from March to May in Bogra, Jessore , Feni District considering 13 standard weeks have been used for Table- 4.3.2.The Severe drought prone weeks are found in Bogra District which are drought index values DI=0.16,0.16,0.3,0.18, Jessore District which are drought index values DI=0.18, 0.14, 0.14, 0.13, Feni District which are drought index values DI=0.16, 0.15, 0.13, 0.14.

Table 4.3.2. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Pre-Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.40	0.40	0.40	5.11	3.11	0.16	Severe
	10 Years (1981-1990)	0.40	0.41	0.40	5.20	3.18	0.16	Severe
	10 Years (1991-2000)	0.36	0.36	0.36	4.68	2.99	0.13	Severe
	10 Years (2001-2010)	0.42	0.42	0.42	5.46	3.17	0.18	Severe
Jessore	30 Years (1981-2010)	0.42	0.42	0.42	5.46	3.17	0.18	Severe
	10 Years (1981-1990)	0.37	0.39	0.39	5.07	3.01	0.14	Severe
	10 Years (1991-2000)	0.38	0.37	0.37	4.81	2.81	0.14	Severe
	10 Years (2001-2010)	0.36	0.37	0.36	4.67	2.98	0.13	Severe
Feni	30 Years (1981-2010)	0.40	0.42	0.41	5.20	3.18	0.16	Severe
	10 Years (1981-1990)	0.39	0.41	0.41	5.33	3.15	0.15	Severe
	10 Years (1991-2000)	0.36	0.36	0.36	4.68	2.99	0.13	Severe
	10 Years (2001-2010)	0.39	0.37	0.39	5.07	3.01	0.14	Severe

The daily rainfall of Kharif season of 10 years (1991-2000) during the period from June to October in Bogra, Jessore, Feni District considering 22 standard weeks have been used for Table-4.3.3.The occasionally drought prone weeks are found in Bogra District which are drought index values DI = 0.61, 0.60, 0.58, 0.58, Jessore District which are drought index values DI = 0.56, 0.59, 0.57, 0.75, Feni District which are drought index values DI = 0.65, 0.57, 0.59, 0.76.

Table: 4.3.3. Analysis of probability of wet and dry weeks and index of drought-proneness in Bogra, Jessore, Feni District for Kharif by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.78	0.78	0.78	16.99	3.75	0.61	Occasional
	10 Years (1981-1990)	0.77	0.78	0.77	16.44	3.86	0.60	Occasional
	10 Years (1991-2000)	0.81	0.81	0.81	17.82	4.01	0.58	Occasional
	10 Years (2001-2010)	0.76	0.76	0.76	16.72	4.01	0.58	Occasional
Jessore	30 Years (1981-2010)	0.79	0.79	0.79	17.80	3.99	0.56	Occasional
	10 Years (1981-1990)	0.76	0.78	0.78	17.16	3.93	0.59	Occasional
	10 Years (1991-2000)	0.80	0.80	0.80	17.81	4.00	0.57	Occasional
	10 Years (2001-2010)	0.86	0.86	0.86	11.30	1.46	0.75	Occasional
Feni	30 Years (1981-2010)	0.78	0.84	0.81	15.06	3.22	0.65	Occasional
	10 Years (1981-1990)	0.74	0.77	0.76	16.72	4.26	0.57	Occasional
	10 Years (1991-2000)	0.76	0.78	0.78	17.16	3.93	0.59	Occasional
	10 Years (2001-2010)	0.87	0.87	0.87	11.31	1.47	0.76	Occasional

The daily rainfall of Rabi season of 10 years (1991-2000) during the period from November to February in Bogra, Jessore , Feni District considering 17 standard weeks have been used for Table-4.3.4.The Chronic drought prone weeks are found in Bogra District which are drought index values DI=0.006, 0.003, 0.012, 0.004, Jessore District which are drought index values DI=0.002, 0.005, 0.004, 0.004, Feni District which are drought index values DI=0.002, 0.003, 0.004, 0.003.

Table 4.3.4. Analysis of probability of wet and dry weeks and index of drought- proneness in Bogra, Jessore, Feni District for Rabi by Markov Chain.

District	Year	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
Bogra	30 Years (1981-2010)	0.08	0.08	.08	1.36	1.24	0.006	Chronic
	10 Years (1981-1990)	0.06	0.06	0.06	1.02	0.94	0.003	Chronic
	10 Years (1991-2000)	0.11	0.11	0.11	1.87	1.66	0.012	Chronic
	10 Years (2001-2010)	0.07	0.07	0.07	1.19	1.11	0.004	Chronic
Jessore	30 Years (1981-2010)	0.07	0.27	0.09	1.57	1.23	0.002	Chronic
	10 Years (1981-1990)	0.12	0.39	0.17	2.87	1.94	0.005	Chronic
	10 Years (1991-2000)	0.14	0.29	0.17	2.85	1.98	0.004	Chronic
	10 Years (2001-2010)	0.13	0.42	0.18	3.06	2.06	0.004	Chronic
Feni	30 Years (1981-2010)	0.07	0.31	0.09	1.46	1.24	0.002	Chronic
	10 Years (1981-1990)	0.16	0.22	0.17	2.88	1.97	0.003	Chronic
	10 Years (1991-2000)	0.11	0.33	0.14	2.46	1.32	0.004	Chronic
	10 Years (2001-2010)	0.11	0.24	0.12	2.04	1.13	0.003	Chronic

4. Test of Significance

4.4 Dry-wet transition Probability Matrix for Rainfall 2.5 mm for Bogra District

The probabilities of rainfall occurrence were derived from the probability model and require two conditional probabilities P1=Pr{wet week / previous week wet}=Pr{w/w}, Po=Pr{wet week / previous week dry}=Pr{w/d}.The fit of the Markov chain model had been tested on data of rainfall in Bogra, Jessore , Feni district for a period of 30 years from 1981 to 2010.The conditional probabilities in a Markov chain were estimated by using maximum likelihood estimation techniques.

The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.4.1 The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 2.1.1) was Pr { $\chi^2 \geq 404.13$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.4.1 The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	533	201	734
Wet	195	674	869
Total	728	875	1603
Cal χ^2	404.13		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.4.2). The chi-squire value of the transition matrix (Table 4.4.2) was Pr $\{\chi^2 \geq 119.26\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.4.2 The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	160	63	223
Wet	70	226	296
Total	230	289	519
Cal χ^2	119.26		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.4.3). The chi-squire value of the transition matrix (Table 4.4.3) was Pr$\{\chi^2 \geq 145.11\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.4.3. The occurrence and non- occurrence rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	170	65	235
Wet	57	226	283
Total	227	291	518
Cal χ^2	145.11		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.4.4). The chi-squire value of the transition matrix (Table 4.4.4) was Pr{ $\chi^2 \geq 140.35$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.4.4.The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	203	73	276
Wet	68	222	290
Total	271	295	566
Cal χ^2	140.35		
χ^2 (1 d.f. at 5% level)	0.00393		

4.5 Dry-wet transition Probability Matrix for Rainfall 2.5 mm for Jessore District

The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.5.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.5.1) was Pr { $\chi^2 \geq 406.17$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.5.1 The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	531	203	734
Wet	198	671	869
Total	729	874	1603
Cal χ^2	406.17		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.5.2). The chi-squire value of the transition matrix (Table 4.5.2) was Pr { $\chi^2 \geq 117.16$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.5.2 The occurrence and non-occurrence rainfall in Jessore district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	162	61	223
Wet	69	227	296
Total	231	288	519
Cal χ^2	117.16		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.5.3). The chi-squire value of the transition matrix (Table 4.5.3) was Pr{ $\chi^2 \geq 143.13$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.5.3. The occurrence and non-occurrence rainfall in Jessore district for the 10 consecutive years from 1991 to 2000. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	168	67	235
Wet	59	224	283
Total	227	291	518
Cal χ^2	143.13		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.5.4). The chi-squire value of the transition matrix (Table 4.5.4) was Pr{ $\chi^2 \geq 141.31$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.5.4. The occurrence and non-occurrence rainfall in Jessore district for the 10 consecutive years from 2001 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	203	72	275
Wet	68	223	290
Total	271	295	566
Cal χ^2	141.31		
χ^2 (1 d.f. at 5% level)	0.00393		

4.6 Dry-wet transition Probability Matrix for Rainfall 2.5 mm for Feni District

The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.6.1. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.6.1) was Pr { $\chi^2 \geq 401.33$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table : 4.6.1 The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	534	201	735
Wet	195	673	868
Total	729	874	1603
Cal χ^2	401.33		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.6.2). The chi-squire value of the transition matrix (Table 4.6.2) was Pr $\{\chi^2 \geq 117.23\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table : 4.6. 2 The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted bystate 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	160	63	223
Wet	70	224	294
Total	230	287	517
Cal χ^2	117.23		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.6.3). The chi-squire value of the transition matrix (Table 4.6.3) was Pr$\{\chi^2 \geq 143.15\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.6.3. The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 1991 to 2000. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	171	63	234
Wet	56	228	284
Total	227	291	518
Cal χ^2	143.15		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.6.4). The chi-squire value of the transition matrix (Table 4.6.4) was Pr{ $\chi^2 \geq 140.35$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.6.4. The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 2001 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	71	273
Wet	69	224	293
Total	271	295	566
Cal χ^2	140.35		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.7.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.7.1) were Pr{ $\chi^2 \geq 39.35$}for Pre-kharif, Pr{ $\chi^2 \geq 98.21$ } for Kharif, Pr{ $\chi^2 \geq 4.64$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.7.1 The occurrence and non - occurrence data of pre - kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	128	69	197
Wet	67	133	200
Total	195	202	397
Cal χ^2	39.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	48	42	90
Wet	67	524	591
Total	115	566	681
Cal χ^2	98.21		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	323	54	377
Wet	56	18	74
Total	379	72	451
Cal χ^2	4.64		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.7.2.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.7.2) were Pr{ $\chi^2 \geq 38.13$}for Pre-kharif, Pr{ $\chi^2 \geq 97.23$ } for Kharif, Pr{ $\chi^2 \geq 4.73$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.7.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	126	67	193
Wet	69	138	207
Total	195	205	400
Cal χ^2	38.13		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	49	41	90
Wet	66	525	591
Total	115	566	681
Cal χ^2	97.23		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	323	53	376
Wet	55	18	73
Total	378	71	459
Cal χ^2	4.73		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.7.3.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.7.3) were Pr{ $\chi^2 \geq 39.31$}for Pre-kharif, Pr{ $\chi^2 \geq 98.21$ } for Kharif, Pr{ $\chi^2 \geq 4.41$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table :4.7.3 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	129	69	198
Wet	66	133	199
Total	195	202	397
Cal χ^2	39.31		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	48	42	90
Wet	67	524	591
Total	115	566	681
Cal χ^2	98.21		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	321	54	375
Wet	56	19	75
Total	377	73	450
Cal χ^2	4.41		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.8.1). The chi-squire value of the transition matrix (Table 4.8.1) were Pr{ $\chi^2 \geq 17.25$}for Pre-kharif, Pr{ $\chi^2 \geq 40.41$ } for Kharif, Pr{ $\chi^2 \geq 1.29$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.8.1 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	36	24	60
Wet	18	55	73
Total	54	79	133
Cal χ^2	17.25		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	16	9	25
Wet	23	170	193
Total	39	179	218
Cal χ^2	40.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	117	23	140
Wet	21	8	29
Total	138	31	169
Cal χ^2	1.29		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.8.2). The chi-squire value of the transition matrix (Table 4.8.2) were Pr{ $\chi^2 \geq 17.25$}for Pre-kharif, Pr{ $\chi^2 \geq 40.41$ } for Kharif, Pr{ $\chi^2 \geq 1.29$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.8.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	36	24	60
Wet	18	55	73
Total	54	79	133
Cal χ^2	17.25		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	16	9	25
Wet	23	170	193
Total	39	179	218
Cal χ^2	40.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	117	23	140
Wet	21	8	29
Total	138	31	169
Cal χ^2	1.29		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.8.3). The chi-squire value of the transition matrix (Table 4.8.3) were Pr{ $\chi^2 \geq 19.25$ }for Pre-kharif, Pr{ $\chi^2 \geq 39.41$ } for Kharif, Pr{ $\chi^2 \geq 1.21$ } for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.8.3 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	36	25	61
Wet	18	54	72
Total	54	79	133
Cal χ^2	19.25		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	16	9	25
Wet	23	170	193
Total	39	179	218
Cal χ^2	39.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	117	24	141
Wet	20	8	28
Total	137	32	169
Cal χ^2	1.21		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.9.1). The chi-squire value of the transition matrix (Table 4.9.1) were Pr $\{\chi^2 \geq 14.35\}$ for Pre-kharif, Pr$\{\chi^2 \geq 52.74\}$ for Kharif, Pr$\{\chi^2 \geq 0.33\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.9.1 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	41	18	59
Wet	24	43	67
Total	65	61	126
Cal χ^2	14.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	25	15	40
Wet	22	177	199
Total	47	192	239
Cal χ^2	52.74		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	83	18	101
Wet	19	5	24
Total	102	23	125
Cal χ^2	0.33		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.9.2). The chi-squire value of the transition matrix (Table 4.9.2) were Pr $\{\chi^2 \geq 14.35\}$ for Pre-kharif, Pr$\{\chi^2 \geq 52.74\}$ for Kharif, Pr$\{\chi^2 \geq 0.33\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.9.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	41	18	59
Wet	24	43	67
Total	65	61	126
Cal χ^2	14.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	25	15	40
Wet	22	177	199
Total	47	192	239
Cal χ^2	52.74		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	83	18	101
Wet	19	5	24
Total	102	23	125
Cal χ^2	0.33		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.9.3). The chi-squire value of the transition matrix (Table 4.9.3) were Pr $\{\chi^2 \geq 14.35\}$ for Pre-kharif, Pr$\{\chi^2 \geq 52.74\}$ for Kharif, Pr$\{\chi^2 \geq 0.33\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.9.3 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	41	18	59
Wet	24	43	67
Total	65	61	126
Cal χ^2	14.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	25	15	40
Wet	22	177	199
Total	47	192	239
Cal χ^2	52.74		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	83	18	101
Wet	19	5	24
Total	102	23	125
Cal χ^2	0.33		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.10.1). The chi-squire value of the transition matrix (Table 4.10.1) were Pr{ $\chi^2 \geq 7.70$}for Pre-kharif, Pr{ $\chi^2 \geq 5.04$} for Kharif, Pr{ $\chi^2 \geq 3.03$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.10.1 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	51	27	78
Wet	25	35	60
Total	76	62	138
Cal χ^2	7.70		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	7	18	25
Wet	22	177	199
Total	29	195	224
Cal χ^2	5.04		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	123	13	136
Wet	16	5	21
Total	139	18	157
Cal χ^2	3.03		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.10.2). The chi-squire value of the transition matrix (Table 4.10.2) were Pr{ $\chi^2 \geq 7.70$}for Pre-kharif, Pr{ $\chi^2 \geq 5.04$} for Kharif, Pr{ $\chi^2 \geq 3.03$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.10.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	51	27	78
Wet	25	35	60
Total	76	62	138
Cal χ^2	7.70		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	7	18	25
Wet	22	177	199
Total	29	195	224
Cal χ^2	5.04		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	123	13	136
Wet	16	5	21
Total	139	18	157
Cal χ^2	3.03		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.10.3). The chi-squire value of the transition matrix (Table 4.10.3) were Pr{ $\chi^2 \geq 6.80$}for Pre-kharif, Pr{ $\chi^2 \geq 4.94$} for Kharif, Pr{ $\chi^2 \geq 3.13$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.10.3 The occurrence and non-occurrence data of pre-kharif (MarchMay), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	51	27	78
Wet	25	35	60
Total	76	62	138
Cal χ^2	6.80		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	7	18	25
Wet	22	177	199
Total	29	195	224
Cal χ^2	4.94		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	123	13	136
Wet	16	5	21
Total	139	18	157
Cal χ^2	3.13		
χ^2 (1 d.f. at 5% level)	0.00393		

4.11 Dry-wet transition Probability Matrix for Rainfall 5 mm for Bogra District

The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.11.1 The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.The chi-squire value of the transition matrix (Table 4.11.1) was Pr{ $\chi^2 \geq 336.89$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.11.1 The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	637	196	833
Wet	218	508	726
Total	855	704	1559
Cal χ^2	336.89		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.11.2). The chi-squire value of the transition matrix (Table 4.11.2) was Pr{ $\chi^2 \geq 105.46$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.11.2 The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	66	268
246Wet	74	172	246
Total	276	238	514
Cal χ^2	105.46		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.11.3). The chi-squire value of the transition matrix (Table 4.11.3) was Pr{ $\chi^2 \geq 120.52$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.11.3. The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	205	63	268
Wet	75	184	259
Total	280	247	527
Cal χ^2	120.52		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.11.4). The chi-squire value of the transition matrix (Table 4.11.4) was Pr{ $\chi^2 \geq 110.91$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.11.4. The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	230	67	297
Wet	69	152	221
Total	299	219	518
Cal χ^2	110.91		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.12.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.12.1) were $\Pr\{\chi^2 \geq 17.41\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 103.35\}$ for Kharif, $\Pr\{\chi^2 \geq 14.66\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.12.1. **The occurrence and non-occurrence data of pre-kharif (March-May),kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.**

Pre-Kharif	Dry	Wet	Total
Dry	137	91	228
Wet	68	106	174
Total	205	197	402
Cal χ^2	17.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	57	54	111
Wet	61	447	508
Total	118	501	619
Cal χ^2	103.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	407	48	455
Wet	44	17	61
Total	451	65	516
Cal χ^2	14.66		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.12.2). The chi-squire value of the transition matrix (Table 4.12.2) were Pr{$\chi^2 \geq 8.26$}for Pre-kharif, Pr{$\chi^2 \geq 33.59$} for Kharif, Pr{$\chi^2 \geq 7.57$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.12.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	43	32	75
Wet	19	49	68
Total	62	81	143
Cal χ^2	8.26		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	15	15	30
Wet	19	157	176
Total	34	172	206
Cal χ^2	33.59		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	132	17	149
Wet	17	8	25
Total	149	25	164
Cal χ^2	7.57		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.12.3). The chi-squire value of the transition matrix (Table 4.12.3) were Pr{ $\chi^2 \geq 4.87$}for Pre-kharif, Pr{ $\chi^2 \geq 41.47$ } for Kharif, Pr{ $\chi^2 \geq 0.80$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.12.3. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	48	27	75
Wet	30	53	83
Total	78	80	158
Cal χ^2	4.87		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	30	20	50
Wet	24	125	149
Total	54	145	199
Cal χ^2	41.47		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	131	19	150
Wet	16	4	20
Total	147	23	170
Cal χ^2	0.80		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.12.4). The chi-squire value of the transition matrix (Table 4.12.4) were Pr{ $\chi^2 \geq 4.16$ }for Pre-kharif, Pr{ $\chi^2 \geq 28.31$ } for Kharif, Pr{ $\chi^2 \geq 7.09$ } for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.12.4. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	46	32	78
Wet	26	27	53
Total	72	59	131
Cal χ^2	4.16		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	12	19	31
Wet	18	165	183
Total	30	184	214
Cal χ^2	28.31		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	144	12	156
Wet	11	5	16
Total	155	17	172
Cal χ^2	7.09		
χ^2 (1 d.f. at 5% level)	0.00393		

4.13 Dry-wet transition Probability Matrix for Rainfall 5 mm for Jessore District

The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.13.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.The chi-squire value of the transition matrix (Table 4.13.1) was Pr{ $\chi^2 \geq 326.89$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.13.1. The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	637	196	833
Wet	218	502	720
Total	855	708	1553
Cal χ^2	326.89		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.13.2). The chi-squire value of the transition matrix (Table 4.13.2) was Pr{ $\chi^2 \geq 103.16$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.13.2. The occurrence and non-occurrence rainfall in Jessore district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	65	267
246Wet	74	171	245
Total	276	238	512
Cal χ^2	103.16		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.13.3). The chi-squire value of the transition matrix (Table 4.13.3) was Pr{ $\chi^2 \geq 119.12$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.13.3. The occurrence and non-occurrence rainfall in Jessore district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	63	265
Wet	73	184	257
Total	275	247	522
Cal χ^2	119.12		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.13.4). The chi-squire value of the transition matrix (Table 4.13.4) was Pr{ $\chi^2 \geq 109.31$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.13.4. The occurrence and non-occurrence rainfall in Jessore District for the 10 consecutive years from 2001 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	230	67	297
Wet	67	150	217
Total	297	217	514
Cal χ^2	109.31		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Jessore district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.14.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.14.1) were Pr{ $\chi^2 \geq 17.41$}for Pre-kharif, Pr{ $\chi^2 \geq$ 103.35} for Kharif, Pr{ $\chi^2 \geq 14.66$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.14.1. **The occurrence and non-occurrence data of pre-kharif (March May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.**

Pre-Kharif	Dry	Wet	Total
Dry	137	91	228
Wet	68	106	174
Total	205	197	402
Cal χ^2	17.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	57	54	111
Wet	61	447	508
Total	118	501	619
Cal χ^2	103.35		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	407	48	455
Wet	44	17	61
Total	451	65	516
Cal χ^2	14.66		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.14.2). The chi-squire value of the transition matrix (Table 4.14.2) were Pr{ $\chi^2 \geq 8.26$}for Pre-kharif, Pr{ $\chi^2 \geq 33.59$} for Kharif, Pr{ $\chi^2 \geq 7.57$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.14.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	43	32	75
Wet	19	49	68
Total	62	81	143
Cal χ^2	8.26		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	15	15	30
Wet	19	157	176
Total	34	172	206
Cal χ^2	33.59		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	132	17	149
Wet	17	8	25
Total	149	25	164
Cal χ^2	7.57		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.14.3). The chi-squire value of the transition matrix (Table 4.14.3) were Pr{ $\chi^2 \geq 4.87$}for Pre-kharif, Pr{ $\chi^2 \geq 41.47$ } for Kharif, Pr{ $\chi^2 \geq 0.80$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.14.3. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	48	27	75
Wet	30	53	83
Total	78	80	158
Cal χ^2	4.87		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	30	20	50
Wet	24	125	149
Total	54	145	199
Cal χ^2	41.47		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	131	19	150
Wet	16	4	20
Total	147	23	170
Cal χ^2	0.80		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Jessore district (Table 4.14.4). The chi-squire value of the transition matrix (Table 4.14.4) were Pr{ $\chi^2 \geq 4.16$}for Pre-kharif, Pr{ $\chi^2 \geq 28.31$ } for Kharif, Pr{ $\chi^2 \geq 7.09$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.14.4. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Jessore district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	46	32	78
Wet	26	27	53
Total	72	59	131
Cal χ^2	4.16		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	12	19	31
Wet	18	165	183
Total	30	184	214
Cal χ^2	28.31		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	144	12	156
Wet	11	5	16
Total	155	17	172
Cal χ^2	7.09		
χ^2 (1 d.f. at 5% level)	0.00393		

4.15 Dry-wet transition Probability Matrix for Rainfall 5 mm for Feni District

The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.15.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.The chi-squire value of the transition matrix (Table 4.15.1) was Pr{ $\chi^2 \geq 336.89$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.15.1. **The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010. Annual dry week is denoted by state 0 and a wet week is denoted by state 1**.

	Dry	Wet	Total
Dry	637	196	833
Wet	218	508	726
Total	855	704	1559
Cal χ^2	336.89		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.15.2). The chi-squire value of the transition matrix(Table 4.15.2) was Pr{ $\chi^2 \geq 105.46$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.15.2. The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 1981 to 1990. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	66	268
246Wet	74	172	246
Total	276	238	514
Cal χ^2	105.46		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.15.3). The chi-squire value of the transition matrix (Table 4.15.3) was Pr{ $\chi^2 \geq 120.52$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.15.3. The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 1991 to 2000. Annual dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	205	63	268
Wet	75	184	259
Total	280	247	527
Cal χ^2	120.52		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.15.4). The chi-squire value of the transition matrix (Table 4.15.4) was Pr{ $\chi^2 \geq 110.91$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.15.4. The occurrence and non-occurrence rainfall in Feni district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	230	67	297
Wet	69	152	221
Total	299	219	518
Cal χ^2	110.91		
χ^2 (1 d.f. at 5% level)	0.00393		

The occurrence and non-occurrence rainfall in Feni district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.16.1.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1. The chi-squire value of the transition matrix (Table 4.16.1) were Pr{ $\chi^2 \geq 17.41$}for Pre-kharif, Pr{ $\chi^2 \geq$ 103.35} for Kharif, Pr{ $\chi^2 \geq 14.66$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.16.1. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
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Wet	68	106	174
Total	205	197	402
Cal χ^2	17.41		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
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Wet	61	447	508
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Wet	44	17	61
Total	451	65	516
Cal χ^2	14.66		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.16.2). The chi-squire value of the transition matrix (Table 4.16.2) were Pr{ $\chi^2 \geq 8.26$ }for Pre-kharif, Pr{ $\chi^2 \geq 33.59$ } for Kharif, Pr{ $\chi^2 \geq 7.57$ } for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.16.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	43	32	75
Wet	19	49	68
Total	62	81	143
Cal χ^2	8.26		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	15	15	30
Wet	19	157	176
Total	34	172	206
Cal χ^2	33.59		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	132	17	149
Wet	17	8	25
Total	149	25	164
Cal χ^2	7.57		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.16.3). The chi-squire value of the transition matrix (Table 4.16.3) were Pr{ $\chi^2 \geq 4.87$}for Pre-kharif, Pr{ $\chi^2 \geq 41.47$ } for Kharif, Pr{ $\chi^2 \geq 0.80$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.16.3. The occurrence and non-occurrence data of pre-kharif (March May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	48	27	75
Wet	30	53	83
Total	78	80	158
Cal χ^2	4.87		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	30	20	50
Wet	24	125	149
Total	54	145	199
Cal χ^2	41.47		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	131	19	150
Wet	16	4	20
Total	147	23	170
Cal χ^2	0.80		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Feni district (Table 4.16.4). The chi-squire value of the transition matrix (Table 4.16.4) were Pr{ $\chi^2 \geq 4.16$ }for Pre-kharif, Pr{ $\chi^2 \geq 28.31$ } for Kharif, Pr{ $\chi^2 \geq 7.09$ } for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.16.4. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Feni district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	46	32	78
Wet	26	27	53
Total	72	59	131
Cal χ^2	4.16		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	12	19	31
Wet	18	165	183
Total	30	184	214
Cal χ^2	28.31		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	144	12	156
Wet	11	5	16
Total	155	17	172
Cal χ^2	7.09		
χ^2 (1 d.f. at 5% level)	0.00393		

4.17 Dry-wet transition Probability Matrix for Rainfall 10 mm for Bogra Jessore and Feni District

The results were found of the Bogra district (Table 4.17.1). The chi-squire value of the transition matrix (Table 4.17.1) were Pr{ $\chi^2 \geq 336.89$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.17.1. The occurrence and non-occurrence rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	637	196	833
Wet	218	508	726
Total	855	704	1559
Cal χ^2	336.89		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.17.2). The chi-squire value of the transition matrix (Table 4.17.2) was Pr{ $\chi^2 \geq 105.46$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.17.2. The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	202	66	268
Wet	74	172	246
Total	276	238	514
Cal χ^2	105.46		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.17.3). The chi-squire value of the transition matrix (Table 4.17.3) was Pr{ $\chi^2 \geq 120.52$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.17.3. The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	205	63	268
Wet	75	184	259
Total	280	247	517
Cal χ^2	120.52		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.17.4). The chi-squire value of the transition matrix (Table 4.17.4) was Pr{ $\chi^2 \geq 187.18$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.17.4. The occurrence and non-occurrence rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

	Dry	Wet	Total
Dry	230	67	297
Wet	69	152	221
Total	299	219	518
Cal χ^2	110.91		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.18.1). The chi-squire value of the transition matrix (Table 4.18.1) were Pr{ $\chi^2 \geq 15.16$}for Pre-kharif, Pr{ $\chi^2 \geq$ 17.60} for Kharif, Pr{ $\chi^2 \geq 63.00$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.18.1 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 30 consecutive years from 1981 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	169	74	243
Wet	66	68	134
Total	235	142	377
Cal χ^2	15.16		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	50	93	143
Wet	95	419	514
Total	145	512	657
Cal χ^2	17.66		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	400	30	430
Wet	33	24	57
Total	433	54	487
Cal χ^2	63.00		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.18.2). The chi-squire value of the transition matrix (Table 4.18.2) were Pr{ $\chi^2 \geq 5.06$}for Pre-kharif, Pr{ $\chi^2 \geq 11.05$} for Kharif, Pr{ $\chi^2 \geq 19.39$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.18.2 The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1981 to 1990. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	51	24	75
Wet	25	27	52
Total	76	51	127
Cal χ^2	5.06		
χ^2 (1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	22	32	54
Wet	28	136	164
Total	50	168	218
Cal χ^2	11.05		
χ^2 (1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	121	13	134
Wet	10	9	19
Total	131	22	153
Cal χ^2	19.17		
χ^2 (1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.18.3). The chi-squire value of the transition matrix (Table 4.18.3) were Pr{ $\chi^2 \geq 7.87$}for Pre-kharif, Pr{ $\chi^2 \geq$ 0.93} for Kharif, Pr{ $\chi^2 \geq 16.89$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.18.3. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June-Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 1991 to 2000. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	67	25	92
Wet	19	21	40
Total	86	46	132
Cal χ^2	7.87		
χ^2(1 d.f. at 5% level)	0.00393		

Kharif	Dry	Wet	Total
Dry	10	30	40
Wet	33	147	180
Total	43	177	220
Cal χ^2	0.93		
χ^2(1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	131	11	142
Wet	18	10	28
Total	149	21	170
Cal χ^2	16.89		
χ^2(1 d.f. at 5% level)	0.00393		

The results were found of the Bogra district (Table 4.18.4). The chi-squire value of the transition matrix (Table 4.18.4) were Pr{ $\chi^2 \geq 1.64$}for Pre-kharif, Pr{ $\chi^2 \geq 5.07$} for Kharif, Pr{ $\chi^2 \geq 31.87$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table: 4.18.4. The occurrence and non-occurrence data of pre-kharif (March-May), kharif (June - Oct) and rabi (Nov-Feb) seasons of rainfall in Bogra district for the 10 consecutive years from 2001 to 2010. A dry week is denoted by state 0 and a wet week is denoted by state 1.

Pre-Kharif	Dry	Wet	Total
Dry	49	30	79
Wet	22	20	42
Total	71	50	121
Cal χ^2	1.64		
χ^2(1 d.f. at 5% level)	0.00393		

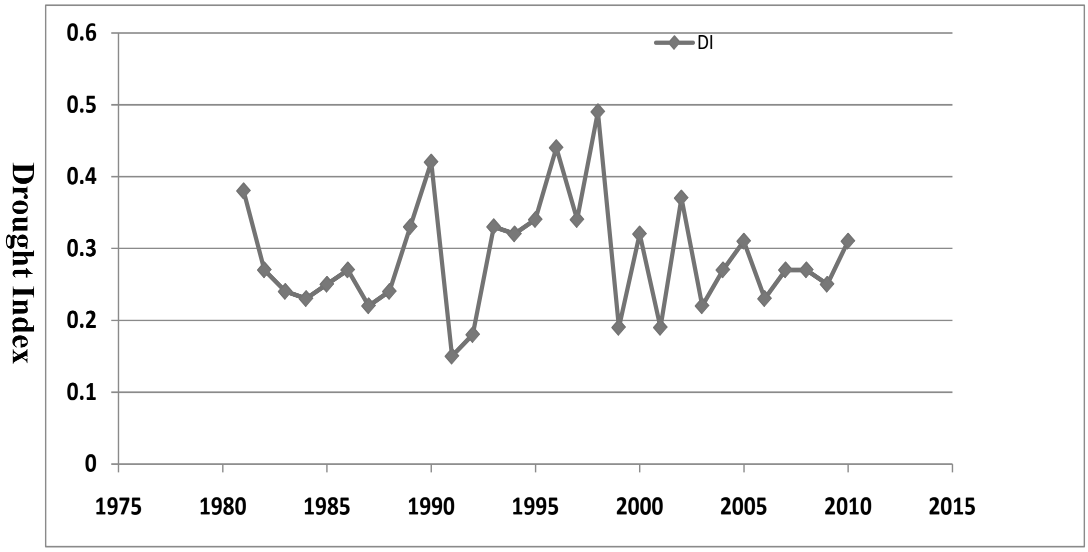
Kharif	Dry	Wet	Total
Dry	18	31	49
Wet	34	136	170
Total	52	167	219
Cal χ^2	5.07		
χ^2(1 d.f. at 5% level)	0.00393		

Rabi	Dry	Wet	Total
Dry	148	6	154
Wet	5	5	10
Total	153	11	164
Cal χ^2	31.87		
χ^2(1 d.f. at 5% level)	0.00393		

Table: 4.19.1 Annual Drought Index Scenario for 2.5 mm of Bogra district :

Year	Drought Index
1981	0.38
1982	0.27
1983	0.24
1984	0.23
1985	0.25
1986	0.27
1987	0.20
1988	0.24
1989	0.33
1990	0.42
1991	0.15
1992	0.18
1993	0.33
1994	0.32
1995	0.34
1996	0.44
1997	0.34
1998	0.49
1999	0.19
2000	0.32
2001	0.19
2002	0.37
2003	0.22
2004	0.27
2005	0.31
2006	0.23
2007	0.27
2008	0.27
2009	0.25
2010	0.31

Figure-1: Annual Drought Index Scenario for 2.5 mm of Bogra district

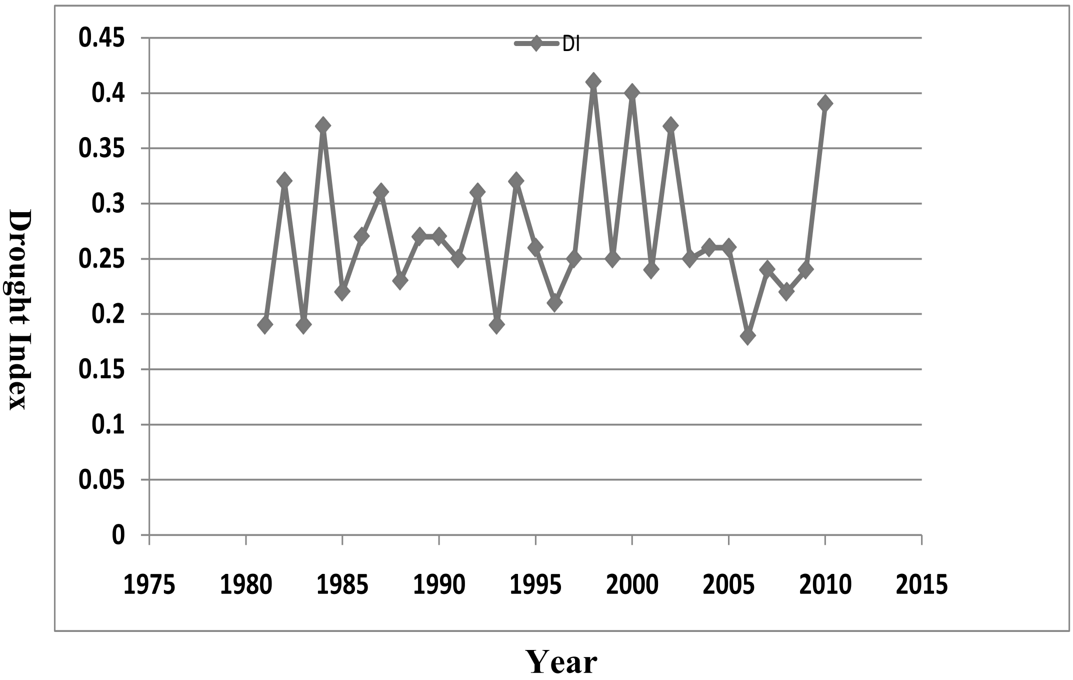


We observed from the above table 4.19.1 and figure-1 which are indicate that the years 1991, 1992 are severe drought; the years 1984, 1987, 1999, 2001, 2003, 2006 are moderate drought; the years 1982, 1983, 1985, 1986, 1988, 2004, 2005, 2007, 2008, 2009, 2010 are mild drought and the years 1981, 1989, 1990, 1993, 1994, 1995, 1996, 1997, 1998, 2000, 2002 are occasionally drought.

Table: 4 .19.2 Annual Drought Index Scenario for 5 mm of Bogra district:

Year	Drought Index
1981	0.19
1982	0.32
1983	0.19
1984	0.37
1985	0.22
1986	0.27
1987	0.31
1988	0.23
1989	0.27
1990	0.27
1991	0.25
1992	0.31
1993	0.19
1994	0.32
1995	0.26
1996	0.21
1997	0.25
1998	0.41
1999	0.25
2000	0.40
2001	0.24
2002	0.37
2003	0.25
2004	0.26
2005	0.26
2006	0.18
2007	0.24
2008	0.22
2009	0.24
2010	0.39

Figure-2: Annual Drought Index Scenario for 5 mm of Bogra district:

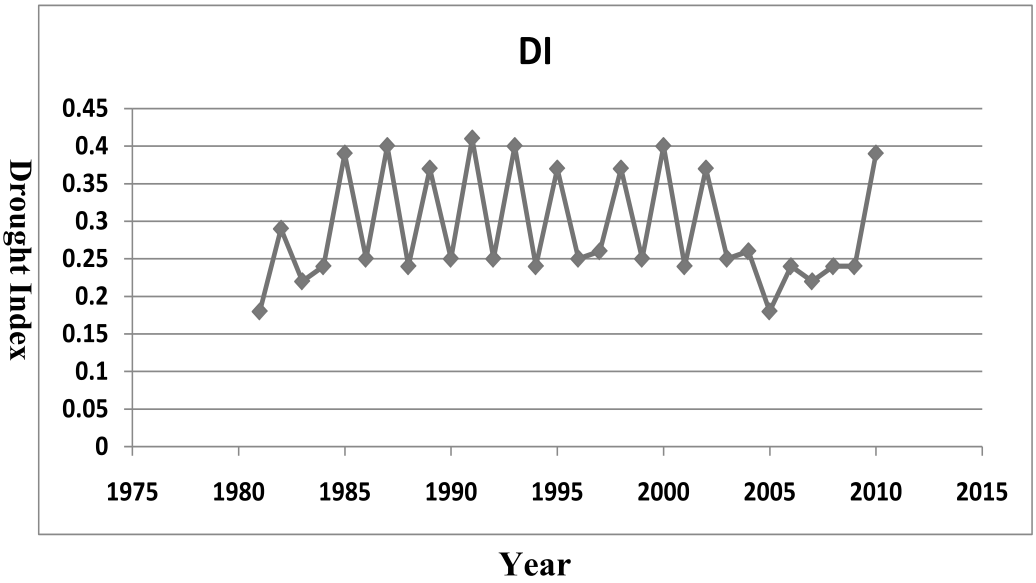


We observed from the above table 4.19.2 and figure-2 which are indicate that the year 2006 is severe drought; the years 1981, 1983, 1985, 1988, 1993, 1996, 2008 are moderate drought; the years 1986, 1987, 1991, 1992, 1995, 1997, 1999, 2001, 2003, 2004, 2005, 2007, 2009 are mild drought and the years 1982, 1984, 1989, 1990, 1994, 1998, 2000, 2002, 2010 are occasionally drought.

Table: 4.19.3 Annual Drought Index Scenario for 10 mm of Bogra district:

Year	Drought Index
1981	0.18
1982	0.24
1983	0.22
1984	0.24
1985	0.39
1986	0.25
1987	0.40
1988	0.24
1989	0.37
1990	0.25
1991	0.41
1992	0.25
1993	0.40
1994	0.24
1995	0.37
1996	0.25
1997	0.26
1998	0.37
1999	0.25
2000	0.40
2001	0.24
2002	0.37
2003	0.25
2004	0.26
2005	0.26
2006	0.18
2007	0.24
2008	0.22
2009	0.24
2010	0.39

Figure-3: Annual Drought Index Scenario for 10 mm of Bogra district:



We observed from the above table 4.19.3 and figure-3 which are indicate that the years 1981, 2006 are severe drought; the years 1983, 2008 are moderate drought; the years 1982, 1984, 1988, 1990, 1992, 1994, 1996, 1997, 1999, 2001, 2003, 2004, 2005, 2007, 2009 are mild drought and the years 1985, 1987, 1989, 1991, 1993, 1995, 1998, 2000, 2003, 2010 are occasionally drought.

CHAPTER–V

5. Concluding Remarks

5.1 Conclusion

Rainfall is the most important weather parameters affecting non-irrigated crop areas. The crop yield in the area will depend on variation of rainfall in monsoon. Markov chain model have been used to estimate probabilities of getting a sequence of wet-dry weeks over this region. An index based on the parameters of this model has been suggested for agricultural climate measurement in this region. The result indicate that the regions were found the severe ($0.125 < DI \leq 0.180$) to moderate drought proneness ($0.180 < DI \leq 0.235$) in the kharif season, Mild drought proneness ($0.235 < DI \leq 0.310$), Occasional ($0.310 < DI \leq 1.000$) and Chronic drought proneness ($0.000 \leq DI \leq 0.125$) found in the Rabi season.

Bogra, Jessore and Feni district are the region of study area. The result of our research for Bogra, Jessore and Feni district are stated below:

Bogra District:

For annualy (1981- 2010) rainfall data we observed the moderate drought prone weeks are drought index values DI= 0.30, 0.30, 0.31, 0.30.

For Pre-kharif (1981- 2010) rainfall data we observed the mild occasional and moderate drought prone weeks are drought index values DI=0.26, 0.34, 0.22, 0.21.

For kharif (1981- 2010) rainfall data we observed the occasional drought prone weeks are drought index values DI=0.64, 0.57, 0.59, 0.76.

For rabi (1981- 2010) rainfall data we observed the chronic drought prone weeks are drought index values DI=0.02, 0.03, 0.03, 0.01.

Jessore District:

For annual (1981- 2010) rainfall data we observed the moderate drought prone weeks are drought index values DI= 0.29, 0.28, 0.27, 0.28.

For Pre-kharif (1981- 2010) rainfall data we observed the mild occasional and moderate drought prone weeks are drought index values DI=0.25, 0.57, 0.21, 0.22.

For kharif (1981- 2010) rainfall data we observed the occasional drought prone weeks are drought index values DI=0.65, 0.57, 0.59, 0.76.

For rabi (1981- 2010) rainfall data we observed the chronic drought prone weeks are drought index values DI=0.02, 0.03, 0.04, 0.02.

Feni District:

For annual (1981- 2010) rainfall data we observed the moderate drought prone weeks are drought index values DI= 0.30, 0.29, 0.25, 0.28.

For Pre-kharif (1981- 2010) rainfall data we observed the mild occasional and moderate drought prone weeks are drought index values DI=0.29, 0.34, 0.22, 0.21.

For kharif (1981- 2010) rainfall data we observed the occasional drought prone weeks are drought index values DI=0.65, 0.57, 0.59, 0.76.

For rabi (1981- 2010) rainfall data we observed the chronic drought prone weeks are drought index values DI=0.02, 0.03, 0.03, 0.01.

Since the effect of drought-proneness' have the relation chronic < severe < moderate < mild < occasional. Hence the area shows occasional drought has more effect than mild than moderate than severe than chronic.

We observes the kharif for Bogra, Jessore and Feni shows occasional drought then its drought proness higher than other season.

5.2. Suggestions and Recommendation

Agricultural production is very expensive and risky, often it is not possible for the farmers to grow crops profitably at the individual level due to the shortage of required water. If the studies are properly utilized in cultivating crops it will be the driving force for increasing production of food crops, especially rice and white. In severe and extremely severe drought affected areas, government decision for strengthening supplementary irrigation during the transplanted aman season will continue. So the findings of the studies will help in proper implementation of agricultural policy to increase overall agricultural production in Bangladesh, which is expected to bring about significant positive change in the economic of the country.

The finding would also help the all reassured, poly maker and all kinds of decision about water supply.

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