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Study of Climate Variability and Agriculture Drought in Bangladesh

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Department of Statistics
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Study of Climate Variability and Agriculture Drought in Bangladesh

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Dedicated To My

Late Mother and

Respected Father

DECLARATION

I hereby certify that the thesis entitled **"Study of Climate Variability and Agriculture Drought 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 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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CERTIFICATE

This is to certify that the thesis entitled **"Study of Climate Variability and Agriculture Drought in Bangladesh"** submitted by Md. Abdul Matin, Lecturer, Department of statistics, Noongola Degree College, Bogra 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 climate plays significant role in the agriculture of a country. Rainfall is the most important climate parameter affecting non-irrigated crop areas for Rangpur, Faridpur and Mymensingh. Water deficits and excess water are the greatest constraints for rain fed rice yields in this region. The daily rainfall data for 30 years during the period 1981-2010 of the station Rangpur, Faridpur and Mymensingh districts are considered in this study. This study also considered weekly rainfall for 5 mm and 10 mm. The daily data were reduced in the weekly form and the drought index has been calculated using the probability of Markov chain model and goodness of fit using chi-square test. Drought is temporary but complex feature of the climate system. Agriculture 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 best on the parameters of this model has been suggested for agriculture drought measurement in this region. The results indicate that the Rangpur, Faridpur and Mymensingh districts are as follows:

For Drought Index of Rainfall 5 mm and 10 mm in Rangpur District: the results indicate that the Rangpur region were found the mild drought in Annual, the occasionally drought in pre-kharif and kharif season, and the chronic drought Proneness in Rabi season. For Drought Index Rainfall 5 mm and 10 mm in Faridpur District: the Faridpur region were found the occasionally drought in Annual, pre-kharif and kharif season, and the chronic drought Proneness in Rabi season. For Drought Index Rainfall 5 mm and 10 mm in Mymensingh District: the results indicate that the region were found the mild drought in Annual, the occasionally drought in pre-kharif and kharif season, and the chronic drought Proneness in Rabi season.

This study will be constructive to agricultural planners and irrigation engineers to identifying there as where agricultural development should be focused as a long –term drought improvement strategy. The level of drought proneness helps the early detection of agricultural drought and the crop production that is useful for talking timely release and remedy measures and other decisions by several organization of Bangladesh. It will also contribute toward a better understanding of the climatology of drought in major monsoon region of the world.

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The Author

CONTENTS

LIST OF TABLE

Test of significance

LIST OF NOTATIONS

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

P= Probability 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.

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 week

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

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

CHAPTER-I

1. Introduction

Bangladesh is located between $20^{o}34^{/}$ to $26^{o}38^{/}$ North latitude and $88^{o}01^{/}$ to $92^{o}42^{/}$ East longitude. It is bordered on the west, north and east by India, on the south-east by Myanmar and on the south by the Bay of Bengal. The country occupies an area of 147,570 sq. km (BBS, 2005).

The word “drought” has been drawn the world-wide attention in recent years because of its widespread effect in the U.S.A. in 1987-88 (Ahmed, 1991) and its devastating effect in the Somalia in 1991-93, and similar effect in Ethiopia few years ago and in the Sahel region of Africa in the late 1980’s. In the dependent agriculture region of the world availability of rainwater is one of the most important considerations of agriculture planning. Rainfall varies from year to year and place to place, sometimes leading to the occurrence of drought. It is obvious, when drought occurs during climate season, it effects both crop season, increasing the food shortage and misery of the people. 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 (Ahmed, 1995).

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), and Ahmad (1991) and reviewed extensively by Gregory (1986) and Nieuwolt (1986).

The summer is the hottest period with maximum temperature exceeding 40 ^{0}C and is characterized by Northwest thunderstorms as well as high evaporation rate. Temperature in varies between 3.2 ^{0}C to 42 ^{0}C. It peaks during April and minimum is recorded in January. The Northwest region in Bangladesh is the driest part where rainfall is the lowest and experiencing aridity and drought condition. Winter extends from November to February with minimum temperature ranging from 3.2 ^{0}- 13 ^{0}C and that of maximum 24 ^{0}C-42 ^{0}C. The monsoon starts in June and lasts until October and this accounts for 80% of total rainfall. Average annual rainfall varies from 1200 to 2500 mm. Maximum rainfall is recorded in the coastal areas of Chittagong and northern Sylhet district. (UNCCD, 2000)

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), and Ahmad (1991) and reviewed extensively by Gregory (1986) and Nieuwolt (1986).

Droughts of various intensity occur in almost all parts of Bangladesh during the eight months from October to May and they may occur in both wet and dry seasons. Droughts are particularly severe in the Northwest part of Bangladesh where monsoon rain occurs for about three months as compared to five months in the Northeast. In 1995, Bangladesh had a major drought when about 47% of the area and 53% of the population were affected. Bangladesh also experienced severe drought conditions in 1951, 1958, 1961, 1979, 1981, 1982, and 1989 (Task Force Report, 1991).

Statistical inference is an essential tool for concluding any research. The probability theory of Markov chain has been extensively developed, whereas 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 climatologically 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 (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; Lee et al., 1970).

1.1. Objectives of the study

The aims and objectives of my study are as follows:

(i) to estimate the conditional probabilities P_{01} and P_{11} using Markov chain model for 5 mm and 10 mm of Pre-Kharif, Kharif and Rabi season.

(ii) to estimate the mean and variance of number of wet weeks

(iii) to estimate the agriculture drought index (DI) for 5 mm and 10 mm of seasonal and annual data of 30 years period

(iv) to test the significance of occurrence and non occurrence of rainfall.

CHAPTER II

2. Literature Review

2.1. Climate

The climate is controlled primarily by summer and winter winds, and partly by pre-monsoon and post-monsoon circulation. Monsoon originates over the Indian Ocean, 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, K.E. 2000).

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, 1995).

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- i) the cool dry season from November to February, ii) the pre-monsoon hot season from March to May and iii) 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 by short 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 CO_2 in the atmosphere has increased from 280 to 350 pars per million (Bazzaz and Fajer, 1992). The increase of CO_2 and several other green house gases such as methane, nitrous oxide, chlorofluorocarbons (CFCs) could an increase global temperature of about 4.2^{0}C and possibly a change in precipitation patterns and amounts in some regions. 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).

2.1.1. 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 – 1^0C 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 1.3^0-4^0C. In low and tropical latitudes the change would be very small (only 0.05^0-0.25^0C).On the other hand, temperature increase would be much higher in the middle and high latitude regions (5^0-9^0C).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).

The World Meteorological Organization (1975a), the distinction should be made between drought and aridity. Aridity is usually defined in terms of low-average precipitation, available water, or humidity and setting aside the possibility of climatic change, is a permanent climatic feature of a region. Climate change will largely affected irrigation, tourism, physical and natural environments of the world, including India and Bangladesh by 2010, according to latest study by North, South, East and West (NSEW). The off season a downpour this time in Bangladesh due to tidal surges in the Bay of Bengal is likely to hit hard in coming years. Geographers predicted that being drenched in India toxic. Surface acid, the Bengal basins might have to receive worse ever consequences, either in terms of green house emission or ecology. According to latest geographical survey, worldwide climate change may take a violent mood by 2010 touching Indian basins in harmful effects. It is likely to be caused by alarming increase in the harmful emission of carbon dioxide (CO_2). Due to growing generation of sulfuric acids in India air, the subcontinent is already at the risk position with level of CO_2. It may be largely caused by unplanned industrialization and the decaying trend in the physical and natural environments. Foods, droughts, disease, natural and man-made disaster are set some part of India neighboring countries including Bangladesh are suffering heat waves and sea level rise. Climate change already touches every corner of the planet and every aspect of people's life. As the global temperature increase, its impact will be come even more extreme (NSEW) (Arnab, 2006).

2.1.2. 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 climatic conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agricultural productivity. 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 (BARC, 1991).

To estimate the impacts, we need: a model which relates weather and/or climate characteristics with the characteristics of the system being studied (hydrological cycle in the river basin, crop growth in a specified location) climatic and/or weather data for present-climate and change-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 agriculture 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 (Ahmad 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 ton the change of climate in near future. The potential subjects of the climate change impacts include, e.g. hydrological 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. However, the effect on production is expected to vary by crop and location, as well as by the magnitude of warming, the direction and magnitude of precipitation change (Adams et al., 1998).

2.2. Drought

The word "drought" has been drawn world-wide attention in recent years because of its widespread effect in the USA in 1987-88 (Ahmed, 1991) and its devastating effect in the Somalia in 1991-93, and similar effect in Ethiopia few years ago and in the Sahel region of Africa in the late 1980's. In the rain dependent agricultural regions of the world availability of rainwater is one of the most important considerations of agricultural planning. Rainfall varies from year to year and from place to place, sometimes leading to the occurrence of drought. It is obvious, when drought occurs during climate season, its effect both crop sea-sons-Hereby increasing the food shortage and misery of the people (Ahmed, 1995).

Hence the crop yield in the area will depend on variation of rainfall in this season. Drought is temporary but complex feature of the climatic system of a given region with wide-spread 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 (Ahmed, 1995). Although we can recognize a drought when it hits a given region, there is no universal definition of this term. Various characteristics of droughts, including definitions and their meteorological, hydrological and economic aspects were discussed Lands berg (1982); Dennet et al. (1985); Olapido (1985); Ahmed (1991) and reviewed extensively by Gregory (1986) and Nieuwolt (1986).

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 develop 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 growing season, can result in an agriculture drought that severely 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. Droughtare common in the northwestern districts of Bangladesh. 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/C_0284.HTM).

Socioeconomic drought associates the supply and demand of some economic good with elements of meteorological and hydrological drought. The relationship between the different types of drought is complex. The agricultural drought may lag that of a meteorological drought, depending on the prior moisture status of the surface soil layers. Precipitation deficits over a prolonged period that affect surface or subsurface water supply, thus reducing stream flow, groundwater reservoir, and lake levels, will result in a hydrological drought, which will persist long after a meteorological drought ended. For example, stream flow is the key variable to analyze in describing droughts for many water supply activities such as hydropower generation on water availability in the stream (Richard, 2002). The effect 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 sever impact of drought when it does occur (Sui et al., 2002).

2.2.1. Agricultural Drought

Agriculture is the backbone of the economy of developing countries with more than 70% of the working population engaged in this sector. The dependence of the majority of farmers on rain feed agriculture and pastures have made the economy extremely vulnerable to the vagaries of weather. As a result, failure of rains and the occurrence of drought during any particular growing season lead to severe food shortage. The knowledge of current weather throughout the growing season helps the early detection of agricultural drought and/or the crop condition and the crop production that is useful for timely relief and rehabilitation measures and other decisions by several governmental and non-governmental agencies (Reddy, 1986).

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield.

The agricultural planners and irrigation engineers to identifying the areas where agricultural development should be focused as long terms drought mitigation strategy. It will also contribute toward a better understanding of the climatologic of drought in a major drought-prone region of the world (Rahman, 2001).

Sui et al., (2002) was made to identify severe drought events in a 50-year period and their links to large scale oscillations. Two indices were identified: one to indicate the strength or duration of the two monsoon seasons, namely northeasterly and southwesterly winds; the other exposure to severe drought periods. In the same presentation, Ming-Hsu Li described the ongoing development of a drought warning system. The system incorporates dynamical, regional-scale climate forecasting and basin-scale hydrological modeling to provide quantitative estimates of future water supply as well as water demand by human, industrial, and agricultural usages.

Drought intensity at a given location depends on evapotranspiration, condition of crops, the rainfall distribution pattern, and water table depth and soil structure. The agriculture production system in drought prone area is further aggravated by soil constrains. Therefore it is an urgent need to develop a program of integrated drought-flood prone agriculture supported by appropriate research (Karim, 1999). Drought are annually affects about 2.3 million hectares in the Kharif season and 1.2 million hectares in the dry (Rabi and pre-kharif) season. Kharif drought severely affects T. aman rice, resulting in a reduction of about 1.5 million tons, about 8% of the total annual production.

In Bangladesh, water problems are caused by the uneven distribution of rainfall; about 80% of the monsoon rainfall occurs during a short period from June to October. Average annual rainfall variws from 1190 mm to 3450 mm. Moreover, the monsoon is erratic and can cause floods and drought in the same year (Nasiruddin, 1999).

The planning of agricultural operations in any region particularly in drought prone areas requires understanding of the rainfall characteristics at each rainfall station in greater detail. Frequency distribution of daily, weekly and monthly rainfall of specified amounts and evaluation of their probabilities of occurrence, frequency of dry spells of various lengths and their probabilities, chance of a day or weeks based on rainfall situations in preceding weeks etc, are essential prerequisites for judicious use in water management and crop planning. It is well known those consecutive spells of low rainfall in variability results in drought conditions and poor yields. Successive of high rainfall days also results in indication of the extent of the moisture stress and agricultural drought experienced by crop during the rainy season (Das and Datar, 1996).

2.2.2. Agricultural Drought Index

Much of the work in developing drought indices has focused on meteorological or agricultural applications. Developing an Agricultural Drought Index, for example, include consideration of vegetation, soil type (which determines soil moisture capacity), antecedent soil moisture, and evapotranspiration as influenced by wind speed and the temperature and humidity of the air. Many of these climatic elements were not widely measured, or could not be incorporated into a drought index. The climatologically statistics alone fail to give a sufficient agricultural accurate conception either of the duration or intensity of agricultural drought. Supplementary observations upon the condition of vegetation in each locality are especially needed (Richard, 2002).

The Crop Moisture Index (CMI) was specifically designed as an agricultural drought index and depends on the drought severity at the beginning of the week and the evapotranspiration deficits (drought) and excessive wetness (precipitation is more than enough to meet evapotranspiration demand and recharge the soil) (Wilhite and Glantz, 1985).

Sensitivity studies have found that the value of the PDSI is highly dependent on 1) the weighting factor used to make it comparable between different months and regions, 2) the value specified for the available water capacity in the soil (Karl, 1983), and the calibration period used to compute the CAFEC quantities (Karl, 1986),with longer calibration periods providing more consistent estimates of the CAFEC quantities and index values.

New drought indices have developed by researchers in other countries for applications and locales where the Palmer Index proved inadequate. Dependable rains (DR), defined as the amount of rainfall that occurs statistically in four out of every five years, have been applied by Le Houorou et al. (1993) to the African continent. The National Rainfall Index (RI), used by Gommes and Petrassi (1994) in another study of Precipitation patterns in Africa, allows comparison of Precipitation patterns across time and from country to country. The RI is a national scale index, computed by weighting the national annual precipitation by the long-term averages of all of the stations within the nation.

The agronomical relevant homogeneous classes that help in the better utilization of natural resources under dry-land agriculture in developing countries at a given location. The risk parameters, namely, drought, planting and excess water were used to define the inputs/plant population that go with the suggested farming systems (Reddy, 1993). This information was provided in advance though current weather data from a well be distributed network of stations using agro meteorological technique proposed by Reddy (1993).

2.2.3. Hydrological Drought

Common to all types of drought is the fact that they originate from a deficiency of precipitation that result in water shortage for some activity or for some group (Wilhite and Glantz, 1985). Reliable rainfall observations became available about two centuries ago, and as a result, practically all drought indices and drought definitions included this variable either singly or in combination with other meteorological elements (World Meteorological Organization, 1975a). Early meteorological drought definitions incorporated some measure of precipitation over a given period of time (Tannehill 1947; World Meteorological Organization, 1975a; Wilhite and Glantz, 1985).

Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply. The frequency and severity of hydrological drought is often defined on a watershed or water basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system. Hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrologic system such as soil moisture, stream flow, and ground water and reservoir levels (NDMC, 2006).

The hydrological studies involving the rate of flow in steams, It is important to distinguish between the two components of total flow: direct runoff and base flow (Linsley et al., 1958). Direct or surface runoff is water that travels over the ground surface to a channel. It reaches the stream soon after its occurrence as rainfall and appears as the crest point in a hydrograph. Base flow results from the discharge of groundwater into the stream where the water table intersects the stream channels of the basin. Base flow is also referred to as groundwater flow and dry-weather flow (Linsley et al., 1958) and appears as the recession point on a hydrograph. Drought studies utilizing stream flow data have relied on base flow measurements or the mean flow over some period (e.g., monthly or annual flows) to average out the direct runoff crests (Yevjevich 1967; Frick et al., 1990).

Palmer (1965) carries out a monthly hydrologic accounting for a long series of years using five parameters: precipitation, evapotranspiration, soil moisture loss and recharge, and runoff. Potential and actual values are computed for the last. Palmer used monthly averages, but other timescales (such as weeks or days) can be used as well. Means of the potential and actual values for these parameters are computed over a calibration period that is usually, but not necessarily, the data period of record.

The Palmer index was specifically designed to treat the drought problem in semiarid and dry sub-humid climates where local precipitation is the sole or primary source of moisture (Doesken et al., 1991). Palmer himself cautioned that extrapolation beyond these conditions may lead to unrealistic results (Palmer, 1965; Guttman, 1991). These concerns fall into two broad categories: the use of water balance models in general and Palmer's model in particular (Richard, 2002). The Surface Water Supply Index (SWSI) an empirical hydrologic drought index developed for Colorado in 1981 was designed to complement the PDSI by integrating snow-pack, reservoir storage, stream-flow, and precipitation at high elevation as a measure of surface water status (Wilhite and Glantz, 1985; Doesken et al., 1991). While noting that the index is very useful in assessing (and predicting) the surface water supply status, Does ken et al. (1991) expressed several concerns about the SWSI, including the following: there is a lack of consensus over the definition of surface water supply; the factor weights vary from state to state and , in some cases, from month to month, resulting in SWSIs with differing statistical properties; and the hydro-climatic differences that characterize river basins in the western United States result in SWSIs that do not have the same meaning and significance in all areas and at all times.

2.2.4. 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 defines 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 any 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 studied; 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.

2.2.5. Meteorological Drought

Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. For example, some definitions of meteorological drought identify periods of drought on the basis of the number of days with precipitation less than some specified threshold. This measure is only appropriate for regions characterized by a year round precipitation regime such as a tropical rainforest, humid subtropical climate, or humid mid-latitude climate (NDMC, 2006).

2.2.6. Predicting and Planning Drought

Predicting drought depends on the ability to forecast 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, produces should know the extent of their current drought conditions and what the expectations are for the coming week, month and season (NDMC, 2006).

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 (risk management). In addition 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 rain fed 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).

2.2.7. The Drought Monitor

The DM draws its strength from the collaborative input at the federal (USDA, NOAA), regional (NOAA Regional Climate Centers), state, and local levels and from the objective synthesis of several drought-related indices. A limitation of the DM lies in its attempt to show drought at several temporal scales (from short tem drought to long tem drought) on one map product. The intent of the DM is not to replace any local or state information or subsequently declared drought emergencies or warnings, but rather to provide a general assessment of the current state of drought around the United States, Pacific possessions, and Puerto Rico (Svoboda, 2000).

NOAA has applied satellite-based technology to the real-time monitoring of drought. The vegetation condition index (VCI), computed from satellite Advanced Very High Resolution Radiometer (AVHRR) radiance (visible and near infrared) data and adjusted for land climate, ecology, and weather conditions, showed promise when used for drought detection and racking. The VCI allows detection of drought and measurement of the time of its onset and its intensity, duration, and impact on vegetation. However, since the VCI is based on vegetation, it is primarily useful during the summer growing season. It has limited utility during the cold season when vegetation is largely dormant.

The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions. It is designed to monitor short-term moisture conditions affecting a developing crop, the CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. For example, a beneficial rainfall during a drought may allow the CMI value to indicate adequate moisture conditions, while the long-term drought at that location persists. Another characteristic of the CMI that limits its use as a long-term drought monitoring tool is the CMI typically begins and ends each growing season near zero. This limitation prevents the CMI from being used to monitor moisture conditions outsides the general growing season, especially in droughts that extend over several rears (Hayes, 2006).

The drought affects all Rabi crops, such as HYV Boro, Aus, Wheat, Pulses and potatoes especially where irrigation possibilities are limited. It also affects sugarcane production. Kharif droughts in the period June to October, created by sub-humid and dry conditions in the highland and medium highland areas of the country. Shortage of rainfall affects the critical reproductive stages of transplanted Aman crops in December, reducing its yield, particularly in those areas with low soil moisture holding capacity.

2.3. Rainfall

Rainfall water that is condensed from the aqueous vapor in the atmosphere and falls in drops from the sky to the earth is called rain; and the total amount of rain that falls in a particular area within a certain time is called rainfall. The single most dominant element of the climate of Bangladesh is the rainfall. Because of the country’s location in the tropical monsoon region, the amount of rainfall is very high. However, there is a distinct seasonal pattern in the annual cycle of rainfall, which is much more pronounced than the annual cycle of temperature.

The Himalayas, that forms the major part of the rainfall of Bangladesh. The Monsoon rains start from the end of May and continue till mid October. The total rainfall in these months varies in different parts of the country. It is 122cm in the northwestern part, 149cm in the central part, 338cm in the coastal areas, and over 500cm in the northeastern part-across the borders from Cherapunji and Mawsyriem, two of the rainiest places in the world. The averages rainfall in drier and wetter regions is 1500mm and 5000mm per year respectively (BARC, 1991).

The mean annual rainfall varies widely within the country according to geographical location, ranging from 1,200 mm in the extreme west to 5,800 mm in the east and northeast. There are three main periods of rainfall, with distinct sources of precipitation: (1)The western depression of winter rains, mainly from 20th January to 25th February, when it rains from 1cm to 4cm. (2) The pre-monsoon thunderstorms, known as the Northwest (North-westerlies), which begin about the 10th of March. The Northwest arise due to a variety of reasons, the main ones being the steady flow of cool dry air above 1800 meters altitude from the Northwest (Anti-Trases), a warm, moist current below 1800 meters from the south, intense evapo-transpiration in the Bengal Basin and Assam, and katabolic winds from the surrounding mountains. (3) The summer rains known as the Monsoons. The main rainy period begins with the coming of the moisture-laden Southwest Trades, popularly known as the Monsoons, which are drawn to the Indian sub-continent by the intense heat, and consequent low pressure (Rahman and Alam, 2003).

The weather plays a significant role in the agriculture of a country. The rainfall, which can be considered as one of the most important of the weather factors in Bangladesh, is highly variable and hence sometime unpredictable. The rainfall probability is an approach to sound planning against hardships caused by large variation in rainfall. A Markov chain model is established to fit Rajshahi daily rainfall data for the various aspect 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 exact mean and variance were also the same as the asymptotic mean and variance for each month. The distribution of the number of success is asymptotic normal distribution. The rainfall probability was not found to be varying 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 said, one would presume continuous variation in these probabilities also within monthly, seasonally and annually. Based on these findings and using chi-square test, it could be concluded that the model fit is good. The probability of occurrence of rainfall is of importance in efficient planning and execution of water programs for agricultural development and environmental strategies in Bangladesh. This kind of information is very helpful in determining water needs for supplemental irrigation for translated in terms of worth for additional reservoir storage, if there is storage of water, or suitable drainage system if there is excessive rainfall (Rahman and Mian, 2002).

Markov chain models have been used to evaluate probabilities of getting a sequence of wet and dry weeks during southwest monsoon period over the districts Purilia in West Bengal and Girdih in Bihar state and dry farming tract in the state of Moharastra of India. An index based on the parameters of this model has been suggested to a region (Banik et al., 2000).

Sustainable agro-hydrological and water management planning requires knowledge of possible long terms rainfall patterns. A stochastic model based on a first order Markov chain was developed to simulate daily rainfall. The model is capable of simulating a daily rainfall data of any length, based on the estimated transitional probabilities, mean, standard deviation and skew coefficients of rainfall amounts. In this paper investigate methods to obtain estimates of the conditional probabilities, the probability of success and its probability distribution to describe the seasonal variability in the parameters for a stochastic rainfall model. Parameters are obtained from a two-state Markov chain model for wet and dry day occurrence (Rahman, 1999 b).

Daily rainfall is more critical than monthly rainfall. Rainfall of 100 mm/month distributed evenly, is preferable over 200 mm/month for 2 to 3 (De Mota, 1980).Variability of rainfall distribution is the most important factors of limiting yield of rained rice. It is about 80% of the growing rice in south and south-east Asia. The coefficient of variation of the same amount of rainfall is higher in tropics than in the temperature area (De Datta, 1981). To estimate whether rainfall is sufficient to meet the water requirement of a rained rice crop, both gains and losses of water must be considered. Both climate and soil affect water requirement of rice crop. Humidity temperature and solar radiation are primary determinants of evapo-transpiration (Satake and Yoshida, 1978).

Simulated rainfall data was compared with actual rainfall data in different ways. The results of these comparisons indicate that the performance of the model is generally satisfactory. Simulated rainfall data were sufficiently representative of historical rainfall data (Rahman, 1999b).

The occurrence of an extreme rainfall deficit over a wet season, leading to drought conditions, may usually be seen as leading to crop yield deficits, food shortages and famines, the intensity of the latter will vary widely. Much depends on organization structures in the country concerned, its communication and transport infrastructure and the availability of accessible food supplies from elsewhere in the country or from neighboring countries. Again excessively high rainfall condition will almost certainly lead to considerably increase run-off and flooding, possibly together with widespread soil vary widely depending on antecedent rainfall and ground water conditions, the geo-morphological characteristics of the area, the nature of the farming practices within the catchments involved and such issues as the degree of deforestation that may have occurred (Gregory, 2000).

The major climatic characteristics that limit crop production are rainfall levels, the yearly variation in the onset and end of the monsoon, incidence of very heavy or erratic rainfall, flash and seasonal floods, and the incidence cyclones and associated storm surges. The entire country has a tropical climate and receives rain during the summer monsoons. Rainfall levels decline from east to west and from south to north. Thus, rainfall in the western and northern regions is 32% less than in the rest of the country. In the coastal districts, the rainy season is longer (around 6 months) (Ateng, 1998).

The calendar window available for growing diversified crops is primarily during the rabi season, whenever low-lying are not flooded by the monsoons and temperatures are moderate. Thus, one strategy for farmers to engage in more commercial-scale diversified agriculture is to make their rabi season cropping pattern more flexible. This can be accomplished either by reducing the growing calendar of boro rice in order to free land (even low-lying land) during the Rabi season for no rice crop cultivation, or by switching the focus of rice production to HYV T.Aman rice technology during the kharif season (Ateng, 1998).

2.4. Evaporation

Efforts to measure depletion of soil moisture focused on evaporation, and measurement of the amount of moisture used by plants focused on transpiration. Evaporation and transpiration depend on solar radiation, wind speed, humidity, nature of vegetation and condition of the soil, with solar radiation being the dominant factor (Richard, 2002).

The direct measurements of solar radiation are not generally available, it was found that the mean daily temperature, latitude, and the time of year could be used to approximate the amount of water loss to the atmosphere by evaporation when it is assumed that there is an adequate supply of moisture in the soil for the vegetation at all times.

This measure is called potential evapotranspiration (PE).The difference between actual and potential evapotranspiration depends on the availability of moisture in the soil. If adequate soil moisture is available, actual evapotranspiration equals potential evapotranspiration; otherwise, it is less. Crop evapotranspiration is determined by the climate environment and the specific crops characteristics (Oldeman, 1980). Evapotranspiration estimates are important to irrigation engineers, agronomists and other involved in agricultural planning. Apart from rainfall temperature affected irrigated rice culture significantly. Although apparently these are unalterable factors, manipulations in culture practices to avoid the deleterious effects of extremes can significantly improve the rice production environment. The combination of improved Management and better performing varieties seems to have the best chance of contributing significantly to increase rice production.

The model computes evaporation from soils and plants separately as described by Ritchie (1972). Potential soil water evaporation is water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil water evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET and leaf area index (Srinivasan et al., 1997).

The moisture adequacy index, developed by McGuire and Palmer (1957) as an outgrowth from the concept of potential evapotranspiration, compared a location's moisture need to the actual moisture supply (rainfall plus available soil moisture). The moisture adequacy index is expressed as a percentage ratio of the actual moisture supply to the moisture need, where 100% indicates the supply is sufficient to meet the need. They plotted a map of these index values to show the general spatial pattern of drought during 1957 in the eastern United States.

2.5. Soil Moisture

The soil characteristics of Bangladesh were obtained after digitization survey of Bangladesh soil map with many properties like soil texture, soil pH and soil depth. Weather data were obtained and their surfaces were generated using World Meteorological Organization station throughout Bangladesh (Ahmed and Shibasaki, 2000).

The most effective when applied to the measurement of impacts sensitive to soil moisture conditions, such as in agriculture, and it has also been used to start or end drought response actions (Willeke et al., 1994).

The model for a drought index that incorporated antecedent precipitation, moisture supply, and moisture demand based on the pioneering evapotranspiration. Palmer (1965) used a two layered model for soil moisture computations and made certain assumptions concerning field capacity and transfer of moister to and from the layers. These assumptions include the following: the top soil layer (plough layer) has a field capacity of 1 inch (2.54 cm), moisture is not transferred to the bottom layer (root zone) until the top layer is saturated, runoff does not occur until both soil layers are saturated, and all of the precipitation occurring in a month is utilized during that month to meet evapotranspiration and soil moisture demand or be lost as runoff.

Lateral subsurface flow in the soil profile (0-2 m) is calculated simultaneously with percolation. A kinematics storage model is used to predict lateral flow in each soil layer. The model accounts for variation in conductivity, slope, and soil water content. It also allows for flow upward to an adjacent layer or to the surface (Srinivasan et al., 1997).

The ground water flow contribution to total stream flow is simulated by creating the shallow aquifer storage (Arnold et al., 1993). Percolate from the bottom of the root zone is recharge to the shallow aquifer. A recession constant, derived from daily stream flow records. is used to lag flow from the aquifer to the stream. Other components include evaporation, pumping withdrawals, and seepage to the deep aquifer.

2.6. Temperature

Daily average soil temperature is simulated at the center of each soil layer for use in hydrology and residue decay. The temperature of the soil surface is estimated using daily maximum and minimum air temperature and snow, plant and residue cover for the of interest plus the four days immediately preceding. Soil temperature is simulated for each layer using a function of damping depth, surface temperature, and mean annual air temperature. Damping depth is dependent upon bulk density and soil water.

The abstractions, or transmission losses, reduce runoff volumes as the flood wave travels downstream. SWAT uses Lane's method described in Chapter 19 of the SCS Hydrology Handbook to estimate transmission losses. Channel losses are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when transmission losses occur (Srinivasan et al., 1997).The are three main seasons: (1) a hot summer season, with high temperatures (5 to 10 days with more than 40^{0} C maximum in the west), highest rate of evaporation, and erratic but heavy rainfall from March to June; (2) a hot and humid monsoon season (temperatures ranging from 20^{0}C to 36^{0}C), with heavy rainfall from June to October (about two thirds of the mean annual rainfall); and (3) a relatively cooler and drier winter from November to March (temperatures ranging from to 15^{0}C), when minimum temperatures can fall bellow 5^{0}C in the north, though frost is extremely rare (Rahman and Alam, 2003).

There are two general approaches to determine future climate change i.e. a) projection based on observed historical data, and b) using available climate model. It is found from the observed data that the temperature is generally increasing in the monsoon season. Average monsoon maximum and minimum temperature shows an increasing trend annually at the rate of 0.05 ^{0}C and 0.03 ^{0}C respectively. On the other hand average winter maximum and minimum temperature shows decreasing and increasing trend annually at the rate of 0.001 ^{0}C and 0.016 ^{0}C respectively. SAARC Meteorological Research Centre (SMRC) has studied surface climatologically data on monthly and annual mean maximum and minimum temperature, and monthly and annual rainfall for the period of 1961-90. It is found that the annual mean minimum temperature is likely to decrease by 0.06 ^{0}C and 0.11 ^{0}C by 2050 and 2100 respectively. The overall annual mean temperature is likely to increase by 0.21 ^{0}C and 0.39 ^{0}C by 2050 and 2100 respectively. The most important finding of the study is seasonal variation of future trend of temperature and rainfall. It is found that in the pre-monsoon season the mean maximum temperature is likely to decrease by 0.44 ^{0}C and 0.80 ^{0}C by 2050 and 2100 respectively. Conversely in the southwest monsoon season the mean maximum temperature is likely to increase by 0.90 ^{0}C and 1.65 ^{0}C by 2050 and 2100 respectively, and increasing trend is statistically significant in winter, the 9.7 ^{0}C and 26.6 ^{0}C respectively. In the summer, the average maximum temperature is about 32.2 ^{0}C (BARC, 1991). Climate change vulnerability studies have used different climate change scenarios to assess impacts, adaptation and vulnerability for different sectors. Climate Change Country Study, a comprehensive study on assessing impacts, adaptation and vulnerability, has used General Circulation Model to develop climate scenarios. The model estimated monthly average rate of change in temperature and precipitation for those locations were super imposed on the observed time-series monthly average data to obtain data for the projection years. The results revealed that the average increase in temperature would be 1.3 ^{0}C and 2.6 ^{0}C for the year 2030 and 2070, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4^{0}C change in the winter and 0.7^{0}C in the monsoon months in 2030. For 2070 the variation would be 2.1 ^{0}C and 1.7 ^{0}C for winter and monsoon, respectively. There would be excessive rainfall in the monsoon causing flooding and very little to no rainfall in the winter forcing drought. It was also found that there would be drastic changes in evaporation in both winter and monsoon seasons in the projection year 2075. It was inferred from the GCM output that moderate changes regarding climate parameters would take place for the projection year 2030, while for the projection year 2075 severe changes would occur. The calibrated future temperature of Bangladesh shows that the averages increase of temperature would be 1.3 ^{0}C and 2.6 ^{0}C for the year 2030 and 2070, respectively (Rahman and Alam, 2003).

The Asian summer monsoon has a significant impact on the regional climate and it also plays an important role in the global climate system. It has been thought that land-sea heating contrast is a fundamental mechanism driving the summer monsoon circulation (e.g. Webster, 1987). They found that the intensity of the Asian summer monsoon.

Rice growth duration is primarily dependent upon the variety characteristics and the environmental conditions. Assessing the influence of climate conditions on rice growth duration is of significance for adjusting crop and variety disposition, choosing optimum cropping systems, selecting suitable sowing date, forecasting seasonal operations and making management decisions. It is well to known that rice growth and development are influenced by temperature. However, efforts to develop a temperature summation function for rice growth duration have not been successful. One of the major reasons is that only temperature as a single factor is considered in the traditional temperature summation method. In fact, light in addition to furnishing energy, also serves an important function in regulating flowering and maturing date of rice plants (Gao et al., 1987).

However, the local hydrological process plays a different role in determining the location of the monsoon rainfall and the intensity of the summer monsoon. For instance, the drier Eurasian landmass has less evaporation to maintain the monsoon rainfall, so the Asian summer monsoon rainfall decreases (Chou, 2003). Xue (1996) showed that the effect in a desertification experiment in central Asia, so the Asian monsoon is weakened.

Air temperature is a fundamental input requirement for many agricultural models, particularly crop growth models. For the validation of agricultural models and for climatologically purposes, many of the available data consist of only the daily minimum and maximum temperatures. Temperature is only of the critical variables that drive all biological systems. For many models it is often useful to obtain an approximation of hourly temperature for a particular location and time of the year. Daily maximum temperature did not appear to affect of accuracy of any of the models. If accurate timing of temperature input to models is critical, the results indicate that direct measurement of hourly temperature may be necessary (Reicosky et al., 1989).

The positive rainfall anomalies in Africa and Asia appear to connect to each other and the Asian summer monsoon extends farther northward than the African summer monsoon (Liu and Yanai, 2001). This -northeast tilt of the positive rainfall anomalies is induced by similar mechanisms to the idealized monsoon study in Chou et al., (2001). The horizontal temperature gradient is more dominant than the troposoheric temperature itself in determining the summer monsoon rainfall. As the positive monsoon rainfall anomalies extend into the African content, the southwesterly monsoon flow and the easterly trade wind merge at tropical Africa instead of south.

2.7. Solar Radiation

Solar Radiation is the most important environmental element for the crop production system, which provides the energy to photosynthesis and is fundamental to crop metabolism. Acquisition of radiant energy and carbon dioxide is critical to growth and ecological success of crops. Physiologically, light has both direct and indirect effects.

Solar Radiation reaching vegetation has two components; 1) irradiance of direct sunlight and 2) diffusion irradiance from both clouds and clear sky. The maximum flux density of bright sunlight depends on the solar constant (1400 Wm^{-2}). Typical instantaneous values for photosynthetic active radiation (PAR) values at vegetation surfaces are 500-1000 Wm^{-2} for overcast skies (Monteith and Unsworth, 1990). Daily maximum and minimum air temperature and solar radiation are generated from a normal distribution corrected for wet-dry probability state. The correction factor is used to provide more deviation in temperatures and radiation when weather changes and for rainy days. Conversely, deviations are smaller on dry days. The correction factors are calculated to insure that long that long-term standard deviations of daily variables are maintained (Srinivasan et al., 1997).

2.8. Crop Growth Model

Crop Growth Models are powerful tool in predicting the impact on crop production of global environmental change owning to the increased content of the green house gases in the atmosphere. A crop simulation model is more or less non linear with respect to the responses to environmental variables and to the change in model coefficients. This non linearity causes the discrepancy of the model responses from the frame work, which based on the linear approximation (Kobayashi, 1994).

A crop model is a simple representation of a crop, used to study crop growth and to compute growth responses to the environment. Crop models in common use can be distinguished as descriptive and explanatory models. A descriptive model defines the behavior of a system in a simple manner. The model reflects little or none of the mechanisms that are causes of the behavior. An explanatory model consists of a quantitative description of the mechanisms and processes that cause the behavior of a system. The crop modeling approach draws together knowledge from different areas: soil science, crop physiology, agro climatology, physiopathology, agricultural economics, and so on.

A sustainable solution, the worsening scarcity of water for rice cultivation must be addressed from various scientific angles. Greater attention should be given to developing water management systems that will be maximizing the efficiency and productivity of water in rice culture. Concurrently, we need to harness the biological potential of the crop to a fuller extent, with advanced technologies, as necessary, so that production gains can be achieved and sustained with less irrigation required (Bhuiyan, 1999).

Rahman (2001) reported that the study would be useful to agricultural scientists, decision makers, policy planners and researches in order to identify the areas where agricultural development should be focused as a long term environmental strategy for Bangladesh. Water is a precious commodity during the dry period. This is even true in areas where agriculture is practiced in climatologically marginal areas. Water resource could be considered and the labor cost and power consumption could be reduced, in order to determine the requirement of a crop that Suggested the simulation model perform adequately for many applications including agricultural development and environmental strategy.

A single model is used in SWAT for simulating all crops. Energy interception is estimated as a function of solar radiation and the crop's leaf area index. The potential increase in biomass for a day is estimated as the product of intercepted energy and a crop parameter for converting energy to biomass. The leaf area index is simulated with equations dependent upon heat units. Crop yield is estimated using the harvest index concept. Harvest index increases as a non-linear function of heat units from zero at planting to the optimal value at a maturity. The harvest index may be reduced by water stress during critical crop stages (usually between 30 and 90% of maturity) (Srinivasan et at., 1997). The SWAT approach to estimating soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phrase as described by Leonard and Wauchope (Knisel, 1980). Because P is mostly associated with the sediment phase, the soluble P runoff is predicted using labile P concentration in the top soil layer, runoff volume, and a partitioning factor. Crop use of P is also estimated with the supply and demand approach.

GLEAMS (Leonard et al., 1987) technology for simulating pesticide transport by runoff, percolate, soil evaporation, and sediment was added to SWAT. Pesticides may be applied at any time and rate to plant foliage or below the soil surface at any depth. The plant leaf-area index determines what fraction of foliage is applied pesticide reaches the soil surface. Also, a fraction of the application rate (called application efficiency) is lost to the atmosphere. Each pesticide has a unique set of parameters including solubility; half of life in soil and on foliage and in the soil degrades exponentially according to the appropriate half of lives. Pesticide transported by water and sediment is calculated for each runoff event and pesticide leaching is estimated for each soil layer when percolation occurs.

SWAT allows for unlimited years of crop rotations and up to three crops per year. The user can also input irrigation, nutrient, and pesticide application dates and amounts. The user has the option simulate dry land or irrigated agriculture.

The prospect of global climate change makes the issue particularly urgent. It is well established that atmospheric concentration of CO_2 is increasing and this would be beneficial for crop growth and productivity. But the nature and magnitude of climate change associated with the increase of CO_2 and other radioactive trace gases are uncertain. Thus, it is difficult to predict the combined impact of increasing atmospheric CO_2 on agricultural productivity. Crop simulation models are used widely to predict the crop growth and development in studies of the impact of climate change. Climate based models for estimating potential productivity are used for this purpose. These models are relatively easy to apply, but they fail to estimate actual productivity and possible effects of mitigation measures. Crop models are advantageous to estimate actual productivity, but they are applied to only limited numbers of test sites due to heavy data requirement in applying them for wide areas.

A comprehensive GIS- based biophysical crop simulation model, Spatial-EPIC, was use din order to demonstrate the crop growth response to the combined effects of CO_2 concentration increase and CO_2-induced climate change at the national level. Modeling within a GIS offers a mechanism to integrate the many scales of data developed in and for agriculture research (Ahmed and Shibasaki, 2000).

Despite technological advances such as improved crop varieties and irrigation system, weather and climate are still key factors in agricultural productivity. The rise of CO_2 level in the atmosphere and the concomitant climate change will have a direct impact on agriculture. Crop simulations models can be used predict the impact. These models can provide away to estimate crop production under climate-change condition.

To the simulate country level Bangladeshi agro ecosystem with the help of Spatial-EPIC. Modeling within a GIS offers a mechanism to integrate the many scales of data developed in and for agricultural research. Agro ecosystems are complex entities, which span several levels or scales, with different processes dominating each scale. Geographic data are either as a vector model or Raster model fit best for modeling type of analysis involving natural resources data such as land use, soils and vegetation as their is spatial control for continuous variable and also uniform sampling of the surface being modeled (Ahmed and Shibasaki, 2000).

Traditional decision support systems based on crop simulation models are normally site-specific. The effects of spatial variability of soil conditions and weather variables on crop production from one place/region to other, GIS is link with biophysical agricultural management simulation model EPIC, which is known as "Spatial-EPIC".

Bangladesh will need a more diversified cropping pattern, including an increase in the contribution of non-rice crops to output ratio to attain higher agricultural growth rates in the future. Besides enhancing growth, diversification also contributes to nutrition, poverty alleviation, employment generation and sustainable natural resources management. Resource Base Opportunities for Crop Diversification Availability of resources such as land, water, labor and sunlight are critical for crop diversification schemes. Abundant water (rainfall and groundwater) is one of the most resources for agricultural development in the country. Irrigation potential is substantial and labor is also abundant and relatively cheap. Land, however, is a constant on diversification, at least in the short run (Ateng, 1998).

For most crops, which are produced in the dry (rabi) season, the alternative rice crop is assumed to be irrigated HYV boro rice. For crops raise in the wet (kharif) season, Aus or Aman rice is assumed to be the alternative crop, depending on how early in the season the crop is planned. For crops which extend over two or more seasons, the returns are compared to production of both HYV Aman HYV Boro rice. The justification for comparisons with HYV rice crops rather than traditional varieties is that these more intensive crops represent the long-run alternative to other crops. All agriculture and rice in particular, is expected to intensify as greater population pressure is placed on agricultural resources. Clearly, this assumption raises the financial returns to rice per hectare in all seasons, thereby increasing the returns from other crops necessary to make them look attractive (Ateng, 1995).

Current cropping patterns suggest that specialization at the regional level will largely be influenced by investments in infrastructure, support services, or processing facilities. Technical, financial and economic feasibility of both existing and potential new crops has been examined here. In each case, financial and economic returns are compared to those for the most commonly product HYV rice crop on land types and in the season in which that alternative crop would probably be grown (Ateng, 1995).

The three facets of crop production, namely (i) crop development, (ii) crop growth and (iii) insects/pests/diseases are primarily controlled by weather (Reddy, 2004).

CHAPTER-V

5.1. Conclusion

Agriculture is the backbone of the economy of developing countries with more than 70% of the working population engaged in this sector. So the Failure of rains and the occurrence of drought during any particular growing season lead to severe food shortage. Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced ground water reservoir levels.

Markov chain model have been used to estimate probabilities of getting a sequence of dry -wet weeks for Rangpur, Faridpur and Mymensingh districts in Bangladesh. The crop yield in the area will depend on variation rainfall in monsoon season. An index based on the parameters of this model has been suggested for agricultural drought measurement on these regions.

For Drought Index of Rainfall 5 mm and 10 mm in Rangpur District

(i) As $0.235 < DI \leq 0.310$, the results indicate that the Rangpur region were found the mild drought in Annual season.

(ii) $0.310 < DI \leq 1.000$, the region were found the occasionally drought in pre-kharif and kharif season.

(iii) $0.000 < DI \leq 0.125$, the region were found the chronic drought Proneness in Rabi season.

For Drought Index Rainfall <5 mm and 10 mm in Faridpur District

(i) $0.310 < DI \leq 1.000$, the region were found the occasionally drought in Annual, pre-kharif and kharif season.

(ii) $0.000 < DI \leq 0.125$, the region were found the chronic drought Proneness in Rabi season.

For Drought Index Rainfall <5 mm and 10 mm in Mymensingh District

(i) As $0.235 < DI \leq 0.310$, the results indicate that the region were found the mild drought in Annual season.

(ii) $0.310 < DI \leq 1.000$, the region were found the occasionally drought in pre-kharif and kharif season.

(ii) $0.000 < DI \leq 0.125$, the region were found the chronic drought Proneness in Rabi season.

Based on these findings and using Markov chain model is established to fit daily rainfall data for the various aspects of rainfall occurrence patterns and using chi-square test, I got that the model fit was good. These were also established to fit the observed data .The distribution of the number of success is asymptotically normal. 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 and failure to rains and the occurrences of drought during any particular growing season lead to severe food shortages.

The scenarios of the study could be prepared by showing the net irrigation requirement of different crops in different seasons and developing agencies for adopting drought management practices. The study will contribute to policy formulation and strategic planning in the areas such as, agricultural practices and crop diversification, investments in irrigation development works, and allocation of water to different uses.

P_{11} is always greater than Pie conditional probability is always greater than stationary probability which suggests that the effective of persistence is significant. A good regional drought plan can help farmers to increase crop production even in the most sever drought condition. Agricultural drought links meteorological drought and deficits of soil moisture to impacts on crop production.

The impacts of drought can be reduced through mitigation and preparedness (risk management). In addition to drought planning at the regional 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 rain fed 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.

The probability of occurrence of rainfall is of vital importance in efficient planning and execution of water programs for agricultural development environmental strategies in Bangladesh. This kind of information is very helpful in determining water needs for supplemental irrigation for agriculture and also for urban areas. These requirements could be translated in terms of worth for additional reservoir storage if there is storage of water, or suitable drainage system if there is excessive rainfall (Rahman and Basher, 2000).

The results of this study would be useful to agricultural scientists, decision makers, policy planners and researchers in order to identify the areas where agricultural development should be focused as a long-term environmental strategy for Bangladesh. Disaster Management Bureau (DMB) of the Government of Bangladesh monitors drought and other hazardous events. Bangladesh Meteorological Department (BMD) SPARRSO, BWDB, BARC also collaborate with BMD by providing necessary information on weather, water and soil condition and suggesting appropriate action for mitigating the effects of drought and desertification.

5.2. Suggestions and Recommendations:

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 wheat. In severe and extremely severe drought affected areas, government Aman season will continue.

The production of crops, especially Aman crop is heavily damaged every year due to inadequate soil moisture regime prevailing in drought affected areas. To struggle this situation government, Agriculturist and farmers will adopt the following policies:

i) Supplementary irrigation will be ensured in service and extremely severe drought effected areas in Rangpur, Faridpur and Mymensingh districts.

ii) Proper strategy will be pursued for cultivating crops.

So the findings of the studies will help in proper implementation of agricultural policy to increase overall agricultural production in Rangpur, Faridpur and Mymensingh districts which is expected to bring about significant positive change in the economic of the country and also help the government and relevant organization to identity methods for reducing poverty and achieving sustainable development in agriculture and land use.

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CHAPTER-III

3. Materials and Methods

3.1. Data and Study Area

In this research, the main goal is to study of climate variability and agriculture drought in Bangladesh using rainfall data. The objective of my research, I collect data for the region Rangpur, Faridpur and Mymensingh districts. The measurement unit of rainfall is millimeter (mm) with measurement instrument is standard rain gauge. The study data collected from Bangladesh meteorological department, Dhaka, Bangladesh over the range January, 1981 to December, 2010 (30 years).

3.2. Climate and seasons of the Selected Area

The climate conditions of Rangpur, Faridpur and Mymensingh districts are fairly uniform. In Bangladesh there are three agro-climatic seasons (1) Pre-kharif (summer) which includes the pre-monsoon months March to May (2) Kharif which includes monsoon months June to October in which 80% of the total occurs (Rahman and Alam, 1997) and (3) Rabi (winter) season which identify from November to February. Limited surface water supplies are available in tanks. Ground water supplies generally are poor in the more highly western part but somewhat better in valleys and more shallowly dissected areas towards the eastern boundary of the region. (Rahman and Mian, 2002).

3.3. Markov Chain Model

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

Future State

		Dry	**Wet**
Present State	**Dry**	1-α	α
	Wet	β	1-β

Let us consider the conditional probabilities which are denoted by

$$P_0 = \Pr \{W/D\} \quad (1)$$

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

This sequence is irreducible Markov chain with two argotic states. Its stationary probability distribution has a probability of success

$$p = \frac{P_{01}}{1-(P_{11}-P_{01})} \quad (2)$$

3.4. Method of Markov chain

Several authors have found that a simple Markov chain model can describe sequences in daily rainfall occurrences. The first successful application of such a model seems to have been made by Gabriel and Neumann (1962) for Tel-Aviv. Additional evidence to indicate the feasibility of using a Markov chain model has been presented by Caskey (1963); Weiss (1964); Hopkins and Robillard (1964); Rahman (1999a, b).

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

$$X_n = \begin{cases} 0 & \textit{if the nth week is dry} \\ 1 & \textit{if the nth week is wet} \end{cases} \quad (3)$$

Firstly we assume that,

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

Where x_0, x_1,.........., $X_{n+1} \in \{0, 1\}$.

In other words, it is assumed that probability of wetness of any week depends only on whether the previous week was wet or dry. Given the event on previous week, the probability of wetness is assumed independent of further preceding weeks. So the stochastic process $\{X_n$, n= 0, 1,2,.........$\}$ is a Markov chain (Medhi, 1981).

Consider the transition matrix

$$P_{ij} = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \quad (4)$$

Where $P_{ij}=P(X_1=j \mid X_0=i)$ 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

$$[1\text{-P} \quad \text{P}] \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} = [1\text{–P} \quad \text{P}] \tag{5}$$

Which gives

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

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

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

For large n, Y follows normal distribution with

Mean =n p and

$$\text{Variance}=\text{n p (1-p)}\frac{1+P_{11}-P_{01}}{1-P_{11}+P_{01}} \tag{7}$$

Where p is the stationary probability of a week being wet.

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

3.5. Index of Drought-Proneness

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

Hence an index of drought-proneness may be defined as:

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

From the equation (2) we have calculated higher Transition Probability Matrix when $P_{ij}^{\,n} = P_{ij}^{\,n+1}$ is the condition. Using Stable Transition Probability Matrix we finally calculated $DI=P_{01} \times P_{11}$. Zero and one bound this index of droughts. Higher the value of DI, lower will be the degree of drought-proneness. The level of drought-proneness is given below:

Table 1: Index of drought-proneness

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

3.6. Statistical Inference for Markov Chain Model

Statistical Inference is an essential tool for concluding any research. The probability theory of Markov chain has been extensively developed, whereas, statistical inference concerning Markov chain model has not yet been comparatively developed (Billingsley, 1961).

Drought occurs when various combinations of the physical factors of the environment produce an internal water stress in crop plants sufficient to reduce their productivity. In the low rainfall areas especially in tropics, the importance of rainfall overrides that of all other climatic factors, which determine yield. So, agricultural drought is mainly concerned with inadequacy of rainfall.

The rainy season is mainly due to Southwest monsoon and it ranges from June to September. Hence the crop yield in the area depends on variation of rainfall in this season (Banik et al., 2000).

Different units of time period are used for rainfall analysis. For agriculture, week may be nearer to the optimum length of time. The week with rainfall greater than the threshold value (a minimum amount, say 2.5-mm) is considered to be a wet week. The expected number of wet weeks in a given period of time can decide the crop production of an area. The probability of sequences of wet can indicate the adequacy of water and that of dry weeks indicate the reverse and recurrence of the risk of crop failure. Wet and dry sequences of weeks can be well represented by the Markov chain model (Banik et al., 2000; Richardson, 1981; 1982). The occurrence of daily precipitation at a station can seldom be properly considered as an independent random event described by Bernoullis trials. Analysis of daily precipitation time series always tends to reveal the existence of stochastic dependence.

Drought is a temporary but complex feature of the climatic system of a given region with wide spread significance (Olapido, 1985), which is usually caused by precipitation deficit (Gregory, 2000).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 region, there is no universal definition of this term. Various characteristics of droughts, including definitions and their meteorological, hydrological and economic aspects were discussed by Landsberg (1982), Dennet et al., (1985), Olapido (1985), and reviewed extensively by Gregory (1986) and Nieu wolt (1986).

3.7. Maximum Likelihood Estimation Techniques

Let the states be i=1, 2,......, m. Though the state i is usually though of as an integer running from 1 to m, no actual use is made of this ordered arrangement so that i might be, for example, a political party, a geographical place, a pair of numbers (a,b), etc (Anderson and Goodman, 1957). Let the times of observation be t= 0, 1, 2 ....T. Let $p_{ij}(t)$ (i,j=1,2,......,m; t=1,2,......,T) be the probability of state j at time t, given state i at time t-1. An observation on a given individual consists of the sequence of states the individual is in at t=0,1,....T, namely i(0), i(1), i(2), ...i(T).Given the individual state i(o), there are m^T possible sequences. These represent mutually exclusive events with probabilities

$$p_{i(0)i(1)}\, p_{i(1)i(2)} \ldots\ldots\ldots\ldots\, p_{i(T-1)i(T)} \qquad (3.1)$$

When the transitional probabilities are stationary. (When the transitional probabilities are not necessarily stationary, symbols of the form $p_{i(t-1)i(t)}$ should be replaced by $p_{i(t-1)i(t)}(t)$ throughout).

Let $n_{ij}(t)$ denotes the number of individuals in state i at t-1 and j at t. we shall show that the set of $n_{ij}(t)$ (i,j=1,2,.....m; t=1,2,......T), a set of m^2T numbers, form a set of sufficient statistics for the observed sequences. Let

$n_{i(0)i(1)i(2)......i(T)}$ be the number of individuals whose sequence of states is i(0), i(1), i(2), ...i(T). Then n_{gj} (t)= $\sum n_{i(0)i(1)i(2).....i(T)}$, (3.2)

where the sum is over all values of the i's with i(t-1)=g and i(t)=j. The probability, in the nmT dimensional space describing all sequences for all n individuals (for each initial state there are nT dimensions), of a given ordered set of sequences for the n individual is

$$= \prod \left[pi(0)i(1)\,(1)\; pi(1)i(2)\,(2).....\; pi(T-1)i(T)\,(\mathrm{T}) \;\right]^{n_{i(0)i(1)....i(T)}}$$

$$= \left(\prod \left[pi(0)i(1)\,(1) \;\right]^{n_{i(0)i(1)....i(T)}} \right)......\left(\prod \; pi(T-1)i(T)\,(\mathrm{T}) \right)^{n_{i(0)i(1)....i(T)}}$$

$$= \left(\prod_{i(0),i(1)} p_{i(0)i(1)}\,(1)^{n_{i(0)i(1)....i(T)}(1)} \right)......\left(\prod_{i(T-1),i(T)} p_{i(T-1)i(T)}\,(T)^{n_{i(T-1)i(T)}(T)} \right) \quad (3.3)$$

$$= \left(\prod_{i=g,j}^{T} \prod p_{gj}\,(t)^{n_{gj}(t)} \right)$$

Where the products in the first two lines are over all values of the T+1 index. Thus, the set of numbers $n_{ij}(t)$ form set of sufficient statistics, as announced.

The actual distribution of $n_{ij}(t)$ is (3.3) multiplied by appropriate function of factorials. Let $n_i(t-1) = \sum_{j=1}^{m} n_{ij}(t)$.

Then the conditional distribution of $n_{ij}(t)$, j=1, 2,...,m,

given $n_i(t-1)$ (or given $n_k(s)$, k=1,2,...m; s=0,1....t-1 is

$$\frac{n_i(t-1)!}{\prod_{j=1}^{m} n_{ij}(t)!} \prod_{j=1}^{m} p_{ij}(t)^{n_{ij}(t)} \qquad (3.4)$$

this is the same distribution, as one would obtain if one had $n_i(t-1)$ observations on a multinomial distribution with probability $p_{ij}(t)$ and with resulting numbers $n_{ij}(t)$. The distribution of the $n_{ij}(t)$ (conditional on the $n_i(0)$) is

$$\prod_{t=1}^{T} \left\{ \prod_{i=1}^{m} \left[\frac{n_i(t-1)!}{\prod_{j=1}^{m} n_{ij}(t)!} \prod_{j=1}^{m} p_{ij}(t)^{n_{ij}(t)} \right] \right\} \qquad (3.5)$$

For a Markov chain with stationary transitional probabilities, a stronger result concerning sufficiency follows from (3.3); namely, the set $n_{ij} = \sum_{t=1}^{T} n_{ij}(t)$ forms a set of sufficient statistics. This follow from the fact that, when the transitional probabilities are stationary, the probability (3.3) can be written in the form

$$\prod_{t=1}^{T} \prod_{g,f} p_{gj}{}^{n_{gj}(t)} = \prod p_{ij}{}^{n_{ij}} \qquad (3.6)$$

For not necessarily stationary transitional probabilities $p_{ij}(t)$, the $n_{ij}(t)$ are a minimum set of sufficient statistics.

The stationary transitional probabilities p_{ij} can be estimated by maximizing the probability (3.6) with respect to the p_{ij}, subjected of course, to the restrictions $p_{ij} \geq 0$ and

$$\sum_{j=1}^{m} p_{ij} = 1, \quad i=1,2,....,m, \tag{3.7}$$

when the n_{ij} are the actual observations. This probability is precisely of the same form, except for a factor that does not depend on p_{ij}, as that obtained for m independent samples, where the ith sample (i=1,25,.....,m) consists of $n_i^* = \sum_j n_{ij}$ multinomial trials with probabilities p_{ij} (i,j=1,2,....,m). For such sample, it is well-Known and easily verified that the maximum likelihood estimates for p_{ij} are

$$\hat{p}_{ij} = \frac{n_{ij}}{n_i^*} = \sum_{t=1}^{T} n_{ij}(t) / \sum_{k=1}^{m}\sum_{t=1}^{T} n_{ik}(t) \tag{3.8}$$

$$= \frac{\sum_{t=1}^{T} n_{ij}(t)}{\sum_{t=0}^{T-1} n_i(t)},$$

and hence this is also true for any other distribution in which the elementary probability is of the same form except for parameter-free factors, and the restrictions on the p_{ij} are the same . In particular, it applies to the estimation of the parameters p_{ij} in (3.6).

When the transitional probabilities are not necessarily stationary, the general approach can still be applied, and the maximum likelihood estimates for the $p_{ij}(t)$ are found to be

$$\hat{p}_{ij}(t) = n_{ij}(t) / n_i(t-1) = \frac{n_{ij}(t)}{\sum_{k=1}^{m} n_{ik}(t)} \tag{3.9}$$

The same maximum likelihood estimates for the $p_{ij}(t)$ are obtained when we consider the conditional distribution of $n_{ij}(t)$ given $n_i(t-1)$ as when the joint distribution of $n_{ij}(1), n_{ij}(2)....., n_{ij}(T)$ is used.

The estimates can be desired in the following way: Let the entries $n_{ij}(t)$ for given t are entered in a two-way m×n table. The estimate $p_{ij}(t)$ is the i,jth entry in the table divided by the sum of the entries in the ith row. In order to estimate p_{ij} for stationary chain, it is necessary to add the corresponding entries in the two-way tables for t=1, 2,....T, obtaining a two-way table with entries $n_{ij}(t) = \sum_{t=1}^{T} n_{ij}(t)$. The estimate of p_{ij} is the i,j th entry of the table of n_{ij}'s divided by the sum of the entries in the i-th row (Anderson and Goodman, 1957;Medhi,1981).

3.8. Asymptotic Behavior of Estimators

Let P =(p_{ij}) and let $p_{ij}^{(t)}$ be the elements of the matrix p^t. Then $p_{ij}^{(t)}$ is the probability of state j at time t given state i at time 0.Let $n_{k;ij}(t)$ be the number of sequences including state k at time 0, i at time t-1 and j at time t. Then we seek the low order moments of

$$n_{ij}(t) = \sum_{k=1}^{m} n_{k;ij}(t) \qquad (3.10)$$

The probability associated with $n_{k;ij}(t)$ is $p_{ki}^{[t-1]} p_{ij}$ with a sample size of $n_k(0)$.

Thus, $E\{n_{k;ij}(t)\} = n_k(0) p_{ki}^{[t-1]} p_{ij}$. (3.11)

$$\text{var}\{ n_{k;ij}(t)\} = n_k(0) p_{ki}^{[t-1]} p_{ij} [1 - p_{ki}^{[t-1]} p_{ij}] \qquad (3.12)$$

To find the Asymptotic Behavior of the $\hat{p}_{ij}$, first consider the $n_{ij}(t)$. Let us consider that $n_k(0) \big/ \sum n_j(0) \rightarrow \eta_k$ ($\eta_k > 0$, $\sum \eta_k = 1$) as $\sum n_j(0) \rightarrow \infty$. For each i(0), the set $n_{i(0)i(1)i(2)......i(T)}$ are simply multinomial variables with sample size $n_{i(0)}(0)$ and parameter $p_{i(0)i(1)} p_{i(1)i(2)...............} p_{i(T-1)i(T)}$, and hence are asymptotically normally distributed as the sample size increases. The $n_{ij}(t)$ are linear combinations of these multinomial variables, and hence are also asymptotically normally distributed (Rahman, 1999a, b and Rahman and Mian, 2002).

3.9. Hypothesis Testing

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 We make use of the fact that under the null hypothesis the $(n_i^*)^{1/2}(\hat{p}_{ij} - p_{ij}^0)$have a limiting normal distribution with means zero, and variances and co-variances depending on p_{ij}^0 in the same way as observations for multinomial estimates. We can use standard asymptotic theory for multinomial or normal distribution to test a hypothesis about one or more p_{ij}, or determine a confidence region for one or more p_{ij}.

As a specific example consider testing the hypothesis that $p_{ij} = p_{ij}^0$, j=1, 2,.....,m, for given i.

Under the null hypothesis,

$$\sum_{j=1}^{m} n_i^{*} \frac{\left(\hat{p}_{ij} - p_{ij}^{0}\right)^2}{p_{ij}^{0}} \tag{3.13}$$

has an asymptotic χ^2- distribution with m-1 degrees of freedom (according to the usual asymptotic theory of multinomial variables). Thus the critical region of first test of this hypothesis at significance level α consists of the set $\hat{p}_{ij}$ for which (3.13) is greater than the significance point of the χ^2-distribution with m-1degrees 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 are

$$\hat{p}_{ij}(t) = n_{ij}(t) / n_i(t-1) \tag{3.14}$$

The likelihood function maximized under the null hypothesis is

$$\prod_{t=1}^{T} \prod_{i,j} \hat{p}_{ij}^{\,n_{ij}(t)} \tag{3.15}$$

The likelihood function maximized under the alternate is

$$\prod_{t} \prod_{ij} \hat{p}_{ij}^{\,n_{ij}(t)}(t) \tag{3.16}$$

The ratio is the likelihood ratio criterion

$$\lambda = \prod_{t}\prod_{ij}\left[\frac{\hat{p}_{ij}}{\hat{p}_{ij}(t)}\right]^{n_{ij}(t)} \tag{3.17}$$

For a given i, the set $\hat{p}_{ij}$(t) has the same asymptotic distribution as the estimates of multinomial probabilities $p_{ij}^{(t)}$ for T independent samples. The asymptotic distribution of -2logλ_i is χ^2 with (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 (3.17) can be written as

$$\sum_{i=1}^{m} -2\log\lambda_i = -2\log\lambda. \tag{3.18}$$

CHAPTER- IV

4. Results and Discussions

4.1. Drought Index calculated by using Rainfall 5 mm in Rangpur District

The daily rainfall of 30 years during the period from 1981-2010 in Rangpur District considering 52 standard weeks have been used for Table - 4.1.1.

Table 4.1.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Rangpur District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.54	0.56	0.55	28.65	13.89	0.30	Mild drought
10 years (1981-1990)	0.54	0.55	0.55	28.36	13.02	0.29	Mild drought
10 years (1991-2000)	0.51	0.55	0.53	27.63	14.07	0.28	Mild drought
10 years (2001-2010)	0.54	0.58	0.56	29.25	13.94	0.31	Mild drought

The mild and occasionally drought prone weeks are found in Rangpur District which is shown in Table-4.1.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Rangpur District considering 13 standard weeks have been used for Table-4.1.2.

Table 4.1.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Rangpur District for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.64	0.65	0.65	33.62	12.0	0.41	Occasionally drought
10 years (1981-1990)	0.63	0.65	0.64	8.36	3.13	0.40	Occasionally drought
10 years (1991-2000)	0.57	0.60	0.59	7.64	1.06	0.28	Mild drought
10 years (2001-2010)	0.69	0.71	0.70	9.15	2.82	0.48	Occasionally drought

The occasionally and Mild drought prone weeks are found in Rangpur District which is shown in Table-4.1.2.

The daily rainfall of Kharif season of 30 years (1981-2010) during the period from June to October in Rangpur District considering 22 standard weeks have been used for Table-4.1.3.

Table4.1.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Rangpur District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.83	0.84	0.84	43.60	7.12	0.69	Occasionally drought
10 years (1981-1990)	0.82	0.82	0.82	18.03	3.57	0.67	Occasionally drought
10 years (1991-2000)	0.86	0.86	0.86	18.92	2.65	0.73	Occasionally drought
10 years (2001-2010)	0.84	0.84	0.84	18.48	2.96	0.71	Occasionally drought

The occasionally drought prone weeks are found in Rangpur District which is shown in Table-4.1.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Rangpur District considering 17 standard weeks have been used for Table-4.1.4.

Table 4.1.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Rangpur District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.11	0.11	0.11	5.72	5.09	0.012	Chronic drought
10 years (1981-1990)	0.13	0.14	0.13	2.23	1.98	0.018	Chronic drought
10 years (1991-2000)	0.11	0.12	0.11	1.89	1.72	0.012	Chronic drought
10 years (2001-2010)	0.10	0.10	0.10	1.71	1.53	0.010	Chronic drought

The chronic drought prone weeks are found in Rangpur District which is shown in Table-4.1.4.

4.2. Drought Index calculated by using Rainfall 10 mm in Rangpur District

The daily rainfall of 30 years during the period from 1981-2010 in Rangpur District considering 52 standard weeks have been used for Table - 4.2.1.

Table 4.2.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Rangpur District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.46	0.51	0.48	25.18	14.47	0.23	Moderate drought
10 years (1981-1990)	0.48	0.51	0.49	25.73	13.94	0.24	Mild drought
10 years (1991-2000)	0.48	0.50	0.49	25.47	13.52	0.24	Mild drought
10 years (2001-2010)	0.48	0.51	0.49	25.73	13.94	0.24	Mild drought

The mild and moderate drought prone weeks are found in Rangpur District which is shown in Table-4.2.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Rangpur District considering 13 standard weeks have been used for Table-4.2.2.

Table 4.2.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Rangpur District for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean (Y)	Variance	DI	Comment
30 years (1981-2010)	0.58	0.58	0.58	7.54	3.17	0.34	Occasionally drought
10 years (1981-1990)	0.55	0.56	0.56	7.22	3.24	0.31	Occasionally drought
10 years (1991-2000)	0.51	0.53	0.52	6.76	3.38	0.27	Mild drought
10 years (2001-2010)	0.65	0.65	0.65	8.45	2.96	0.42	Occasionally drought

The occasionally and Mild drought prone weeks are found in Rangpur District which is shown in Table-4.2.2.

The daily rainfall of Kharif season of 30 years 1981-2010) during the period from June to October in Rangpur District considering 22 standard weeks have been used for Table-4.2.3.

Table 4.2.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Rangpur District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.79	0.79	0.79	17.38	3.65	0.62	Occasionally drought
10 years (1981-1990)	0.78	0.79	0.79	17.33	3.57	0.62	Occasionally drought
10 years (1991-2000)	0.81	0.81	0.81	17.82	3.39	0.66	Occasionally drought
10 years (2001-2010)	0.77	0.71	0.73	16.06	3.85	0.60	Occasionally drought

The occasionally drought prone weeks are found in Rangpur District which is shown in Table-4.2.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Rangpur District considering 17 standard weeks have been used for Table-4.2.4.

Table 4.2.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Rangpur District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.07	0.08	0.07	1.2	1.95	0.005	Chronic drought
10 years (1981-1990)	0.10	0.10	0.10	1.70	1.53	0.010	Chronic drought
10 years (1991-2000)	0.08	0.08	0.08	1.36	1.25	0.006	Chronic drought
10 years (2001-2010)	0.05	0.05	0.05	0.85	0.81	0.002	Chronic drought

The chronic drought prone weeks are found in Rangpur District which is shown in Table-4.2.4.

4.3 Drought Index calculated by using Rainfall 5 mm in Faridpur District

The daily rainfall of 30 years during the period from 1981-2010 in Faridpur District considering 52 standard weeks have been used and the results in Table-4.3.1.

Table 4.3.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Faridpur District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.57	0.61	0.59	30.88	13.72	0.36	Occasionally drought
10 years (1981-1990)	0.57	0.62	0.60	31.20	13.79	0.35	Occasionally drought
10 years (1991-2000)	0.57	0.59	0.58	30.24	13.09	0.34	Occasionally drought
10 years (2001-2010)	0.55	0.61	0.59	30.43	14.06	0.34	Occasionally drought

The mild and occasionally drought prone weeks are found in Faridpur District which is shown in Table-4.3.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Faridpur District considering 13 standard weeks have been used for Table-4.3.2.

Table 4.3.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Faridpur District for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.64	0.65	0.65	8.39	2.93	0.42	Occasionally drought
10 years (1981-1990)	0..71	0.72	0.72	9.36	2.67	0.51	Occasionally drought
10 years (1991-2000)	0.61	0.62	0.62	8.01	2.98	0.38	Occasionally drought
10 years (2001-2010)	0.60	0.60	0.60	7.8	3.12	0.36	Occasionally drought

The occasionally prone weeks are found in Faridpur District which is shown in Table-4.3.2.

The daily rainfall of Kharif season of 30 years (1981-2010) during the period from June to October in Faridpur District considering 22 standard weeks have been used for Table-4.3.3.

Table 4.3.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Faridpur District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.62	0.63	0.63	13.58	1.83	0.53	Occasionally drought
10 years (1981-1990)	0.86	0.88	0.88	19.36	2.23	0.76	Occasionally drought
10 years (1991-2000)	0.90	0.90	0.90	19.8	1.98	0.81	Occasionally drought
10 years (2001-2010)	0.09	0.10	0.09	1.58	1.41	0.009	chronic drought

The occasionally and chronic drought prone weeks are found in Faridpur District which is shown in Table-4.3.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Faridpur District considering 17 standard weeks have been used for Table-4.3.4.

Table 4.3.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Faridpur District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.14	0.14	0.14	2.46	2.05	0.023	Chronic drought
10 years (1981-1990)	0.14	0.14	0.14	2.38	2.05	0.019	Chronic drought
10 years (1991-2000)	0.20	0.21	0.20	3.43	2.70	0.042	Chronic drought
10 years (2001-2010)	.09	0.10	0.09	1.58	1.41	0.009	Chronic drought

The chronic drought prone weeks are found in Faridpur District which is shown in Table-4.3.4.

4.4 Drought Index calculated by using Rainfall 10 mm in Faridpur District

The daily rainfall of 30 years during the period from 1981-2010 in Faridpur District considering 52 standard weeks have been used and the results in Table-4.4.1.

Table 4.4.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Faridpur District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.51	0.55	0.53	27.56	14.03	0.28	Moderate drought
10 years (1981-1990)	0.53	0.55	0.54	28.08	13.44	0.29	Mild drought
10 years (1991-2000)	0.51	0.55	0.53	27.56	14.03	0.28	Mild drought
10 years (2001-2010)	0.50	0.54	0.52	13.00	6.76	0.27	Mild drought

The mild and occasionally drought prone weeks are found in Faridpur District which is shown in Table-4.4.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Faridpur District considering 13 standard weeks have been used for Table-4.4.2.

Table 4.4.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Faridpur District for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.58	0.58	0.58	7.50	3.11	0.34	Occasionally drought
10 years (1981-1990)	0.67	0.67	0.67	8.71	2.87	0.45	Occasionally drought
10 years (1991-2000)	0.54	0.54	0.54	7.02	3.23	0.29	Mild drought
10 years (2001-2010)	0.52	0.52	0.52	6.76	3.24	0.27	Mild drought

The occasionally and Mild drought prone weeks are found in Faridpur District which is shown in Table-4.4.2.

The daily rainfall of Kharif season of 30 years (1981-2010) during the period from June to October in Faridpur District considering 22 standard weeks have been used for Table-4.4.3.

Table 4.4.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Faridpur District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.84	0.85	0.85	18.68	2.75	0.71	Occasionally drought
10 years (1981-1990)	0.81	0.82	0.82	18.00	3.18	0.66	Occasionally drought
10 years (1991-2000)	0.84	0.85	0.85	18.67	2.74	0.71	Occasionally drought
10 years (2001-2010)	0.88	0.88	0.88	19.36	2.32	0.77	Occasionally drought

The occasionally drought prone weeks are found in Faridpur District which is shown in Table-4.4.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Faridpur District considering 17 standard weeks have been used for Table-4.4.4.

Table 4.4.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Faridpur District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.09	0.09	0.09	1.59	1.43	0.009	Chronic drought
10 years (1981-1990)	0.12	0.12	0.12	2.04	1.80	0.014	Chronic drought
10 years (1991-2000)	0.10	0.10	0.10	1.70	1.53	0.010	Chronic drought
10 years (2001-2010)	0.06	0.06	0.06	1.02	0.96	0.003	Chronic drought

The chronic drought prone weeks are found in Faridpur District which is shown in Table-4.4.4.

4.5 Drought Index calculated by using Rainfall 5 mm in Mymensingh District

The daily rainfall of 30 years during the period from 1981-2010 in Mymensingh District considering 52 standard weeks have been used and the results in Table-4.5.1.

Table 4.5.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Mymensingh District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.53	0.56	0.55	28.41	13.58	0.30	Mild drought
10 years (1981-1990)	0.55	0.57	0.56	29.18	13.36	0.31	Mild drought
10 years (1991-2000)	0.51	0.56	0.54	27.92	14.19	0.29	Mild drought
10 years (2001-2010)	0.48	0.53	0.51	26.27	14.22	0.25	Mild drought

The mild and occasionally drought prone weeks are found in Mymensingh District which is shown in Table-4.5.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Mymensingh District considering 13 standard weeks have been used for Table-4.5.2.

Table 4.5.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Mymensingh District for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.84	0.87	0.87	11.31	1.56	0.73	Occasionally drought
10 years (1981-1990)	0.61	0.59	0.60	7.80	2.99	0.36	Occasionally drought
10 years (1991-2000)	0.57	0.57	0.57	7.41	3.19	0.32	Occasionally drought
10 years (2001-2010)	0.68	0.70	0.69	9.02	2.97	0.48	Occasionally drought

The occasionally and Mild drought prone weeks are found in Mymensingh District which is shown in Table-4.5.2.

The daily rainfall of Kharif season of 30 years(1981-2010) during the period from June to October in Mymensingh District considering 22 standard weeks have been used for Table-4.5.3.

Table 4.5.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Mymensingh District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.84	0.84	0.84	18.48	2.96	0.71	Occasionally drought
10 years (1981-1990)	0.85	0.87	0.87	19.08	2.58	0.74	Occasionally drought
10 years (1991-2000)	0.89	0.90	0.90	19.78	1.96	0.80	Occasionally drought
10 years (2001-2010)	0.78	0.81	0.80	17.69	3.76	0.63	Occasionally drought

The occasionally drought prone weeks are found in Mymensingh District which is shown in Table-4.5.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Mymensingh District considering 17 standard weeks have been used for Table-4.5.4.

Table 4.5.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 5 mm in Mymensingh District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.38	0.38	0.38	6.46	4.00	0.144	Severe drought
10 years (1981-1990)	0.11	0.11	0.11	1.87	1.66	0.012	Chronic drought
10 years (1991-2000)	0.13	0.14	0.13	2.21	2.66	0.018	Chronic drought
10 years (2001-2010)	0.08	0.08	0.08	1.36	1.25	0.064	Chronic drought

The chronic and severe drought prone weeks are found in Mymensingh District which is shown in Table-4.5.4.

4.6 Drought Index calculated by using Rainfall 10 mm in Mymensingh District

The daily rainfall of 30 years during the period from 1981-2010 in Mymensingh District considering 52 standard weeks have been used and the results in Table-4.6.1.

Table 4.6.1. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Mymensingh District for Annual by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.48	0.51	0.49	25.73	13.93	0.24	Mild drought
10 years (1981-1990)	0.47	0.52	0.49	25.73	14.97	0.24	Mild drought
10 years (1991-2000)	0.39	0.52	0.45	23.31	16.65	0.20	Moderate drought
10 years (2001-2010)	0.46	0.50	0.48	24.92	14.04	0.22	Moderate drought

The mild and moderate drought prone weeks are found in Mymensingh District which is shown in Table-4.6.1.

The daily rainfall of Pre-Kharif season of 30 years (1981-2010) during the period from March to May in Mymensingh District considering 13 standard weeks have been used for Table-4.6.2.

Table 4.6.2. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in District Mymensingh for Pre-Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.57	0.60	0.59	7.67	3.33	0.34	Occasionally drought
10 years (1981-1990)	0.54	0.54	0.54	7.02	3.23	0.29	Mild drought
10 years (1991-2000)	0.54	0.56	0.55	7.16	3.35	0.30	Mild drought
10 years (2001-2010)	0.62	0.64	0.63	8.19	3.35	0.40	Occasionally drought

The occasionally and Mild drought prone weeks are found in Mymensingh District which is shown in Table-4.6.2.

The daily rainfall of Kharif season of 30 years (1981-2010) during the period from June to October in Mymensingh District considering 22 standard weeks have been used for Table-4.6.3.

Table 4.6.3. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Mymensingh District for Kharif season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	0.83	0.82	0.82	18.08	3.18	0.68	Occasionally drought
10 years (1981-1990)	0.79	0.79	0.79	13.73	2.88	0.62	Occasionally drought
10 years (1991-2000)	0.81	0.83	0.83	18.26	3.23	0.67	Occasionally drought
10 years (2001-2010)	0.79	0.79	0.79	17.38	3.65	0.62	Occasionally drought

The occasionally drought prone weeks are found in Mymensingh District which is shown in Table-4.6.3.

The daily rainfall of Rabi season of 30 years (1981-2010) during the period from November to February in Mymensingh District considering 17 standard weeks have been used for Table-4.6.4.

Table 4.6.4. Analysis of probability of wet and dry weeks and index of drought-proneness for rainfall 10 mm in Mymensingh District for Rabi season by Markov chain.

	P_{01}	P_{11}	P	Mean E(Y)	Variance	DI	Comment
30 years (1981-2010)	.06	0.07	0.06	1.03	0.99	0.004	Chronic drought
10 years (1981-1990)	0.07	0.07	0.07	1.19	1.11	0.004	Chronic drought
10 years (1991-2000)	0.08	0.08	0.08	1.36	1.25	0.006	Chronic drought
10 years (2001-2010)	0.05	0.05	0.05	0.85	0.81	0.002	Chronic drought

The chronic drought prone weeks are found in Mymensingh District which is shown in Table-4.6.4.

4.7 Scenario of Annual Dry –Wet Transition Probability Matrix for Rainfall 5 mm in Rangpur district

The occurrence and non-occurrence rainfall in Rangpur 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.

Table 4.7.1. The occurrence and non-occurrence rainfall in Rangpur 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	555	154	709
Wet	156	689	845
Total	711	843	1554
Cal χ^2	554.79		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.1) was Pr { $\chi^2 \geq 554.79$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.2. The occurrence and non-occurrence rainfall in Rangpur 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	170	55	225
Wet	57	229	286
Total	227	284	511
Cal χ^2	157.81		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.2) was
Pr { $\chi^2 \geq 157.81$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.3. The occurrence and non-occurrence rainfall in Rangpur 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	194	50	244
Wet	50	226	276
Total	244	276	520
Cal χ^2	195.92		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.3) was Pr $\{\chi^2 \geq 195.92\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.4. The occurrence and non-occurrence rainfall in Rangpur 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	171	49	220
Wet	49	244	293
Total	220	293	513
Cal χ^2	190.91		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.4) was Pr$\{\chi^2 \geq 190.91\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

The occurrence and non-occurrence rainfall in Rangpur district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.7.5.The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.

Table 4.7.5. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	57	185
Wet	33	162	196
Total	161	219	380
Cal χ^2	106.21		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	28	43	71
Wet	65	514	579
Total	93	557	650
Cal χ^2	41.04		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	409	47	456
Wet	45	13	58
Total	454	60	514
Cal χ^2	7.31		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.5) were $\Pr\{\chi^2 \geq 106.21\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 41.04\}$ for Kharif, $\Pr\{\chi^2 \geq 7.31\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.6. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	42	24	66
Wet	13	53	66
Total	55	77	132
Cal χ^2	26.22		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	12	14	26
Wet	23	170	193
Total	35	184	219
Cal χ^2	19.68		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	132	18	150
Wet	17	5	22
Total	149	23	172
Cal χ^2	181.81		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.6) were $\Pr\{\chi^2 \geq 26.22\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 19.68\}$ for Kharif, $\Pr\{\chi^2 \geq 181.81\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.7. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	53	17	70
Wet	11	54	65
Total	64	71	135
Cal χ^2	46.72		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	8	16	24
Wet	21	170	191
Total	29	186	215
Cal χ^2	9.11		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	139	13	152
Wet	14	6	20
Total	153	19	172
Cal χ^2	8.28		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.7) were $\Pr\{\chi^2 \geq 46.72\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 9.11\}$ for Kharif, $\Pr\{\chi^2 \geq 8.28\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.7.8. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	33	16	49
Wet	9	55	64
Total	42	71	113
Cal χ^2	33.73		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	8	13	21
Wet	21	174	195
Total	29	187	216
Cal χ^2	17.36		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	138	16	154
Wet	14	2	16
Total	152	18	170
Cal χ^2	0.07		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.7.8) were Pr{$\chi^2 \geq 33.73$}for Pre-kharif, Pr{$\chi^2 \geq$ 17.36} for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected but Pr{ $\chi^2 \geq 0.07$} for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

4.8 Scenario of Annual Dry –Wet Transition Probability Matrix for Rainfall 10 mm in Rangpur district

Table 4.8.1. The occurrence and non-occurrence rainfall in Rangpur 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	622	170	792
Wet	166	603	769
Total	788	773	1561
Cal χ^2	508.19		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.1) were Pr{ $\chi^2 \geq 508.19$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.8.2. The occurrence and non-occurrence rainfall in Rangpur 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	207	59	268
Wet	56	198	254
Total	263	257	510
Cal χ^2	158.78		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.2) was $\Pr\{\chi^2 \geq 158.78\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.8.3. The occurrence and non-occurrence rainfall in Rangpur 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	209	59	268
Wet	58	195	253
Total	267	254	521
Cal χ^2	162.17		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.3) was $\Pr\{\chi^2 \geq 162.17\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.8.4. The occurrence and non-occurrence rainfall in Rangpur 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	206	52	258
Wet	52	210	262
Total	258	262	520
Cal χ^2	187.18		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.4) was $\Pr\{\chi^2 \geq 187.18\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.8.5. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	142	70	212
Wet	44	138	182
Total	186	208	394
Cal χ^2	52.00		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	39	66	105
Wet	95	462	557
Total	134	528	662
Cal χ^2	17.60		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	432	33	465
Wet	36	6	42
Total	468	39	507
Cal χ^2	2.81		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.5) were Pr{ $\chi^2 \geq 52.00$} for Pre-kharif, Pr{ $\chi^2 \geq$ 17.60} for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But Pr{ $\chi^2 \geq 2.81$} for Rabi season being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.8.6. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	49	24	73
Wet	15	43	58
Total	64	67	131
Cal χ^2	22.03		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	13	21	34
Wet	31	154	185
Total	44	175	219
Cal χ^2	13.40		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	136	13	149
Wet	15	3	18
Total	151	16	167
Cal χ^2	1.17		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.6) were $\Pr\{\chi^2 \geq 22.03\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 13.40\}$ for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

But Pr{ $\chi^2 \geq 1.17$} for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.8.7. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	56	22	78
Wet	14	39	53
Total	70	61	131
Cal χ^2	26.12		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	12	24	36
Wet	30	154	184
Total	42	178	220
Cal χ^2	5.49		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	143	13	156
Wet	13	1	14
Total	156	14	170
Cal χ^2	0.024		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.7) were Pr{ $\chi^2 \geq 26.12$}for Pre-kharif, Pr{ $\chi^2 \geq 5.49$} for Kharif, Pr{ $\chi^2 \geq 0.024$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected but Pr{ $\chi^2 \geq 0.024$} for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.8.8. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Rangpur 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	37	24	61
Wet	15	56	71
Total	52	80	132
Cal χ^2	21.47		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	14	21	35
Wet	34	154	188
Total	48	175	223
Cal χ^2	8.41		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	**Dry**	Wet	Total
Dry	153	7	160
Wet	8	2	10
Total	161	9	170
Cal χ^2	4.58		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.8.8) were Pr{ $\chi^2 \geq 21.47$}for Pre-kharif, Pr{ $\chi^2 \geq 8.41$ } for Kharif, Pr{ $\chi^2 \geq 4.58$}

for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

4.9 Scenario of Annual Dry –Wet Transition Probability Matrix for Rainfall 5 mm in Faridpur district

The occurrence and non-occurrence rainfall in Faridpur district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.9.1. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.

Table 4.9.1. The occurrence and non-occurrence rainfall in Faridpur 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	509	151	660
Wet	147	753	900
Total	656	904	1560
Cal χ^2	600.60		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.1) was Pr $\{\chi^2 \geq 600.60\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

The chi-squire value of the transition matrix (Table 4.9.2) was Pr$\{\chi^2 \geq 209.41\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.9.2. The occurrence and non-occurrence rainfall in Faridpur 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	165	51	216
Wet	49	255	304
Total	214	306	520
Cal χ^2	209.41		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.2) was $Pr\{\chi^2 \geq 209.41\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

The chi-squire value of the transition matrix (Table 4.9.3) was $Pr\{\chi^2 \geq 156.86\}$ being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.9.3. The occurrence and non-occurrence rainfall in Faridpur 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	160	58	218
Wet	56	246	302
Total	216	304	520
Cal χ^2	156.86		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.3) was Pr{ $\chi^2 \geq 156.86$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.9.4. The occurrence and non-occurrence rainfall in Faridpur 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	184	42	226
Wet	42	252	294
Total	226	294	520
Cal χ^2	234.33		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.4) was Pr{ $\chi^2 \geq 234.33$} being very small indicating the null hypothesis that chain of order 0 is rejected.

The occurrence and non-occurrence rainfall in Faridpur district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.9.5. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.

Table 4.9.5. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Faridpur 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	97	67	164
Wet	48	168	216
Total	145	235	380
Cal χ^2	52.83		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	16	32	48
Wet	49	541	590
Total	65	573	638
Cal χ^2	29.23		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	384	44	428
Wet	37	17	54
Total	421	61	482
Cal χ^2	14.39		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.5) were Pr{$\chi^2 \geq 52.83$}for Pre-kharif, Pr{$\chi^2 \geq$ 29.23} for Kharif, Pr{$\chi^2 \geq 14.39$} for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.9.6. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Faridpur 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	22	23	45
Wet	17	68	85
Total	39	91	130
Cal χ^2	13.48		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	8	12	20
Wet	21	179	200
Total	29	19	220
Cal χ^2	13.88		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	133	18	151
Wet	15	5	20
Total	148	23	171
Cal χ^2	2.58		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.6) were Pr$\{\chi^2 \geq 13.48\}$ for Pre-kharif, Pr$\{\chi^2 \geq 13.88\}$ for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But Pr$\{\chi^2 \geq 2.58\}$ for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.9.7. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Faridpur 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	37	23	60
Wet	17	55	72
Total	54	78	132
Cal χ^2	19.62		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	5	13	18
Wet	17	185	202
Total	22	198	220
Cal χ^2	6.87		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	125	17	142
Wet	21	6	27
Total	146	23	169
Cal χ^2	2.02		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.7) were $\Pr\{\chi^2 \geq 19.62\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 6.87\}$ for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But $\Pr\{\chi^2 \geq 2.02\}$ for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.9.8. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Faridpur 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	38	21	59
Wet	14	45	59
Total	52	66	118
Cal χ^2	19.73		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	3	7	10
Wet	11	177	188
Total	14	184	198
Cal χ^2	8.48		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	126	9	135
Wet	12	6	18
Total	138	15	153
Cal χ^2	12.78		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.9.8) were $\Pr\{\chi^2 \geq 19.73\}$ for Pre-harif, $\Pr\{\chi^2 \geq 8.48\}$ for Kharif and $\Pr\{\chi^2 \geq 12.78\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

4.10 Scenario of Annual Dry –Wet Transition Probability Matrix for Rainfall 5 mm in Mymensingh district

The occurrence and non-occurrence rainfall in Mymensingh district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.10.1. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.

Table 4.10.1. The occurrence and non-occurrence rainfall in Mymensingh 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	515	141	656
Wet	138	756	894
Total	653	897	1550
Cal χ^2	617.32		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.1) was Pr {$\chi^2 \geq 617.32$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.10.2. The occurrence and non-occurrence rainfall in Mymensingh 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	177	47	224
Wet	44	243	287
Total	221	290	511
Cal χ^2	244.16		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.2) was Pr{ $\chi^2 \geq 244.16$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.10.3. The occurrence and non-occurrence rainfall in Mymensingh 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	161	45	206
Wet	45	269	314
Total	206	314	520
Cal χ^2	144.29		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.3) was Pr{ $\chi^2 \geq 144.29$} being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.10.4. The occurrence and non-occurrence rainfall in Mymensingh 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	177	49	181
Wet	49	244	293
Total	181	293	474
Cal χ^2	260.91		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.4) was Pr{ $\chi^2 \geq 260.91$} being very small indicating the null hypothesis that chain of order 0 is rejected.

The occurrence and non-occurrence rainfall in Mymensingh district for the 30 consecutive years from 1981 to 2010 were shown in Table 4.10.5. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1.

Table 4.10.5. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Mymensingh 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	75	61	136
Wet	41	177	218
Total	116	238	454
Cal χ^2	184.87		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	19	27	46
Wet	47	546	593
Total	66	573	639
Cal χ^2	51.81		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	39	42	433
Wet	44	16	60
Total	435	58	493
Cal χ^2	220.41		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.5) were $\Pr\{\chi^2 \geq 184.87\}$ for Pre-kharif, $\Pr\{\chi^2 \geq 51.81\}$ for Kharif, $\Pr\{\chi^2 \geq 220.41.\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected.

Table 4.10.6. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Mymensingh 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	35	22	57
Wet	13	58	71
Total	48	80	128
Cal χ^2	23.46		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	5	9	14
Wet	19	187	206
Total	24	196	220
Cal χ^2	18.67		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	135	14	149
Wet	14	5	19
Total	149	19	168
Cal χ^2	3.23		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.6) were Pr{ $\chi^2 \geq 23.46$} for Pre-kharif, Pr{ $\chi^2 \geq 18.67$ } for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But Pr{ $\chi^2 \geq 3.23$} for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.10.7. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Mymensingh 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	36	18	54
Wet	15	61	76
Total	51	79	130
Cal χ^2	27.74		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	4	9	13
Wet	12	195	207
Total	16	204	220
Cal χ^2	2.38		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	130	17	147
Wet	17	8	25
Total	147	25	172
Cal χ^2	7.18		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.7) were Pr$\{\chi^2 \geq 27.74\}$for Pre-kharif, Pr$\{\chi^2 \geq 7.18\}$ for Rabi seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But Pr$\{\chi^2 \geq 2.38\}$ for Kharif seasons being very high indicating the null hypothesis that chain of order 0 is accepted.

Table 4.10.8. The occurrence and non-occurrence data of Pre-kharif (March-May), Kharif (June-Oct) and Rabi (Nov-Feb) seasons of rainfall in Mymensingh 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	25	21	46
Wet	13	58	71
Total	38	79	117
Cal χ^2	16.21		
χ^2 (1 d.f. at 5% level)	3.84		

Kharif	Dry	Wet	Total
Dry	10	9	19
Wet	16	164	180
Total	26	173	199
Cal χ^2	42.05		
χ^2 (1 d.f. at 5% level)	3.84		

Rabi	Dry	Wet	Total
Dry	126	11	137
Wet	13	3	16
Total	139	14	153
Cal χ^2	1.97		
χ^2 (1 d.f. at 5% level)	3.84		

The chi-squire value of the transition matrix (Table 4.10.8) were Pr{$\chi^2 \geq 16.21$}for Pre-harif, Pr{$\chi^2 \geq$ 42.05} for Kharif seasons being very small indicating the null hypothesis that chain of order 0 is rejected. But Pr{$\chi^2 \geq 1.97$} for Rabi seasons being very high indicating the null hypothesis that chain of order 0 is accepted.