

## Chapter 6

# Markov Chain Analysis of Weekly Rainfall Data for Predicting Agricultural Drought

A.T.M. Jahangir Alam, M. Sayedur Rahman, and A.H.M. Sadaat

**Abstract** In the semiarid Barind region, episodes of agricultural droughts of varying severity have occurred. The occurrence of these agricultural droughts is associated with rainfall variability and can be reflected by soil moisture deficit that significantly affects crop performance and yield. In the present study, an analysis of long-term (1971–2010) rainfall data of 12 rain monitoring stations in the Barind region was carried out using a Markov chain model which provides a drought index for predicting the spatial and temporal extent of agricultural droughts. Inverse distance weighted interpolation was used to map the spatial extent of drought in a GIS environment. The results indicated that in the Pre-Kharif season drought occurs almost every year in different parts of the study area. Though occurrence of drought is less frequent in the Kharif season the minimum probability of wet weeks leads to reduction in crop yields. Meanwhile, the calculation of 12 months drought suggests that severe to moderate drought is a common phenomenon in this area. Drought index is also found to vary depending on the length of period. The return period analysis suggests that chronic drought is more frequent in the Pre-Kharif season and the frequency of moderate droughts is higher in the Kharif season. On the contrary severe drought is more frequent for a 12-month period.

**Keywords** Markov chain model • GIS • Agricultural droughts • Barind region

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## 6.1 Introduction

Drought is a complex natural phenomenon that has affected civilization throughout history. It occurs with varying frequency in all types of economic systems and in both developed and less developed countries. Almost all year around, drought occurs in one part of the globe. The wide variety of sectors affected by drought, its diverse geographical and temporal distribution, and the human demand placed on water supply make it difficult to develop a single definition of drought (Richard and Heim 2002). According to Al-Salihi (2003), Ben-Zvi (1987), and Darcup et al. (1980), drought is mainly caused by deficiency of rainfall which leads to severe agricultural and hydrological hazard. They described drought as a lack of rainfall, which cannot be prevented by social forces. In the context of Bangladesh, Brammer (1987) defined drought as a condition when soil moisture is less than the requirement of satisfactory crop growth during the seasons when crops are normally grown. Similarly, Heathcote (1974) defined drought as a situation when the short-fall of water is harmful for man's agricultural activities.

Drought is a recurring phenomenon in the northwestern part of Bangladesh. Though the drought has attracted less attention from the science community than flood or cyclone, several authors found that the impact of drought can be more defenseless than flood and cyclone (Brammer 1987; Shahid and Behrawan 2008; Shahid 2008; Alam et al. 2012a, b). This is also evident by statistics. For example, the loss of 1978/1979 drought was greater than the loss of flood in 1974 (Paul 1998). Rice production losses in the drought of 1982 were 50 % more than the losses caused by the flood in the same year (Ramsey et al. 2007). Furthermore, in the 1997 drought the national production of food grains reduced by one million tons, of which 0.6 million tons were T. aman (Ramsey et al. 2007).

On the global level, impacts of natural hazards and disasters are staggering. In Bangladesh, the major natural hazards are also in line with global patterns. In the context of global warming, most of the climate models project a decrease in precipitation in the dry season and an increase during the monsoon season in South Asia (Christensen et al. 2007; Shahid and Behrawan 2008). This will cause a cruel combination of more extreme floods and droughts in the region. Due to the land use changes within the country and its neighboring countries, Bangladesh has already showed an increased frequency of droughts in recent years (Shahid and Behrawan 2008). Concern among scientists has grown on changes of precipitation and frequent occurrence of droughts in Bangladesh. Moreover, agriculture is the largest sector of Bangladesh's economy and has an overwhelming impact on major macroeconomic activities like employment generation, poverty alleviation, human resource development, and food security (Shahid, 2010). Consequently, the impact of agricultural drought ultimately affects the overall social status of the people of Bangladesh. Therefore, it is important to analyze the agricultural drought severity and predict the time, area, and probability of its occurrence.

Markov chain models have been successfully used to derive agricultural drought indices in the Indian subcontinent (Alam 2010; Alam et al. 2011,

Alam et al. 2013; Banik et al. 2002; Barkotulla 2007). They have been used for determining drought proneness (Banik et al. 2002; Barkotulla 2007), analyzing rainfall drought correlation (Alam et al. 2011), analyzing agricultural droughts (Biamah et al. 2005), and predicting critical wet and dry spells (Ochola and Kerkidis 2003). Several studies also suggested that the reliability of meteorological persistence can be best described through Markov chain models of proper order (Rahman 1999a, b). However, the first-order Markov processes are adequate in representing the occurrence of rainfall events (Jimoh and Webster 1999). In addition, Markov chain models are found to be promising in simulating the length of the longest dry and wet spells and largest rainfall during monsoons (Sharma 1996; Biamah et al. 2005). In the present study, the first-order Markov chain model was chosen because of its flexibility to give a variety of useful statistical results. The spatial and temporal patterns of agricultural droughts were analyzed and the probability of wet weeks also estimated because it determines the soil moisture holding capacity, thus influences crop yields.

## 6.2 Study Area and Method

### 6.2.1 Climatic Condition of the Barind Region

Barind Tract is the largest Pleistocene physiographic unit of the Bengal Basin which covers an area of about 7,770 km<sup>2</sup>. Three distinct seasons can be recognized in this region: (1) the dry winter season from December to February, (2) the pre-monsoon hot summer season from March to May, and (3) the rainy monsoon season which lasts from June to October (Shahid 2011). Climatically, the region is characterized by high fluctuating rainfall and the ratio of dry to rainy months is found to be highest in Bangladesh. It is observed that the annual average rainfall vary between 1,300 and 1,600 mm and the seasonal distribution of rainfall shows that more than 90 % rainfall occurs during May to October (Shahid 2011). Although the whole region has long cool winter, the maximum number of days with temperature above 40 °C is observed in summer (Rahman 1999a). The location of the rainfall stations used in this study is given in Fig. 6.1.

Geologically Barind Tract belongs to an old alluvial formation which is usually composed of massive argillaceous beds of pale reddish brown color that often turns yellowish on weathering. Lime nodules and pisolitic ferruginous concretions occur throughout the soil. Locally the soils are rich in lime. Soils are deficient in nitrogen and phosphorus (Moslehuddin et al. 2008). The top soil of Barind Tract is reddish in color which is mainly in origin of Madhupur clay. Most of the soil is clay though a small amount of silt and fine sands are also encountered (Yasmin 2008). In the dry season the soil becomes very hard and in the wet season it becomes slippery rather than soft. The mean elevation of the area is 25 m above the mean sea level and is quite flat. The digital elevation model of the study area is given in Fig. 6.2.

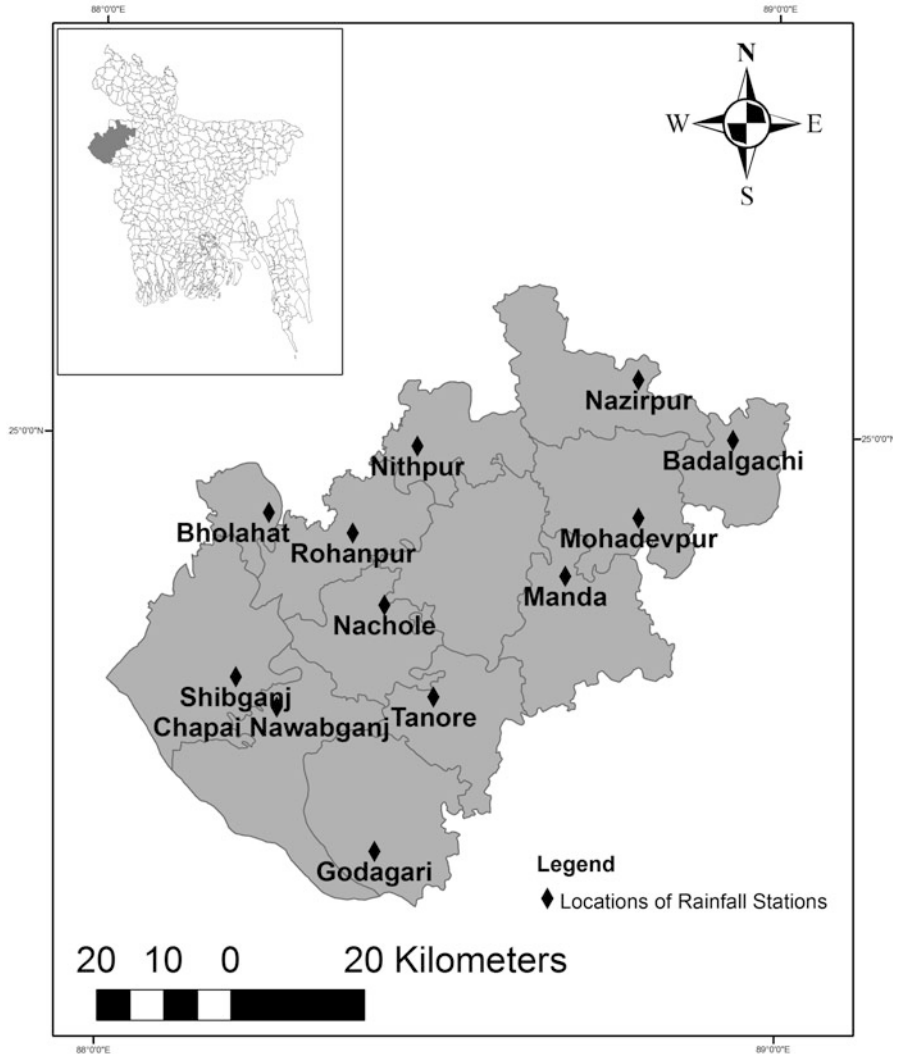
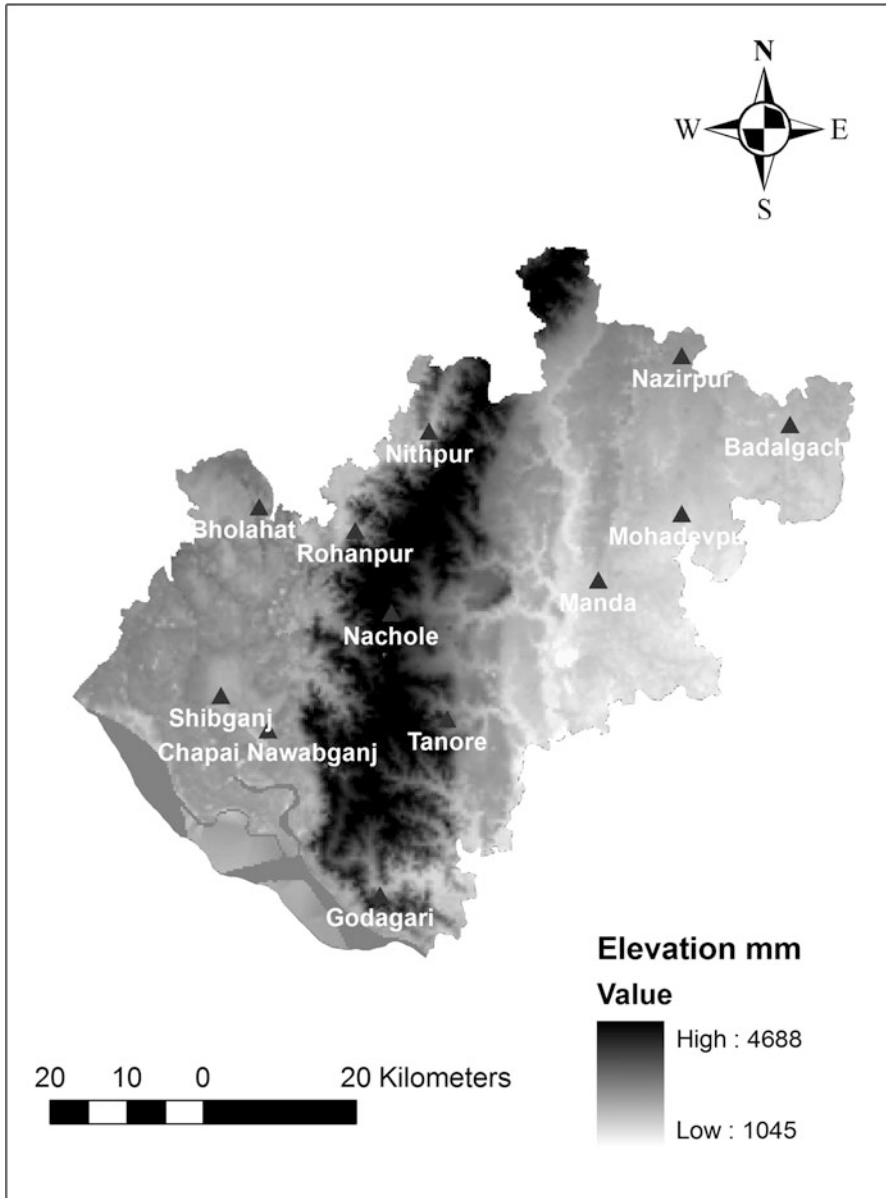


Fig. 6.1 Location of the rainfall stations

### 6.2.2 Markov Chain Agricultural Drought Index

Several authors have found that the sequences in daily rainfall occurrences can be described by a simple Markov chain model (Kazt 1974; Anderson and Goodman 1957; Rahman 1999a, b; Banik et al. 2002; Barkotulla 2007; Alam et al. 2011). The theory of Markov chain is described below by following Banik et al. (2002):



**Fig. 6.2** Digital elevation model of the study area

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

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

Firstly, it is assumed that,

$$\begin{aligned}
 P(X_{n+1} = x_{n+1} | X_n = x_n, X_{n-1} = x_{n-1} \dots X_0 = x_0) \\
 = P(X_{n+1} = x_{n+1} | X_n = x_n)
 \end{aligned}
 \tag{6.1}$$

where  $x_0, x_1, \dots, x_{n+1} \in \{0,1\}$ .

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

Considering the following transition matrix

$$\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

where  $P_{ij} = P(X_1 = j | X_0 = i), i, j = 0, 1, P_{00} + P_{01} = 1$  and  $P_{10} + P_{11} = 1$ .

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

For a stationary distribution,

$$[1 - p \quad p] \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} [1 - p \quad p]
 \tag{6.2}$$

which gives

$$p = \frac{P_{01}}{1 - (P_{11} - P_{01})}
 \tag{6.3}$$

It is further assumed that  $P_{ij}$  remains constant over the years. The maximum likelihood estimates of  $P_{01}$  and  $P_{11}$  are appropriate relative functions.

A wet spell of length  $k$  is defined as a sequence of  $k$  wet weeks preceded and followed by dry weeks. Dry spells are defined correspondingly. The probability of a wet spell of length  $k$ , given that this week is wet, is calculated as

$$P(W = k) = (1 - P_{11})P_{11}^{k-1}$$

The probability of wet sequences with length greater than  $k$  is

$$P(W > K) = \sum_{t=k+1}^{\infty} P(W = t) = P_{11}^k
 \tag{6.4}$$

Similarly, the probability of a dry spell of length  $m$  is

$$P(D = m) = (1 - P_{01})P_{01}^{m-1}$$

**Table 6.1** 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

And the probability of dry sequences with length greater than  $m$  is

$$P(D > m) = (1 - P_{01})^m \tag{6.5}$$

Let  $Y$  be a random variable such that  $Y =$  the number of wet weeks among an  $n$  weeks period, i.e.,

$$Y = X_0 + X_1 + \dots + X_{n-1}$$

For a large  $n$ ,  $Y$  follows a normal distribution with

$$\text{Mean} = n \times p \tag{6.6}$$

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

Hence, an index of drought proneness may be defined as

$$DI = P_{11} \times P_{01} \tag{6.7}$$

This index of drought proneness is bounded by 0 and 1. The higher the value of DI, the lower the degree of drought proneness. The extent of drought proneness is given in Table 6.1 (Banik et al. 2002).

### 6.2.3 Test of Null Hypothesis

Hypothesis testing arises for Markov chains just as it does for independent processes. The theory of hypothesis testing described below follows Medhi (1994):

Consider a time homogeneous Markov chain with a finite number,  $m$ , of states  $(1, 2, \dots, m)$  and having a transitional probability matrix  $P = (P_{jk}), j, k = 1, 2, \dots, m$ . Suppose that the number of observed direct transitions from the state  $j$  to the state  $k$  is  $n_{jk}$ , and that the total number of observations is  $(N + 1)$ , then we can put

$$\sum_{k=1}^m n_{jk} = n_j \quad \text{and} \quad \sum_{j=1}^m n_{jk} = n_k, \quad j, k = 1, 2, \dots, m$$

Suppose the observation comes from a Markov chain with a given transition, i.e., matrix  $P^0 = (P_{jk}^0)$  then  $t$  the null hypothesis is

$$H_0 : P = P^0$$

For a large  $N$ , the test statistic is given as

$$\sum_{k=1}^m n_j \frac{(P_{jk} - P_{jk}^0)^2}{P_{jk}^0}, \quad j = 1, 2, \dots, m \quad (6.8)$$

which is distributed as  $\chi^2$  with df (degrees of freedom) of  $m - 1$ . Here,  $P_{jk}^0$  is excluded when it equals to 0. Alternatively, a test for all  $P_{jk}$  can be obtained by calculating,

$$\sum_{j=1}^m \sum_{k=1}^m \frac{n_j (P_{jk} - P_{jk}^0)^2}{P_{jk}^0} \quad (6.9)$$

which has an asymptotic  $\chi^2$  distribution with  $m(m - 1)$  df ( the number of df being reduced by the number of  $P_{jk}^0$  which equals to 0, if any for  $j, k = 1, 2, 3, \dots, m$ ).

The likelihood ratio criterion for  $H_0$  is given by

$$\lambda = \prod_j \prod_k \left( \frac{P_{jk}}{P_{jk}^0} \right)^{n_{jk}} \quad (6.10)$$

Under the null hypothesis, the test statistic

$$-2 \log \lambda = 2 \sum_j \sum_k n_{jk} \log \frac{n_{jk}}{(n_j) P_{jk}^0} \quad (6.11)$$

has an asymptotic  $\chi^2$  distribution with  $m(m - 1)$  df

Here  $n_{jk}$  is the number of observed direct transition from state  $j$  to state  $k$  and  $P_{jk}^0$  is the probability of transition from state  $j$  to  $k$  under null hypothesis.

### 6.2.4 Mapping the Spatial Extent of Agricultural Drought

Inverse distance weighted (IDW) interpolation was used for mapping the spatial extent of agricultural droughts, which is expressed as

$$\hat{Z}(s_0) = \sum_{i=1}^N \lambda_i Z(s_i) \quad (6.12)$$



where

$\hat{Z}(s_0)$  = The drought index value to be predicted for location  $s_0$

$N$  = the number of the measured sample points (rainfall stations in this case) surrounding the prediction location

$\lambda_i$  = the weight assigned to the measured point  $i$  which decreases with distance from the prediction location

$Z(s_i)$  = the measured drought index value at location  $s_i$

As the IDW is chosen to predict spatial variations of agricultural drought, cross validation is essential to validate critical parameters that could affect the interpolation accuracy of drought index. In this case, a value was evaluated for optimal parameters. This ensures the overall utility of the IDW models and enables optimal data prediction that is comparable to the observed data.

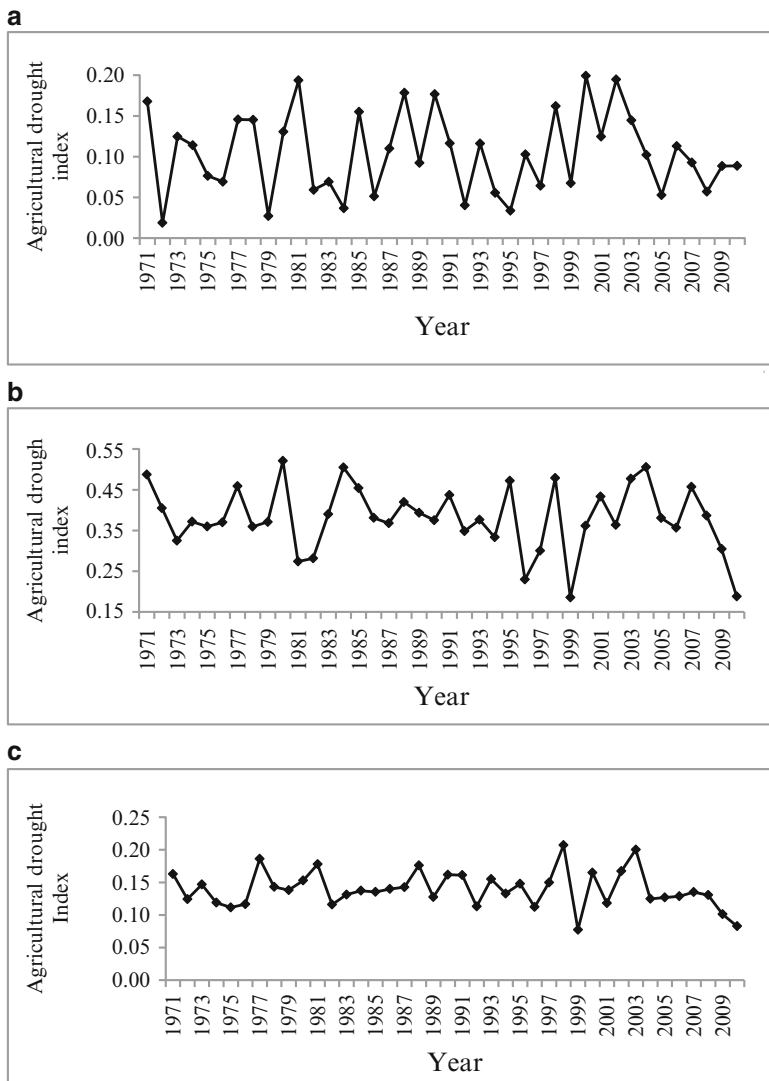
The IDW surface calculation depends on the selection of a power parameter ( $p$ ) and neighborhood search strategy. In this study, the root mean squared prediction error (RMSPE) was adopted to assess the IDW models performances. The best IDW model has the lowest RMSPE with mean error (ME) nearest 0 (Johnston et al. 2001). In the present study Geostatistical Analyst tool of Arc Map 9.3 was used to find the optimal powers of the IDW which produce minimum RMSPE and mean prediction error.

## 6.3 Results and Discussion

The daily rainfall data from 1971 to 2010 of the 12 rainfall stations were obtained from Bangladesh Water Development Board. The daily data were converted to weekly data because week is close to the optimum period for agriculture (Banik et al. 2002). As a Markov chain model is a threshold-based model, 20 mm weekly rainfall is considered as the threshold value on the basis of the findings of Alam et al. (2012a). Moreover, 13 and 21 standard weeks were considered for the Pre-Kharif and Kharif seasons, respectively. In order to find out the yearly drought scenario of Barind Tract, 12 months drought has also been calculated using 52 standard weeks.

### 6.3.1 Temporal and Spatial Characteristics of Agricultural Drought

The time series of agricultural drought occurrence is given in Fig. 6.3. Figure 6.3a indicated that during the Pre-Kharif growing season almost all years were affected by chronic to moderate agricultural drought. Although the severity of drought varies from year to year, the occurrence of chronic drought was more frequent



**Fig. 6.3** Time series of average agricultural drought index (a) Pre-Kharif season (b) Kharif season (c) over a 12-month period

during the period of 1991–1999. On contrast, the occurrence of the Kharif agricultural drought was less frequent.

During 1971–2010 around 5–6 Kharif agricultural droughts occurred in the area (Fig. 6.3b). As these drought indexes were calculated on the basis of the average data of the rainfall stations, they are not representative to some areas where chronic droughts occurred almost every year. Indeed the Kharif droughts also occur every year in some places in the Barind region. In addition, the Kharif agricultural droughts

were more frequent during the late 1990s, and after 2006 there were four consecutive drought events observed during this season. The 12 months drought indexes are given in Fig. 6.3c. It depicts that severe to moderate droughts occurred every year in the Barind region. Similar to the Kharif season, there were four consecutive chronic drought events observed during 2006–2010. This is because most of the rainfall in the Barind region occurs during the Kharif season. The Kharif season drought index primarily determines the occurrence of drought in a 12-month period.

The study also tried to understand the spatial distribution of the major drought events in the Pre-Kharif and Kharif seasons as well as over 12 months periods. The spatial distributions of the most important Pre-Kharif drought events every year is shown in Fig. 6.4. During this growing season, chronic droughts occur almost every year in some parts of the study area. From Fig. 6.4 it is evident that during 1971–2010 there were at least 5 years (1972, 1979, 1995, 2005, and 2008) when the entire study area was affected by chronic droughts, resulted from very low rainfall (almost 0) and high temperature which influenced the moisture holding capacity of soil (Alam 2010). The chronic agricultural droughts during the Pre-Kharif growing season increased the groundwater irrigation demand in *Boro* rice fields which share almost 70 % of the total rice production of Bangladesh. But in the Barind region, the lack of rain or chronic droughts compelled farmers not to seed their *Boro* rice. Moreover, around 85 % of the land remained fallow during this season in the Barind region (Alam et al. 2011; Saadat et al. 2009).

During the Kharif growing season, nine major drought years were identified during the period of 1971–2010. Among these, four drought years were identified during the last decade of the twentieth century (Fig. 6.5). A large variation is also observed in the spatial extent of these drought events. In 1982, around 32 % of the area was affected by moderate droughts and the drought severity was higher in the central part compared to other parts of the study area (Fig. 6.5). However, in 1994 the percentage of the moderately affected area is reduced to around 4 % and most severe drought events shifted from the central part to the central eastern part (Fig. 6.5). Among the Kharif drought events, in 2010 around 6 and 30 % of the area was affected by chronic and severe droughts, respectively (Fig. 6.5), and the northern part of the area was hardest hit. Along with these, in 1997, 1999, and 2009 the drought severity was higher in the western corner. These imply that the Kharif agricultural droughts may affect any place in the area in any year. The results of these drought events are also in line with the global patterns (Shahid and Behrawan 2008). It is well known that the last decade of the twentieth century was the driest in the last 100 years. The agricultural droughts of 1994 led to a decrease in rice and wheat production by  $3.59 \times 10^6$  tons (Shahid 2008 and Shahid and Behrawan 2008). Moreover, Dey et al. (2011) marked 1994 as the driest year in the contemporary period which had devastating impacts on the northwestern part of Bangladesh. The drought events of 1997 produced a shortfall of one million tons of food grains, of which 0.6 million tons were T. aman (Ramsey et al. 2007). Ramsey et al. (2007) also confirmed that around 2.32 million hectares of T. aman rice crops were damaged due to agricultural droughts every year in Bangladesh. On the other hand, Alam et al. (2011) and Rahman (2000) indicate this amount is 0.574–1.748

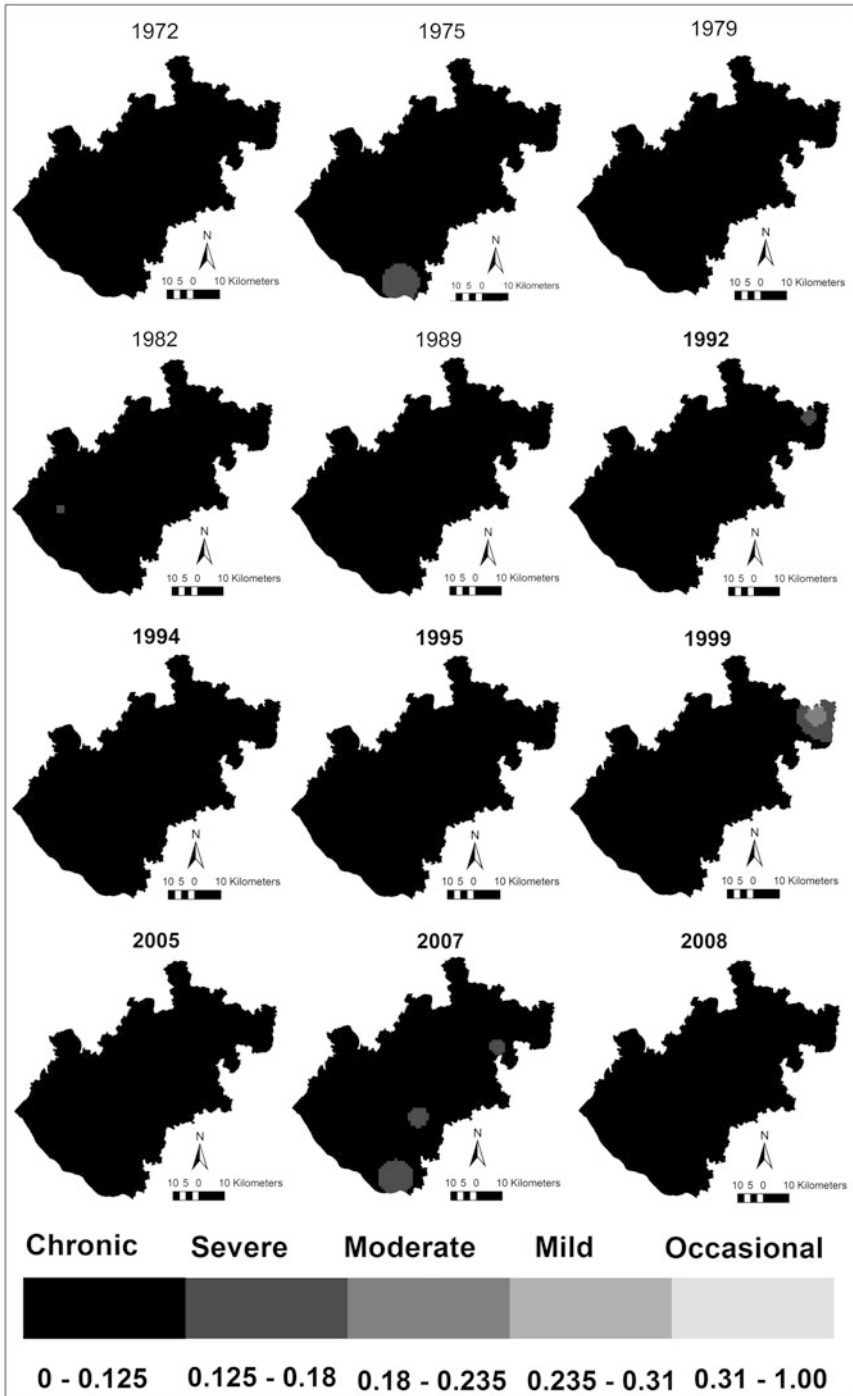


Fig. 6.4 Major agricultural drought events in the Pre-Kharif season

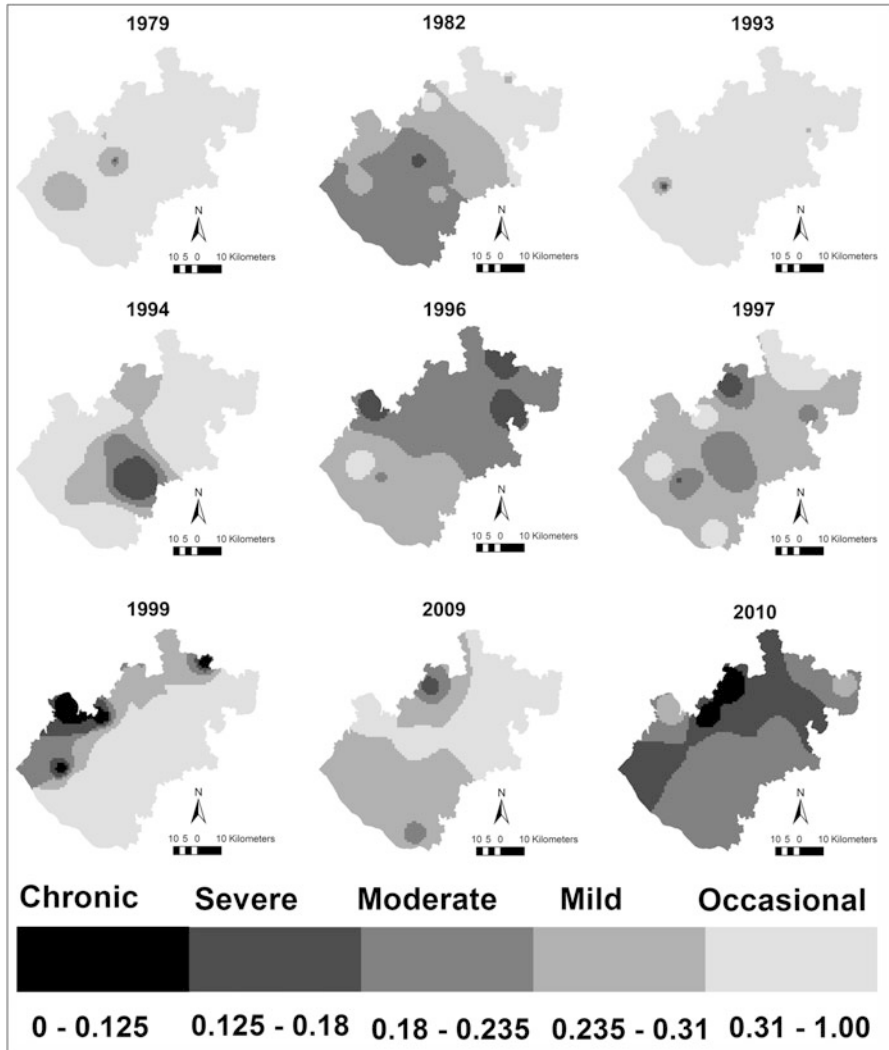


Fig. 6.5 Major agricultural drought events in the Kharif season

millions of hectares. Therefore it can be concluded that the results of these drought indexes are in line with historical drought events of the country.

The 12 months period drought index is calculated for the period from January to December. The major 12 months drought events are given in Fig. 6.6, which shows that drought may occur in any place of the Barind region. During the 12 months period, the agricultural drought does not follow any regular pattern. In 1972 the whole study area was affected by chronic droughts except the north eastern and north western corners. In 1974 the chronic droughts affected only the southern part.

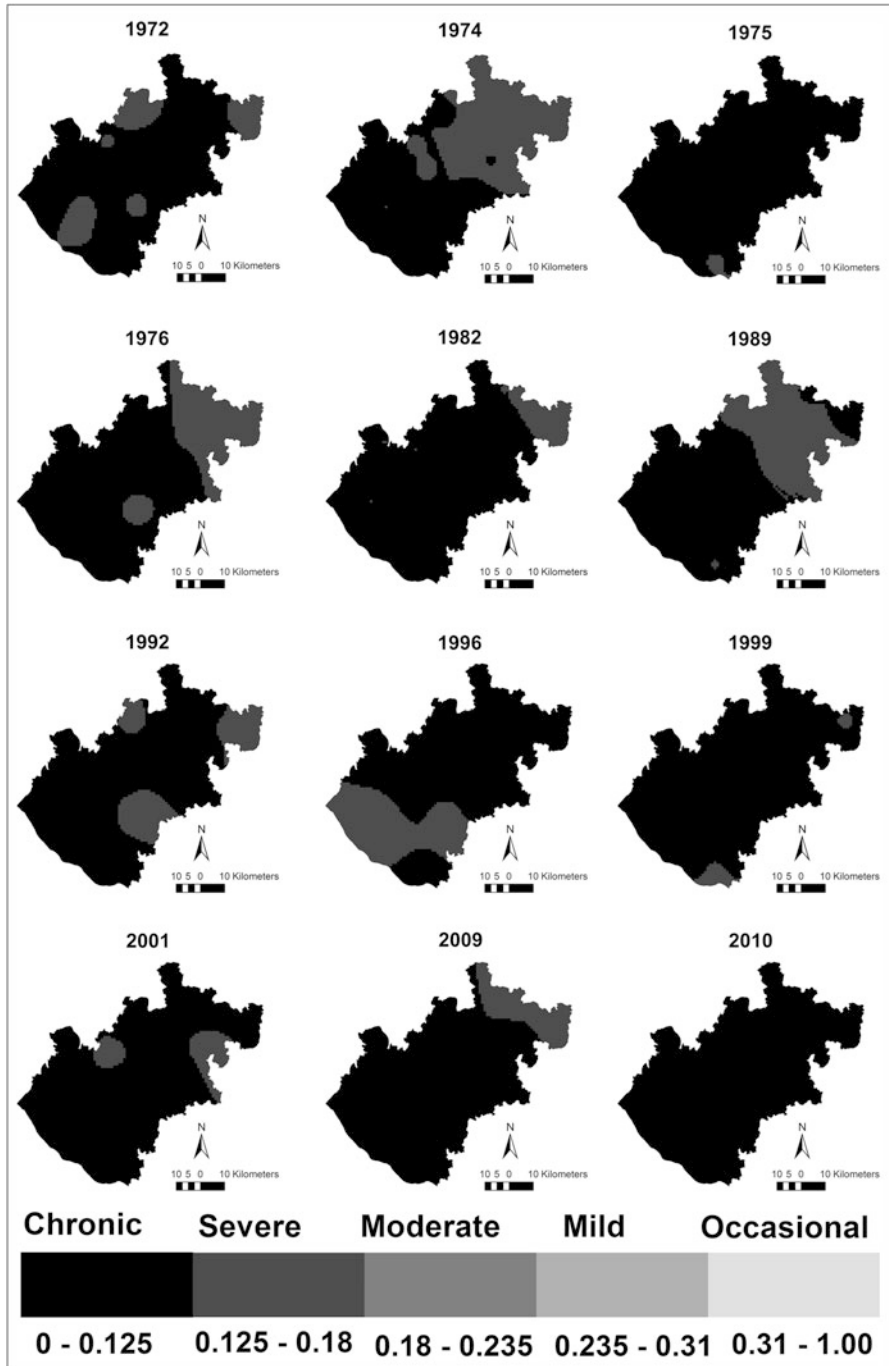


Fig. 6.6 Major agricultural drought events in 12 months period

On the contrary in 1996 the drought severity was higher in the northern Barind region (Fig. 6.6). The most severe consecutive drought years were observed during 2009 and 2010. The spatial distribution of drought in 2009 indicates that almost the whole study area except a small northern portion was affected by chronic droughts and in 2010 the whole study area experienced chronic droughts.

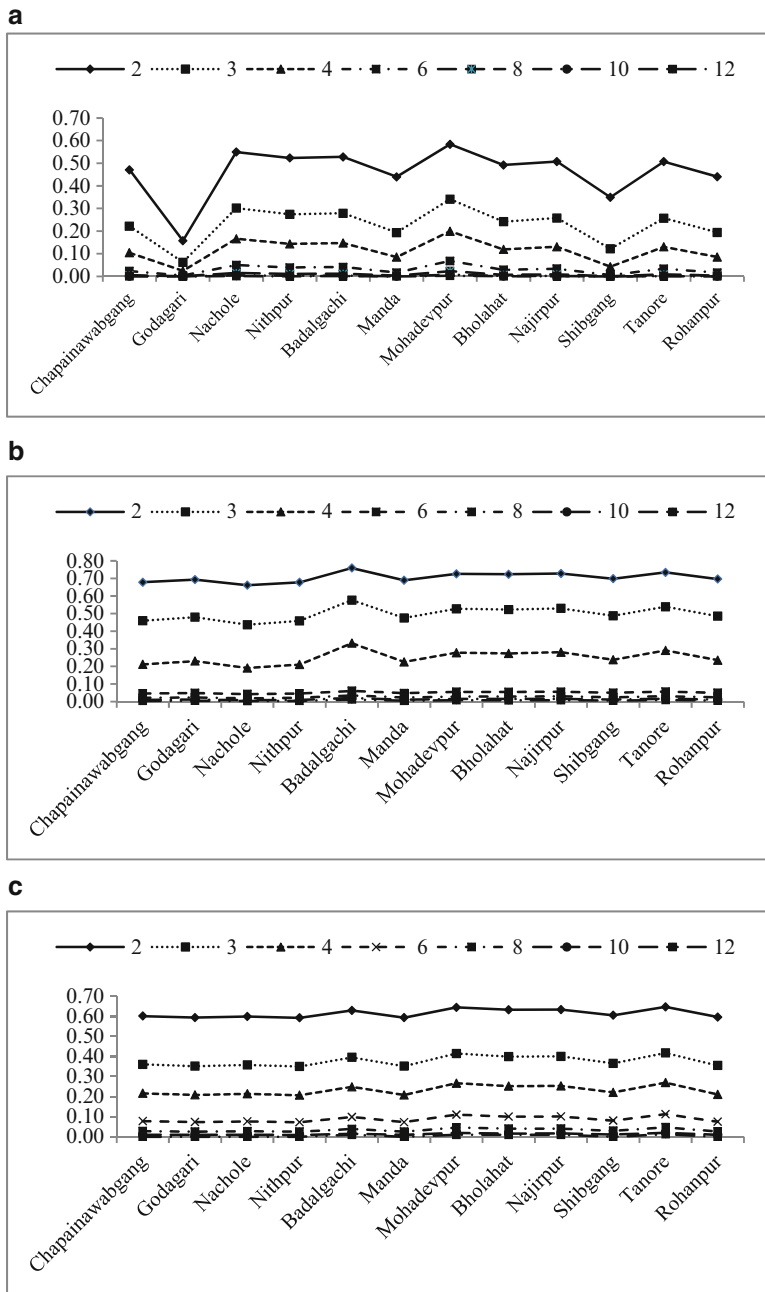
### ***6.3.2 Probability of Wet Spell***

As the soil moisture storage of the area depends on rainfall, an analysis of the probability of wet spell is carried out to predict the water holding capacity of the soil (Rahman et al. 2012). According to Banik et al. (2002) and Alam (2010), it is necessary to have 10–12 wet weeks for better crop production. Equation (6.4) was used to calculate the probability of wet spell. It is evident from Fig. 6.7a that the average probability of a wet spell of 5 or more weeks during the Pre-Kharif season approaches 0 at all rainfall stations. In Godagari station the probability of consecutive 4 or more wet weeks tends to 0 (Fig. 6.7a). Therefore, cropping is quite impossible without artificial irrigation during this season. In the Kharif season, the probability of a wet spell of longer than 5 weeks is close to 0. This result validates the statement of Saadat et al. (2009) that the most devastating drought occurred during this season because farmers totally depend on rain to sow their seeds. A small amount of rainfall (more than the threshold value) may be hindering to identify severe droughts in the Kharif season, but the very low probability of wet spell indicates that the area may be affected by future chronic to severe droughts.

To find out a suitable time for crop growing, the probability of annual wet spells was calculated. This probability suggests low chances of more than 5 consecutive wet weeks (Fig. 6.7c) and recommends the necessity of irrigation for better cropping in this region.

### ***6.3.3 Relative Frequency of Occurrence of Agricultural Drought***

The frequency analysis is commonly used in meteorology and hydrology to assess the return period of a particular event. The percentage of drought occurrence is computed by taking the ratio of agricultural drought occurrence in each season to the total agricultural drought occurrence in the same season for different drought categories. From Table 6.2 it can be noticed that in Chapai Nawabganj station the frequencies of chronic drought in the Pre-Kharif and Kharif seasons and over 12 months are 67.5 %, 0 %, and 52.5 %, respectively. This suggests that in the Pre-Kharif season the chronic drought may occur around three times in the 4 years duration, while as a 12-month event, the return period of chronic drought is 2 years.



**Fig. 6.7** Forty years average probability of wet weeks in (a) Pre-Kharif season (b) Kharif season (c) 12 months period



**Table 6.2** Relative frequency of occurrences (%) of agricultural drought at different rainfall stations of Barind in different seasons

Name of the station	Pre-Kharif			Kharif			12 months period		
	<i>C</i>	<i>S</i>	<i>M</i>	<i>C</i>	<i>S</i>	<i>M</i>	<i>C</i>	<i>S</i>	<i>M</i>
Chapai Nawabganj	67.5	17.5	10	0	2.5	17.5	52.5	32.5	10
Godagari	75	10	7.5	0	10	10	35	40	20
Nachole	77.5	5	10	2.5	7.5	12.5	42.5	45	7.5
Nithpur	65	25	2.5	2.5	5	7.5	35	45	12.5
Badalgachi	47.5	27.5	15	0	2.5	12.5	22.5	52.5	17.5
Manda	75	12.5	5	0	5	2.5	35	52.5	5
Mohadevpur	57.5	20	12.5	0	5	5	30	47.5	12.5
Bholahat	80	7.5	5	2.5	5	7.5	42.5	40	10
Nazirpur	72.5	12.5	7.5	2.5	2.5	5	32.5	55	2.5
Rohanpur	82.5	10	2.5	5	0	2.5	25	65	5
Shibganj	82.5	10	5	7.5	2.5	7.5	47.5	42.5	5
Tanore	57.5	22.5	5	0	2.5	7.5	57.5	32.5	2.5

*C* chronic drought, *S* severe drought, *M* moderate drought

**Table 6.3**  $\chi^2$  test for reliability of the occurrence and nonoccurrence rainfall recorded at different weather stations of BWDB at Barind region during 1971–2010

Stations	Value of $-2\log \lambda$		
	Pre-Kharif	Kharif	12 months period
Chapai Nawabganj	13.21	7.00	17.77
Godagari	5.51	8.18	5.5
Nachole	24.57	6.7	24.57
Nithpur	19.45	6.19	19.45
Badalgachi	16.23	7.84	16.23
Manda	16.95	6.62	9.45
Mohadevpur	27.96	8.79	27.96
Bholahat	17.18	19.27	17.18
Nazirpur	16.94	23.28	16.94
Shibganj	3.98	13.22	3.98
Tanore	14.85	13.41	14.85
Rohanpur	10.45	9.26	10.46

The frequency analysis of different categories of drought suggests that the occurrence of chronic drought is higher in the Pre-Kharif season, but during the Kharif season, the return period of moderate drought is shorter. Meanwhile, severe droughts more frequently affected the study area when considered as 12 months events.

### 6.3.4 Result of Hypothesis Testing

Hypothesis testing is an important requirement for running any statistical model. In the present study, a null hypothesis was tested against seasonal and annual wet and dry spells in every year using  $\chi^2$  test. The test of null hypothesis that the chain is of order 0 against the alternative hypothesis that is of order 1 is given in the Table 6.3.

The  $\chi$  value of the transition matrix in all the rainfall stations being very small ( $\chi^2 = 0.00393$  at 1 df at 5 % level) indicating the null hypothesis that chain of order 0 is rejected. Therefore, it can be said that the performance of the model is statistically satisfactory.

## 6.4 Conclusions

In the present study, seasonal and annual drought indexes of the Barind region of Bangladesh were calculated. Chronic droughts were found to occur in the Pre-Kharif season and farmers abstain from seeding. In the Kharif season good crops may grow depending on the blessing of adequate rain in time. Also moderate droughts were found to be more frequent during the Kharif growing season. A long-term probability calculation suggests that the area is potentially prone to future chronic and severe droughts. The modeling method can be replicated by considering crop diversity and various crop growing periods in different seasons under prevailing agroclimatic conditions. The outcome of this study might be helpful for the agricultural planners and irrigation engineers in operational responses to agricultural drought risk reduction in Bangladesh.

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