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Agricultural drought analysis of Chapai Nawabganj district in Bangladesh

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Abstract

The occurrence of agricultural drought is associated with seasonal rainfall variability and can be reflected by seasonal soil moisture deficits that significantly affect crop production. The stochastic behaviors of the largest rainfall amounts were predicted using a first order Markov model. The analysis was carried out using mean, variance, simple and conditional probabilities of dry and wet days. An analysis of variance (ANOVA) was carried out on the rainfall data of some studied areas established and it was found that the annual and seasonal rainfall variability between the stations were insignificant. The daily rainfall data was used to represent the rainfall features of the Chapai Nawabganj district in this study. The monthly rainfall analysis of the different rainy seasons showed high variability. There was also significant monthly variability in rainy days. The analysis of rainfall found that approximately 75% rainfall amount occurred in the months June to September. The seasonal probabilities of occurrencr of rainfall amount were derived from the cumulative distribution function of rainfall amount. During the Kharif season, there were the highest rainfall amounts when compared with other seasons.

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Introduction

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. However, drought can also occur in areas that lack of moisture in soil and air. Due to drought severity, the estimated yields of different crops are more reduced even may be more for transplanted aman and other rice varieties. In the study area, the major factor that controls agricultural productivity is rainfall. The variability of rainfall from one year to another causes significant differences in agricultural production with frequent low yields of subsistence crops.

The impacts of climate change on agricultural food production are of global concerns and they are very important for Bangladesh. Agriculture is the single most and the largest sector of economy of Bangladesh, with more than 70% of the working population engaged in this sector. In Bangladesh, agriculture is always under pressure, because of the huge and increasing demands for food, and also because of land and water resources depletion (Ahmed and Shibasaki, 2000). A wet spell occurs when there is an uninterrupted sequence of rainy days (Bogardi et al, 1988), and a dry spell l occurs when the wet spell is below some threshold crop water demand (critical soil moisture). Thus, a seasonal agricultural drought occur when a number of consecutive dry spells and subsequent cumulative soil moisture deficits. The severity of a critical agricultural drought is best described by the duration in days or months and expected soil moisture deficit in relation to crop water demand (Biamah et al., 2004).

Analysis of drought requires long term historical rainfall data. The strong variability in rainfall from year to year and season to season makes it necessary to use long periods of observation to obtain meaningful rainfall indices. A period of about 30 years must be considered the absolute minimum for a rainfall event analysis (Nieuwolt, 1978). Droughts are natural phenomena that is difficult to control or prevent, however, they are predictable. Prediction of droughts helps to provide the necessary information for drought preparedness through an early warning system. However, the occurrence of agricultural drought cannot be predicted with certainty and hence must be treated as random variables that can be investigated by the theories of probability and stochastic processes (Sharma, 1994). The stochastic behavior of rainfall can be predicted using the theory of runs (Yevjevich, 1967; 1972), Poisson distribution of the occurrence of spells, geometric distribution of the length of spells and the Weibull distribution of the total rain (rainfall amount) in a wet spell (Sharma, 1996). This study aims to determine the characteristics of annual, seasonal and monthly rainfall influencing agricultural drought in Chapai Nawabganj district. A stochastic model for the largest rainfall amounts using a first order Markov model was performed.

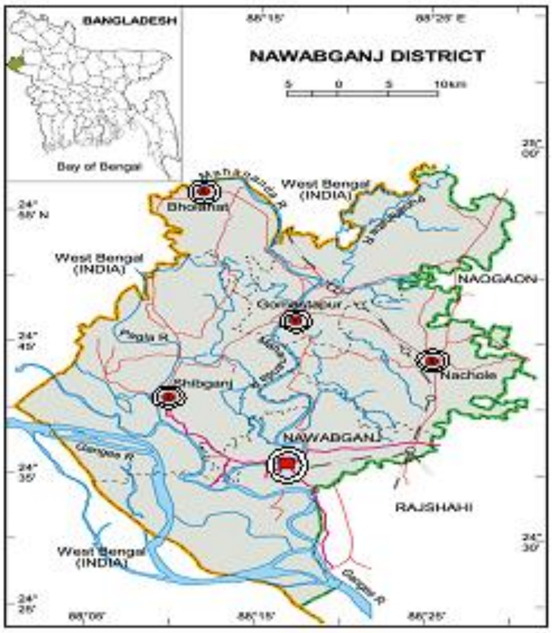

Fig. 1. Atlas of Chapai Nawabganj district in Bangladesh.

Chapai Nawabganj district (Figure 1) is located in a high Ganges floodplain and high Barind tract that is in the north-western part of Bangladesh. Its area is 1744.33 sq km. The district is consisted by 5 upazilas namely Chapai Nawabganj Sadar, Shibganj, Gomastapur, Nachle and Bholahat. Main occupations of the people are agriculture and agricultural labourer.

Analysis of rainfall characteristics

Rainfall data were collected for 30 years (1980-2009) from five rainfall recording stations in Bangladesh Water Development Board (BWDB). The data were analyzed for rainfall characteristics such as: variations in maximum, minimum and mean rainfall; and variations in annual, seasonal and monthly rainfall. An analysis of variance (ANOVA) was conducted to test of significant differences in rainfall between the five stations. The ANOVA was done using annual and seasonal rainfall data. An analysis of the number of rainy days and rainfall amount per rain day was done on a monthly basis to establish the distribution and reliability of rainfall within inter annual seasons. In Bangladesh there are three agro-climatic seasons, namely (1) Rabi (Winter) season which starts from November to February (2) Pre-Kharif (Summer) which includes the pre- heavy rain months of March to May and (3) Kharif which includes heavy rain months of June to October (Rahman and Alam, 1997).

Stochastic analysis and modeling of drought

A Markov process of order one (day) means that each day's state depends only on one previous day, it is the simplest type of dependence. The probability of occurrence of spells is often considered on the basis of simple (unconditional) and conditional probabilities. Let a day with rainfall more than zero is defined as a wet day (w) and with no rainfall is defined as a dry day (d). Thus the simple probability of any day being a wet day is defined as: p=P(w) and that of any day being a dry day is defined as q = P(d) such that p+q=1. The conditional probability of a wet day (t) given that the previous day (t-1) was also wet is defined as $P_{11}=P(w_t \mid w_{t-1})$ and the conditional probability of a dry day (t) given that the previous day (t-1) was also dry is defined as $P_{oo}=P(d_t|d_{t-1})$. The stochastic analysis of the largest rainfall amounts required estimate of probability parameters q, p, P_{oo}, P_{11}, means=E(x); and variances=V(x) These parameters need to be estimate, from a long term daily rainfall data. The first order Markov model was chosen to analyze the stochastic behavior of the largest rainfall amounts.

Methods

The feasibility of using a simple Markov chain model has been presented by Katz (1974), Anderson and Goodman (1957), Todorovic and Woolhiser (1975), Sharma,1996 and Rahman (1999 a & b). ,.

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

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

Consider the transition matrix as

$$\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} \quad (2)$$

where ;

$P_{ij} = P(X_1 = j \mid X_o = i)$ for, i,j = 0,1.

And;

$P_{oo}+P_{o1} = 1$ and $P_{10}+P_{11} = 1$

The probability distribution of the length of spells follows geometric distributions (Gabrial and Neumann, 1957; 1961, Sen, 1980; Kottegoda, 1980; Bogardi et al, 1988) and expressed as follows (Sharma, 1996; Ochola and Kerkides, 2003):

Thus the probability of a wet spell with a length of j days is:

$$P(L_w = j) = (1-P_{11})P_{11}^{j-1} \quad (3)$$

Similarly, probability of a dry spell of length m is

$$P(L_d = m) = (1-P_{o1})P_{o1}^{m-1} \quad (4)$$

Sen (1977) has derived the following relationships for the expected values of L_w denoted by $E(L_w)$ for Markovian runs as:

$$E(L_w) = \frac{1}{(1-P_{11})} \quad (5)$$

In a wet spell analysis, an additional element that appears is the total rain, denoted by S. Following the above analysis, the probability distribution of S_m (largest rainfall amount) can be expressed by the following relationship (Todorovic and Woolhiser, 1975; Sen, 1980; Sharma, 1996; Biamah et al, 2004):

$$P(S_m \le D) = \exp[-np(1-P_{11})P(S > D)] \quad \text{for}$$

$0 < S < \infty$ (6)

where n is the sample size(number of days). P(S ≤D) is the probability of a rainfall amount being less than or equal to a particular value D (say 5, 10, 15, 20, ..., 120 mm).

The probability distribution of S follows a Weibull distribution (Bonacci, 1993; Sharma1996), where;

$$P(S \le D) = 1 - \exp\left[-\left(\frac{D}{B}\right)^A\right] \quad (7)$$

or

$$P(S > D) = \exp\left[-\left(\frac{D}{B}\right)^A\right] \quad (8)$$

To estimate the parameters A and B of the Weibull PDF, the method of moments are used, the values of the mean, E(S) and variance, V(S) are needed. The estimated mean and variance of the daily rainfall sequence are as follows (Şen, 1978; 1980; Llamas, 1987; Biamah et al, 2004):

$$E(S) = \frac{kE(x)}{p} \quad (9)$$

$$V(S) = \left[\frac{pV(x) + qE(x)^2}{p^2}\right]\left[k + 2r\frac{k(1-r)-(1-r^k)}{(1-r)^2}\right] \quad (10)$$

where r is the lag 1 serial correlation coefficient between daily rainfalls ,and k is the mean length of wet spell and can be obtained by the equation:

$$k = E(L_w) = \left[\frac{1}{1-P_{11}}\right] \quad (11)$$

The mean E (x) and variance V (x) can be calculated using the daily rainfall data for a season.

Results and discussion

Characteristics of rainfall

The mean annual rainfall in Chapai Nawabganj district (based on 30 years rainfall record) of the five rainfall recording stations was 1470 mm (millimetre) with a station rainfall range from 1370 mm (Chapai Nawabganj Station) to 1605 mm (Bholahat Station). During the thirty years of rainfall record, mean annual rainfall amounts were below the mean in ten years. The coefficients of variation (CV) of rainfall station ranged from 21.97% to 33.87%, which shows that the variability in rainfall amounts between these stations is low. The Rabi season is bring about 41 mm (2.78%) and the pre-Kharif season about 202 mm (13.71%) and the Kharif season about 1227 mm (83.517%) of the total annual rainfall (1469.69 mm). Maximum rainfall exists in the Kharif (Autumn) season, that is from July to September (Fig 2). During the seasonal rainfall periods, the coefficients of variation ranged between 77.12% to 133.17% (Rabi season) and 33.87% to 68.84% (pre-Kharif season) and 23.57% to 34.52% (Kharif season) (Table 1).

Also found that the mean coefficient of variation of the Kharif season (CV=28.14%) is the smallest than that of the pre-Kharif (CV=51.63%) and Rabi season (CV=98.81%) implying that the Kharif are most uniform that the other. These results also confirm that the Kharif season is the main season for crop production in the study area.

A one-way analysis of variance (ANOVA) was carried out to establish if the rainfall at these stations belongs to the same population; i.e., the average rainfall amounts in the five stations are equal (Table 2). Table (2) shows that, the five populations (stations) do not differ significantly (α= 5%), thus, the variability is zero. However; the monthly rainfall in Chapai Nawabganj station is significantly high over a 39 years period (1971-2009), as exhibited from the coefficients of variation, given in Table 3. This is so even for the wettest months of July (Kharif season) and May (pre-Kharif season) but every month is very dry in Rabi season. The variability of mean monthly rainfall during the drier months is significantly higher than the wet months. From this analysis, it is evident that the driest months in Chapai Nawabganj station are November December, January, February and March.

An analysis of the number of rainy days and the rainfall amounts received per month is exhibited in Fig 3. It shows that the average number of seasonal rainy days is 4 days for the Rabi season (December to February): 12 days for the pre-Kharif season (March to May) and 61 days for the Kharif season (June to October).

Table 1. Annual and seasonal rainfall data (mm) for 30 years (1980-2009) from five rainfall stations in Chapai Nawabganj district.

Rainfall	Parameter	Chapai Nawabganj	Sibganj	Gomostapur	Nachole	Vholahat	Mean
Annual	Mean	1370	1463.7	1432.3	1478.2	1604.7	1470
	CV	24.82	26.92	21.97	22.9361	33.87	26.10
	Max	2069.5	2276	2433.5	2568.9	3265	2522.58
	Min	600.964	718	995	796.29	807.4	783.53
Rabi	Mean	35.5	38.8	40.3	38.4	52.2	41
	CV	93.9	80.32	77.12	109.56	133.17	98.81
	Max	113	148	150.5	160.4	365	187.38
	Min	0	0	0	0	0	0
	% Annual mean	2.59	2.65	2.81	2.60	3.25	2.78
Pre-Kharif	Mean	194	177.6	193.8	200.3	243.5	201.8
	CV	48.56	57.69	49.21	68.84	33.87	51.63
	Max	357.2	426.72	498.1	493.27	1345	624.05
	Min	61.72	63	74	12	57	53.54
	% Annual mean	14.17	12.13	13.53	13.55	15.18	13.71
Kharif	Mean	1140	1247.3	1198.2	1239.5	1309	1226.8
	CV	27.31	29.07	23.57	26.21	34.52	28.14
	Max	1875.3	1983	2077	2366.9	2432	2146.84
	Min	446.53	561	785	676.66	540	601.84
	% Annual mean	83.24	85.21	83.66	83.85	81.57	83.51

Table 2. The ANOVA table for rainfall between five rainfall stations in Chapai Nawabganj district (N=150).

Season	Source of variation	Degrees of freedom	Sum of square	Mean square	F_{cal}	$F_{tab,5\%}$
Annual	Station	4	893520.48	223380.12	1.43	2.37
	Error	145	22624305.83	156029.70		
Rabi	Station	4	5032.25	1258.06	0.65	2.37
	Error	145	280010.91	1931.11		
Pre-Kharif	Station	4	78588.28	19647.07	1.02	2.37
	Error	145	2790955.67	19247.97		
Kharif	Station	4	470751.2	117687.8	0.95	2.37
	Error	145	17920614	123590.4		

This analysis of annual, seasonal and monthly rainfall variation in Chapai Nawabganj district has shown that annual rainfall variations are low, seasonal rainfall variations are slightly higher, while average monthly rainfall values have the highest variability.

Stochastic behavior of rainfall

The values of the probability parameters p, q, P_{00}, P_{11}, E(x) and V(x) were estimated from the daily rainfall data of Chapai Nawabganj station (1991-2009) and also estimated probability parameters for annual and different seasons (Table 4).

Table 3. Mean monthly rainfall behavior for 39 years (1971-2009) at Chapai Nawabganj station.

Month	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	mean
Mean	8.06	12.3	18.52	35.09	135.8	216.3	285.7	234.5	251.4	102.8	8.33	5.03	109.5
CV	177.6	146	151.8	105.3	62.34	65	44.33	44.04	66.56	78.17	173.1	345.1	121.6
Max	56	78.2	116.2	143.7	451	541.3	671	511.8	872.3	266.8	60.6	105	322.8
Min	0	0	0	0	0	7.6	33.1	66.6	43.70	0	0	0	12.58
%	0.61	0.94	1.41	2.67	10.34	16.47	21.74	17.85	19.13	7.82	0.63	0.38	

Table 4. Annual and seasonal parameters values of Chapai Nawabganj station (1971-2009)

Parameter	Annual	Rabi	Pre-Kharif	Kharif
p	0.204	0.029	0.383	0.134
q	0.796	0.971	0.617	0.866
P_{11}	0.528	0.279	0.598	0.267
P_{oo}	0.879	0.978	0.749	0.889
E(x)	3.601	0.279	2.074	7.112
V(x)	159.575	6.211	72.393	309.448
Lag-1	0.262754	0.176793	0.15357	0.224056
A	0.721	0.645	0.66	0.815
B	30.40	9.605	15.75	41.30

Table 5. Probabilities of rainfall amounts of annual and different seasons in Chapai Nawabganj station (1971-2009).

Rainfall	Annual	Rabi	Pre-kharif	Kharif
0	100	100	100	100
10	64	36	48	73
20	48	20	31	57
30	37	12	22	46
40	30	8	16	38
50	24	6	12	31
60	20	4	9	26
70	16	3	7	21
80	13	2	5	18
90	11	1	4	15
100	9	1	3	13
110	8	1	3	11
120	7	1	2	9
130	6	0	2	8
140	5	0	1	7
150	4	0	1	6

The seasonal probabilities of occurrence of rainfall amount of derived from the cumulative distribution function of Chapai Nawabganj station are presented in Table 5. Generally, during the Kharif season, there is a highest rainfall amounts when compared with the other seasons. For example, the probability of occurrence of rainfall amounts with 80 mm or more level is 18% for Kharif season, 5% for pre-Kharif and 2% for Rabi season but 13% for annual. The largest rainfall amounts at 50% or more probability (median) are 26.3 mm for Kharif season, 9.0 mm for pre-Kharif and 5.4 mm for Rabi season where as 18.0 mm for annual. This analysis has confirmed that the Kharif season is more reliable for crop production than other seasons.

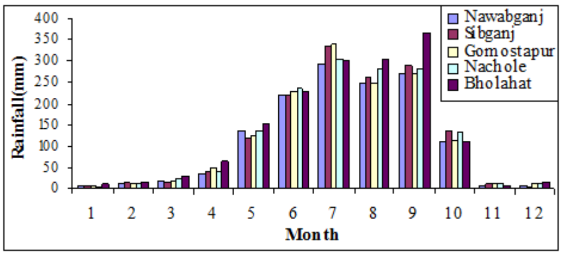

Fig. 2. The mean monthly rainfall among the rainfall stations in five Chapai Nawabganj districts.

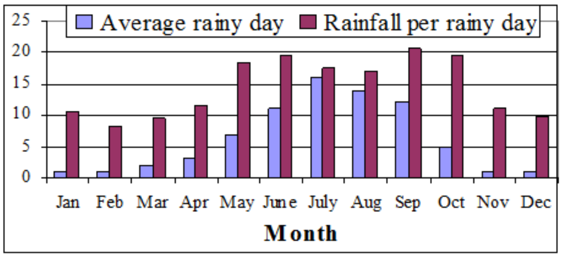

Fig. 3. Average rain days and rainfall depth per rain day at Chapai Nawabganj station for the periods (1971-2009).

Conclusions

An analysis of variance (ANOVA) carried out on Chapai Nawabganj district rainfall data established that annual and seasonal rainfall variability between the stations is not significant and hence Chapai Nawabganj station's daily rainfall data was used to represent the rainfall features in this study. The monthly rainfall analysis of the three rainy seasons showed high variability of monthly rainfall. There was also significant monthly variability in rainy days. On a monthly basis, the analysis of rainfall showed that approximately 75% rainfall amount occurred in the months June to September. The Markov model performed well in simulating the largest rainfall amounts during every season in Chapai Nawabganj district. The median values of probability parameters based on the daily rainfall data were used in these predictions. The largest rainfall amount can be used to determine the water discharge that would assist in the design of flood and waterlog and the design of runoff water control system. The statistics from this analysis have shown that the Kharif season (June to October) is evenly distributed, reliable and adequate for crop production. On the contrary, the pre-Kharif season (March to May) is poorly distributed, unreliable and inadequate for crop production. Also severe drought is occurred during the Rabi season (November to February).

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