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Stochastic Modelling of Daily Rainfall at Naogaon District in Bangladesh: A Comparative Study

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Abstract

The weather plays a significant role in the agriculture of a country. Rainfall is the most important weather parameter affecting non-irrigated crop areas. The region lies in the driest part of the country in terms of rainfall and is semi-arid in character. Markov chain model has been used to evaluate probabilities of getting a sequence of wet-dry weeks over this region. A non-linear proceed, the model is tested using multivariate logistic regression technique. The results showed the relative frequency of rain against the estimated value of P using the logistic regression at 7 days interval. The results of the relative frequencies of 0.29 and 0.71 are similar in the study area. The logistic regression technique allows flexibility in deciding between areas of indicated rain or no rain. The results indicate that no rain is predicted when the estimated value of P is less than 0.5 and rain, when it is greater than 0.5. Therefore when the estimated P is less than 0.1, it is almost not raining. Basically this type of information gives the advantages of logistic regression over a simple threshold technique to agricultural planners and irrigation engineers in identifying the areas where agricultural development should be focused as a long-term drought mitigation strategy.

Key word: Rainfall, Markov chain, logistic regression, probability, parameter, relative frequency.

1. Introduction

Agro-ecologically the Barind Tract is divided into three regions: Level Barind Tract, High Barind Tract and Northeastern Barind Tract. The High Barind Tract is located in Rajshahi, Nawabganj and Naogaon districts. The region lies in the driest part of the country and is semi-arid in character. The mean annual rainfall is about 1,350 mm (NAP, 2005). Groundwater supplies are generally poor in the more hilly western part. The predominant land use is transplanted aman grown as a single crop during the rainy season. The rest of the year is arid and basically crop less. Non-irrigated land generally remains fallow in the dry season. Early rabi crops are grown where irrigation is available. Shortage of rainfall affects the critical reproductive stages of transplanted aman crops in October, reducing its yield, particularly in those areas with low soil moisture holding capacity (WARPO- EGIS, 1996).

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

Changes in global temperatures and precipitation have enormous impacts, such as on the geographical range of crop cultivation; this type of information is essential when discussing the impacts of global warming on humanity. Variability of rainfall is especially important because it effects on both hydrology and agriculture of a drought prone high Barind region in Bangladesh (Rahman and Alam, 1997, Barkotulla et al., 2007)

Rahman (1999b) developed a simulation rainfall model and tested it using a multivariate logistic regression technique to estimate the probability of rain events. The model used historical data to estimate model parameters. The estimated parameters could be used in the model to produce a daily-simulated rainfall. The Markov chain model is useful to have a measure of the certainty of the decision. This information may be useful for both instantaneous and climate time scale.

Several studies have demonstrated significant changes in local, regional, and global surface air temperature and precipitation patterns measured over the past century (Vinnikov et al., 1987; Jones, 1988; Hensen and Lebedeff, 1988; IPCC, 1997). Climatic system is not simple to be understood due to its non-linearity of interactions among many physical and dynamical processes under external forcing (Oh and Lee, 2000).

After 1971 Bangladesh has experienced droughts of major magnitude in 1973, 1978, 1979, 1981, 1982, 1989, 1992, 1994, and 1995. Although droughts are not always continuous in any area, they do occur sometimes in the low rainfall zones of the country. As listed above, Bangladesh experienced consecutive droughts in 1978-1979, 1981-1982, and 1994-1995. The droughts of 1994-95 in the northwestern districts of Bangladesh led to a shortfall of rice production of 3.5 million tons (Paul, 1995). Two critical dry periods are distinguished (Karim et al., 1990). Rabi and pre-Kharif drought (January - May), due to: (i) the cumulative effect of dry days; (ii) higher temperatures during pre-Kharif (> 40 degrees Celsius in March-May); and (iii) low soil moisture availability (NAP, 2005).

2. Description of the Study Area

Naogaon district is the western part of Bangladesh with an area of 3435.67 sq km, which is bounded by West Bengal of India on the north, Natore and Rajshahi districts on the south, Joypurhat and Bogra districts on the east, Chapai Nawabganj district and West Bengal (India) on the west. Most of the people of the area are related to agriculture and agricultural labour. There are three seasons in a year: summer, monsoon and winter. The summer covers the period from March to May. The monsoon season is spread over the months of June to October. Eighty percent of the rainfall occurs during the monsoon season. The winter season is spread over the months of November to February of the following year. There are hardly any rains during the winter season.

The rainfall is either monsoonal, inter-monsoonal or cyclonic in origin (http://www.banglapedia.net/HT/C_0288.HTM). Rainfall varies from place to place as well as year to year. The minimum annual rainfall is 1002.4 mm at Mohadevpur in the year 2001 and the maximum rainfall is 2421.9 mm at Badolgachi in the year 1998 and the annual average rainfall 1607.68 during the study period. The annual temperature is maximum 37.8°C although occasionally it rises up to 40^0C and the minimum is 11.2°C sometimes it falls to about 5°C. It is the driest part of the country which has been already identified as the high Barind region (agro-ecological zone no. 26).

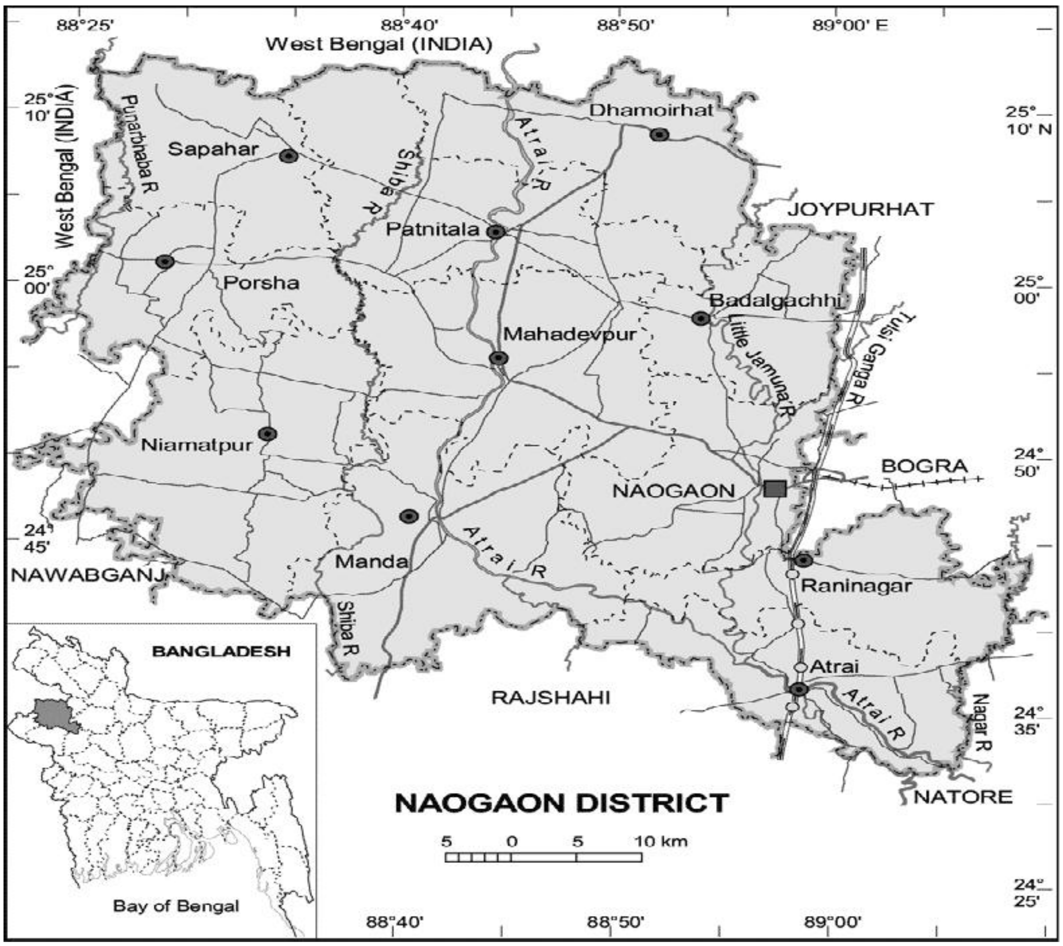

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Fig.1: Map of the study area

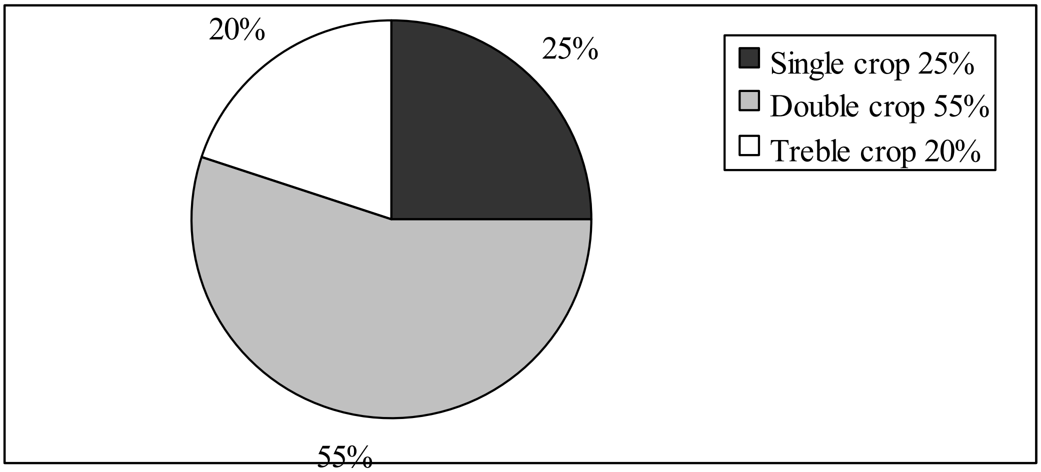

Fig.2: The percentage of agricultural land use for crop production

2.1 Data Collection

There are six rainfall stations located at Naogaon district of high Barind region in Bangladesh. The stations are Naogaon, Sapahar, Mohadevpur, Badolgachi, Najipur (Patnitala) and Nitpur (Porsha) (Fig. 1). The daily rainfall data for 8 years during the period 1994-2001 of the six rainfall stations in Naogaon district have been considered in this paper. The secondary data of daily rainfall (mm) were collected from Bangladesh Water Development Board. In Bangladesh, there are three agro-climatic seasons, namely (1) Pre-kharif (summer) which includes the pre-monsoon months of March to May, (2) Kharif which includes monsoon months of June to October in which 80% of the total rainfall occurs (Rahman and Alam, 1997), and (3) Rabi (winter) season which starts from November to February.

2.2 Multivariate Logistic Regressions

The significance of rainfall analysis has been highlighted in hydrological and climatological studies because of its influence in all human activities such as agricultural, industrial and domestic. Using multivariate logistic regression technique to estimate the probability of rain event, the probability of rain can be used to map regions of very likely rain; that probability is close to 1, possibly rain and very unlikely rain, the probability is close to 0.

2.2.1 Procedures

Multivariate logistic regression is used to predict dichotomous events. Let $P(X_1, X_2, \ldots, X_k)$ be the probability that it is raining. Let the logistic response function P is the form $P(X_1, X_2, \ldots, X_k) = \exp(f)/\{1+\exp(f)\}$,

Where, $f = \beta_0 + \Sigma\beta_j X_j$.

It is a monotonic function of f and its value lies between 0 and 1. Dichotomous variables Y may be defined as

$$Y = \begin{cases} 0, & \textit{not raining} \\ 1, & \textit{raining} \end{cases} \quad (1)$$

Then consider a set of vectors, $X_i^{/} = (Y_i, X_{1i}, X_{2i}, \ldots, X_{ki})$, $i=1,2,\ldots,n$. To estimate the β 's, the following procedure can be used,

$$P(Y_i = 1) = P_i = \exp(f)/\{1+\exp(f)\} \quad (2)$$

$$P(Y_i = 0) = 1 - P_i$$

The joint distribution of $Y_1, Y_2, \ldots\ldots, Y_n$ is given by

$$g(y_1, y_2, \ldots\ldots, y_n) = \prod P_i^{y_i} (1-P_i)^{1-y_i} \quad (3)$$

To minimize the negative log of g is equal to maximize the joint distribution function. Therefore, the loss function is

$$\text{loss} = -[\sum Y_i \log(P_i) + \sum(1-Y_i)\log(1-P_i)] \quad (4)$$

A two state Markov Chain method involve the calculation of two conditional probabilities: (1) α, the probability of wet day following a dry day, and (2) β, the probability of dry day following a wet day. The wet-dry probabilities are not available; it can be estimated using the average number of days of rainfall,

$$P_j(W/D) = \beta \,.\, dp_j / dm_j \quad (5)$$

$$P_j(W/W) = 1 - \beta + P_j(W/D) \quad (6)$$

where, $P_j(W/D)$ is the probability of rainfall of wet day after dry day in month j, $P_j(W/W)$ is the probability of rainfall of wet day after wet day in month j, dp is the days of rainfall in month j and β is equal to .75 for the model. Given the initial wet-dry state, the model determines stochastically if rainfall occurs. A random number (0-1) is generated and compared with the appropriate wet-dry probabilities. If the random number is less than or equal to the wet-dry probability, rainfall occurs on that day. If random number is greater than the wet-dry probability, no rainfall occurs (Rahman, 1999b).

3. Results and Discussions

A non-linear proceed, the model is tested using multivariate logistic regression technique. The estimated probability of P is denoted by

$$\widehat{P} = \exp(f)/\{1 - \exp(f)\}$$

This is especially interesting since the logistic function is approximately linear in f for P values between 0.2 and 0.8. The result is in agreement with the findings of Neter *et al.* (1989). The estimated values of P were then placed in the class interval. The simulation results gave estimated values of P against the no-rain / rain values in frequency and the relative frequency of rain (Rahman, 1999b).

The logistic regression technique allows flexibility in deciding between areas of indicated rain or no rain. Neter *et al*. (1989) suggest a decision rule that no rain is predicted when the estimated value of P is less than 0.5 and rain, when it is greater than 0.5. Rahman (1999b) used daily simulation rainfall data and suggests that if estimated P is less than 0.1, it is almost not raining. Basically this type of information gives the advantages of logistic regression over a simple threshold technique. The data used to predict P and subsequently the results obtained are given in Table 1 to 6. The results showed the relative frequency of rain against the estimated value of P using the logistic regression at 7 days interval. The results of the relative frequencies of 0.29 and 0.71 are similar in the study area.

Table 1. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Naogaon station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Naogaon	0.0-0.2	1606	67	0.04
	0.2-0.4	310	124	0.29
	0.4-0.6	256	241	0.48
	0.6-0.8	52	130	0.71
	0.8-1.0	15	118	0.89
	Total	2239	680	

Table 2. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Sapahar station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Sapahar	0.0-0.2	1889	71	0.04
	0.2-0.4	210	84	0.29
	0.4-0.6	201	184	0.48
	0.6-0.8	50	125	0.71
	0.8-1.0	11	94	0.90
	Total	2361	558	

Table 3. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Mohadevpur station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Mohadevpur	0.0-0.2	1635	66	0.04
	0.2-0.4	270	108	0.29
	0.4-0.6	227	214	0.49
	0.6-0.8	64	160	0.71
	0.8-1.0	18	157	0.90
	Total	2214	705	

Table 4. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Badolgachi station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Badolgachi	0.0-0.2	1645	56	0.03
	0.2-0.4	290	116	0.29
	0.4-0.6	271	275	0.50
	0.6-0.8	34	85	0.71
	0.8-1.0	15	132	0.90
	Total	2255	664	

Table 5. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Najipur station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Najipur	0.0-0.2	1636	58	0.03
	0.2-0.4	275	110	0.29
	0.4-0.6	259	245	0.49
	0.6-0.8	38	95	0.71
	0.8-1.0	21	182	0.90
	Total	2229	690	

Table 6. Relationship between the estimated P values using the rainfall data at 7 days interval and the measured incidence of rain of Nitpur station at Barind region

	Estimated values of P	No rain	Rain	Rain /total
Nitpur	0.0-0.2	1896	64	0.03
	0.2-0.4	240	96	0.29
	0.4-0.6	223	204	0.48
	0.6-0.8	28	70	0.71
	0.8-1.0	8	90	0.92
	Total	2395	524	

4. Conclusions

Climate change occurs due to natural and anthropogenic disturbances in our environment. The lack of rainfall and high air temperature are the main causes hampering agricultural production in this region. The findings of this paper have provided confidence in the use of modeling techniques for land use in the Barind region. Application of the results is necessary for the development of an operational methodology that could be used in land use planning. The emphasis needs to be placed on site and season-specific technologies and extension messages to farmers, agricultural scientists, policy makers and the general public.

The logistic regression technique should be considered, where the model is satisfied in certain conditions and is useful to have a measure of the certainty of the decision. This information may be useful for both instantaneous and climatic time scale. The data used to predict P and the results were obtained. The results of the relative frequencies of 0.29 and 0.71 of rain against the estimated value of P using the logistic regression of 7 days interval are similar in the study area. The probability of occurrence of rainfall is of vital importance in efficient planning and execution of water programs for agricultural development and environmental strategies in Bangladesh.

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