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A STOCHASTIC ANALYSIS OF THE LONG TERM RAINFALL OF BATTICALOA IN RELATION TO CROP-CLIMATIC PATTERNS

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Abstract

Long term monthly rainfall records (1870-1985) was subjected to statistical analysis known as 'Markov Chain Modelling'. This work in the field of 'Stochastic Analysis' proved to be a very valuable technique in Agricultural Planning. Long-term data series has been classified into several states or levels of rainfall by using various degrees of standard deviations. The long-term probabilities obtained for classified states give much insight about the data series and this classification could be correlated effectively with crop production. It is also found that this classification very much suites with paddy cultivation in the Batticaloa district and our findings will be helpful for water resources management in the future.

keywords : Markov chain, North East Monsoon, South West Monsoon, Inter Monsoon, Limiting probability

1 Introduction

Rainfall is one of the life sources for every human-kind. Importance of rain water for a nation whose economy is basically agricultural immense. Rainfall variability causes disastrous damage to crop production in the Batticaloa district. Droughts and floods not only affect the crop but are also responsible for famine, outbreak of various diseases, and economic crisis. Therefore, a study of rainfall data in agro-climatological perspective has immense value for the agriculture development and planning of this district.

Many researchers have done works on crop-climatic relationship in Sri Lanka [2][8][10] [12]. These studies have been done by using different graphical devices and basic statistical measures of rainfall data. Rainfall variability techniques particularly mean deviation and standard deviation are used to study the crop-climatic relationships in these studies. Further, rainfall fluctuation study for Batticaloa reveals that there are dry and wet phases with irregular periods of rainfall [6]. It evidently shows how crop failure occurs when 'dry phases' prevailed. However, the previous studies attempted to correlate paddy crop with rainfall by means of correlation technique or deviation technique.

Meanwhile, the present technique tends to group long series data into several 'categories' or 'states' using limiting probabilities in Markov's process and these groups are then used to elucidate the crop-climatic relationship.

2 Crop and Climatic features of study area

The area selected for this study is an administrative district 'Batticaloa', situated in the centre of Eastern province of Sri Lanka. It is represented by the unbreakable rainfall data since 1869. The areal extent of this district is 2467.2 sq. km. and its population was 3,30,899 in the last census year 1981. Among the land available, 50924.7 Ha is under paddy cultivation. It is nearly 8% of the total extent of paddy crop and ranked third in all administrative district of Sri Lanka. Approximately 30-40 percent of the total land of this district is under cultivation. In the agriculture sector, 99.77% (47,858 Ha) is under small holdings and 3066.6 Ha belongs to the state. The lands under cultivation from 1962 (2.4%) to 1982 (2.6%) is only expanded by 0.2%. While rainfall farming practice (30,450 Ha.) is dominant, major irrigation (15,669 Ha.) and minor irrigation (1,338 Ha.) share respectively (Statistical Abstract, 1985).

The above details reveal the agricultural importance of this district. Further, it is also noticeable that when disastrous damage occur, in cultivation higher percentage of small holdings will suffer very much. It is evident from the damages of 1978 cyclone, which devastated the agricultural economy of Batticaloa. In view of the above, the study of climatic-crop relationship has practical value and the present study will focus mainly on the occurrence of dry and wet conditions at different scales. An attempt is also made to correlate these scales with the yield pattern in the domestic agriculture of Batticaloa district.

Several weather patterns of this district is very much similar to the Island as a whole. Due to the tropical location, Island experiences high temperature, over 30 degree Celsius all over the low lands which includes the Batticaloa district. Rainfall varies remarkably in seasonal and inter-annual. Two monsoons South-West monsoon (May-September), North-East monsoons (December-February) and two inter monsoons (March-April and October-November) prevail in this district. Batticaloa district receives its seasonal rainfall during the inter monsoons season of October to November and the North-East monsoon season. It is the cropping season of this district and referred as 'Kala pokam' or 'Maha' season. Seasonal dryness prevails during the South-West monsoon season and the cultivation practiced tank irrigation referred as 'Siru pokam' or 'Yala' season.

Random occurrences of seasonal rainfall play a vital role in determining the success of paddy cultivation. Failure of rain in due season not only affects the 'Kala pokam' crop, but also severely limits the 'Siru pokam' due to lack of adequate supply of water. Further, excess rainfall while causing flood damage to cultivation, is beneficial for the 'Siru pokam' crop. In this context, a study of crop-climatic relationship will elucidate some useful facts, which will benefit agriculture planning.

3 Methodology

Long term rainfall data of the Batticaloa meteorological station was collected from the manuscripts of the department of meteorology, Colombo. Monthly rainfall data from 1870 to 1985 was used in this study [4]. Crop data, particularly paddy production data was obtained from the statistical abstracts of Sri Lanka year books and agriculture census of Sri Lanka.

Markov's chain model has been used to study the time series data in this study. The condition of this model requires that a particular data of the time series should be independent from all the previous occurrences. Since, rainfall in a particular year does not depend on the previous years, the above condition of stochastic process fits farely well into the rainfall series considered for the present study. This method produced successful results for similar data elsewhere[3].

This statistical technique is efficient enough to reduce and classify the long series rainfall data into some specified 'states'. The state means that the specified range in rainfall data, which has boundary points. In this paper an attempt was made to classify the 'states' by using the mean (μ) and standard deviation (σ). Accordingly eight states have been defined for the classification of rainfall series, in order to elucidate the dry and wet conditions prevailed. These are given in Table 1 and the lower and upper boundary points of these 'states' are given Table 2.

Table 1: Classified states.

Wet states	Dry states
Disastrous wet (DW)	Disastrous dry (DD)
Severe wet (SW)	Severe dry (SD)
Moderate wet (MW)	Moderate dry (MD)
Average wet (AW)	Average dry (AD)

Table 2: **States and their boundary points.**

States	**Rainfall lower limit**	**Rainfall upper limit**
DW	$\mu + 2\sigma$	
SW	$\mu + \sigma$	$\mu + 2\sigma$
MW	$\mu + 0.5\sigma$	$\mu + \sigma$
AW	μ	$\mu + 0.5\sigma$
AD	$\mu - 0.5\sigma$	μ
MD	$\mu - \sigma$	$\mu - 0.5\sigma$
SD	$\mu - 2\sigma$	$\mu - \sigma$
DD		$\mu - 2\sigma$

Since, the number of states defined above are finite, the 'state space' is also finite and it can be given by; S = DW, SW, MW, AW, AD, MD, SD, DD
In Markov's chain the process visits from a state to another state is said to be 'transition'. In this study, one year is considered as one transition period. According to the prescribed states classification an 8x8 transition-probability matrix was derived. The 64 elements of the transition probability matrix are the transition probabilities of each of the 64 transitions. Transition probability is defined as the conditional probability of a process visits to a state from a given state. Since, all the above transitions occur in one year period as stated before the above matrix is referred as 'First-step transition probability matrix' which is denoted as,

$$P(1) = ((P_{ij})) : 8x8,$$

where, P_{ij} = Pr [The process visits to a state i from the given state j in one transition]. Using the above method five first-step transition probability matrices were obtained from annual and seasonal rainfall series. From the above 'first-step transition matrix', it is desirable to obtain second, third, fourth, and n^{th} step transition probability matrices.
The state space must be decomposed into communication classes if we need to formulate the limiting transition probability matrix from the first-step transition probability matrix, By using the decomposed classes, first-step transition probability matrix is rearranged and partitioned into sub-matrices. This form is referred as 'canonical form'. Limiting transition probability matrix could then be determined from this canonical form. The sub-sets of a state space are generally said to be the communicating classes. Further, in a state space communicating classes are the sub-sets of that state space in which all the states should be communicated with some other states in this sub-set. If a process visits to a state from another state and vice-versa; these two states are said to be communicated. In this study, the decomposition of state space seems to be impossible as all the states in the state space are communicating with each other. Therefore the state space is considered as a single communicating class [9].

Since, the decomposition of the state is impossible, a canonical form to determine the limiting probability matrix is not feasible. Therefore limiting probability matrices for the above five Markovian process, were obtained by iterative method using computer programe. When we find the limiting probability matrix, the conditions of the stationary distributions were considered. It implies that in the limiting probability matrices, all the entries in a column become equal when the iteration number is large. Hence, each row could be considered as stationary distribution of time series, and it gives the probability of the occurrences for each of the states classified. In this analysis the probabilities were obtained accurately for each of the states and the total of the eight limiting probabilities become one [11].

4 Results

The analytical part of this research begins with the classification of categories stated in the following table (Table 3):

Table 3: Mean and Standard Deviation of Annual and Seasonal Rainfall.

Categories	Mean ($\overline{x}$)	Standard Deviation (σ)
Annual Rainfall	65.64	14.83
Inter-Monsoon I	5.42	3.94
South West Monsoon	8.65	3.66
Inter-Monsoon II	19.80	7.79
North East Monsoon	31.70	12.81

From the above two parameters of each of the five series of Batticaloa rainfall seven cut-off points have been obtained and used for 'states' classification. Table 4 gives this details bellow.

Table 4: States and their cut-off points

Cut-off points Categories	DW→|←SW $\overline{x}+2\sigma$	SW→|←MW $\overline{x}+\sigma$	MW→|←AW $\overline{x}+0.5\sigma$	AW→|←AD $\overline{x}$	AD→|←MD $\overline{x}-0.5\sigma$	MD→|←SD $\overline{x}-\sigma$	SD→|←DD $\overline{x}-2\sigma$
Annual Rainfall	95.29	80.47	73.06	65.64	58.23	50.81	43.40
Inter-Monsoon I	13.30	9.36	7.39	5.42	3.45	1.48	0.00
S. W. Monsoon	15.97	12.31	10.48	8.65	6.82	4.99	1.39
Inter-Monsoon II	35.69	27.59	23.69	19.80	15.90	12.00	4.20
N. E. Monsoon	57.32	44.50	38.10	31.70	25.29	18.89	6.08

To illustrate the Markov 's process and its transitions, annual and one of the seasonal series of states are given below;

Series 1: Annual Rainfall;

SD MW SD AD MD MD MW AD AD MD MD AD MD AW AD AD AD MD MD DD SD AD AW AD MD AD MW AW DW MW AW AD AD AD AW AW SD MD AW SD AW SW SD DW SW AW SD AW AD ME AW AD AD AW AW MW AD SW AW AD MW SW AD MW AD MD SW AD MW MD AW AW MW AD AW SD MW AW AW MW MD AW MD AW AW AD AD DW AD MD SW SW MW DW AD MW SW SW DD AW MW AD AD AD SD MD AD AD AD SW SD SD MD SD SW AD

Series 2: Inter-Monsoon I ;

MD MW MD MW MD AW AD AW AD AW SW MD AW SD AD AD SD SD SD MW AD AD AD DW AD AW MD AW MD MW AD AW AD SD AD SW MD MW AW MD SW SW AD SD AD AW AD SW MD MD AD AD AD MD DW AD MD DW MD AW MD AW AD AD AW AD AW MW DW AW AD AW DW AD MD SW AW AW AD AD SW MW MD MD SW AD MD SD AD MW MW SD MW SW MW MD AW AW MW AD AW MD MD AW AD AW SD AW MW SD SD MD AD SD MW AW

From the above process, five tally matrices were obtained and the first step transition probability matrices were derived from the tally matrices. Such transition probability matrices are given for each categories in Appendix.
The close examination of these matrices reveal a remarkable features that, the matrices 1 and 4 are given with all eight states while other three matrices consists of seven states only. In these three cases the Markov's process didn't visit the state 'Disastrous dry (DD)'. It reveals that in a long series of rainfall data no years fall under the category of 'Disastrous dry' during the period of Inter monsoon I, South-West monsoon and North-East monsoons. On the other hand, the chance to occur 'disastrous dry' in the Inter monsoon II season is likely with very low probability.
The probability occurrences of these states were dealt with 'Limiting transition probability matrices' derived from the first-step transition probability matrices. Limiting transition probability matrix explains the probability distribution of the states in the long run. The limiting transition probability matrix in nothing but the infinite power of the first-step transition probability matrix of the given Markov's chain. The infinite power was achieved by giving a precision for the difference of two consecutive powers of the given first-step transition probability matrix as two consecutive powers become almost identical when the power is very large. Since all the rows of a limiting transition probability matrix are identical, a row is considered as the 'Stationary distribution' of the state space. It explains the long-term probabilities of the states considered. The results are given in Table 5.

Table 5: Stationary distribution' of the rainfall categories

States	Annual	I .M. I	S .W. M	I .M. II	N .E. M
DW	0.03408	0.04299	0.03387	0.05254	0.05226
SW	0.09468	0.06939	0.10407	0.08702	0.10440
MW	0.12177	0.12074	0.14982	0.18133	0.11432
AW	0.19981	0.19885	0.17443	0.11304	0.14802
AD	0.28936	0.26398	0.19635	0.25345	0.23705
MD	0.14816	0.18216	0.16653	0.19046	0.18528
SD	0.09484	0.12189	0.17493	0.11346	0.15867
DD	0.01730	-	-	0.00870	-

5 Discussions : Crop-Climatic relationships

In the paddy cultivation of Batticaloa district, rainfall of Inter-monsoon II and North-East monsoon seasons are significantly important, not only for the water supply in Maha crop but also for the water requirement during the Yala paddy cultivation. Rainfall is comparatively low during the other two seasons, i.e. Inter monsoon I and South-West monsoon, which is significantly important in Yala cultivation.

Studies on rainfall fluctuations revealed that the frequent occurrence of extreme climatic events; floods and droughts, in the long-term rainfall of Batticaloa, cause a major climatic constraint on crop production[5]. However, no attempts were made to study the rainfall pattern in terms of categorization as attempted in this study in relation to paddy cultivation or crop-climatic relationships.

In the present study, the long-term rainfall series was categorized or scaled in a meaningful manner and found that this technique was useful to study crop-climatic relationship. From this analysis, very interesting features have emerged from the long series of rainfall. The transition probabilities reveal that the chances for the occurrence of disastrous floods is likely in all seasons, but the probability for such event is very low; approximately 0.05 (Table 5). However, disastrous drought occurs during inter monsoon II and in the other seasons this category does not occur. The probability for this disastrous drought is approximately 0.008 which is negligible in the context of crop failure.

Chances for the occurrence of severe wet condition is found during South-West monsoon and North-East monsoon seasons. In view of Maha paddy cultivation there is a probable chance for crop failure due to floods. The occurrence of such conditions during South-West monsoon season may be due to monsoon depression and it will have a negative impact on crop.

Similarly, 'Severe Dry' (SD) conditions prevails with higher probabilities (0.17, 0.15) during South-West monsoon and North-East monsoon respectively. It implies that Maha paddy crop has greater susceptibility to be affected by dry weather conditions during the rainy season. Since the period of South-West monsoon is quite dry due to the leeward effect of the central highland on monsoon currents. The existence of higher probability for SD is understandable. The moderate and average categories both in wet and dry conditions will not have greater impact on paddy cultivation. Thus, good harvest could be expected when the rainfall comes under these categories.

The chances for the occurrence of extreme weather conditions such as severe and disastrous drought are 0.12 during Inter monsoon II and 0.15 during North-East monsoon and for the floods 0.13 and 0.15 respectively. Among these, an equal probability chance for drought and flood effects exist during the North-East monsoon season and the probability is very high when compared to the chances in all other seasons. Therefore, paddy crop failure due to the uncertainty of seasonal rainfall is likely to occur. The following table (Table 6) reveals that the share of each categories in the long series (116) of rainfall data.

Table 6: Expected number of years in different categories out of 116 years

Categories	DW	SW	MW	AW	AD	MD	SD	DD
No. of years	06	11	19	13	30	22	14	01
Percentage	5.6	9.4	16.2	11.1	25.7	18.8	12.4	0.8

The figures in the above table reveal that out of 116 years taken for the analysis floods caused damage for paddy crop only in 17 years while severe drought affected 15 years. Among average and moderate categories 44.5 percent of the years (52) fall under drought (AD & MD) conditions while similar wet condition prevail only at 27.2 percent or 32 years. In view of the total wet and conditions 67 years are related to dry conditions, which accounted to 56.7 percent while wet conditions consist of 43.3 percent. It implies that paddy cultivation is mostly affected by the prevalence of dry condition than wet weather conditions.

The above findings could now be related with the actual paddy crop failure data. For this purpose, crop failure data from 1960/61 to 1980/81 for Maha season and from 1961 to 1980 for Yala season were utilized. A comparative analysis between the above rainfall categories and the mean paddy crop failure is carried-out. The following table (Table 7) gives the mean and percentage values of paddy crop failure for Maha and Yala together with the factors causing for such failure. Since the existence of very high inter-annual variability in crop production, mean figures could be a useful aid for the preceding analysis.

Among the natural factors, flooding and drought seem to be the most common causes. For entire dry zone an estimate shows that the Maha season crop failure averaged 28,000 hectares (44% flood) and Yala season 5000 hectares (56% drought, 36% flood) and Yala season 5000 hectares (56% drought, 7% floods). Similarly,

Table 7: Paddy crop failure (acres) and their causes from 1960/61 to 1980/81

Causes	Maha		Yala	
	Failure	Percentage	Failure	Percentage
Seed failure	92.5	1.2	62.25	6.82
Drought	5419.4	77.6	419.78	52.79
Floods	759.1	10.1	168.66	13.64
Pest	525.2	7.0	85.81	12.34
Other	283.2	4.6	114.57	14.41

in the Batticaloa district during Maha, drought is predominant among the adverse factors for crop failure and accounts 77.6%. Similar pattern prevail during Yala season and drought become the major cause (58.8%) for crop failure. Among all the adequate factors drought and floods constitutes 87.7% and 70.2% in Maha and Yala respectively.

It shows drought is the major destructive factor for paddy crop failure in both cropping season. Since Batticaloa receives more rainfall during NEM season, frequent failure of monsoon leads to a natural calamity in agriculture. Since, Uncertainty and lack of reliability are the common characteristics of the seasonal rainfall, depending cultivation upon it will also leads to similar condition. Therefore, risk and uncertainty in paddy cultivation is like a gambling experience for farmers with the weather in Batticaloa.

The four weather seasons become two, when they are considered in terms of agriculture. They are Maha season (September to March) and Yala season (April to August). Generally speaking, IM-II and NEM seasons come under Maha and IM-I and SWM seasons come under Yala. Since Maha paddy cultivation depending upon seasonal rainfall, its variability pattern not only affect the Maha crop but also considerably limit the Yala crop which is practiced by irrigation water stored in tanks with seasonal rain.

When analysing the probability occurrence of extreme weather conditions in Batticaloa, (The two categories 'Disastrous' and 'Severe'), the probabilities range only from 0.1 to 0.3. As noted above, drought is the major destructive factor and the highest probability score (0.33) for SD+DD droughts occur during South-West monsoon season. As a seasonal dryness, this could only limit the extent of Yala cultivation. More important is that the prevalence of high probability score (0.15) for SD+DD during North-East monsoon season and (0.11) for Inter Monsoon II in terms of agriculture as they constitute in Maha.

When considered the cropping season, the probabilities for the occurrence of SD + DD is 0.26 in Maha and is 0.45 in Yala. Although very low probability in Yala, which is climatically dry, the values for Maha are highly significant in terms of crop production.. This value (0.26) indicates the probable drought effect during the major cropping season. However, it is interesting to note that although drought is causing severe damage to the crop production, the prevalence of disastrous drought in any of those four seasons is absent except in 'Inter Monsoon I', which shows an insignificant probability value (0.008).

When compare the probability figures of drought with flood (SW+DW) the chances are comparatively very high (0.15) during North-East monsoon season and in the rest of the seasons the value only range between 0.11 to 0.13. During the North-East monsoon season the probability occurrence of SD + DD is equal to SD + DD which is 0.15. However, the chances for the flooding during IM-II is higher (0.13) than the drought probabilities (0.11) in the same season. Generally, during Maha cropping season, probabilities for severe flooding is slightly greater than that of severe drought.

On the whole, when we consider all drought-wet categories, drought stands as a single and most effective natural disaster and the probable chance for its occurrence is 0.56 and 0.55 during North-East Monsoon and Inter Monsoon II respectively. Similar probabilities exist for Inter Monsoon I (0.56) and South-West Monsoon (0.52) respectively. Unlike the non-existence of DD, chances for DW, although not significant, is existing in all categories. However, during the major cropping season it is comparatively high. This could be seen by heavy rainfall due to occasional cyclone moment and depressions during the respective seasons in the 'Eastern province'.

An estimate of water requirement for the paddy crop shows that the optimum 'water duty' is taken to be around 1,200 mm (per 0.4 hectare) in the wet season and 1,800 mm in the dry season[1]. That is, about four feet (1200 mm) of irrigation water is necessary to mature one acre (0.40 Ha) of wet rice (five month variety), if cultivation takes place during the wet season 'Maha'. Further, about six feet (1800 mm) would be the water requirement during the dry period 'Yala'[2].

Domroz's concepts are crude and only valid for the dry zone of Sri Lanka only. In this point of view. The cut-off points as shown in Table 4 reveal that the average category meets the above requirement (1250 mm) exactly which moderate is slightly high (1550 mm) which will certainly not cause damage to the crops. Therefore, categories SD and DD are causing effects by both floods and drought in terms of paddy. It implies that the years categorized as moderate and average in both cases (wet and dry) are favorable for a good crop production. Because the cut off points for moderate category during Maha (IM-II & NEM) season receives 1200 mm rain is sufficiently enough for paddy production. The probabilities for the occurrences of 'average and moderate' categories of both the wet and dry conditions are 0.3 and 0.4 respectively in all four seasons. Combined probability of AW+MW and AD +MD is 0.7 in all seasons. In other wards 70% of the years experiencing good cropping and the rest subject to drought and flood constraints.

During the Yala season, cultivation takes place solely based on irrigation. Since water availability is the major constraint for agriculture, the areal extent is reduced in relation to the stored water in tanks. Therefore, the crop failure is 20% low during Yala compared to Maha. When agriculture is practiced with irrigation, risk and uncertainty will be reduced. This is why the Yala crop although limited performs well. Still drought is the major destructive factor, which accounts 59% among all factors responsible for crop failure.

It may be lack of proper planning which require the quantitative knowledge in the rate of the evaporation and infiltration of stored water. Further, malpractices prevail in water management is also responsible for water shortage in some stage of crop which leads to crop failure. Another important fact is the dry weather prevail during this season would be responsible for the increment of irrigation water temperature. When the water temperature is above 370C, it will adversely affect the crop[2]. Dry environmental temperature of Batticaloa, owing to the unusual effect of South-West monsoon could easily raises the water temperature of the shallow water bodies and paddy field and it seem to be the most positive limiting factor.

It is also interesting to note that flood damage placed second on the adverse factors accounting 11%. This may be due to occasional heavy rainfall occurs in an undue time of cropping towards the later part of the Yala season, when South-West monsoon wind become weak and attempting gradual withdrawal. The probability for flooding is 0.24, which is less chance than Maha (0.28). Expecting floods during Maha is customary but in Yala, it is unusual.

6 Conclusion

In the light of the above "Markov's Chain Modelling", important seasonal rainfall patterns have been drawn. The long-term rainfall series of Batticaloa has been categorized in a meaningful manner by using mean and standard deviation of the respective rainfall seasonal data series. The 116 years of rainfall record has been classified into eight 'states' of rainfall according to the severity of the rainfall occurrence.

The analysis was carried out based on the weather seasons and cropping seasons of Sri Lanka with the annual rainfall. Stochastic model known as 'Markov's Process' or Markov's chain model was used to elucidate the transition probabilities according to the prescribed eight 'states'. Accordingly, five first step transition probability matrices were found. By using the above matrices limiting probability matrices for the eight categories or states for different seasons and year have been derived by iterative method.

Finally, rainfall pattern and crop productions have been analyzed with the aid of the limiting probabilities. For this purpose paddy crop, failure data from 1961-1980 was used. A comparative analysis was carried out in view of the probabilities of the adverse weather effects and crop failure percentages. This analysis elucidated

that severe and disastrous categories in wet and dry weather conditions are the constraints in terms of paddy cultivation. Prevalence of average and moderate categories in both wet and dry conditions do not have adverse effect on crop production. Further, probability occurrence of disastrous dryness is not found in any weather seasons except Inter Monsoon II which is also negligible. In the case of 'Disastrous Dry', the chances are very remote. Seventy percent of the years falling the moderate categories, which means only 30% in 116 years considered are subject to adverse weather effect. In which drought plays a major role. Since risk and uncertainty in paddy cultivation are predominately caused by rainfall, much attention has to be taken to manage the water resources in this district.
Drought as a single and most disastrous factor to crop during Maha seasons where 56% chance for severe drought effects. However, in Yala it is not surprising to see the drought effect, as it is the dry season. Therefore, proper 'water resource development' will bring good crop during this season without much uncertainty by weather.

References

[1] Arumugam, S. (1969). Water Resources of Ceylon, Water Resources Board, Colombo, Sri Lanka.

[2] Domros, M. (1974). The Agro-Climate of Ceylon, Wiesbaden.

[3] Elankumaran, C. (1986). The potability of Jaffna Ground Water, 'Vingnanam', Journal of the Faculty of Science, University of Jaffna, **Vol.1 No.1**: 29-39.

[4] Meteorology manuscripts,(1987). Department of Meteorology, Colombo, Sri Lanka.

[5] Puvaneswaran, K.M. (1986). The rainfall variability in the Northern region of Sri Lanka, MA Thesis, University of Peradeniya, Unpublished.

[6] Puvaneswaran, K.M. (1988). Rainfall fluctuations in the Eastern region of Sri Lanka, "Sinthanai", Jouraal of the Faculty of Arts, University of Jaffna, **Vol.3 No.1**: 24-29

[7] Statistical abstract of Sri Lanka (1985). Department of Census and Statistics, Colombo, Sri Lanka.

[8] Srinanda, K.M. (1983). Rainfall variability pattern and Agriculture in Sri Lanka, In: Climate, Water and Agriculture in Sri Lanka, edited by Yoshinno et. al, Institute of Geo-Science, University of Tsukuba, Japan.

[9] Srinivasan, S.K. and Mehata,K.M. (1976). Stochastic processes, Tata McGraw Hill publishing company Ltd, India.

[10] Thambyahpillai, G. (1960). Agro-Climatological significance of rainfall variability in Ceylon, Agriculture (Ceylon), **Vol.3:** 13-27.

[11] Toodorove,P. (1978). Stochastic Models of Floods, Water Resources Research, **Vol.14:** 345-350.

[12] Yoshino, M. Kayane, I. and Maduma Bandara, C.M. (1983). Climate, Water and Agriculture in Sri Lanka, Institute of Geo-science, University of Tsukuba, Japan.

Appendix

Matrix 1: First-step transition probability matrix for Annual Rainfall

	DW	SW	MW	AW	AD	MD	SD	DD
DW	0.000	0.250	0.250	0.000	0.500	0.000	0.000	0.000
SW	0.000	0.181	0.092	0.181	0.273	0.000	0.181	0.092
MW	0.071	0.142	0.000	0.214	0.360	0.142	0.071	0.000
AW	0.043	0.043	0.175	0.217	0.304	0.043	0.175	0.000
AD	0.031	0.062	0.156	0.125	0.345	0.250	0.031	0.000
MD	0.000	0.117	0.058	0.355	0.177	0.177	0.058	0.058
SD	0.083	0.083	0.167	0.167	0.167	0.250	0.083	0.000
DD	0.000	0.000	0.000	0.500	0.000	0.000	0.500	0.000

Matrix 2 : First-step transition probability matrix for Inter monsoon I

	DW	SW	MW	AW	AD	MD	SD
DW	0.000	0.000	0.000	0.200	0.500	0.200	0.000
SW	0.000	0.000	0.250	0.125	0.250	0.375	0.000
MW	0.071	0.071	0.071	0.144	0.214	0.285	0.144
AW	0.045	0.045	0.136	0.090	0.367	0.227	0.090
AD	0.033	0.133	0.033	0.302	0.233	0.133	0.133
MD	0.092	0.092	0.181	0.318	0.092	0.133	0.092
SD	0.000	0.000	0.214	0.071	0.359	0.071	0.285

Matrix 3 : First-step transition probability matrix for South-West monsoon

	DW	SW	MW	AW	AD	MD	SD
DW	0.000	0.000	0.000	0.000	0.500	0.500	0.000
SW	0.083	0.000	0.252	0.333	0.083	0.166	0.083
MW	0.000	0.062	0.250	0.126	0.000	0.250	0.312
AW	0.095	0.000	0.095	0.095	0.382	0.095	0.238
AD	0.000	0.260	0.043	0.175	0.217	0.132	0.173
MD	0.052	0.105	0.157	0.105	0.212	0.157	0.212
SD	0.000	0.150	0.200	0.300	0.150	0.150	0.050

Matrix 4 : First-step transition probability matrix for Inter monsoon II

	DW	SW	MW	AW	AD	MD	SD	DD
DW	0.000	0.000	0.166	0.166	0.166	0.336	0.166	0.000
SW	0.100	0.100	0.100	0.100	0.200	0.400	0.000	0.000
MW	0.048	0.048	0.285	0.095	0.190	0.048	0.238	0.048
AW	0.000	0.153	0.076	0.076	0.385	0.076	0.234	0.000
AD	0.071	0.107	0.178	0.178	0.178	0.217	0.071	0.000
MD	0.090	0.090	0.090	0.045	0.505	0.090	0.090	0.000
SD	0.000	0.071	0.288	0.142	0.071	0.428	0.000	0.000
DD	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Matrix 5 : First-step transition probability matrix for North-East monsoon

	DW	SW	MW	AW	AD	MD	SD
DW	0.000	0.166	0.000	0.502	0.166	0.166	0.000
SW	0.000	0.166	0.250	0.166	0.000	0.085	0.333
MW	0.000	0.153	0.076	0.232	0.310	0.153	0.076
AW	0.176	0.118	0.118	0.118	0.000	0.235	0.235
AD	0.035	0.109	0.035	0.142	0.392	0.216	0.071
MD	0.047	0.095	0.190	0.095	0.288	0.095	0.190
SD	0.058	0.000	0.117	0.058	0.294	0.294	0.179