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Arrival Dates of Southwest Monsoon Rains - A Modeling Approach

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ABSTRACT. *Knowledge of the arrival and withdrawal dates of monsoon rains is an important issue in planning many agronomic practices in coconut cultivation. Daily rainfall (1962–1997) of 13 stations representing three agro-ecological regions in the coconut growing areas in Sri Lanka were analyzed to elucidate changes in long-term rainfall and to study the distribution of onset date of south-west monsoon rains. There was a significant decline of annual rainfall over the 36 years period in most of the locations. The drop of the average annual rainfall during 1986–1997 with respect to the corresponding values during 1974–1985 varied from 2 to 25%. The highest drop was observed in low country wet zone (LCWZ) followed by low country wet intermediate zone (LCWIZ). The first inter monsoon rain usually expected from southwest monsoon during March and April has shifted towards April and May. Using the goodness-of-fit chi-square statistic it was found that a gamma distribution can adequately explain the variation of start of southwest monsoon rains irrespective of the locations. A common distribution cannot be fit to the pooled data of onset dates in LCWIZ and low country dry intermediate zone (LCDIZ). A gamma distribution gave an adequate fit for the pooled data of LCWZ. In implementation suitable time for agronomic practices that are based on start of southwest rains, location specific recommendations have to be given for LCWIZ and LCDIZ, but not for LCWZ. The modeling approach for assessing the nature of arrival of rains can be extended to fit probabilistic models to onset and withdrawal of other rains within a year. The results obtained will be useful in planning the agronomic practices in any crop.*

INTRODUCTION

The problem of global climate change effects on the production of agricultural crops has been given much attention by various scientists all over the world (Butterfield and Morrison, 1992; Hanson *et al.*, 1993; Bengtsson, 1994; Bootsma, 1994; Mikkeisen *et al.*, 1995). The change of distribution of rainfall in Sri Lanka has also been reported by many authors (Fernando *et al.*, 1995; Peiris and Mathes, 1997). The change of rainfall pattern directly affects the fluctuation of the productivity of plantation crops in particular.

Among the tree crops in Sri Lanka, coconut is one of the most economically important and valuable tree crops. Coconut is a major component of the diet of Sri

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Lankans. It provides about 20% of the daily caloric intake of the Sri Lankan population, being second only to rice. The domestic coconut consumption per head per year is around 115 nuts.

Effects of rainfall are evident at all stages of development of nuts during the period of 44 months and hence the rainfall significantly influences the economic returns of the crop (Peiris and Thattil, 1995). Even under uniform system of management there is a wide fluctuation of crop between-and-within years and it is almost entirely the result of the variation of amount and distribution of rainfall. For high consistent productivity of coconut lands, timely planned agronomic practices such as preparation of lands, application of fertilizer, weeding, mulching *etc.*, are essential. The effectiveness of these agronomic practices depends on the correct time of application. In order to identify the correct time of application of such practices, the knowledge of starting and ending dates of rains within a year (southwest and northeast monsoon rain, and intermonsoon rains) is very important. The limitation of the direct method of analyzing rainfall data has been discussed by Stern *et al.*, (1982).

Therefore, the present study was conducted to develop a probabilistic model for the onset of southwest monsoon rains and investigate the long-term trends of annual rainfall in 'main' and 'mini' coconut triangle.

MATERIALS AND METHODOLOGY

Rainfall data

Thirty six years (1962–1997) rainfall data from 13 locations of three agro-ecological regions within the 'main' coconut triangle and 'mini' coconut triangle: (a) six from low country wet intermediate zone (LCWIZ), (b) four from low country dry intermediate zone (LCDIZ), and (c) three from low country wet zone (LCWZ) were used in this study. The station index of each station is given in Table 1. The data of Lunuwila, Rajakadaluwa and Ratmalagara were obtained from the Coconut Research Institute, Lunuwila and other data were from the Department of Meteorology, Colombo.

Annual and monthly rainfall distributions

Basic statistics of annual rainfall such as mean annual rainfall, coefficient of variation, maximum, minimum, 20% probability value, that is 80% expectancy value (Q_{20}) and 80% probability value, that is 20% expectancy value (Q_{80}) were computed to compare locations. The comparison of the mean annual rainfall in three different scenarios: (1962–1973, 1974–1985 and 1986–1997) was done to compare the changes of rainfall in different scenarios. The autocorrelation analyses and histograms of 80% expectancy values for monthly values were used to investigate the change of seasonal pattern of rainfall.

Table 1. Station index of the selected rainfall locations.

Location	Agro-Ecological Zone	Latitude (N)	Longitude (E)	Elevation (m)
Horakelle	LCWIZ	7^0 27'	79^0 51'	15.2
Kurunegala	LCWIZ	7^0 28'	80^0 22'	116.1
Lunuwila	LCWIZ	7^0 20'	79^0 53'	30.5
Rajakadaluwe	LCWIZ	7^0 35'	79^0 47'	20.5
Ratmalagara	LCWIZ	7^0 33'	79^0 54'	27.4
Kirama	LCWIZ	6^0 12'	80^0 39'	122.0
Mediyawa	LCDIZ	7^0 53'	80^0 17'	93.0
Nikaweratiya	LCDIZ	7^0 44'	80^0 06'	30.5
Polontalawe	LCDIZ	7^0 42'	80^0 00'	26.2
Ridibendiwela	LCDIZ	7^0 44'	80^0 14'	56.0
Gampaha	LCWZ	7^0 6'	79^0 59'	9.1
Galle	LCWZ	6^0 2'	80^0 13'	12.5
Kalutara	LCWZ	6^0 40'	79^0 57'	3.0

Onset of southwest monsoon rains

To get an idea of the start of first spell of rain, the graphs of 7-day moving totals of rainfall from March to June were used for each location for each year. Based on the visual analysis, the following definition was adopted as the most suitable for the date of onset of southwest rains. The date of onset of southwest monsoon rain (X) is taken as the earliest possible day after the first of March with more than 30 mm of rainfall totaled over 3 consecutive days of which at least two days should be rainy days and there should not be a dry spell of length of seven or more in the next twenty days. The dates in a year were numbered from 1 to 365 excluding the 29^{th} February in leap years to use the day number as a random variable. The mean dates of onset were computed with their standard errors.

Modeling approach

Based on the shape of the frequency distribution of the observed values X on each station three types of probability distributions namely normal, gamma and beta were considered as the possible models to represent the variation of X. To estimate the expected frequencies based on each model, the parameters of the models were derived using the method of moment. The chi-square goodness of fit statistics was used to select the best-fit model. This method was applied for each location as well as pooled data across the agro-ecological zones.

RESULTS AND DISCUSSION

Annual rainfall

The long-term annual mean rainfall is a simple statistic, which helps in making useful comparisons among locations and to get some idea about the potential of agricultural crops. The statistics Q_{20} and Q_{80} values represent the chance of a larger event occurring in four out of five years and one out of five years respectively. That is, probability of annual rainfall $\geq Q_{20} = 0.80$ and probability of annual rainfall $\geq Q_{80} = 0.20$. These probabilities were computed directly from the relative frequency occurrence and no distribution for the total rainfall was assumed. The above statistics in respect of selected locations are shown in Table 2.

Table 2. **Basic statistics of the rainfall data of 13 different locations for the period of 1962– 1997.**

Location	AER	Long-term mean (mm)	Minimum	Maximum	CV	Q_{20}	Q_{80}
Horakelle	LCWIZ	1582	938 (83)	2443 (63)	18	1417	1724
Kurunegala	LCWIZ	2041	1339 (73)	2923 (72)	19	1757	2285
Lunuwila	LCWIZ	1883	1191 (86)	2564 (63)	15	1672	2054
Rajakadaluwe	LCWIZ	1422	850 (89)	2389 (84)	25	1153	1767
Ratmalagara	LCWIZ	1570	1035 (83)	2394 (84)	19	1360	1764
Kirama	LCWIZ	2183	1015 (91)	3090 (63)	22	1697	2542
Mediyawa	LCDIZ	1244	45 (82)	1927 (93)	32	861	1609
Nikaweratiya	LCDIZ	1370	786 (86)	1928 (97)	18	1161	1601
Polontalawe	LCDIZ	1350	679 (86)	2304 (95)	27	1097	1533
Ridibendiwela	LCDIZ	1348	411 (85)	2062 (62)	23	1106	1617
Gampaha	LCWZ	2434	1640 (76)	3986 (63)	18	2120	2721
Galle	LCWZ	2328	1550 (83)	3858 (63)	16	2086	2535
Kalutara	LCWZ	2753	1561 (81)	4626 (63)	20	2442	2981

Values in parenthesis are the years corresponding to the maximum and minimum values
CV = Coefficient of variation; Q_{20} = 20% probability values; Q_{80} = 80% probability values

Table 2 indicates that long-term mean annual rainfall during 1962–1997 has varied among the locations (ranging from 1244 mm to 2753 mm) and also locations within each agro-ecological zone. Of the locations in the LCWIZ and LCDIZ the highest mean annual rainfall was reported at Kirama while the lowest was at Mediyawa. The 20% and 80% expectancy values of annual rainfall were very different within the agro-ecological regions.

Annual rainfall variability

By fitting a trend line for temporal variation of annual rainfall, a significant ($p<0.05$) declining trend was found in many locations. The plot of autocorrelation function of the annual rainfall for each location indicated that there was no cyclic or seasonal pattern in the rainfall in all the locations. Similar trend was found for the pooled data within agro-ecological zones.

A significant negative correlation ($r = -0.74^{***}$, $n = 36$) was found between coefficient of variation and 80% expectancy value of annual rainfall. It indicates that the high rainfall areas have lower inter annual variation and the low annual rainfall areas have higher inter annual variation.

Change of rainfall in different scenarios

The mean annual rainfall for the period 1986–1997 in all stations were lower, compared to that of during 1962–1973. The drop varied from 2–25%. The highest drop was observed in the locations of LCWZ followed by the locations of LCWIZ. The mean annual rainfall during 1986–1997 is also lower than that of during 1974–1985 in the locations of LCWIZ and LCWZ, but it is higher in the locations of LCDIZ. However, the mean annual rainfall during 1986–1997 in almost all the stations (irrespective of the agro-ecological regions) is lower than the long-term average based on 36 years period.

Seasonal rainfall distribution

The rainfall in Sri Lanka is received from weather phenomena associated with the Inter Tropical Convergence Zone (ITCZ) and from the two monsoons: the southwest and the northeast monsoons. Detailed descriptions of seasonal distribution and atmospheric circulation variation of rainfall in Sri Lanka are given by Domroes (1974) and Suppial (1988). The rainfall distribution in many parts of Sri Lanka has been classified into four groups, namely first inter monsoon (FIM) during March and April, southwest monsoon (SWM) from May to September, second inter monsoon (SIM) during October and November and northeast monsoon (NEM) from December to February. However, detailed study on arrival and withdrawal dates of these rains has not been reported.

The monthly rainfall values provide a better guide to identify the seasonal pattern of rainfall within a year. The mean rainfall, number of rainy days, 80% expectancy values, CV and probabilities of rainfall exceeding some critical value were computed on a monthly basis for all the locations. Based on probability of amount of rainfall received and the number of rainy days in those locations, it can be concluded that the months July, August, September, January and February can be considered as five dry months in a year with few exceptions in September. The histograms of the 80% expectancy value of monthly rainfall confirm that the rainfall follows a bimodal pattern in all locations. In almost all the locations, two peaks were observed during April and May and October and November. It confirmed that the FIM has shifted towards April and May and consequently first rain spell in a year is due to the combined effect of both FIM and SWM. In fact, Suppiah (1989) has mentioned that the first peak of the rainfall has mixed with southwest rains. Thus the rain during March to June can be taken as the southwest monsoon rains.

The analysis indicates that the both mean monthly rainfall and the number of rainy days increase from January to May in all the locations in LCWIZ and LCWZ. The monthly rainfall and the number of rainy days in all the locations in LCDIZ increase from January to April as well and then from August to October. Irrespective of agro-ecological zones the rainfall in November or October in all locations is higher than that in any other month in a year.

A significant negative correlation was found between monthly coefficients of variations and monthly rainfall amounts. The highest monthly rainfall variability was observed in the months of January, February, July and August in all locations. The lowest variability was observed in October and November. The higher coefficient of variation in the months during March to June compared to that of October to November indicated that rainfall in the second spell in a year (October/November) is more certain than the first spell in the year. This is confirmed as no significant relation was established between first spell of rain and SOI (Suppaiah, 1996).

Onset of southwest monsoon rain

The demarcation of the onset of rain is not straightforward due to the intermittent and patchy nature of the tropical rainfall in Sri Lanka. Some of the characteristics of the onset of the monsoon rains are heavier rainfall (amount and distribution), high humidity, cloudiness, low temperature and change in wind speed and direction.

Of these characteristics, changes in relative humidity and temperature are not significant enough to be used as a marker to detect the onset (Ramanayake and Zubair, 1998; Ahmed and Karmakar, 1993). The cloudiness cannot be considered as a good indicator for this purpose and also such data are not available. The rise in wind speed and change in wind direction has been used to define the start of southwest monsoon rains in Sri Lanka by Ramanayake and Zuhair (1998). They assumed that if a 30% of rise of wind intensity from one week to the next is sustained for another three weeks then the first week was taken as the week of rain onset. However, the authors have not established a relationship between rainfall and wind rise. Further, occurrence of the southwesterly wind does not correspond to the onset of southwest monsoon rains (Suppaih, 1988) and thus such a criteria too is not suitable to derive the dates of start of rains. Therefore, in this study start of rains is defined solely on rainfall amount and length of dry spell. In fact Stern *et al.* (1982) suggested that the combination of rainfall and the dry spell is a better criteria as a definition of onset and end of rains.

Based on the definition, the mean dates of onset along with their standard errors are shown in Table 3.

The results in Table 3 indicates that in coconut growing areas, the mean starting dates of southwest monsoon rain varies within agro-ecological zones as well as between agro-ecological zones. Thus the time of implementation of agronomic practices in coconut cultivation has to be location specific. The earliest average onset of rains in the selected location was on the 29 March at Kirama (Table 3) with a standard error of 4 days. For other stations the average start was in early April. In general, the southwest monsoon rains had commenced early in the LCWZ. The high standard errors and late start of rains were observed in the locations of LCWIZ.

Table 3. Mean date and standard deviation of starting dates of southwest monsoon rains for 13 different locations.

Location	Agro-ecological region	Mean day number (day/month)	Standard error (days)
Horakelle	LCWIZ	118 (27 April)	4.1
Kurunegala	LCWIZ	94 (3 April)	3.0
Bandirippuwa	LCWIZ	98 (7 April)	3.3
Rajakadaluwa	LCWIZ	105 (14 April)	4.0
Ratmalagara	LCWIZ	105 (14 April)	3.5
Kirama	LCWIZ	89 (29 March)	4.0
For pool data		100 (9 April)	1.5
Mediyawa	LCDIZ	95 (4 April)	2.9
Nikaweratiya	LCDIZ	100 (9 April)	2.8
Polontalawa	LCDIZ	98 (7 April)	3.2
Ridibendiwela	LCDIZ	101 (10 April)	2.8
For pool data		99 (8 April)	1.5
Gampaha	LCWZ	92 (1 April)	2.6
Galle	LCWZ	98 (7 April)	3.0
Kalutara	LCWZ	92 (1 April)	2.6
For pool data		95 (5 April)	1.6

The mean date of onset rains for each agro-ecological zone was computed by pooling all data within an agro-ecological zone. Table 3 indicates that the mean date of onset of southwest rain in LCWIZ, LCDIZ and LCWZ are 9 April, 8 April and 5 April with the standard errors of 1.5 for each zone. These results are useful not only for the implementation of agronomic practices on coconut, but can be utilized for other crops as well.

Because of the high standard error of the mean date of onset rain, it is important to derive probabilities of onset of rains occurring in a given range of days. For that it is necessary to fit a suitable probability model for the date of onset rains.

Model fitting for each location

The probability distribution functions and their parameters for three distributions considered are given in Table 4. As the range for beta distribution is 0 and 1, the X variable was transformed using [X – Min (X)]/d, where d = Max (X) - Min (X) in fitting beta distribution.

Table 4. Details of three fitted distributions and estimated parameters.

Probability Distribution	Density function	Parameters	Parameter Estimation (Method of Moments)
Normal	$f(x) = \frac{1}{\sqrt{2\Pi}\sigma} * \exp(x-\mu)^2/\sigma^2$	μ σ^2	$\mu = \bar{x}$ $\sigma^2 = s^2$
Gamma	$f(x) = \frac{\lambda^r}{\Gamma(r)} x^{(r-1)} \exp^{(-\lambda x)}$	λ r	$\lambda = \bar{x} / s^2$ $r = (\bar{x})^2 / s^2$
Beta	$f(y) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)} y^{(\alpha-1)} y\text{-}1^{(\beta-1)}$	α β	$\alpha = \frac{A - s^2(1+A)^2}{s^2(1+A)^3}$ $\beta = A*\alpha$, where
	y = transformed value		$A = (1-\bar{y})/\bar{y}$

The probability values of test for the three distributions on each location are shown in Table 5. In all stations the χ^2 statistics was not significant for normal and gamma distributions. However, the probability values for gamma distribution were higher than that for normal except on two occasions. Thus, gamma distribution is a better fit than the normal distribution. For the beta distribution, χ^2 statistics are not significant (at 5% level) only for some locations. Also the probability values with respect to beta distribution were lower than that of gamma and normal. Thus beta distribution is not suitable to represent the variability of X for each location. Therefore, it can be concluded that the best-fit model is gamma irrespective of the locations. The Table 5 gives the probabilities associated with the fitted models.

Modeling for each agro-ecological zone

Pearson χ^2 statistic was used to test whether a common model (gamma distribution) can be fitted for the pooled data within agro-ecological zones. The Pearson

χ^2 statistic for the pooled data was not significant at p=0.05 for LCWZ. The Pearson χ^2 statistic was significant (at P=0.1) for LCWIZ. For LCDIZ the χ^2 statistic was significant at the 5% level. It indicates that a common distribution can be recommended only for LCWZ. For the other two agro-ecological regions, it is recommended that the different distributions have to be fitted for the locations within the agro-ecological zones.

Table 5. Chi-square probability values of three fitted distributions for different locations.

Location	DF	Normal	Gamma	Beta
Horakelle	3	0.8113	0.9428	0.2087
Kurunegala	4	0.7334	0.8544	0.0828
Bandirippuwa	3	0.7900	0.7573	0.0595
Rajakadaluwa	3	0.7316	0.8570	0.4295
Ratmalagara	4	0.8667	0.9546	0.7126
Kirama	3	0.6368	0.7685	0.0146
Mediyawa	3	0.7163	0.8305	0.4312
Nikaweratiya	4	0.8922	0.9521	0.6699
Polontalawa	3	0.3906	0.5067	0.0027
Ridibendiwela	3	0.6233	0.6838	0.4861
Gampaha	3	0.9435	0.9736	0.9971
Galle	3	0.5660	0.7453	0.1751
Kalutara	3	0.8557	0.7108	0.9057

Use of the model

Using the models fitted for each location in LCWIZ, LCDIZ the probability that gives highest value for 15-day and 21-day intervals were computed separately for each location. Similar computation was done for LCWZ using the single model fitted for LCWZ irrespective of the locations within LCWZ. The results are shown in Table 6.

The results in Table 6 indicates that in future there is a 50% probability that the southwest monsoon rains will start during the first week to third week of April in Nikaweratiya, Polonthalawa and Ridibendiwela in LCDIZ. Thus, we recommend the implementation of agronomic practices related to the onset of southwest monsoon rains according to Table 6. We can predict with 50% confidence that the southwest monsoon rains in Mediyawa area will start during the last week of March to second week of April. Similarly recommendation can be derived for other locations. However, more specific recommendations can be given after fitting models for withdrawal and length of the rain for both southwest and northeast monsoons and second inter-monsoon rains.

Table 6. Probability (P) values of the onset of southwest rains for 15 days and 21 days intervals.

Location	15 days		21 days	
	Interval	P value	Interval	P value
Horakelle	April 5 -April 19	0.232	April 3- April 23	0.326
Kurunegala	March 25-April 8	0.308	March 23-April 12	0.429
Bandirippuwa	March 28-April 11	0.278	March 25-April 14	0.389
Rajakadaluwa	April 4-April 18	0.243	April 1-April 21	0.342
Ratmalagara	April 4-April 18	0.264	April 1-April 21	0.371
Kirama	March 18-April 1	0.251	March 15-April 4	0.353
Mediyawa	March 27-April 10	0.338	March 24-April 13	0.467
Nikaweratiya	April 4-April 18	0.330	March 29-April 18	0.462
Polontalawa	March 30-April 13	0.331	March 27-April 16	0.459
Ridibendiwela	April 2-April 16	0.363	March 30-April 19	0.499
Wet Zone	March 20-April 3	0.309	March 17-April 6	0.429

CONCLUSIONS

The modeling approach is a powerful tool and has considerable potential than distribution free methods in analysing rainfall events. The gamma distributions can be used to predict the dates of onset of southwest monsoon rains in all the locations in coconut growing areas. The models for each location within agro-ecological regions can be replaced by a single gamma distribution only for LCWZ. Suitable time for agronomic practices related to the onset of southwest monsoon rains, can be recommended for specific locations in the areas of LCWIZ and LCDIZ. A common recommendation of time for agronomic practices can be given for the areas in LCWZ. The methodology described in this paper has to be extended to fit probabilistic models for withdrawal dates of southwest rains, onset and withdrawal dates of northeast and second inter-monsoon rains and length of rains. The results obtained in this study are useful in agricultural research and planning.

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