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Variability in Rainfall Pattern and Its Impact on Tea in Uva Region of Sri Lanka

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ABSTRACT

A thorough understanding of climatic parameters, particularly the variability in the amount and distribution of rainfall are essential for planning and implementation of cultural practices in Tea. Variability in rainfall and its impact has been given much attention by various scientists in the recent past, as there are strong evidences on change in global climate. However, in-depth assessments on the variability in the amount and distribution of rainfall and its impact on tea have not been studied in detail.

This study was conducted using daily rainfall data for the period 1983-2002, collected over 26 estates that represent all tea growing agro ecological regions (AER) in Uva region of the intermediate zone of Sri Lanka. In all the estates, more than 50% of the annual rainfall was found to be concentrated in the period of October to January of the year and only less than 25% of the annual rainfall is contributed by the five consecutive months from May to September. The observed 75% expectancy values of monthly rainfall of estates were significantly lower than the values expected for the AER. The total number of rainy days per year has declined over the period of 20 years. Clearly evidence was found in change in distribution of rainfall but not the total amount over the period. The poor correlation between Southern Oscillation Index and monthly rainfall reveals that this relationship cannot be used for predicting the changers in rainfall. However, a detailed study conducted at Welimada estate showed that occurrence of El Nino was associated with SIM (Second Inter monsoon) and NEM (North East Monsoon) rains. The results clearly indicated that site-specific analysis of rainfall could provide valuable guidelines for planning and implementation of management practices of tea in Uva region.

Key words: rainfall variability, rainfall distribution, El Nino/Southern Oscillation

INTRODUCTION

The problem of climate change and its effect on the production of agricultural crops has received much attention among various scientists around the world, as there is strong evidence on global climatic changes (Bengtsson, 1994). Several studies done in the recent past have shown that among all the climatic parameters, the variability in rainfall is an important issue for agriculture in the recent years (Butterfield and Morrison, 1992; Bengtsson, 1994; Bootsma, 1994; Mikkeison *et al.*, 1995). Any pragmatic crop planning needs a thorough understanding of the climatic parameters particularly the variability in the amount and distribution of rainfall. Such studies are helpful in identifying the risk levels for various planning activities in the management of tree crops.

Researchers claim that not only the changes in the amount of rainfall, its distribution pattern is also equally important for crop production. This is because most of the cultural practices of tea such as land preparation, planting, infilling, replanting, fertilizer application and pruning are planned according to the rainfall pattern. Hence in studying changes in rainfall it is necessary to focus on both aspects i.e. amount and distribution.

The understanding of the impact of global climatic change on the weather pattern of Sir Lanka is essential, because this knowledge facilitates the predictability of unexpected extremes of rain and change in weather pattern. El Nino / Southern Oscillation (ENSO) is a global climatic change phenomenon that influences the climate of half of the planet (Punyawardena and Cherry, 1999). Southern Oscillation Index (SOI) is a simple index used to study the pressure variation in the atmosphere. Correlation between SOI and rainfall can be used to predict the rainfall fluctuation of a region (Suppiah, 1989).

In Sir Lanka, tea, *Camellia sinensis* (L) O. Kuntze, is special among all other perennial plantation crops due to its high contribution to the national economy. Tea is categorized into High, Medium and Low grown depending on the elevation of the cultivated area. High grown tea plays a very vital role in the tea industry producing high quality tea.

In Sri Lanka, except Uva, Maturata, Hewaheta and Eastern flank of the Knuckles all the other tea-growing areas belong to the wet zone of the country. The tea in Uva region belongs to the intermediate zone and the margin of 75% expectancy annual rainfall is 1600 mm, which is critical for tea growth (Tea Master Plan, 1980). The occurrence of prolong dry season during southwest monsoon period is a characteristic feature of this region. Owing to the dry season, tea in Uva is vulnerable for drought effects, and for this reason, Uva region was selected for the study.

The objective of this study was to have an in-depth analysis on the long-term rainfall variability in terms of amount and distribution and to predict the occurrence of adverse climatic events using the relationship between SOI and monthly rainfall in the region.

METHODS

Secondary data

Daily rainfall data that spans over the period of 1983-2002 from 38 tea estates in the Uva region were used for the study. In the rain gauges, any non-zero values below 0.1 mm had been recorded as zero. Based on that, the number of dry days was counted for the analysis.

The 38 estates selected as the sample out of 64 estates (Tea Master Plan, 1980) was considered represent almost all the tea growing agro ecological regions in Badulla district. However 12 estates from the selected 38 were not considered for the analysis due to lack of data. Site details of each selected estate are presented in Table 1.

Various exercises were carried out to ascertain the quality of the data. All records were investigated for outliers using the data obtained from nearby agro meteorological stations and all dubious records were discarded. All the locations coming under the purview of the study were visited to inspect the rain gauges that were on operation during the study period. Simple exploratory analysis was carried out to delete the unusual features of the data. Southern Oscillation Index values and the El Nino years from 1930 to 2002 were downloaded from the Bureau of Meteorology website Australia (www.bom.gov.au). Monthly figure for the parameter was considered in the assessment.

Table. 1: Site details of the selected estates

Estate	AER	Elevation	Longitudes	Latitudes	Location
Roeberry	IU2	0975-1249	80° 45'	6° 30'	Pitamaruwa
Cocagala	IU2	1280	80° 45'	6° 30'	Metigahatenna
Verallapathana	IU2	0914-1326	80° 45'	6° 30'	Madulsima
Batawatta	IU2	1077-1538	80° 45'	6° 30'	Madulsima
Mahadowa	IU2	1200-1368	80° 45'	6° 30'	Madulsima
EL Tab	IU2	0610-1200	80° 45'	6° 30'	Madulsima
Sania	IU2	0792-1676	80° 40'	6° 30'	Badulla
Shawland	IU2	0790-1173	80° 45'	6° 04'	Lunugala
Haputale	IU3a	0515-1418	80° 35'	6° 20'	Haputale
Nayabedde	IU3a	1374-1924	80° 45'	6° 22'	Bandarawela
Pitaratmalle	IU3b	0515-1173	80° 35'	6° 20'	Haputale
Blairlomond	IU3c	- *	80° 45'	6° 30'	Udapussellawa
Cannavarella	IU3c	1312	80° 45'	6° 30'	Nmunukula
Downside	IU3c	0917-1213	80° 40'	6° 20'	Welimada
Hindagala	IU3c	0760-2130	80° 40'	6° 30'	Namunukula
Kahagalla	IU3c	1219-1528	80° 35'	6° 20'	Haputale
Kinellan	IU3c	1057-1097	80° 45'	6° 30'	Nmunukula
Queenstown	IU3c	0660-1080	80° 40'	6° 04'	Hali Ela
Wewasse	IU3c	0930-1524	80° 45'	6° 30'	Badulla
Springvelly	IU3c	0792-1679	80° 45'	6° 30'	Badulla
Hakgala	IU3d	*	80° 30'	6° 27'	Boragas
Welimada	IU3e	0714-1219	80° 30'	6° 24'	Welimada
Rapphannock	IM1a	*	80°45'	6° 30'	Udapussellawa
Telbedda	IM1a	0997-1402	80° 45'	6° 30'	Badulla
Adawatta	IM2b	0795	80° 45'	6° 30'	Lunugala
Hopton	IM2b	*	80° 45'	6° 04'	Lunugala

* Not available

Measures Used and Analysis Performed in the Study

1. 75% Expectancy of Rainfall

Although the mean values give an easy understanding about the rainfall of different locations, it provides very limited information because there is only 50% chance for a particular location to receive greater or less than the mean rainfall. Instead, the 75% expectancy of annual rainfall is normally used in rainfall data analysis. This statistic is more meaningful and useful in planning and implementing cultural practices that depends on the rainfall distribution.

2. Time Series Plots and Autocorrelation Analysis

Summary statistics of various time series were examined to determine any temporal pattern in the data. The plots were made for each location separately and both monthly and annual time scales were used for plots. The auto regressive integrated moving average (ARIMA) procedure was used to identify any cyclic pattern of the annual rainfall over the last 20 years. The residual series were investigated for any established autocorrelation.

3. Association between El Nino Years and Seasonal Rainfall

Observed deviations of seasonal rainfall from the expected according to AER during El Nino years (Extreme phase of SOI) were analyzed to determine whether there is any association between El Nino years and the seasonal rainfall. This analysis was done using the data of Welimada estate, for which monthly rainfall data was available for the period of 1930-2002 (73 years). The monthly rainfall data were grouped into four seasons (First Inter Monsoon (FIM) - March to April, South West Monsoon (SWM) - May to September, Second Inter Monsoon (SIM) - October to November and North East Monsoon (NEM)- December to February) and the long-term mean and the standard deviation were calculated using only the rainfall in normal years i.e. excluding El Nino years. The number of years with above and below normal expected rainfall was counted during the El Nino years. These counts were tested for randomness using the exact binomial test.

4. Simple Linear Regression for Trend Analysis

Simple linear regression was performed to study the trend in annual rainfall during the period 1983-2002. The trend lines were fitted for the annual rainfall of 1983-1992 and 1993-2002 periods separately in order to find the critical period of climate change.

RESULTS AND DISCUSSION

Annual Rainfall

Basic statistics of annual rainfall of the selected estates in Badulla district are presented in Table 2. The long-term mean annual rainfall during 1983-2002 varied from 1242.8 to 3878.8 mm. It was revealed that the maximum rainfall was recorded for 9 locations in 1994, for five locations in 1997 and for another 4 locations in 1986. Similarly six locations recorded their minimum rainfall in 1983 and another six in 1998.

Within AER IU2, the 75% expectancy value of annual rainfall varied from 1950.6 to 3221.6 mm. In the IU3c sub region 75% expectancy value of annual rainfall varied from 1215.2 to 2115.4 mm. The highest 75% expectancy value of annual rainfall was 3221.6 mm in Cocagala estate in IU2 and the lowest was 1029.4 mm in Welimada estate of IU3e.

Table 2. Basic statistics of annual rainfall of the selected estates

Estate	AER	Long-term average (mm)	CV %	75% expectancy (mm)	Minimum (mm)	Maximum (mm)
Roeberry	IU2	3370.1	22.4	2976.0	2469.5 (97)	5846.7 (94)
Cocagala	IU2	3878.8	30.0	3221.6	2475.8 (85)	7778.0 (84)
Verallapathana	IU2	2521.2	15.9	2275.7	1652.9 (98)	3593.5 (94)
Batawatta	IU2	2676.3	18.0	2393.7	1975.0 (83)	3766.0 (92)
Mahadowa	IU2	2474.0	15.7	2174.7	1859.0 (98)	3343.4 (02)
EL Tab.	IU2	2760.5	12.9	2456.8	2358.2 (96)	3525.8 (94)
Sania	IU2	2177.7	15.8	1950.6	1877.7 (99)	2866.2 (94)
Shawland	IU2	2404.4	17.8	2113.8	1877.7 (83)	2876.1 (86)
Haputale	IU3a	2445.5	25.3	1998.8	1790.0 (99)	4411.5 (94)
Nayabedde	IU3a	2827.6	28.1	2156.3	1539.8 (98)	4649.0 (94)
Pitaratmalle	IU3b	2553.6	29.1	2110.2	1242.3 (86)	4165.1 (87)
Blairlomond	IU3c	2227.0	16.0	2037.7	1975.0 (83)	3766.0 (92)
Cannavarella	IU3c	2443.2	22.0	2115.4	1576.6 (83)	4180.0 (97)
Downside	IU3c	1493.9	21.0	1252.0	960.3 (83)	2263.7 (97)
Hindagala	IU3c	2173.5	20.9	1829.8	1572.0 (92)	3384.5 (97)
Kahagalla	IU3c	1904.7	22.4	1585.8	1251.9 (98)	2938.2 (94)
Kinellan	IU3c	1792.6	14.8	1579.3	1266.9 (98)	2205.4 (97)
Queenstown	IU3c	1892.2	14.1	1755.5	1475.0 (89)	2432.0 (97)
Wewasse	IU3c	2281.4	17.5	2035.4	1551.9 (98)	3220.9 (86)
Springvelly	IU3c	2296.6	18.5	2076.5	1752.6 (98)	3656.0 (88)
Hakgala	IU3d	1628.0	31.1	1272.8	916.0 (89)	2846.7 (93)
Welimada	IU3e	1242.8	20.0	1029.4	929.7 (89)	1916.0 (02)
Rapphannock	IM1a	2141.8	17.1	1973.7	1370.0 (84)	2896.4 (86)
Telbedda	IM1a	2065.6	19.8	1791.6	1321.7 (83)	2876.1 (86)
Adawatta	IM2b	3256.7	14.0	2999.2	2222.0 (89)	4432.0 (94)
Hopton	IM2b	2696.2	12.7	2507.2	2169.0 (93)	3553.0 (94)

(CV= coefficient of variation, AER= Agro Ecological Region, values in parenthesis indicate the years)

Spatial Variability of Annual Rainfall

The plot of 75% expectancy of annual rainfall vs coefficient of variation (CV) is given in Figure 1.

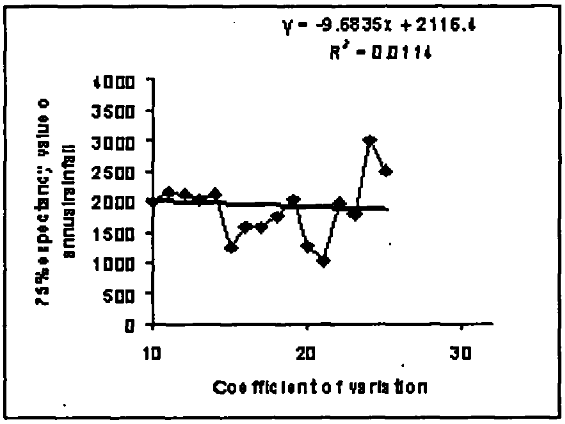

Figure 1. The plot of 75% expectancy value of annual rainfall vs. coefficient variation

In general, if the 75% expectancy value of the annual rainfall is low, the CV is expected to be high. However, in contrary this results (Figure 1) showed that there is no linear relationship between 75% expectancy of annual rainfall and CV. As an exception, the highest 75% expectancy value of annual rainfall (3221.6 mm) in Cocagala estate resulted the highest CV (30%). In 26 estates CV varied from 12.7% to 31.1%. Further it was noticed that in 12 estates out of 26 the CV was less than 20%.

The mean annual rainfall computed for the periods of 1983-1992 and 1993-2002 and the percentage drop of rainfall during 1993-2002 relative to 1983-1992 period are presented in Table 3.

Table 3. Changes in mean annual rainfall (MAR) and mean annual rainy days (MARD) during 1993-2002 relative to 1983-1992

Estate	AER	MAR of 1983 to 1992	MAR of 1993 to 2002	% drop of RF wrt 83-92	MARD 1983 to 1992	MARD 1993 to 2002	% drop of Rainy Days wrt 83-92
Roeberry	IU2	3237.3	3502.9	-8.2	165	144	12.7
Cocagala	IU2	4058.1	3462.1	14.7	152	143	5.9
Verallapathana	IU2	2535.2	2507.2	1.1	137	129	5.8
Batawatta	IU2	2626.3	2726.4	-3.8	148	141	4.7
Mahadowa	IU2	2770.5	2355.3	15.0	132	128	3.0
El Tab	IU2	2801.1	2719.9	2.9	161	143	11.2
Shawland	IU2	2221.1	2587.8	-16.5	142	144	-1.4
Sania	IU2	2292.5	2108.3	8.0	153	145	5.2
Haputale	IU3a	2321.9	2569.1	-10.6	153	148	3.3
Nayabedde	IU3a	3024.0	2631.2	13.0	153	156	-2.0
Pitaratmalle	IU3b	2385.4	2721.8	-14.1	171	142	17.0
Blairlomond	IU3c	2272.2	2229.0	1.9	137	141	-2.9
Cannavarella	IU3c	2319.6	2566.8	-10.7	133	145	-9.0
Downside	IU3c	1317.7	1670.1	-26.7	157	145	7.6
Hindagala	IU3c	1955.6	2391.5	-22.3	127	139	-9.4
Kahagalla	IU3c	1954.7	1854.7	5.1	147	134	8.8
Kinellan	IU3c	1717.5	1867.8	-8.8	150	134	10.7
Queenstown	IU3c	1887.6	1896.9	-0.5	152	131	13.8
Wewasse	IU3c	2268.3	2294.6	-1.2	142	139	2.1
Springvelly	IU3c	2187.7	2228.9	-1.9	102	128	-25.5
Hakgala	IU3d	1567.8	1688.3	-7.7	149	139	6.7
Welimada	IU3e	1158.1	1327.6	-14.6	169	131	22.5
Rapphannock	IM2a	2074.6	2209.1	-6.5	165	144	12.7
Telbedda	IM2a	2285.8	1845.4	19.3	152	143	5.9
Adawatta	IM2b	2961.3	3545.9	-19.7	137	129	5.8
Hopton	IM2a	2646.5	2746.0	-3.8	148	141	4.7

(wrt= with respect to)

The summary results of the analysis of change in two periods are presented in Table 4. According to test statistics, there is no evidence for change in the mean annual rainfall but there is evidence for a drop in mean annual wet days. It indicated that the amount of rainfall had not been affected by the climatic change but the pattern of rainfall has been affected.

Table 4. Summary of change in mean annual rainfall (MAR) and mean annual wet days (MAWD) during 1993-2002 compared to 1983-1992.

	Number of estates		X^2 value	P
	Increase	Drop		
MAR	15	9	1.5	0.2207
MAWD	6	16	5.5	0.0330

Temporal Variability of Annual Rainfall

There was no autocorrelation in annual rainfall in all the estates explaining that there was no seasonal or cyclic pattern of annual rainfall in any location. Therefore, a time series model cannot be fitted to explain the variability of annual rainfall.

Simple linear regression analysis revealed that for two estates (Telbedda and Cocagala) decline in annual rainfall ($P= 0.05$ $R^2=0.19$ and $P= 0.03$ $R^2=0.23$ respectively) and for three estates (Adawatta, Downside and Hindagala) increase in annual rainfall ($P= 0.03$ $R^2=0.23$, $P= 0.03$ $R^2=0.24$ and $P= 0.06$ $R^2=0.18$ respectively) over time.

Separate simple linear regression analysis for two periods (1983-1992 and 1993-2002) revealed that out of 24 estates, Blairolomond estate had a mild drop ($P= 0.09$ $R^2= 0.32$) during 1983-1992 period whereas Nayabedde had a considerable drop ($P= 0.02$ $R^2=0.53$) during 1993-2002 period. Therefore, it cannot be considered that there was a marked increase or decline in rainfall during two periods.

Monthly Rainfall

According to the basic statistics of monthly rainfall (mean, 75% expectancy value, coefficient of variation, minimum and maximum), the coefficient of variation of dry months was higher than that of the wet months in all the estates. In general, the monthly rainfall variability was higher than that of the annual rainfall variability.

Monthly Contribution to the Annual Rainfall

According to Table 5 (a-d), in all the estates, about 50% of the annual rainfall was contributed by the rainfall received during October, November, December and January. Some estates that belong to IU2, IM1a, and IM2b, the contribution during the same months was about 55%. Among the other 8 months, contribution during April only, was about 10% in most of the estates. The contribution from May to September was less than 25% in all the estates.

Table 5. Percentage contribution of monthly rainfall to the annual rainfall in 8 selected AER in Uva

(a) AER IU2

Month	Roeberry	Cocagalla	Veralapathana	Batawatta	Mahadowa	El-tab	Sarnia	Shawlands
Mar	5.0	6.1	5.8	5.5	7.0	8.1	5.1	6.9
Apr	6.5	7.0	9.2	9.0	10.6	10.5	10.2	9.0
May	3.9	3.6	4.9	4.5	6.0	5.8	5.7	5.5
Jun	0.9	2.0	1.7	1.3	2.3	2.4	1.3	2.2
Jul	2.6	2.4	2.7	2.9	3.2	3.8	2.9	3.1
Aug	1.4	2.4	3.3	3.4	4.3	3.7	4.0	4.0
Sep	4.1	4.9	6.0	5.4	6.4	6.2	6.3	6.5
Oct	8.9	10.5	11.3	11.2	12.6	13.1	12.6	12.4
Nov	15.3	15.0	15.6	16.0	15.4	15.5	15.6	15.3
Dec	21.8	21.3	17.5	18.4	14.1	13.6	15.8	16.0
Jan	20.0	16.3	14.3	14.6	11.1	10.2	14.0	11.0
Feb	9.7	8.5	7.6	7.9	7.2	7.0	6.4	8.1

(b) AER IU3c

Month	Blairolomond	Cannaveralle	Downside	Hindagala	Kahagalla	Kinelan	Queens town	Wewasse
Mar	5.4	6.2	5.5	6.0	6.9	6.5	5.2	6.0
Apr	8.0	12.1	9.5	14.5	11.6	11.8	9.2	10.3
May	4.7	7.8	8.0	7.5	7.2	7.7	6.4	5.9
Jun	1.4	2.9	2.4	2.6	2.7	2.6	1.7	3.2
Jul	2.6	4.4	4.4	3.5	4.0	4.4	3.6	3.4
Aug	3.0	4.6	4.7	4.0	4.2	5.6	4.6	5.6
Sep	4.8	8.4	8.1	7.1	8.6	8.0	6.5	7.6
Oct	10.4	15.1	13.3	14.6	15.5	14.2	11.6	13.3
Nov	15.6	14.1	14.2	16.2	14.3	15.2	15.8	15.1
Dec	18.1	10.6	13.4	11.2	11.1	10.3	14.9	13.9
Jan	17.4	8.1	10.5	6.9	7.2	7.9	13.9	9.9
Feb	8.5	5.9	6.1	5.9	6.9	5.8	6.6	5.7

(c) AER IM2b, IM1a and IU3a

Month	Adawatta	Hopton	Month	Rapphan.	Telbedda	Month	Haputale	Nayabedde
Mar	5.5	7.4	Mar	4.4	6.9	Mar	6.9	6.6
Apr	7.5	10.0	Apr	8.7	9.3	Apr	13.4	12.3
May	3.7	5.9	May	4.4	6.1	May	7.6	7.4
Jun	2.1	2.3	Jun	1.7	2.2	Jun	2.4	2.5
Jul	2.8	3.4	Jul	2.8	4.2	Jul	3.1	3.6
Aug	3.7	4.0	Aug	2.5	6.3	Aug	3.6	4.0
Sep	6.0	6.6	Sep	5.6	6.6	Sep	7.2	8.0
Oct	11.7	12.2	Oct	10.3	12.0	Oct	16.3	14.3
Nov	15.1	15.1	Nov	15.8	14.4	Nov	15.9	14.5
Dec	19.3	13.5	Dec	19.4	13.6	Dec	9.9	11.5
Jan	14.3	10.9	Jan	17.5	12.8	Jan	7.3	9.0
Feb	8.3	8.8	Feb	6.8	5.8	Feb	6.5	6.3

(d) AER IU3b, IU3d and IU3e

Month	Pitaratmalee	Month	Hakgala	Month	Welimada
Mar	7.0	Mar	5.5	Mar	4.5
Apr	13.8	Apr	7.9	Apr	9.8
May	9.1	May	7.4	May	8.6
Jun	2.6	Jun	5.7	Jun	2.8
Jul	3.3	Jul	6.4	Jul	4.1
Aug	4.8	Aug	5.6	Aug	5.5
Sep	8.0	Sep	7.7	Sep	9.0
Oct	16.3	Oct	16.2	Oct	12.5
Nov	15.2	Nov	10.6	Nov	13.9
Dec	9.9	Dec	11.3	Dec	13.3
Jan	5.1	Jan	9.7	Jan	10.1
Feb	5.0	Feb	6.0	Feb	5.8

The length of the dry period was greater than the wet period. For better growth and production of tea, an even distribution without any marked seasonality is ideal (Watson, 1986). However the problem in the intermediate zone is that the rainfall contribution from five consecutive months (May-September) is less than 25%. Although the 75% expectancy values of annual rainfall fulfill the annual requirement of tea in most of the estates, the distribution of rainfall is extremely poor compared to the wet zone.

75% Expectancy of Monthly Rainfall

Test results of the deviation in 75% expectancy of the monthly rainfall of each estate from that of the expected value for the AERs are presented in Table 6. The AERs showed bimodal pattern of monthly rainfall for both observed and expected rainfall. Two peaks of the bimodal rainfall pattern could be clearly identified in the AERs of IU3a, IU3b, IU3c, IM1a and IM2b and IU2 and IU3e, only the second peak was prominent. In all the AERs, 75% expectancy values for October to January were greater than 150 mm. Similarly, in all the AERs, February to March rainfall was less than 50 mm except for few estates in IU2 and IM2b where 75% expectancy value for February was greater than 50 mm.

Table 6: X^2 test statistics and probability for deviation of 75% expectancy values from AER

Estate	AER	X^2	P
Roeberry	IU2	963.3	<0.001
Cocagala	IU2	1178.0	<0.001
Veralpathana	IU2	87.1	<0.001
Batawatta	IU2	191.6	<0.001
Mahadowa	IU2	80.1	<0.001
Eltab	IU2	183.3	<0.001
Sarnia	IU2	86.7	<0.001
Shawland	IU2	120.7	<0.001
Nayabedde	IU3a	881.2	<0.001
Haputale	IU3a	57.9	<0.001
Koslanda	IU3a	96.4	<0.001
Pitaratmali	IU3b	94.0	<0.001
Aislaby	IU3c	66.1	<0.001
Attampitya	IU3c	60.8	<0.001
Queenstown	IU3c	176.8	<0.001
Blairlomond	IU3c	631.1	<0.001
Springvelly	IU3c	97.9	<0.001
Cannaveralla	IU3c	198.6	<0.001
Hindagala	IU3c	129.4	<0.001
Wewasse	IU3c	145.9	<0.001
Kinnelan	IU3c	74.4	<0.001
Downside	IU3c	147.8	<0.001
Kahagalla.	IU3c	42.7	<0.001
Hakgala	IU3d	350.1	<0.001
Welimada	IU3e	107.2	<0.001
Rapphanock	IM1a	108.3	<0.001
Telbedde	IM1a	72.1	<0.001
Adawatta	IM2b	1486.3	<0.001
Hopton	M2b	319.2	<0.001

The X^2 test statistics in Table 6 clearly showed that observed 75% expectancy values of the monthly rainfall were significantly different from that of the expected values for the AER.

Within IU2 the 75% expectancy value of January was greater than 200 mm. In two estates Cocagala and Roeberry, this value was exceptionally high (greater than 400 mm) and it was 150% higher than that of the expected values of the AER. In those two estates, the rainfall in February was greater than that of the other estates within the IU2. The rainfall in December of the above two estates was greater than 500 mm (759 mm & 734 mm respectively) which was 100% higher than that of the expected values of the AER. In IU2, rainfall was considerably less in June (75% expectancy value was less than 30 mm) and IU2 rainfall in June was the lowest rainfall among all the AERs under the study. In all the estates of IU2, the 75% expectancy value of June was 50% less than that of the expected values of the AER.

In IU3c, the rainfall in January was less than 100 mm. However in six estates out of 11, the 75% expectancy value was greater than 100 mm. The expected April rainfall of the AER was greater than 100 mm. However, there were four estates where April rainfall was found less than 100 mm. These results indicate that within an AER, the monthly rainfall can be significantly different from the expected values of the region. Therefore, it is questionable as to how accurate the regional values used for planning and implementation of cultural practices in tea estates.

Seasonal Rainfall

The percentage contribution of four seasons to the annual rainfall in each estate is presented in Table 7. The highest contribution (60%) was by both NEM (December-February) and SIM (October- November). The FIM (March- April) contributed about 15% of annual rainfall in all the estates. Only December and January rainfall mainly contributed to the NEM, because the contribution from February was very low in most of the estates. There was an extended dry season during SWM (May to September). The percentage contribution from these five months was less than 25% in all the estates. These results clearly indicate the seasonal differences occurring in the annual rainfall and as to how these seasonal rainfalls contribute to the total annual rainfall.

Table 7. Percentage contribution of four seasons to the annual rainfall

Estate	AER	FIM	SWM	SIM	NEM
Roeberry	IU2	11.5	12.8	24.2	51.4
Cocagala	IU2	13.1	15.2	25.5	46.2
Veralapathana	IU2	15.0	18.8	26.9	39.4
Batawatta	IU2	14.4	17.5	27.2	40.8
Mahadowa	IU2	17.5	22.1	28.0	32.4
Eltab	IU2	18.6	21.9	28.6	30.8
Sarnia	IU2	15.3	20.3	28.2	36.2
Shawland	IU2	16.0	21.2	38.2	35.1
mean		**15.2**	**18.7**	**28.3**	**39.1**
Haputale	IU3a	20.3	23.8	42.9	23.7
Nayabedda	IU3a	18.9	25.4	40.7	26.9
mean		**19.6**	**24.6**	**41.8**	**25.3**
Pitaratmali	IU3b	20.8	27.7	120.2	20.0
Blairolomond	IU3c	13.4	16.5	33.9	44.0
Cannaveralla	IU3c	18.2	28.0	42.2	24.6
Downside	IU3c	15.0	27.5	40.3	29.9
Hindagala	IU3c	20.4	24.7	41.9	24.0
Kahagalla	IU3c	18.4	26.7	42.6	25.1
Kinelan	IU3c	18.3	28.2	43.0	24.1
Queenstown	IU3c	14.4	22.8	38.5	35.4
Wewase	IU3c	16.3	25.8	41.6	29.5
Springvelly	IU3c	15.8	26.3	42.0	29.4
mean		**16.7**	**25.2**	**40.7**	**29.6**
Hakgala	IU3d	13.4	32.7	40.1	27.0
Welimada	IU3e	14.4	30.1	40.9	29.2
Rapphanoc	IM1a	13.2	17.0	34.1	43.7
Telbedda	IM1a	16.2	25.3	39.2	32.1
mean		**14.7**	**21.2**	**36.7**	**37.9**
Adawatta	IM2b	12.9	18.3	36.6	41.9
Hopton	IM2b	17.4	22.1	37.8	33.3
mean		**15.2**	**20.2**	**37.2**	**37.6**

Rainy Days of the Year

Mean number of rainy days had dropped in 16 estates out of 22 estates over the years (Table 3). Only six estates showed an increase in the mean number of rainy days relative to 1983-1992 period. The frequency of drop in rainy days (16) was significantly higher than that of the frequency of increase (6) (X^2 =5.55 P= 0.04). Thus it could be seen a change in rainfall with respect to number of rainy days, but no change with respect to mean annual rainfall (Table 4).

Relationship between monthly Southern Oscillation Index (SOI) and the monthly rainfall

Lag periods of 0-10 were studied and it was not possible to detect any correlation between rainfall and SOI. Therefore SOI cannot be used for any prediction purpose.

Influence of El Nino Episode on Seasonal Rainfall

Table 8 shows the number of years receiving the rainfall below and above the expected rainfall in four different rainy seasons during El Nino years at Welimada. The season was considered dry if the standardized rainfall was below –1 and wet if the standardized rainfall was above +1.

Table 8. Number of years with rainfall above the normal rainfall during El Nino years and number of dry and wet rainy seasons at Welimada.

Season	Number of years			
	Above the normal rainfall	Below the normal rainfall	Number of wet rainy seasons	Number of dry rainy seasons
FIM	9	4	4	3
SWM	6	7	0	1
SIM	11*	2*	6	0
NEM	3*	10*	0	2

Total number of El Nino years =13
* Significantly different at $P = 0.025$

According to Table 8, the number of years was significant only for SIM and NEM seasons. Thus it seems that there had not been any effect of El Nino on FIM and SWM seasons but there had been some El Nino effect on rainfall of SIM and NEM seasons. However it is still unclear how El Nino has affected only on certain seasons.

The past studies on the influence of occurrence of El Nino episodes on FIM have revealed similar results (Punyawardana and Cherry, 1999). According to literature, during FIM the El Nino events are at their early stage of development in the east and central Pacific Ocean. The magnitude of the increase (decrease) in sea surface temperature over the Pacific Ocean with a newly developed El Nino event is rather small. Such a small increase (decrease) of sea surface temperature would not be strong enough to influence the general circulation of the atmosphere and thereby the tropical rain (Punyawardana and Cherry, 1999).

The significant relationship between occurrence of El Nino events and rainfall of SIM suggests that the increased rainfall during SIM in El Nino years at Welimada was not due to chance and probably due to change in general circulation. It is unlikely that El Nino would cause drought condition during SIM season at Welimada, because none of the El Nino years has received rainfall below –1. The observed results of rainfall of SIM were consistent with the study conducted by Punyawardana and Cherry (1999) for Ratnapura district.

The significant relationship between occurrence of El Nino and NEM at Welimada estate were different compared to that of the study of Punyawardana and Cherry (1999) for rainfall at Ratnapura. Moreover, the present study used only the data of Welimada estate to study the El-Nino effect of long-term rainfall. Hence it is suggested to explore this relationship in other areas of the Uva region.

CONCLUSIONS

The total annual rainfall has not changed during the period of 1983-1992 to 1993-2002. However, the total number of rainy days per year has declined in majority of the estates form 1983-1992 to 1993-2002. Thus there is evidence for the change in the distribution of rainfall but not the amount over past 20 years. Although monthly rainfall distribution of all the estates follows the expected pattern according to AER, the 75% expectancy values of monthly rainfall significantly deviated from that of AER values. Therefore, present site-specific analysis of long-term rainfall variability provides valuable guidelines for planning and implementation of management practices for tea lands in the Uva region. The present study clearly indicated that more than 50% of the annual rainfall is concentrated into few months (October- January) of the year. Only less than 25% of rainfall was contributed by the five consecutive months from May to September. Thus, with respect to optimum growth of tea it is clear that there is marked imbalance in distribution of rainfall in the Uva region. This information can be used to minimize the drought effects on tea lands by pre- planning of management practices.

Although the relationship of monthly rainfall and SOI values found to be weak the influence of occurrence of El Nino events on seasonal rainfall of Welimada estate showed that there is a significant relationship between occurrence of El Nino events and the SIM rain. It suggests that the increase in SIM rains during El Nino years was not due to chance and probably due to change in general circulation.

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