Assessment of Climate Variability for Coconut and Other Crops: A Statistical Approach

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Abstract

Public opinion in Sri Lanka has been seriously concerned about the possible impact of climate change on different sectors, and in particular for the agricultural sector. Annual and weekly climate data were analyzed to provide useful information to farmers, planners and scientists to assess the suitability of different types of crops. The statistical methodology of the analysis is illustrated using daily rainfall and air temperature from 1951 to 2001 for Hambantota, a major coconut growing district in Sri Lanka. The increase in maximum air temperature and decrease in the amount of rainfall per effective rainy day (> 5mm) are the significant features of the climate variability in the Hambantota area. The warming rate for maximum air temperature was significantly higher (p<0.005) than that for minimum, mean and diurnal temperature, irrespective of time scales. The annual rate of increase of maximum temperature after 1995 is 0.026^0C. The intensity of rainfall per effective rainy day (> 5mm) decreased significantly (p<0.005). Distribution of weekly rainfall during January to September is uncertain. The probability of weekly rainfall greater than 20 mm does not exceed 50% in any week during this period. Long-term weekly rainfall was greater than 30 mm only during mid October to early December, but the probability of weekly rainfall greater than 30 mm exceeds 50% only during the first three weeks of November. The probability of occurrence of dry spells of duration greater than 60 days in a year is around 70%, but the time of occurrence of such dry spell is not consistent among years. These findings suggest that the expected future climate would not be suitable for coconut cultivation, if growers do not apply the recommended practices to face long dry spells. Also the increasing temperature could impact to dominate plant pest during dry periods.

Keywords: Coconut, climate change, climate variability, climate analysis.

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Introduction

Climate in a narrow sense is usually defined as the "average weather", or more rigorously, climate is the long term variability of weather parameters. The variability can be described using statistical parameters such as the mean and variance of climate variables. The climate at a given location or a region is determined by the net variability of precipitation, surface air temperature, relative humidity, sunshine duration, wind velocity and numerous other parameters (Peiris, *et al*, 2000). It is one of the most important limiting factors for agricultural crop production. The climate of Sri Lanka is predominantly governed by the seasonally varying monsoon system and the associated air masses that are part of the planetary wind regime over South Asia (Domroes, 1974) and thus there is a high variability in climate between different districts in Sri Lanka.

Hambantota is a rapidly urbanizing area occupying a land area of 100 km^2 and is situated in the southeast of Sri Lanka between the latitudes 6.07°N to 6.54°N and the longitudes 80.64°E to 81.68°E with an altitude of 16 m. The Hambantota area belongs to the low country high dry (DL_5) region of Sri Lanka and the 75% expectancy of annual rainfall is 1000 mm. The economy of Hambantota depends mainly on rain fed crops and it has the greatest coconut extent of about 20000 hectares which is equivalent to 5% of the total coconut extent in Sri Lanka. In addition to coconut, rice and short term crops are grown in this area, which was one of the districts worst affected by the Tsunami of 2004. Variability in precipitation and temperature would strongly affect agricultural crops through their influences on internal plant processes and external factors such as soil water availability and pest and diseases incidence. Past analyses of rainfall in Hambantota, based on annual or monsoon seasons did not produce sufficient information on climate variability for farmers to plan their activities; Malmgren, *et al*., 2003). There have also been claims that the onset of monsoon rains has changed in various locations in Sri Lanka (Peiris, *et al.* 2000). Thus there is a need to assess the suitability of crops from time to time.

The objective of this study was therefore to demonstrate a methodology for statistical analysis of the weekly rainfall and temperature data in the Hambantota area to elucidate the past climate variability and to make inferences regarding future climate variability in the area for the purpose of planning agricultural activities.

Materials and method

Climate data

Daily data on rainfall (RF), maximum air temperature (T_{MAX}) and minimum air temperature (T_{MIN}) in Hambantota (6.12°N, 81.13°E, 16.0m) during the period from 1951 to 2001 were acquired from the climate database of the Biometry Division of the Coconut Research Institute. Data were quality controlled and some missing daily rainfall values were estimated using exponential smoothing techniques (Malmgren *et al*., 2003).

Statistical analysis

Data were analyzed using SAS and Minitab statistical packages. Linear trend analysis was carried out on both yearly and weekly data for four temperature and three rainfall indices namely (i) maximum T_{MAX}, (ii) minimum T_{MIN}, (iii) mean $T_{MEA} = (T_{MAX} + T_{MIN})/2$), (iv) diurnal temperature $T_{DIF} = (T_{MAX} – T_{MIN})$, (v) total RF, (vi) rainfall intensity (RF_I) and (vii) effective rainfall intensity (RF_{EI}). Rainfall intensity (RF_I) and effective rainfall intensity (RF_{EI}) were defined as the amount of rainfall per rainy day (>0 mm) and per effective rainy day (>5 mm). The effective rainfall is generally subjective thing depend on the crop, however it this study it was taken as 5 mm as coconut is concern.

The average water requirement of adult coconut palm is 50 liters per day (Mahindapala and Pinto, 1991). Considering that the radius of the root system is approximately 2.1m and the depth is 1m, the height of requirement of water was calculated as 5mm, excluding a circle of 0.30m radius for the area of root ball. Thus, an effective rainy day for coconut can be considered as 5 mm per day.

To obtain weekly data, a year was divided into 52 weeks (Appendix A). In leap years rainfall on 29th February was added to the 9th week and converted to a 7 day total. The autocorrelation function and single spectrum density function were derived to detect any seasonal or cyclic pattern of the yearly series (Chatfield and Collins, 1980).

The non-parametric statistics u(t) and u'(t) of Mann-Kendall rank correlation test (Turkes, *et al*, 2002) were used to detect any possible significant periods of trend or change points in the RF, T_{MAX}, T_{MIN}, T_{MEA} and T_{DIF} times series. When the value of either u(t) or u'(t) is significant at the 5% level, it can be decided whether one or other trend is increasing (u(t) > 0 ; u'(t)>0) or decreasing (u(t) <0 ; u'(t)< 0.

The length of the three longest dry spells in each year during 1951 to 2001 was computed using an SAS program. The empirical cumulative density functions for dry spells were derived to compute probabilities for the occurrence of dry spells for different lengths under normality assumption. The normality was confirmed using Anderson-Darling statistics (Chatfield and Collins, 1980).

Results and discussion

Annual climate variability

The plot of autocorrelation for all annual series confirmed that there is no cyclic pattern in the series of T_{MAX}, T_{MIN}, T_{MEA}, T_{DIF} or RF. Basic statistics of four temperature and three rainfall indices were used to describe annual climate variability (Table 1).

Annual rainfall during the 51 year period varied from 603 mm to 1825 mm with a mean of 1021 mm. Annual variability of rainfall intensity (cv=26%) is higher than that of total rainfall (cv=25%). Variability of T_{DIF} is significantly higher compared to other temperature indices.

Maximum temperature - T_{MAX}

Figure 1(a) clearly indicates a significant increasing trend for T_{MAX} ($R^2 = 0.51$; $p < 0.001$) at the rate of 0.02°C/year. About 50% of annual variability is explained by the linear model. Figure 2(a) indicates that the significant warming trend of T_{MAX} commenced in 1978. There were no periodic changes during the period 1951 to 2001. After 1978, the increasing rate of T_{MAX} was 0.0260°C/year as compared to 0.0082°C/year prior to 1978.

Minimum temperature - T_{MIN}

T_{MIN} showed a significant increasing trend and the warming rate was 0.007°C/year (Figure 1.b). According to Figure 2(c) u(t) exceeds the critical value during the period from 1966 to 1975 and again after 1995. The analysis also indicates that significant rates of increase and decreases commenced during 1966 and 1995 respectively. The annual rate of increase after 1995 was 0.0204°C/year as against 0.0042°C/year prior to 1995. The u'(t) shows no systematic trend or interaction between u(t) and u'(t). No significant strong linear relationship was found between T_{MAX} and T_{MIN} (r=0.658).

Mean temperature - T_{MEA}

Mean temperature also showed a significant increasing trend ($p < 0.001$), but the rate of increase (0.0135°C/year) was less than that of T_{MAX}. The highest T_{MEA}, 28.4°C,

Table 1: Basic statistics of annual indices of temperature and rainfall

Index	Mean	CV (%)	Minimum	Maximum
T_{MAX} (°C)	30.39	1.37	29.37	31.73

T_{MIN} (°C)	24.22	1.08	23.73	25.08
T_{MEA} (°C)	27.30	1.14	26.68	28.41
T_{DIF} (°C)	6.16	5.10	5.38	6.84
RF (mm yr^{-1})	1020.6	25.1	603.2	1825.0
RF_I (mm d^{-1})	14.7	26.0	7.4	24.2
RF_{EI} (mm d^{-1})	7.5	22.4	4.3	10.4

RF_I - Rainfall intensity, RF_{EI} - effective rainfall intensity

Table 2: Increasing rates for temperature indices

Indicator	Year of significant change	Rate of increase (°C/year)	
		Prior to significant change	After the significant change
T_{MAX}	1978	0.0082	0.0260
T_{MIN}	1995	0.0042	0.0204
T_{MEA}	1983	0.0064	0.0225
T_{DIF}	1980	0.0119	0.0142

Table 3: Mean and CV of the length of three longest dry spell (in days)

Indicator	Longest dry spell	2nd longest dry spell	3rd longest dry spell	Total of 3 dry spells
Mean	53	36	26	114
CV (%)	34.6	25.1	21.4	28.5

was recorded in 1998. There are no periodic changes for T_{MEA} in Figure 2(b). Based on the pattern for u(t) (Figure 2.b) it can be confirmed that a significant change in the increasing mean temperature trend occurred in 1983. The warming rate after 1983 was 0.0225°C/year compared to 0.0064°C/year prior to 1983.

Diurnal temperature - T_{DIF}

T_{DIF} varied from 5.38°C (1961) to 6.84°C (2001). Figure 1(d) shows that the significant increment rate (p< 0.001) of T_{DIF} was 0.0128°C/year. Both u(t) and u'(t) intersect at 1971 (Figure 2.d) confirming that the significant change of T_{DIF} has started during 1971, but the significant increasing trend can be seen clearly only after 1980. The increment rate of T_{DIF} after and prior to 1980 was 0.0142°C/year and 0.0119°C/year respectively.

The comparison of indices for increasing rates of temperature before and after the corresponding significant turning point is given in Table 2.

Based on the results in Table 2, it can be confirmed that warming rates after 1995 are significantly higher for all four temperature indices. In fact 1990-2000 has been identified as the warmest decade on record (IPCC, 2001).

Rainfall – RF

Annual rainfall shows a decreasing linear trend (Figure 3.a), but it is not significant at 5% level. The plot of u(t) and u'(t) for annual rainfall (Figure 3.b) varies within the limiting points and the two curves intersect in 1976. It confirms that there is no turning point to demonstrate significant rainfall change during 1951 to 2001. Thus, analysis of total annual rainfall is less important for climate variability in Hambantota.

Rainfall intensity

Trend analysis showed that rainfall intensity (RF_I) and effective rainfall intensity (RF_{EI}) (Figure 4) have significantly decreased with time. The rainfall intensity decreased much faster than effective rainfall intensity. During the period from 1951 to 2001 rainfall intensity has dropped from about 25 mm/day to about 8 mm/day. Corresponding rates for effective rainfall intensity were 10 mm/day and 5 mm/day.

Dry spells

Mean and coefficient of variation (CV) for the three longest dry spells and the sum of the three dry spells are shown in Table 3.

The length of the longest dry spell had the greatest variability. Based on the empirical cumulative density function shown in Figure 5 the probability of the length of the dry spell in a year being more than 60 days was 31%. It implies that at least a dry spell of 60 days would occur once in three years. Figure 5 indicates that the probability of the length of the dry spell in a year being more than 65 days was 25%. The probability of at least three dry spells of more than 30 days in a year was 40%. The plot of the longest dry spell in a year also showed an increasing trend though it is not statistically significant. The periods of dry spells varied between the years indicating that a specific period can not be recommended for the occurrence of dry spells for all years.

Weekly climate variability

Weekly T_{MAX}

The temporal variability of long term weekly T_{MAX} is shown in Figure 6(a). It indicates that the weekly T_{MAX} has varied with a maximum of 31.4°C (±0.09) during the 13th week (26 Mar - 02 Apr) and a minimum of 29.6°C (±0.11) during the 52nd week (24 – 31 Dec). The temperature during the period from 9th week to 21st week (26 February to 29 May) is generally higher (> 31°C) than other weeks. Similarly, after the 48th week (30th November) temperature is lower than in all previous weeks. Weekly T_{MAX} rapidly increased

Figure 1: Annual variability of T_{MAX}, T_{MEA}, the corresponding trend line

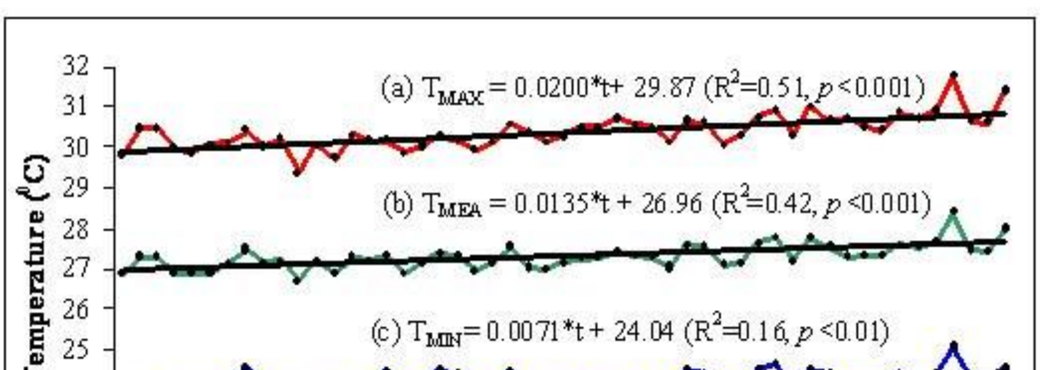


Figure 2: Temporal patterns of the trends in annual T_{MAX}, T_{MIN}, T_{MEA} and T_{DIF} temperature series and sequential values of the statistics *u(t)* and *u'(t)* of the M-K test with critical value of ±1.96 at the 5% level of significance

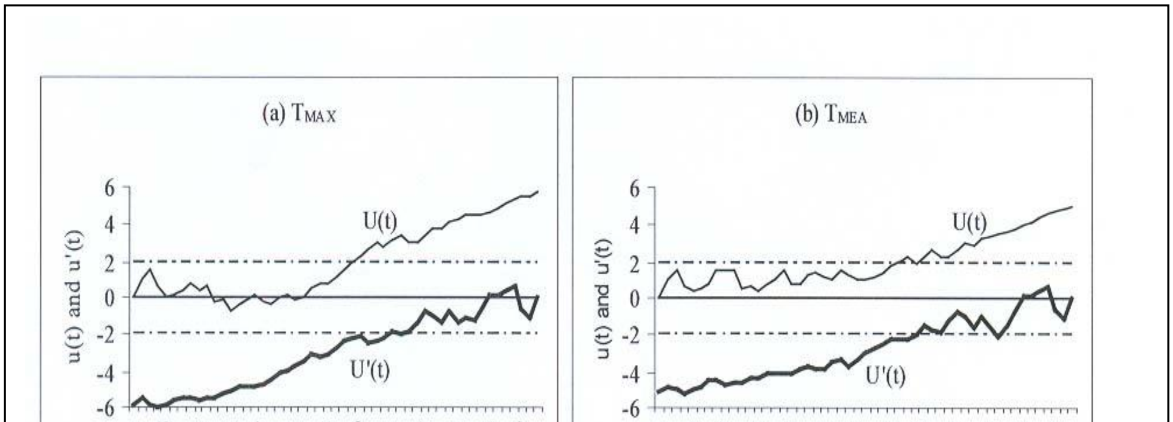


Figure 3: Temporal variability of (a) annual rainfall and (b) u(t) and u'(t) for annual rainfall

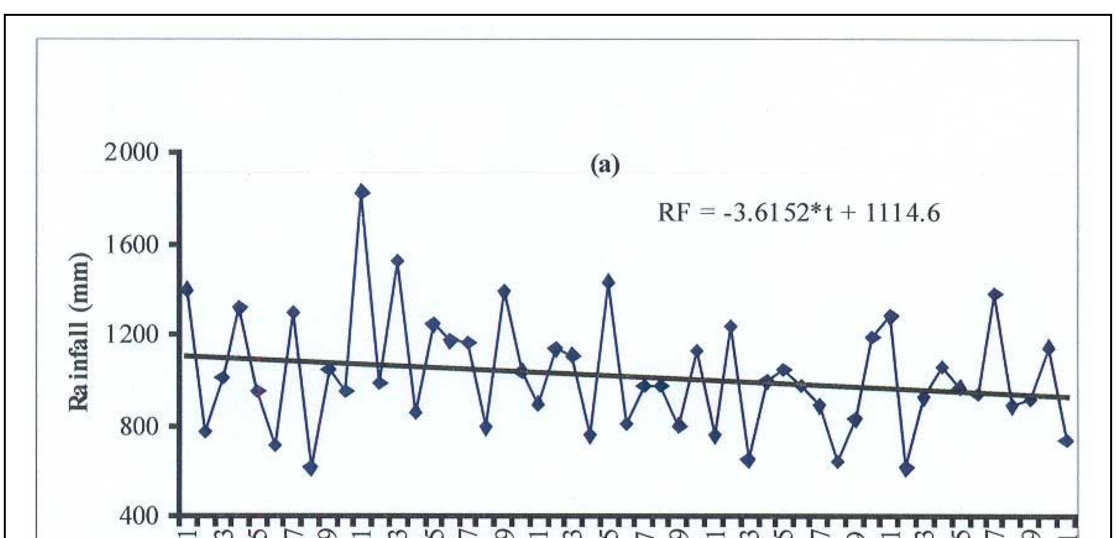
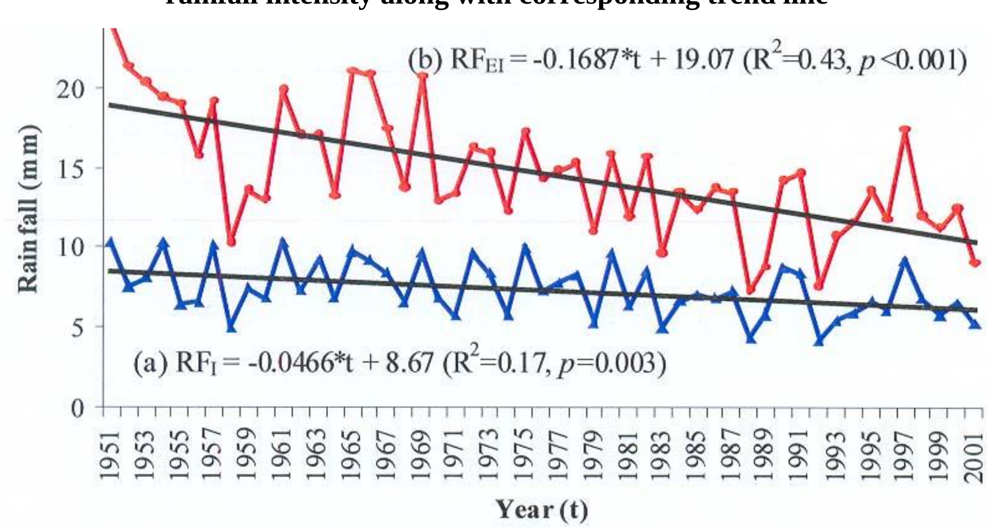


Figure 4: Temporal variability of (a) rainfall intensity and (b) effective rainfall intensity along with corresponding trend line



linearly from the beginning of the year until the 13th week (6 Mar to 02 April) and subsequently decreased slowly up to the 21st week (23-29 May) and then fluctuated around 30°C.

The estimated parameters (b) of the linear trend model (y = a + b*t) fitted for each temperature index on a weekly basis is shown in Appendix B. All weeks, except the 32nd week showed warming trends. Out of 52 weeks, 44 (85%) showed a significant increasing trend ($p < 0.05$). The rate of increase is significantly higher during the 7th to 8th week (12 Feb – 25 Feb) and the 29th to 30th week (19 Jul - 01 Aug). Of these four weeks, the lowest rate of increase was observed during the 7th week (12-18 February). As described above 5 mm of rainfall per day was considered as effective rainfall. Thus a 'rainy week' is defined as a week of which exceeds rainfall more than 35mm) (0.0322°C/year, $p<0.01$). Further, the period from the 9th week (26 Feb – 04 Mar) to the 24th week (13-19 Jun) also showed a high warming rate with a mean of 0.0222°C/year. The 52nd week (24-31 December) also showed a warming rate of 0.02°C/year, but the mean T_{MAX} during that week was below 29°C.

Weekly T_{MIN}

The pattern of temporal variability of weekly T_{MIN} (Figure 6.b) is not as complex as that of T_{MAX}. Weekly T_{MIN} increased from 22.8°C (±0.14) during the 6th week (5-11 Feb) to 25.7°C (±0.09) in the 21st week (30 May – 5 Jun) as depicted in Figure 6(b). The T_{MIN} during the period the 15th to the 22nd week [dates] is higher (> 25°C) than in other weeks. The temperature during the 1st to the 9th week is lower (< 23.5°C) than that of other weeks. During the period from the 6th to the 19th week (05 Feb – 15 May) the weekly T_{MIN} rapidly increased with time and thereafter decreased gradually. As for T_{MAX}, all weeks except the 23rd and 26th weeks showed warming trends. However, only ten weeks in the year 26 Mar – 17 Apr (13-15th week), 25 Apr – 08 May (17-18th week), 09 Nov – 29 Nov (45-47th week) and 21 – 31 Dec (51-52 week) showed a significant increasing trend ($p < 0.05$) for T_{MIN} as shown in Appendix B. A significantly increasing trend for T_{MAX} was also seen during the above weeks. The highest increment rate for T_{MIN} was 0.0173°C/year during the 13th and 17th weeks (26 March – 01 May). The rate of increase was higher for T_{MAX} than for T_{MIN} for all weeks and in most of the cases rate of increase for T_{MAX} was more than double that of T_{MIN} (Appendix B).

Weekly T_{MEA}

The mean temperature increased from the 6th to the 20th week (05 Feb – 22 May) and thereafter T_{MEA} decreased with time (Figure 6.c). The T_{MEA} varied with a maximum of 28.3°C (±0.08) (19th week, 9-16 May) and a minimum of 26.3°C (±0.07) (3rd week, 15-21 January) during the year. The trends in weekly T_{MEA} significantly increased during the 1st to the 18th week (01 Jan – 08 May), the 21st to the 23rd week (30 May-12 June), and the 28th to the 30th week (12 July - 01 Aug) and in almost all weeks after 12th October. The highest rate of increase was observed in the 30th week (26 July-01 Aug) when it was 0.0232°C/year.

Weekly T_{DIF}

Figure 6(d) indicates that the temporal variation of the weekly T_{DIF} increased from the 1st to the 12th week (01 Jan to 25 Mar). The mean diurnal temperature during the 5th to the 12th week (29 Feb – 25 Mar) was above 7°C. During these weeks diurnal temperature was significantly increased with time. T_{DIF} was lowest during the 21st and 22nd weeks (23 May to 05 Jun) and when it was around 5°C.

Weekly RF

The long-term weekly rainfall is shown in Appendix C. It is reasonable to assume that at least 35 mm of rainfall per week is required if coconut is to be grown successfully in any area

(Mahindapala and Pinto, 1991). Appendix C shows that weekly rainfall exceeds 35 mm (5mm per day) only during the period from the 42nd to the 48th week (19 Oct – 06 Dec). Analysis also showed that there is no significant increasing or decreasing trend in weekly rainfall.

Rainfall data described above using arithmetic means provide a general idea of the weekly rainfall variability. In order to develop suitable strategies for agricultural planning and implementation, it is important to have some estimates of the amount of rainfall on a weekly basis. For this purpose, the probability of receiving weekly rainfall greater than a specific amount (e.g. 0, 10, 20, 30, 35 mm) was computed (Appendix C) without assuming any distribution. These threshold values were chosen to enable the user to decide upon appropriate amounts of rainfall considered as sufficient for various field operations related to agriculture. The probability of rainfall on a given week being at least 35 mm exceeds 50% only during the 44th to 46th weeks (02 Nov – 22 Nov). Similarly, the probability of rainfall on a given week being at least 30 mm exceeds 50% only during the 44th to 47th weeks (02 Nov – 28 Nov]. These results confirm that in Hambantota, a reliable rainy spell can be expected only during the 44th –to 47th weeks (02 Nov – 28 Nov).

Discussion

All annual temperature indicators (T_{MAX}, T_{MIN}, T_{MEA} and T_{DIF}) in Hambantota showed significant increasing trends ($p < 0.01$) during the period 1951-2001. The warming rate for T_{MAX} (0.02°C/year) is significantly higher than that for T_{MIN} (0.0071°C/year), T_{MEA} (0.0135°C/year) and T_{DIF} (0.0128°C/year). However, according to the global warming scenario the rate of T_{MIN} is higher than that of T_{MAX}. Thus it can be hypothesized that local effects in Hambantota area are different from the global effects. The scientific reason for this different trend has to be investigated, but the low altitude and proximity to the ocean may contribute to the observed trend in temperature at Hambantota. Similar trends have been observed in parts of other coconut growing

Figure 5: Empirical cumulative density function of (a) longest spell (DS1), (b) second longest dry spell (DS2), (c) third longest dry spell (DS3) and (d) sum of the three longest dry spells

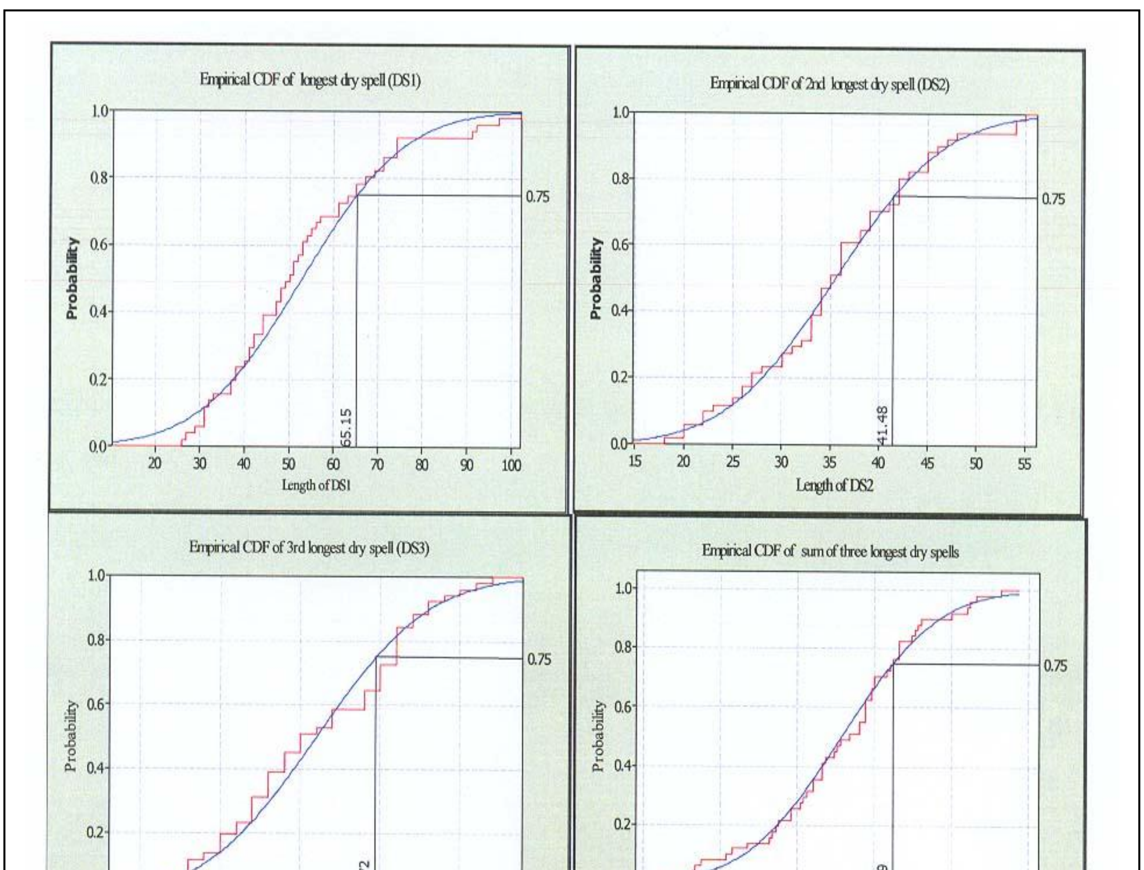
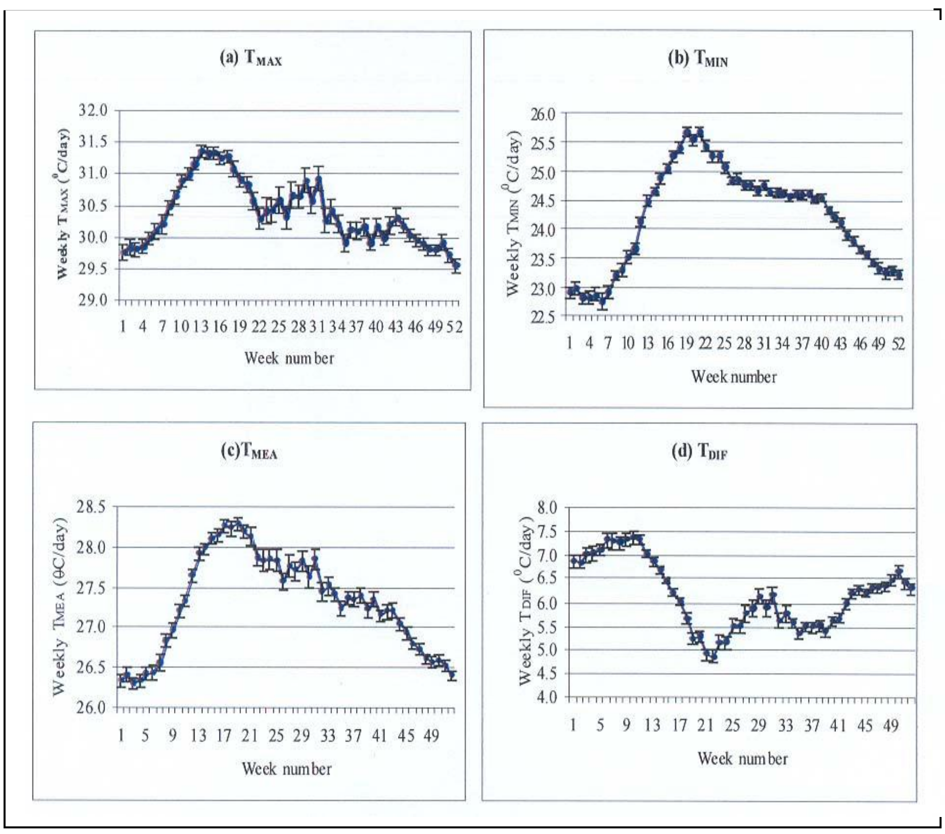


Figure 6: Variability of weekly temperature indices (mean ±SE) for (a) T_{MAX} (b) T_{MIN}, (c) T_{MEA} and (d) T_{DIF}



areas (Peiris, unpublished). The warming rate of T_{MAX} is almost equal to the rate of global warming predicted by the global circulation model. As the rate of increase of T_{DIF} is lower than that of minimum temperature, increase of warmer periods with warming during day and night could be expected in Hambantota in the future.

The increasing temperature could lead to an increased demand for water by plants. This would be a serious problem for both the agriculture and livestock industries in Hambantota. The increase of temperature in Hambantota may also be due to increased greenhouse gas concentrations in the atmosphere due to rapid urbanizing programs in the district.

Annual rainfall showed a significant negative correlation ($p < 0.05$) with maximum air temperature. Thus reduction in the annual rainfall could be expected, though it may not be statistically significant. Decrease of both rainfall intensity and effective rainfall intensity would have serious impacts on agricultural and livestock production in Hambantota. The rate of decline of the amount of effective rain is much higher than that for rainy days. Thus, less rainfall as well as lower intensity of rainfall could be expected in the future, in the Hambantota area.

The probability of dry spells of greater than 60 days in a year is 30%. The probability of at least three dry spells of duration greater than 30 days in a year is 41% indicating three to four months of dry, warm weather within a year, which can occur about twice every five years. This pattern of dry spells would negatively impact on coconut as an inflorescence is produced every month. Thus the expected future climate in Hambantota will not be suitable for high coconut production. Tree crops like cashew and mango would be ideal for the Hambantota area.

Weekly rainfall showed the highest negative significant correlation with the corresponding weekly maximum air temperature. High maximum and minimum temperatures increase water demand and adversely affect planting seed material, establishment of seedlings; reduction of canopy cover and the final yield of any crop. In fact, most of the weeks, rainfall is below 25 mm and only the period between the 44th and 47th weeks have a probability greater than 50% of receiving a weekly rainfall exceeding 30 mm. This analysis suggests that the amount of rainfall in Hambantota is not sufficient to store rainwater in tanks for agricultural purposes. Use of ground water, where available, would be the only water source for both annual and perennial crops in the Hambantota area.

The highest maximum temperature (>31^{o}C) is shown generally during the 11^{th} – 18^{th} weeks (12 Mar – 08 May) in each year. The highest diurnal temperature period also falls during the same period. The probability of weekly rainfall being greater than 25 mm during this period is about 10% confirming that adequate rainfall in the Hambantota area can hardly be expected during the first inter-monsoon. Therefore, this period is not suitable for planting any short term crop. Rice is one of the major crops in Hambantota. During the period from mid September (38^{th} week) to end of December (52^{nd} week), the maximum temperature is below the average and the probability of weekly rainfall being greater than 35 mm is 50%. Hence, early September is suitable for land preparation. The second inter-monsoon rains in Hambantota district commence during the 42^{nd} week (19-25 October) and weekly rainfall is above 35 mm up to the 48^{th} week (30 Nov – 06 Dec) with the rains continuing up to the 51^{st} or 52^{nd} week (20^{th} - 31^{st} December). Paddy planted during early September receives heavy rains during November (44th - 45th weeks) and the harvest can be obtained at the end of December or January in the dry season.

In this paper a more robust method was illustrated in to analyse various climate indicator using long-term rainfall and temperature data in a given location to derive more beneficial inferences to planners, scientists and farmers. The analysis is valid irrespective of crop. Thus more specific information can be obtained if the same techniques are applied to analyse long-term water deficits data for a particular crop or identify relationships between climate and crop yield. An alternative approaches to study the relationship between coconut and rainfall have been discussed by some authors (Peiris *et al* 2008, Peiris and Thattil, 1998).

Conclusion

In the Hambantota area of Sri Lanka, the local effects may have a stronger influence than global effects in determining long term climate variability. All annual temperature indices (maximum temperature, minimum temperature, mean temperature and diurnal temperature) and weekly maximum temperature showed significant increasing trends. Rates of increase are higher since 1995. The amount of rainfall per rainy day (> 0 mm) and that per effective rainy day (> 5 mm) declined significantly over the period between 1951 and 2001. Rainfall and maximum temperature showed a significant negative relationship. The probability of occurrence of a dry spell of more than 60 days duration is 30%. However, the time of the year during which a longer dry spell could occur is not consistent between years. The rate of increase of weekly maximum air temperature is higher than that of weekly minimum air temperature in all weeks in a year. Alternative methods to obtain water such as exploration of ground water are necessary, if agriculture is to be promoted in the Hambantota area in the future. The results derived from this study provide important information on climate variability in Hambantota which have policy implications. These results could also be considered during implementation of crop insurance programs to protect farmers. Similar analysis of weekly rainfall of long-term data is recommended to understand the expected climate variability in any other areas.

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Appendix A

The periods corresponding to the week numbers

Week No	Weekly Period (dates)	Week No	Weekly Period (dates)
1	01 – 07 Jan	27	05 – 11 Jul
2	08 – 14 Jan	28	12 – 18 Jul
3	15 – 21 Jan	29	19 – 25 Jul
4	22 – 28 Jan	30	26 Jul – 01 Aug
5	29 Jan – 04 Feb	31	02 – 08 Aug
6	05 – 11 Feb	32	09 – 15 Aug
7	12 – 18 Feb	33	16 – 22 Aug
8	19 – 25 Feb	34	23 – 29 Aug
9	26 Feb – 04 Mar	35	30 Aug – 05 Sep
10	05 – 11 Mar	36	06 – 12 Sep
11	12 – 18 Mar	37	13 – 19 Sep
12	19 – 25 Mar	38	20 – 27 Sep
13	26 Mar– 02 Apr	39	28 Sep – 04 Oct
14	03 – 09 Apr	40	05 – 11 Oct
15	10 – 17 Apr	41	12 – 18 Oct
16	18 – 24 Apr	42	19 – 25 Oct
17	25 Apr – 01 May	43	26 Oct – 01 Nov
18	02 – 08 May	44	02 – 08 Nov
19	09 – 15 May	45	09 – 15 Nov

20	16 – 22 May	46	16 – 22 Nov
21	23 – 29 May	47	23 – 29 Nov
22	30 May – 05 Jun	48	30 Nov – 06 Dec
23	06 – 12 Jun	49	07 – 13 Dec
24	13 – 19 Jun	50	14 – 20 Dec
25	20 – 27 Jun	51	21 – 23 Dec
26	28 Jun– 04 Jul	52	24 – 31 Dec

Appendix B

Warming rates (°C/year) of the temperature indices by weeks

Week number	T_{MAX}	T_{MIN}	T_{MEA}	T_{DIF}
1	0.0142 *	0.0100 ns	0.0121 *	0.0042 ns
2	0.0243 **	0.0101 ns	0.0172*	0.0143 *
3	0.0232 **	0.0086 ns	0.0159*	0.0146 *
4	0.0279 ***	0.0079 ns	0.0180***	0.0201 *
5	0.0161 *	0.0145 *	0.0153 **	0.0016 ns
6	0.0221 **	0.0114 ns	0.0167 *	0.0107 ns
7	0.0322 ***	0.0099 ns	0.0210 **	0.0223 *
8	0.0338 ***	0.0045 ns	0.0191*	0.0293 **
9	0.0242 **	0.0085 ns	0.0162 **	0.0154 *
10	0.0148 *	0.0022 ns	0.0085 ns	0.0126 ns
11	0.0161 **	0.0076 ns	0.0119 *	0.0085 ns
12	0.0184 **	0.0095 ns	0.0139 *	0.0089 ns
13	0.0270 ***	0.0173 *	0.0222 **	0.0097 ns
14	0.0183 **	0.0117 *	0.0150 **	0.0065 ns
15	0.0180 **	0.0168 *	0.0174***	0.0012 ns
16	0.0204 **	0.0102 ns	0.0152 **	0.0101 *
17	0.0199 *	0.0173 **	0.0186 **	0.0025 ns
18	0.0212 **	0.0128 *	0.0170 **	0.0083 ns
19	0.0099 ns	0.0042 ns	0.0071 ns	0.0056 ns

20	0.0048 ns	0.0043 ns	0.0046 ns	0.0004 ns
21	0.0273 **	0.0112 ns	0.0192 **	0.0161 *
22	0.0275 **	0.0011 ns	0.0143 *	0.0264 **
23	0.0260 **	-0.0047 ns	0.0106 ns	0.0306 ***
24	0.0229 **	0.0017 ns	0.0123 ns	0.0211 *
25	0.0167 *	0.0103 ns	0.0136 ns	0.0064 ns
26	0.0168 *	-0.0026 ns	0.0070 ns	0.0195 ns

(* - p < 0.05, ** - p < 0.01, * - p < 0.001, ns -not significant)**

Appendix B (Continued)

Warming rates (^{0}C/year) of the temperature indices by weeks

Week number	T_{MAX}	T_{MIN}	T_{MEA}	T_{DIF}
27	0.0207 **	0.0030 ns	0.0119 ns	0.0179 ns
28	0.0273 *	0.0018 ns	0.0144 *	0.0249 *
29	0.0345 ***	0.0057 ns	0.0201 *	0.0288 **
30	0.0392 ***	0.0074 ns	0.0232 **	0.0320 **
31	0.0173 *	0.0057 ns	0.0116 ns	0.0117 ns
32	-0.0074 ns	0.0000 ns	-0.0038 ns	-0.0077 ns
33	0.0197 *	0.0016 ns	0.0102 ns	0.0171 ns
34	0.0085 ns	0.0014 ns	0.0055 ns	0.0080 ns
35	0.0227 **	-0.0007 ns	0.0108 ns	0.0231 **
36	0.0047 ns	0.0000 ns	0.0025 ns	0.0049 ns
37	0.0191 *	0.0044 ns	0.0118 ns	0.0147 ns
38	0.0275 **	0.0032 ns	0.0152 **	0.0243 **
39	0.0223 *	0.0033 ns	0.0127 ns	0.0188 *
40	0.0190 *	0.0014 ns	0.0102 ns	0.0176 *
41	0.0200 **	0.0051 ns	0.0125 **	0.0149 *
42	0.0265 **	0.0086 ns	0.0175 **	0.0178 *
43	0.0186 *	0.0019 ns	0.0102 ns	0.0167 *
44	0.0266 **	0.0080 ns	0.0173 *	0.0186 **

45	0.0139 *	0.0127 **	0.0134 **	0.0010 ns
46	0.0135 *	0.0143 *	0.0140 **	-0.0007 ns
47	0.0164 *	0.0109 *	0.0135 **	0.0059 ns
48	0.0150 *	0.0066 ns	0.0108 *	0.0083 ns
49	0.0111 ns	0.0070 ns	0.0095 *	0.0031 ns
50	0.0106 ns	0.0095 ns	0.0101 *	0.0012 ns
51	0.0046 ns	0.0154 *	0.0100 *	-0.0108 ns
52	0.0218 **	0.0114 *	0.0166 *	0.0104 ns

(* - $p < 0.05$, ** - $p < 0.01$, *** - $p < 0.001$, ns -not significant)

Appendix C

Mean rainfall and probability (%) of rainfall greater than 0, 10, 20, 30, 35 mm by weeks

Week number	Amount of rainfall (mm)	Probabilities (%) of rainfall				
		> 0 mm	>10 mm	>20 mm	>30 mm	>35 mm
1	18.5	74.51	37.25	31.37	25.49	17.65
2	19.4	80.39	43.14	27.45	21.57	21.57
3	22.9	64.71	39.22	29.41	19.61	17.65
4	10.7	56.86	29.41	23.53	9.80	9.80
5	16.8	62.75	35.29	29.41	21.57	15.69
6	13.1	52.94	37.25	23.53	19.61	19.61
7	10.8	54.90	29.41	17.65	13.73	13.73
8	11.9	54.90	29.41	21.57	9.80	7.84
9	14.7	56.86	31.37	23.53	13.73	11.76
10	11.4	56.86	29.41	13.73	9.80	7.84
11	13.5	58.82	33.33	21.57	13.73	9.80
12	11.4	58.82	25.49	13.73	9.80	7.84
13	15.1	70.59	33.33	25.49	21.57	13.73
14	22.1	84.31	54.90	33.33	29.41	23.53
15	22.5	74.51	58.82	37.25	27.45	23.53
16	22.6	82.35	45.10	33.33	21.57	19.61
17	19.1	84.31	50.98	37.25	19.61	17.65
18	25.1	88.24	56.86	41.18	27.45	21.57
19	18.9	76.47	39.22	31.37	23.53	17.65
20	20.8	76.47	52.94	35.29	31.37	25.49
21	12.4	74.51	33.33	23.53	11.76	9.80
22	15.4	88.24	33.33	25.49	19.61	17.65

23	11.4	82.35	39.22	15.69	7.84	7.84
24	13.2	78.43	29.41	19.61	11.76	11.76
25	12.9	78.43	33.33	25.49	17.65	17.65
26	13.1	78.43	35.29	17.65	11.76	11.76
27	10.1	68.63	25.49	9.80	7.84	7.84
28	8.1	72.55	27.45	11.76	5.88	5.88
29	12.7	70.59	33.33	19.61	13.73	9.80
30	12.2	72.55	33.33	17.65	13.73	9.80
31	9.8	58.82	23.53	19.61	13.73	9.80

Appendix C (Contd)

Mean rainfall and probability (%) of rainfall greater than 0, 10, 20, 30, 35 mm by weeks

Week number	Amount of rainfall (mm)	Probabilities (%) of rainfall				
		>0 mm	> 10 mm	20 mm	> 30 mm	> 35 mm
32	15.3	80.39	39.22	27.45	19.61	19.61
33	14.8	68.63	37.25	21.57	11.76	11.76
34	7.3	60.78	27.45	11.76	5.88	3.92
35	10.0	68.63	29.41	17.65	13.73	9.80
36	7.4	70.59	21.57	5.88	3.92	3.92
37	16.3	78.43	47.06	27.45	17.65	11.76
38	19.7	86.27	49.02	29.41	19.61	17.65
39	22.1	86.27	52.94	31.37	19.61	17.65
40	15.1	74.51	35.29	25.49	23.53	19.61
41	26.0	82.35	54.90	43.14	33.33	25.49
42	35.6	80.39	58.82	47.06	37.25	35.29
43	36.0	90.20	64.71	54.90	39.22	35.29
44	50.0	98.04	78.43	66.67	54.90	54.90
45	45.4	98.04	78.43	66.67	56.86	49.02
46	49.9	100.00	82.35	66.67	54.90	54.90
47	38.0	98.04	78.43	66.67	50.98	39.22

48	38.8	96.08	74.51	60.78	49.02	45.10
49	21.8	88.24	54.90	39.22	23.53	23.53
50	24.3	86.27	49.02	39.22	27.45	23.53
51	24.7	90.20	52.94	35.29	23.53	21.57
52	26.2	90.20	47.06	31.37	23.53	19.61