Tropical Agricultural Research (2020) 31(4): 13-25

Contents available at: Sri Lanka Journals Online

Tropical Agricultural Research

Journal Home Page: https://tar.sljol.info

Climate Change and Extreme Events in WL_{1a} Agro-ecological Zone of Sri Lanka: Implications on Coconut Production

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ARTICLE INFO

Article history:
Received: 14 August 2019
Accepted: 27 September 2019
Revised version received: 09 September 2020
Available online: 1 October 2020

Keywords:
Rainfall
Temperature
Coconut
WL_{1a}
Sri Lanka

Citation:
Jayalath, K.V.N.N., Punyawardena, B.V.R., Silva, P., Hemachandra, D. and Weerahewa J. (2020). Climate Change and Extreme Events in WL1a Agro-ecological Zone of Sri Lanka: Implications on Coconut Production. Tropical Agricultural Research, 31(4): 13-25

DOI: http://doi.org/10.4038/tar.v31i4.8417

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ABSTRACT

The temporal variations in rainfall, temperature and the associated extreme events were examined with the objective to ascertain their potential effects on coconut production in Ratnapura district of Sri Lanka. Temporal variations were measured using Mann-Kendal test and extreme events were examined using climate indices related to daily rainfall and daily temperature. Daily rainfall and minimum and maximum temperature data of Ratnapura representing Agro Ecological Region, WL_{1a} obtained from the Department of Meteorology of Sri Lanka for the period of 1961 to 2015, were used for the analysis. The base period was considered as 1961 to 1990 as recommended by the World Meteorological Organization. According to the results of the Mann-Kendall tests, minimum temperature had a positive trend and maximum temperature had a negative trend. Among sector-specific climate indices, Standardized Precipitation Evapotranspiration Index in the long-time scale and minimum temperature showed a significant positive trend and the value of the 95th percentile of maximum temperature showed a significant negative trend. The other indices related to drought, extreme rainfall, extreme warm days and maximum annual number of consecutive dry days did not show significant trends during the period 1991 to 2015. Despite the latter, the former indicates an occurrence of drought like situations in the future. Adoption of both short and long-term drought control measures in coconut cultivations if they are to be promoted in Agro Ecological Region of WL_{1a} are recommended as prolonged droughts and high temperatures adversely affect production of coconuts.

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INTRODUCTION

Natural and human systems across the globe are sensitive to changes in climate (IPCC, 2014). Average global temperature has increased by 0.93± 0.07 ^{0}C in 2009-2018 when compared to 1850-1900, the pre-industrial baseline (IPCC, 2018). The direction, frequency and intensity of climate change however differ by location (Duc *et al.*, 2019). While precipitation in the mid latitude land areas in the Northern hemisphere has increased since 1901, long-term positive or negative trend has been observed in other latitudes (IPCC, 2014). According to IPCC (2014), extreme precipitation events and their frequency of incidences have increased over time. Statistically significant increases in extreme precipitation were observed in Belgium (Ntegeka and Willems, 2008) and Italy (Brunetti *et al.*, 2001), and an increase in frequency of extreme precipitation was observed in Bulgaria (Bocheva *et al.*, 2009). In addition, Osborn *et al.* (2000) reported an apperent increase in daily precipitation intensity in winter in the United Kingdom. In South Asia, the increase in air temperature is a main distinctive feature (Sivakumar and Stefanski, 2018). The region also experiences frequent warm extremes (Sheikh *et al.*, 2015) and extreme floods (Mirza, 2011). Regional projections of Intergovernmental Panel on Climate Change (IPCC) based on AR4 atmospheric ocean general circulation models (AOGCMs or simply - GCMs) suggest a significant acceleration of warming in Asia compared to that was observed in the 20th century. Hence, both changes in mean of climate variables and extreme climate events should take into consideration in policy analysis (Katz and Brown, 1992).

Marambe *et al.* (2013), Premalal and Punyawardena (2013), De Costa (2008) and Ministry of Environment Sri Lanka, (2011), who examined climatic conditions in Sri Lanka, revealed an increase in both minimum and maximum ambient temperature in most districts and a decrease of rainy days prolonging the dry spells. The variability of seasonal rainfall of Sri Lanka has increased in recent decades according to Nissanka *et al.* (2011) and there is a warming trend in temperature with occurrence of more frequent droughts according to Premalal and Punyawardena (2013) and Naveendrakumar *et al.* (2018). An increase in the number of consecutive dry days and a decrease in the number of consecutive wet days are also observed (Ratnayake and Herath, 2005; Premalal, 2009). A strong upward trend in warm days and warm nights has also been observed in Sri Lanka (Sheikh *et al.,* 2015).

Climate change and climate extremes threaten global agriculture reducing food production (WMO, 2018). Several studies have revealed that climatic changes (Rosensweig and Parry, 1994; IPCC, 2007), particularly extreme rainfall and temperature (Wolfram and Roberts, 2009; Burke and Emerick, 2016), have adversely influenced agricultural production. The adverse effects of climate change on crop agriculture is expected to be larger in developing countries in the tropics and the level of damage depends on the actual climatic scenario (Seo *et al.,* 2005).

Coconut is one of the predominant food crops in agricultural systems in Sri Lanka and its production is largely determined by climatic factors, and the government of Sri Lanka considers expansion of coconut cultivation beyond geographical areas that are devoted to coconuts. The objective of this study was to examine the long-term climate trends in rainfall and air temperature in a non-traditional coconut growing district, namely Ratnapura, in the Agro Ecological Region (AER) of WL_{1a} to ascertain whether expansion of coconut cultivation is feasible to such areas.

The paper proceeds as follows. The next section provides background information on coconut cultivation in Sri Lanka in light of climate change. The following section describes the data and methods used in the analysis. The estimates of the trends in climatic variables and trends in extreme events are presented next. The last section concludes the study with policy recommendations.

Effects of rainfall and temperature on coconut production

Coconut (*Cocos nucifera L.)* cultivation in Sri Lanka is a key agricultural land use that is second only to rice, which is the staple food. Coconut is grown as a rain fed cultivation and highly sensitive to moisture deficit that can have a lagged impact on production spanning over several years. Coconut palm requires a well distributed rainfall of 1,500 – 2,300 mm/year, mean temperature of 27-29 ^{0}C with diurnal variation of 5-7 ^{0}C and 2,000 sunshine hours/year with at least 120 hours/month (Child, 1964; Mahindapala and Pinto, 1988). Variations from these optimum climatic conditions influence physiology of the palm and ultimately the yield in mature coconut plantations.

The consequences of adverse rainfall and temperature in coconut continue for several years due to its long economic life span and prolonged reproductive phase. The nut (drupe) takes 44 months to develop from flower initiation to a mature nut at harvesting stage. Every stage of nut development is sensitive mainly to rainfall (moisture) and temperature in varying degrees. Percentage of button nut (female flowers after fertilization) fall from the inflorescence is significantly sensitive to total rainfall and minimum air temperature (Peiris *et al.,* 1995; Peiris and Thattil, 1998). The optimum temperature for *in vitro* pollen germination of coconuts is 28 ^{0}C while maximum can go up to 39.7 ^{0}C (Ranasinghe *et al.*, 2015). Critical temperature for successful reproduction of coconuts is 33 ^{0}C (Ranasinghe, 2012). Coconut palm experience moisture stress when it is exposed to temperature above 33 ^{0}C and soil water deficit due to rain free period of longer than consecutive two months (Kasturi Bai *et al.*, 2003). The droughts can cause crop failure due to reduced fertilization, button nut fall, immature nut fall, and palm loss due to death of seedlings, immature and mature palms. Accordingly, extreme rainfall and temperature can cause direct production loss in coconuts.

Traditionally, coconut cultivation is concentrated in the North-Western and Western provinces in Sri Lanka. Increase in demand for land due to population increase, urbanization and general development activities, especially in Western province, has changed the economic dependence of the traditional coconut-based industries. With the increasing demand of land in coconut triangle and increasing demand for coconuts, coconut cultivation was extended to non-traditional coconut growing areas outside the main coconut growing areas. The government of Sri Lanka took many steps to expand coconut cultivation in non-traditional coconut growing areas and Ratnapura is one of the few districts that showed an increase in extent under cultivation of coconuts according to the latest Agricultural Census in 2014 compared to 2002 (Department of Census and Statistics, 2018). However, sustainable production of these cultivated areas will be determined by the major climatic factors, rainfall and temperature.

However, there is a dearth in studies to assess the effects of climate change and extreme events on coconut production in non-traditional coconut growing areas (see Fernando *et al.* (2007) and Pathiraja *et al.* (2017) for general assessments). The studies to assess the effects of climate change on Sri Lankan agriculture are mainly confined to rice and tea (Wijeratne *et al.,* 2007; Jayathilaka *et al.*, 2012). It is expected that climate change may cause negative effects on coconut plantations due to increase in temperature and limited availability of water. Further, the coconut plantations act as carbon sinks that absorbs atmospheric CO_2 which can mitigate climate change (Ranasinghe, 2012). A few studies have attempted to estimate the impacts of extreme events on coconut productivity (Pathmeswaran *et al.,* 2018) but limited to regression analysis between coconut productivity and number of extreme events. However, none has attempted to explore deviations from the optimum growing conditions or thresholds for coconuts.

METHODS OF ANALYSIS AND DATA

As indicated in the previous sections, changes in pattern of climate is studied at global and regional level across space and time (IPCC, 2014) by observing trends and variability in precipitation (Portmann *et al.*, 2009; Karpouzos *et al.*, 2010), temperature, and extreme events (Tan *et al.*, 2017). In this study, trends in precipitation, temperature and extreme events and variability of precipitation and temperature were analysed first. Then, they were compared with the threshold values for coconut.

Trend analysis in climatic variables

Trend analysis is an empirical method that can be used to compute and explain change of a variable over a period of time using available data. Chandler and Scott (2011) considers 'trend' as a long-term temporal variation of statistical properties of a process, where 'long-term' depends on the application. Parametric and non-parametric tests are performed in trend detection and analysis. However, outliers and missing data, which are frequently encountered in meteorological data, adversely affect normality and homogeneity of variance. Non-parametric tests have the advantage over parametric tests for data series that are non-normally distributed and have outliers and missing data.

The time series nature of data may violate some of the assumptions and may give rise to the problems of autocorrelation and heteroscedasticity. In general, this is an undesirable property for many statistical estimations. In meteorological time series data, autocorrelation in observed variables and unobserved error term is possible. Presence of autocorrelation makes the standard errors to be incorrect and therefore the usual hypothesis testing and confidence intervals also become incorrect.

Considering the above limitations, Mann-Kendall (MK) trend test (Mann, 1945; Kendall, 1962) was used to assess long term upward or downward trends in observed climatic variables. This test is widely applied to statistically detect the long-term trend in meteorological time series (Brunetti *et al.*, 2001; De Silva and Sonnadara, 2014; Duc *et al.*, 2019). This is a non-parametric and rank-based test, hence assumptions for distributional properties are not required. The test also allows autocorrelation (Hamed and Rao, 1998). The test calculates the Kendall's Tau statistic and test the null hypothesis that there is no trend existing in the data series under investigation. When the trend parameter is significant, the rate of change can be calculated using the Sen's slope estimator (Campa *et al.*, 2002). In this study, trend analysis was done using R software package.

Extreme event analysis

The climate indices with respect to extreme events related to agriculture sector developed by the World Meteorological Organization Commission for Climatology (CCI) Expert team on Sector -specific Climate Indices (ET-SCI) were used for the analysis. Table 1 provides the list of indices. Data were analysed using ClimPACT2 software package (Alexander and Herold, 2016). In order to compare with the requirement of rainfall and temperature for coconuts, two user defined indices were used, *i.e.* i) The lowest optimum temperature for pollen tube growth of coconut is 26.02 ^{0}C hence, 26 ^{0}C was selected as the user defined index (TNge26) for temperature and ii) the average daily rainfall for better growth and production of coconuts is 5 mm and hence the annual number of days when rainfall is more than or equal 5 mm (R5mm) was selected as the user defined index for rainfall and included in the selected indices in Table 1.

Table 1: Selected sector specific climate indices used for the analysis.

Type	Short Name	Long Name	Description	Unit
Temperature based indices	TX	Maximum temperature	Warmest daily TX	⁰C
	TN	Minimum temperature	Minimum daily TN	⁰C
	TX95t	Vary warm day threshold	Value of 95th percentile of TX	⁰C
	TNge26	Minimum temperature of at least 26 ⁰C	Number of days when TN >= 26 ⁰C	days
	SU35	Very hot days	Annual number of days when TX>= 35 ⁰C	Days
Rainfall based indices	R95pTOT	Contribution from very wet days	Percentage of rainfall of 95th percentile to total rainfall	%
	R99pTOT	Contribution from extremely wet days	Percentage of rainfall of 99th percentile to total rainfall	%
	CDD	Consecutive dry days	Maximum annual number of consecutive dry days (when rainfall< 1.0 mm)	days
	R5mm	Number of customized rain days	Annual number of days when rainfall>= n*	days
	R95p	Total annual RF from heavy rain days	Annual sum of daily rainfall> 95th percentile	mm
	R99p	Total annual RF from very heavy rain days	Annual sum of daily rainfall> 99th percentile	mm
Composite indices	SPI	Standardized precipitation index	Measure of drought on time scale of 3,6 and 12 months	unit less
	SPEI	Standardized precipitation evapotranspiration index	Measure of drought on time scale of 3,6 and 12 months	unit less

Notes: Here, n = 5 mm per day which is the average daily water requirement of coconuts.

Source: Alexander and Herold (2016).

Standardized Precipitation Evapotranspiration Index (SPEI) and Standardized Precipitation Index (SPI) at different monthly levels were used in the analysis as composite measures of drought in addition to the indices based purely on rainfall and temperature. ClimPact2 software recommended by the WMO was used for the extreme event analysis.

Variability analysis

Coefficient of variation (CV) was used to compute the variability in rainfall and temperature. Higher value of CV indicates higher variability and *vice versa*. The decadal variability of rainfall and temperature during the period of 1961 to 2010 namely, 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010, were computed. Time period from 2011-2015 was not considered due to inadequacy of the time period to complete a decade. Variability among base period and 1991-2000 and 2001-2010 were further examined by comparing variances using F test for homogeneity of variance. It was hypothesised that variance of periods 1991-

2000 and 2001-2010 is higher than that of base period.

Threshold levels for coconut production

In general, well distributed annual rainfall of 1,300–2,300 mm, and annual temperature of 27 °C are required for the optimum growth of coconuts. Temperature beyond 33 °C causes moisture stress in general, despite that there are varietal differences. Critical temperature for fruit set under both heat (atmospheric drought) and water stress (soil drought) is 33 °C for 'Sri Lanka Tall' cultivar (Ranasinghe, 2012) which is commonly grown in Rathnapura district. Beyond this, the fruit set is reduced. Optimum (Topt) and maximum (Tmax) temperatures for pollen germination and pollen tube growth differ with the variety (Table 2).

Table 2: Critical temperature (°C) for reproduction in different coconut varieties.

Variety*	Pollen germination		Pollen tube growth	
	Topt	Tmax	Topt	Tmax
CRIC 65 (DBT)	27.35	41.90	29.50	37.10
CRIC 65 (DGT)	27.35	41.90	29.50	37.10
CRISL98 (TSR)	28.3	40.10	29.18	40.40
CRIC 60 (TT)	28.35	39.50	26.02	38.41
CRISL2004 (DGSR)	28.35	39.50	26.02	38.41
CRISL2012 (DBT)	28.05	38.95	29.46	37.25

Notes: *Each variety is a cross between as described. DBT - Dwarf brown x Tall, DGT - Dwarf green x Tall, TSR - Tall x San Ramon, TT - Tall x Tall, DGSR - Dwarf green x San Ramon, DBT - Dwarf brown x Tall (Source: Ranasinghe, 2012).

Data and Data Sources

Ratnapura area which falls within the AER of WL_{1a} was chosen as the study area as it is one of the non-traditional coconut growing areas where extent under coconut cultivation has been increased in the recent years. Rainfall and temperature were explored in this study, as they are the main climate variables that determine production in tropical climate under rain-fed cultivation. Daily rainfall, daily maximum temperature and daily minimum temperature data of WL_{1a} AER for the period 1961-2015 were obtained from the database of Coconut Research Institute of Sri Lanka. The data were originally collected by the Department of Meteorology of Sri Lanka. IPCC definition of climate change was used for the study. World Meteorological Organization has defined 'climate normal' as three-decade average of meteorological parameters including temperature and precipitation. Hence, average rainfall and temperature for 1961-1990 was considered as 'climate normal' which represent long-term climatic conditions and anomalies are calculated based on these values. Percentage of missing data for rainfall, maximum temperature and minimum temperature are 0.06, 0.67 and 1.2 per cent respectively. Missing data were computed by stochastic imputation in R software employing Multivariate Imputation via Chained Equations (MICE) package which uses predictive mean matching.

RESULTS AND DISCUSSION

Results of Trend Analysis

The trends in daily rainfall and temperature in AER of WL_{1a} are presented in Table 3. No significant trend was observed in daily rainfall. This is in line with the findings of Jayawardene *et al.* (2005) who reported that the trends of annual average rainfall in Ratnapura were not significant. Naveendrakuma *et al.* (2018) also found no significant trend in daily rainfall of Rathnapura for the period of 1961 to 2015 whereas De Costa (2008) reported non-significant trend in rainfall at 5% significance level in Rathnapura for the period of 1860 to 2010. Further, Nissanka *et al.* (2011) reported that there was no significant trend in annual rainfall in Rathnapura for the period of 1961 to 2010. The present analysis confirms a significant ($P<0.05$) decrease in maximum temperature and increase in minimum temperature in the long run. Naveendrakuma *et al.* (2018) also found a decreasing trend in maximum temperature during the months of April and December and increasing trend in minimum temperature. The same pattern was also confirmed in the report of Sri Lanka's Second National Communication on Climate Change (Ministry of Environment, Sri Lanka, 2011). Maximum temperature in AER of WL_{1a} in last sixty years has gone beyond 36.8 ^{0}C which is well above the critical temperature of 33 ^{0}C for fruit set of coconuts. Decline of this maximum temperature would be favourable for coconut production.

Table 3: Trends in climate variables for the period of 1991-2015 in AER of WL_{1a}.

Variable	tau value	p-value	Sen's slope	95% CI for slope
Rainfall	-0.0093	0.058	-	-
Maximum temperature	-0.0243	0.00*	-0.00001	-1.7e-05 to -6.0e-06
Minimum temperature	0.0828	0.00*	0.00002	1.9e-05 to2.5e-05

*Significant at 5% significance level.

Trends in extreme events were analysed using ClimPact2 software considering baseline reference period as 1961-1990, and the results are presented in Table 4. Trends in most of the indices were not significant. Minimum daily temperature or night temperature showed statistically significant increasing trend with 0.009 ^{0}C increases per annum. The highest value of minimum temperature observed during 2011 to 2015 period was 26.9 ^{0}C and average minimum temperature during the same period was 23.15 ^{0}C. Therefore, increasing trend of minimum temperature would not be an issue for the production of coconuts in the near future. This is further confirmed by the insignificance of TNge26, user defined index to capture the trend in temperature beyond 26 ^{0}C which is the lowest temperature value for the reproduction of coconuts. Value of the 95th percentile of maximum temperature is the other index that showed a significant trend. In contrast to the other significant indices, this showed a negative trend, indicating that the value of the 95th percentile of maximum temperature is at a declining trend. This can be considered as a favourable condition for the growth of coconuts as this indicates the probability of exposure of coconuts into higher extreme temperature, especially during reproductive stages is low. Plant growth is indirectly linked to temperature, and positive deviations from its optimal value will always be damaging. Precipitation close to water requirement of a particular crop will be beneficial for many crops (Wolfram and Roberts, 2009).

When drought indices were considered, only SPEI at 12 and 24 months were significant with an increasing trend (Figure 1). The increasing trend in drought indices may have negative effects on coconut production in AER of WL_{1a} if this trend is continued in the future.

Results of the variability analysis

Variability was analysed using Coefficient of Variation (CV). Mean, minimum, maximum and CV were compared between decades (Table 5). Variability of daily mean rainfall during the study period has increased as indicated by increase of CV in recent decades. Variability of daily maximum temperature and minimum temperature has not changed heavily as indicated by CV.

Table 4: Trends in extreme events in AER of WL_{1a} for the period 1991-2015.

Type	Indices	Slope	p-value	Trend
Temperature based indices	Tx	0.005	0.463	No
	Tx95t	0.007	0.0*	Negative
	TN	0.009	0.0*	Positive
	SU35	0.016	03.3	No
	TNge26	0.114	0.328	No
Rainfall based indices	R5mm	0.158	0.143	No
	R95p	1.974	0.512	No
	R95pToT	0.027	0.643	No
	R99p	0.571	0.798	No
	R99pToT	0.024	0.645	No
	CDD	0.024	0.679	No
Composite indices	SPEI 3months	0	0.179	No
	SPI 3 month	0	0.384	No
	SPEI 6month	0	0.182	No
	SPI 6month	0	0.489	No
	SPEI 12 month	0.001	0.023*	Positive
	SPI 12 month	0	0.211	No
	SPEI 24 months	0.001	0.001*	Positive
	SPI 24 months	0	0.115	No

Notes: *Significant at 5% significance level.

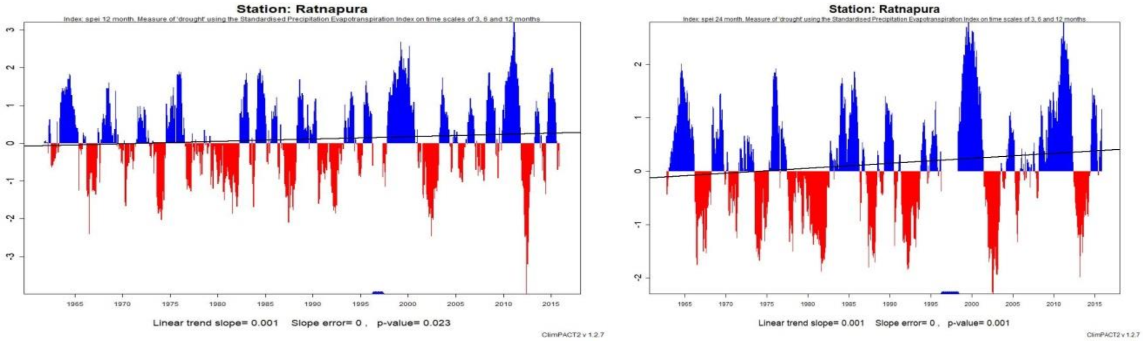

Figure 1: SPEI at 12 and 24 months.

CONCLUSIONS

The results revealed a significant negative trend in maximum temperature, a positive trend in minimum temperatures, and a non-significant trend in precipitation for the period of 1991-2015 when compared to 1961-1990 period. The SPEI of long-time scale and minimum daily temperature showed a statistically significant positive trend while very warm day threshold showed a significant negative trend. Trends with respect to all the other indices were not significant. The negative trend in maximum temperature is a beneficial factor for the growth of coconut as maximum temperature is one of the contributing factors that determines pollen viability. The positive trend in minimum temperature would not cause significant losses as minimum temperature levels in AER of WL_{1a} are below the critical levels. However, the increase of SPEI, which is a drought indicator, constrains coconut cultivation under rain-fed condition. Therefore, short- and long-term measures of drought adaptations at farmer levels in AER of WL_{1a} in Rathanpura district will be required to avoid any potential losses.

Table 5: Decadal variability of rainfall and temperature.

Period	**Decadal variability of rainfall**				**Decadal variability of daily maximum temperature**					**Decadal variability of daily minimum temperature**				
	Mean (mm/day)	**Maximum (mm/day)**	**SD**	**CV (%)**	**Mean (^{0}C)**	**Maximum (^{0}C)**	**Minimum (^{0}C)**	**SD**	**CV (%)**	**Mean (^{0}C)**	**Maximum (^{0}C)**	**Minimum (^{0}C)**	**SD**	**CV (%)**
1961-1970	10.35	294.9	± 18.88	181	31.92	36.8	22.9	± 2.00	6.3	22.69	26.2	16.5	± 1.11	4.9
1971 - 1980	10.13	214.6	± 18.63	184	32.15	37.5	23.4	± 2.11	6.6	22.77	26.6	15.9	± 1.27	5.6
1981 - 1990	10.13	251.7	± 19.69	194	31.95	38.8	23.5	± 2.35	7.4	23.33	31.1	15.6	± 1.18	5.1
1961 – 1990 (base period)	**10.20**	**294.9**	**± 19.04**	**186**	**32**	**38.8**	**22.9**	**± 2.17**	**6.7**	**22.93**	**31.1**	**15.6**	**± 1.23**	**5.3**
1991-2000	10.60	392.5	± 20.01	189	31.78	38.2	23.5	± 2.18	6.9	22.98	29.3	17.5	± 1.20	5.2
2001 - 2010	10.43	345.2	± 19.80	190	31.77	38.6	23.7	± 1.95	6.2	23.09	26.7	16.7	± 1.14	4.9

Note: F test (upper one tailed) results indicated rainfall variance of both 1991-2000 and 2001-2010 periods are significantly ($P<0.05$) higher than that of base period indicating an increase in variability in rainfall over time. Variance of maximum temperature in 1991-2000 period is higher than the base period but the variability of 2001-2010 is not significantly different. There is no significant difference among the variance of minimum temperature in 1991-2000 and 2001-2010 periods and the base period.

ACKNOWLEDGEMENTS

This research was funded by the Coconut Research Institute (CRI) of Sri Lanka. Comments from Dr (Mrs.) C.S. Ranasinghe, Director, CRI, and Dr A.A.F.L.K. Perera, Deputy Director Research, CRI are greatly appreciated. Support extended by Dr. I.M.S.K. Idirisinghe, Head, Agricultural Economics and Agribusiness Management Division, CRI is kindly acknowledged. Dr. N.P.A.D. Nainanayake, Head and Suranga Wickkramaarachchi, Experimental officer, Plant Physiology Division, CRI are highly esteemed for providing climate data. Support provided by the National Science Foundation under the project of "Analysis of home-garden ecosystems in the context of climate resilience and biodiversity in different agro-ecological regions of Sri Lanka", under the grant number NTRP/ 217/CC&ND/TA-04/p-02/01, is highly appreciated. Comments from the two anonymous referees are acknowledged.

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