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Annual and Seasonal Trends in Extreme Temperature Events During 1981 to 2019 in Dry Zone, Sri Lanka

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ABSTRACT

Purpose: *Many parts of Sri Lanka are vulnerable to extreme climatic events, which are stressful in numerous ways, especially the dry zone that is highly responsible for agricultural activities. Paddy, the major crop cultivated throughout the dry zone, is highly sensitive to temperature variations. Thus, it badly affects production so the food security in the country will be negatively impacted. Therefore, studies on temperature extremes and their trends are highly important to mitigate the impact. The objective of this study is to identify the annual and seasonal trends of temperature extremes in the dry zone of Sri Lanka using the daily maximum and minimum temperature data from 1981 to 2019.*

Research Method: *To represent the entire dry zone, 10 locations were selected. As described by the Expert Team on Climate Change Detection and Indices (ETCCDI) 17 extreme temperature indices were selected and another appropriate three were defined by authors as suitable. Temperature extremes were analyzed by RClimDex software package, and MS Excel and the Mann-Kendal test and regression were done to identify trends.*

Findings: *Accordingly, 50% of the selected locations showed a significant ($p<0.05$) rise in daytime temperatures. Similarly, in general, significant positive trends were detected for nighttime temperature annually and seasonally. The increment in daytime temperature was with a lower magnitude than the positive trend in nighttime temperature. A general decreasing trend was detected in the Diurnal Temperature Range and it was mainly driven by the increasing trend of the nighttime temperature across the dry zone.*

Originality/ Value: *In the dry zone, there were dynamic trends with significant patterns as both rising and falling trends were detected in temperature indices during this study.*

Keywords: *Extreme events, Mann Kendal, RClimDex, Temperature indices.*

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (2023), climate change is defined as a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. The 21st century's primary threat to human and natural ecosystems, as well as civilization, has been determined as climate change (De Costa, 2008). Climate change's effects on artificial and natural ecosystems (such as ecosystem services and human well-being) could be both positive and negative (Solomon, 2007). According to Field et al. (2012), climate extremes are "the occurrence of meteorological variables exceeding the thresholds. Climate change is anticipated to increase the frequency and severity of natural catastrophes including heat waves and strong storms (Jayadas and Ambujam, 2019).Since 2014, the occurrence of extreme temperature trends, such as heat waves and droughts, has increased throughout the world (Mukherjee and Mishra, 2021).

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The IPCC (2023) confirms that the unsustainable and unequal land use, along with more than a century of burning fossil fuels, is unmistakably to blame for the rise in global surface temperature, which reached 1.1°C above 1850–1900 in 2011–2020. Widespread negative effects due to extremes in temperature are associated with losses and harm to both nature and people (IPCC, 2023). In terms of frequency and amplitude, extreme temperature occurrences show abnormalities in both warm and cold events (Diffenbaugh *et al.*, 2005). Heat waves, which are severe temperature events that shift dramatically, are a serious global health hazard that is on the rise. Numerous studies have been conducted to identify the global temperature trends. Using data from global stations from 1951 to 2003, Alexander *et al.* (2006) discovered that global general substantial extremes of temperature fluctuation were connected with warming and that the pattern of daily minimum temperatures around the world had changed.

Alexander *et al.* (2006) discovered that global general substantial extremes of temperature fluctuation were connected with warming and that the pattern of daily minimum temperatures around the world had changed and the same study found that less significant variation over the daily maximum temperature indices. However, some regions of the world do show variations in extremes that correspond to drops in temperature, even though such are typically insignificant (Alexander *et al.*, 2006).

Historical analysis of trends in extreme weather revealed that the last few decades have dramatic shifts in the Asian region's frequency of extreme climate events (Griffiths *et al.*, 2005; Choi *et al.*, 2009; Caesar *et al.*, 2011). The Sixth Assessment Report of IPCC (2023) mentioned that there were rising trends of global surface temperatures in during the 20th century. Sheikh *et al.* (2014) utilized temperature records from 210 stations from 1971 to 2000 to assess patterns in climate extreme indicators for the South Asian region. Regarding the shifts in the occurrence of unusual temperatures over the southern part of Asia, the study discovered that those shifts are in line with evidence for the global average as warm extremes have become more common while frosty extremes has become less common. However, the trend patterns for maximum temperature are often more erratic in Asia. Studies on regular extreme temperatures in the South Asian region have indicated a rise in the distributions of both severe cold and extremely warm events (Klein *et al.*, 2006). Most meteorological stations in India, Nepal, Pakistan and Sri Lanka recorded rising overnight temperatures as well as the warmest daytime records (Sheikh *et al.* 2014).

In the recent past, the temperature of number of South Asian countries was above the average. In India, it has increased by 0.51°C over the country's 30-year average (Surinder, 2009). Asia is particularly susceptible to extreme climate occurrences because of climatic change. Over the past few years, Sri Lanka, which is a climatological hotspot in the Asian region, has witnessed numerous extreme temperature events, causing catastrophic droughts and heat waves (Malmgren *et al.*, 2003). Warmer temperatures change weather patterns by allowing the atmosphere to retain, discharge, and absorb more water. As a result, wet areas grow wetter and desert areas become dryer (Trenberth, 2011).

Most of the countries were experiencing an increase in temperature (Chandrapala, 1996; Basnayake *et al.*, 2002; Eriyagama *et al.*, 2010). The annual average temperature has been found to have increased, with the increase in minimum air temperature having a greater impact than the increase in maximum air temperature in the daytime (Basnayake *et al.*, 2002). De Costa (2008) discovered the yearly temperature rise over the long run (1869–2007) in Sri Lanka using monthly mean temperature data. Naveendrakumar *et al.* (2018) found that Sri Lanka is experiencing unbearable temperature increases that are more obvious than clear evidence of the pace of global warming. The Sri Lanka National Report on Disaster Risk, Poverty and Human Development Relationship noted that numerous natural disasters impact Sri Lanka, accordingly landslides, floods, and drought have grown more frequent or more severe, particularly during the previous several decades (Disaster Management Centre, 2016). In addition, the annual report of the disaster management centre of Sri Lanka (Disaster Management Centre, 2016) reported that more than 1 million people were affected by the drought and further estimated that that 69% of the total population affected by disasters was affected by the drought.

According to the previously published information, it is obvious that Sri Lanka's temperature has changed dramatically. Consequently, more consideration must be given to temperature extremes as climate changes can increase the rate of appearance of extreme climatic events. Observing climatic variability for different periods and regions under different climate seasons over Sri Lanka is critically important for policymakers to decide and adapt to climate change and most importantly to extreme climate events. Further, a clear understanding of the relationship between temperature extremes and agriculture will be immensely useful for the proper adaptation and mitigation activities such as crop selection, delaying the season, irrigation management etc. against climate change. Temperature, one of the crucial climatic variables, which determine the climate of the area and mainly affects crop production. For example, paddy crop is highly sensitive to extreme temperature events and spikelet sterilization occurs at extreme temporal conditions (Martínez-Eixarch and Ellis, 2015). Out of the three climatic zones of Sri Lanka (*viz.* Wet zone, Intermediate zone and Dry zone) (Punyawardena *et al.*, 2003), the dry zone covers most of the land area and contributes the major portion of the total paddy production of the country. Therefore, proper investigation of extreme temperature events over the dry zone becomes more significant. That may mitigate the effects of warming temperatures and keep the nation's food supply secure. Therefore, employing historical temperature data from 1981 to 2019, the goal of the current study is to pinpoint recent trends in temperature extremes in dry zone Sri Lanka. It is expected to carry out investigations annually and seasonally. The seasonal analysis is based on the two main agricultural seasons which are *Yala* (May to September) and *Maha* (December to February) (Chithranayana and Punyawardena, 2008).

MATERIALS AND METHODS

Data and Study Area

Ten stations (Figure 01, Table 01) were selected for the study covering the entire geographical area of the Dry Zone. In this exercise, the maximum number of stations with long-term temperature data availability was considered, adhering to the criterion that at least 30 years of data are required to detect trends as Westmacott and Burn (1997). Manually observed temperature data, which consists of daily minimum and maximum temperatures spanning from 1981 to 2019, were obtained for those stations from the Department of Meteorology Sri Lanka.

However, due to civil unrest in the northern and eastern regions of the country during the respective period, data were unavailable for certain years, resulting in gaps at stations such as Jaffna, Pottuvil, and Vavuniya. Therefore, those years were excluded from the analysis. Although this affects the accuracy of the results, those locations were still included due to their geographical significance and the need to ensure representation of the entire dry zone of the country. The data availability and the percentage of missing are shown in Table 01. Trends can only be calculated for an index if the missing percentage is less than 20% of daily data per annum as explained by Keggenhoff *et al.* (2014). Each of the chosen meteorological stations upholds this principle, and most of them have at least 30 years of records. According to Burn and Elnur (2002) and Kahya and Kalayci (2004) data set of 30 years satisfies the minimal requirement length in exploring the tendencies in hydro climatic time-series that indicate climate change.

Data Quality Control

RClimDex (version 4.0.2) software was used for data quality inspection to identify missing values and unrealistic values. In this step, a default-missing marker replaced all user-defined missing values and all unreasonable values were replaced into "NA" (Not Available) such as Leap days. (i.e. 29th February), values for the daytime and nighttime temperatures above or below 70 degrees Celsius, respectively, on a daily basis, daytime temperature less than nighttime temperature, any value that leads to an improbable date (i.e. 30th February 2015), any non-numeric values. The study used the third standard deviation for finer quality control of the data. Since the study deals with extreme events, no attempt was carried out to reconstruct the missing daily temperature records.

Selection of Extreme Indices

Different threshold values and indices have been used by researchers in different studies related to extreme climate events depending on the area of interest and the season. Expert Team on Climate Change Detection and Indices (ETCCDI) has defined some extreme temperature and precipitation indices. Most studies have used those indices to define extreme events, current study also used those indices to define extreme temperature events, and the current study also used those indices to define extreme temperature events (Table 02). The identification of extreme weather occurrences was done using those indices from the results of the indices calculation from RClimDEX software package (version 4.0.2.). The RClimDEX calculates 27 extreme climate indices as described by ETCCDI. For this study, only 12 extreme temperature indices were selected considering the suitability of those to Sri Lanka as well as the study zone. Further, three indices were defined by the authors as TX10p*, TX90p* and TN90p* (Table 03) considering the applicability of those indices to explain the condition of Sri Lanka according to the ETCCDI definitions. Annual extreme temperature events were calculated using the RClimDex software package (version 4.0.2.) while both RClimDex software package (version 4.0.2.) and the Excel software package were used for seasonal analysis.

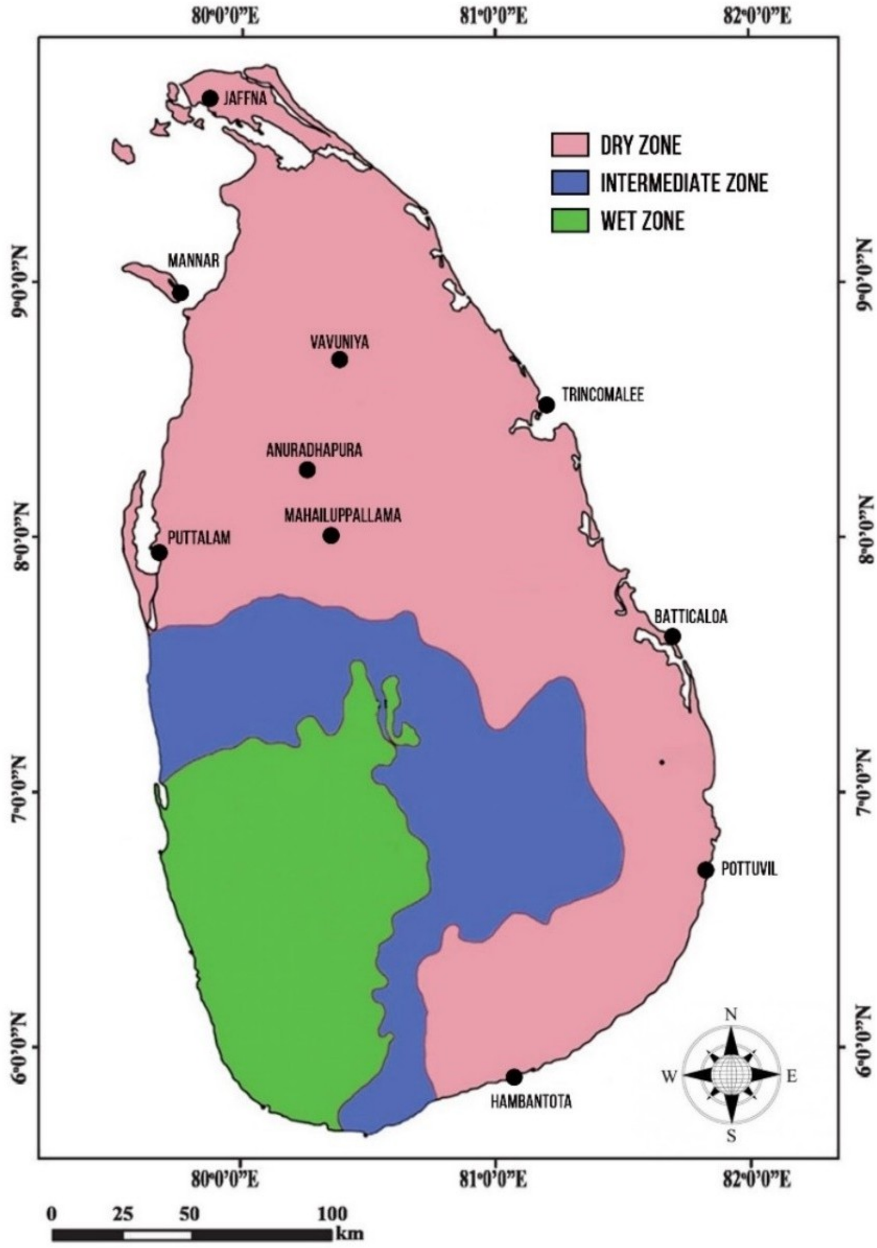

Figure 1: Selected locations in dry zone Sri Lanka

Trend Analysis

The Mann-Kendall trend test was used to determine whether the trends were statistically significant at (p<0.05) level of significance. The method is frequently employed in climatological and hydrological time series analysis (Mann, 1945; Kendall, 1975), in cases where the data is not normally distributed. Hence the method is a non-parametric statistical test.

$$Z_{mk} = \begin{cases} \dfrac{S-1}{\sqrt{\text{var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{\text{var}(S)}} & \text{if } S < 0 \end{cases}$$

$$\sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \text{sgn}(x_k - x_i)$$

$$\text{var}(S) = \frac{n(n-1)(2n+5) - \sum_i e_i(e_i-1)(2e_i+5)}{18}$$

Where Z_{mk} is the Mann-Kendall statistics, x_k, x_i are the sequential data values, n is the data set length, and $\text{sgn}(x_k - x_i)$ is equal to one, 0, or -1 if Θ is $>$, $=$, or $<$ 0 respectively. e_i is the extent of any given tie and $\sum$ denotes the summation of all ties. The null hypothesis H_0 of no trend is accepted if the computed p-value is greater than the significance level ($\alpha = 0.05$). In the case of positive Kendall's tau, there is an "upward trend," while in the case of negative Kendall's tau, the trend is "downward." .The annual and seasonal

Table 1: Locations and altitude of selected stations

Location	Latitude	Longitude	Altitude (m)	Data availability	Missing data %	
					T_{max}	T_{min}
Batticaloa	7.72	81.70	5	1981–2019	0.54%	0.9%
Jaffna	9.68	80.03	5	1981–1983		
2002–2019	0.69%	0.8%				
Puttalam	8.03	79.83	6	1981–2019	0.43%	1.5%
Pottuvil	6.88	81.83	7	1992–1995		
1997–2001						
2007–2008						
2017–2019	7.0%	6.2%				
Mannar	8.98	79.92	8	1981–2019	20.67%	12.37%
Trincomalee	8.58	81.25	8	1981–2019	5.7%	5.6%
Hambantota	6.12	81.13	16	1981–2019	0.54%	1.9%
Anuradhapura	8.35	80.38	81	1981–2019	0.54%	0.9%
Vavuniya	8.75	80.50	99	1984–1986		
1988–1999						
2006–2009						
2018–2019	6.9%	12.28%				
Mahailluppallama	8.12	80.46	113	1981–2019	1.42%	1.65%

analysis have been done, and seasonal analysis is based on the two main agricultural seasons which are *Yala* (May to September) and *Maha* (December to February) (Chithranayana and Punyawardena, 2008).

RESULTS AND DISCUSSION

The study discusses annual and seasonal extreme temperature trends over the past 38 years in the Dry Zone of Sri Lanka. Farmers can better manage their cultivation operations and plan their crops with the assistance of analysis of yearly and seasonal temperature trends. Furthermore, managing and adjusting to long-term dangers like those that drought is greatly facilitated by these assessments. In this study, the behavior of the daytime and nighttime temperature was analyzed during the past 38 years by using several indices as explained by ETCCDI.

Annual Trend Analysis of Extreme Temperature Indices

Daytime temperature:

The behavior of the daytime temperature was explained by the SU, TXX, TXN, TX10p, TX90p, TX10p*, TX90p* and TMAXMEAN. Both increasing and decreasing trends in maximum temperature were displayed by the locations considered for this study in the dry zone. Out of the 5 locations which displayed increasing trends, only Batticaloa showed a significant ($p < 0.05$) trend for the maximum daytime temperature (TXX) while only Anuradhapura showed a significant decreasing trend. Vavuniya and Trincomalee showed significant increasing trends for the summer days (SU).

Significant increase in warm days (TX90p) have been observed at Batticaloa, Hambantota and Jaffna stations during the study period (Figure 02B). However, any station did not display a significant decreasing trend for warm days (TX90p). Unprecedented variations in the number of cool days (TX10p) were shown in the dry zone within the period from 1981 to 2019. Anuradhapura, Puttalam and Mannar showed an increase in cool days along with a decrease in warm days. However, those trends were not significant. Three locations (Batticaloa, Hambantota, Trincomalee) showed significant results for the decrease in cool days (Figure 02A). Batticaloa and Hambantota showed significant trends in a decrease in cool days along with an increase in warm days, which confirmed a very clear increasing trend in daytime temperature.

In general, the mean annual daytime temperature (TMAXMEAN) showed an increasing trend. The

Table 2: Selected temperature indices from the recommendation of the Expert Team on Climate Change Detection and Indices (ETCCDI)

Index	Descriptive name	Definition	Unit
SU	Summer days	Daily $T_{max} > 25°C$ (annual or seasonal count)	Days
TR	Tropical nights	Daily $T_{min} > 20°C$ (annual or seasonal count)	Days
DTR	Diurnal temperature range	The mean difference between T_{max} and T_{min} on an annual and seasonal basis	°C
TN90p	Warm nights	Percentage of days when the T_{min} is higher than the 90th percentile (annual/seasonal)	%
TX90p	Warm days	Percentage of days when the T_{max} is higher than the 90th percentile (annual/seasonal)	%
TXx	Max daytime temperature	Maximum value of daily T_{max} (annual/seasonal)	°C
TNx	Max nighttime temperature	Maximum value of daily T_{min} (annual/seasonal)	°C
TXn	Min daytime temperature	Minimum value of daily T_{max} (annual/seasonal)	°C
TNn	Min nighttime temperature	Minimum value of daily T_{min} (annual/seasonal)	°C
TN10p	Cool nights	Percentage of days when T_{min} is below the 10th percentile (annual/seasonal)	%
TX10p	Cool days	Percentage of days when T_{max} is below the 10th percentile (annual/seasonal)	%
WSDI	Warm spell duration indicator	Count of days with at least 6 consecutive days when $T_{max} > 90^{th}$ percentile (annual/seasonal)	Days
TMAXMEAN	Mean daytime temperature	Mean of T_{max} (annual/seasonal)	°C
TMINMEAN	Mean nighttime temperature	Mean of T_{min} (annual/seasonal)	°C

Table 3: User-defined temperature indices derived from the indices recommended by the Expert Team on Climate Change Detection and Indices

Index	Descriptive name	Definition	Units
TX10p*	Number of cool days	Count of days when T_{max} is lower than 10th percentile (annual/seasonal)	Days
TX90p*	Number of warm days	Count of days when T_{max} is greater than 90th percentile (annual/seasonal)	Days
TN90p*	Number of warm nights	Count of days when T_{min} is greater than 90th percentile (annual/seasonal)	Days

increasing trend detected in Batticaloa, Hambantota, Trincomalee and Jaffna was significant. Further, certain locations (Batticaloa, Hambantota, Trincomalee and Jaffna) showed prominent results for most of the maximum temperature indices, indicating significant warming patterns in the daytime temperature in the dry zone within the study period. However, the behaviour of the daytime temperature in one location (Mahailuppallama) was highly independent of the other locations.

Similar conclusions were drawn by Naveendrakumar *et al* (2018) based on the trend analysis and indicated an overall rise in temperature throughout Sri Lanka, indicating a warming of both daytime and nighttime temperatures.

Nighttime Temperature:

The behavior of the nighttime temperature is explained by the TR, TNX, TNN, TN90p, TN10p, TN10p*, TN90p* and TMINMEAN indices. Accordingly, nighttime temperature showed significant variation in the dry zone within the past 38 years. In general, significant increasing patterns were displayed for nighttime temperature in five locations: Anuradhapura, Hambantota, Batticaloa, Puttalam, and Mannar. However, contrasting results were shown by Jaffna, which is located in the northern part of the country, by showing a significant cooling trend in minimum nighttime temperature (TNN), cool nights (TN10p), and the annual mean of minimum temperature (TMINMEAN). A significant increasing trend was detected for Tropical nights (TR) in Anuradhapura and Batticaloa within the study period.

In general, an increasing trend in minimum nighttime temperature (TNN) was observed in the dry zone within the study period and only the increasing trend in Anuradhapura was significant. However, a decreasing trend was shown in only two locations (Trincomalee and Jaffna), and the trend of both locations is significant. Similarly, maximum nighttime temperature (TNX) also displayed a general increasing pattern with an increasing trend in 7 locations out of 10 selected locations, while Batticaloa and Vavuniya are significant.

Warm nights showed significant increasing trends in the locations of Anuradhapura, Batticaloa, Hambantota and Puttalam (Figure **??**). Only Jaffna showed a decreasing trend in warm nights, which is non-significant. The findings of the present study agree well with the global trend of warm nights. Alexander *et al.* (2006) showed that the frequency of warm nights has increased significantly over time from 1951 to 2003. Similarly, Zhu *et al.* (2022) reveal that consecutive occurrences of hot days and hot nights show an increasing trend in the future and a strong latitudinal gradient increasing from high latitudes to the equator. The present study also identified an increase in warm nights together with a very clear decreasing trend in cool nights within the last 38 years in the dry zone of Sri Lanka. Out of the 10 selected locations, five locations showed a significant decreasing trend in cool nights: Anuradhapura, Batticaloa, Hambantota, Mannar and Puttalam (Figure 03B).

Similar findings of the behavior of the mean nighttime temperature indices were reported by Jayawardene *et al.* (2018) based on a study done using data from 1980–2015. They also reported a significant occurrence of fewer cold nights and more warm nights in Sri Lanka.

A decrease in annual mean minimum temperature is also clearly indicated by the selected locations in the dry zone. The decreasing trends observed in Anuradhapura, Batticaloa, Hambantota, Mannar, Jaffna, and Puttalam were significant within the study period.

The behavior of the nighttime temperature in the dry zone is in line with global trends in minimum temperature. An increasing trend in nighttime temperature has been reported by several studies (Easterling *et al.*, 1997; Folland *et al.*, 2001; Naveendrakumar *et al.*, 2019). Similar behavior of nighttime temperature has also been reported in Sri Lanka. According to Jayawardene *et al.* (2018), Sri Lanka experienced considerable increases in mean minimum temperatures between 1980 and 2015. Naveendrakumar *et al.* (2019) have reported an increasing trend of temperature in almost all the countries in the South Asian region, with significant increasing trends in minimum temperature identified in Bhutan and Sri Lanka.

Diurnal Temperature Range (DTR:

DTR is the difference between daytime and nighttime temperatures, and it serves as a crucial meteorological marker for climate change. DTR is also very important in agriculture in the aspects of plant growth and crop yield. It showed both significant increasing and decreasing trends within the study period. Trincomalee

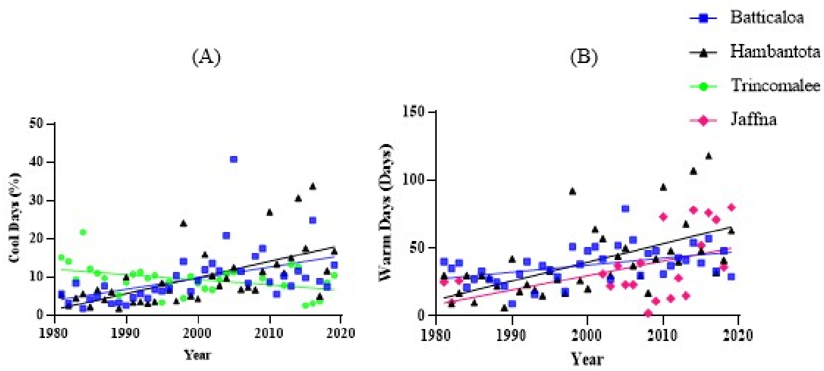

Figure 2: Locations with significant trends for (A) Cool days (B) Warm days (lines indicate linear trends of regression)

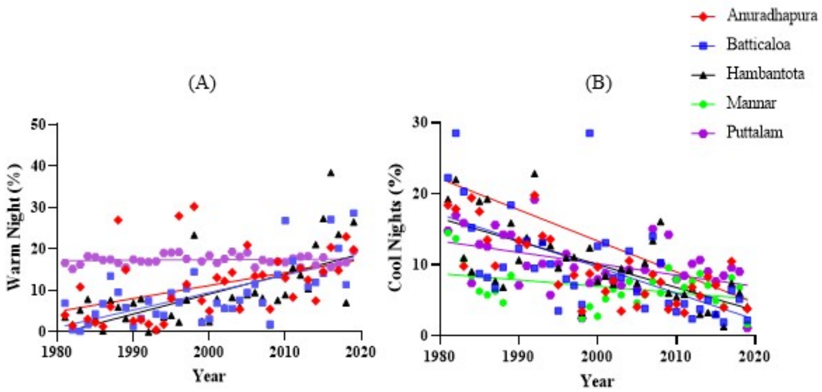

Figure 3: Locations with significant trends for (A) Warm nights (B) Cool nights (lines indicate linear trends of regression)

and Jaffna showed a significant increasing trend while Anuradhapura, Puttalam and Mannar showed a significant decreasing trend (Figure 04).

Wang *et al.* (2014) found a decline in DTR in most parts of the world since the mid-20th century and further noted a fluctuation in circulation in some parts of the Northern Hemisphere. Similar to the findings of the present study, Jayawardene *et al.* (2018) have amply demonstrated that DTR is declining at most of the locations in Sri Lanka, except Hambantota and Trincomalee. The rapidly growing tendency of minimum temperatures was the cause of this declining trend.

Drought Indices:

The probability of the occurrence of drought can be explained by using the Warm Spell Duration Indicator (WSDI). Accordingly, Hambantota and Jaffna showed a significantly increasing trend for drought occurrence. Not all the other stations in the dry zone of Sri Lanka showed a significant increasing or decreasing trend for the occurrence of drought.

Seasonal Trend Analysis of Extreme Temperature Indices – *Yala* Season

Daytime Temperature:

The seasonal count (days) of daily maximum temperature higher than 25°C, which is explained by the summer days (SU), showed a definite increasing trend within the study period, while a significant increase has been observed in Vavuniya and Hambantota.

Most of the locations showed a general increasing trend for the seasonal minimum daytime temperature (TXn) within the *Yala* season in the dry zone of Sri Lanka. The seasonal minimum temperature trends of Anuradhapura, Batticaloa and Jaffna are significant. No decreasing trends displayed are significant.

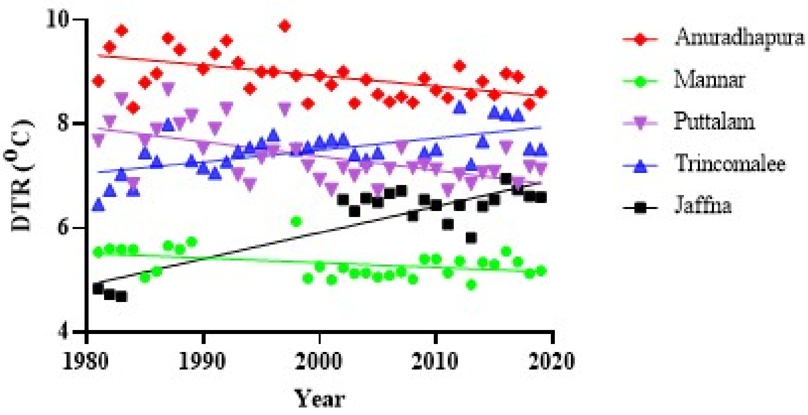

Figure 4: Locations with significant trends for diurnal temperature range

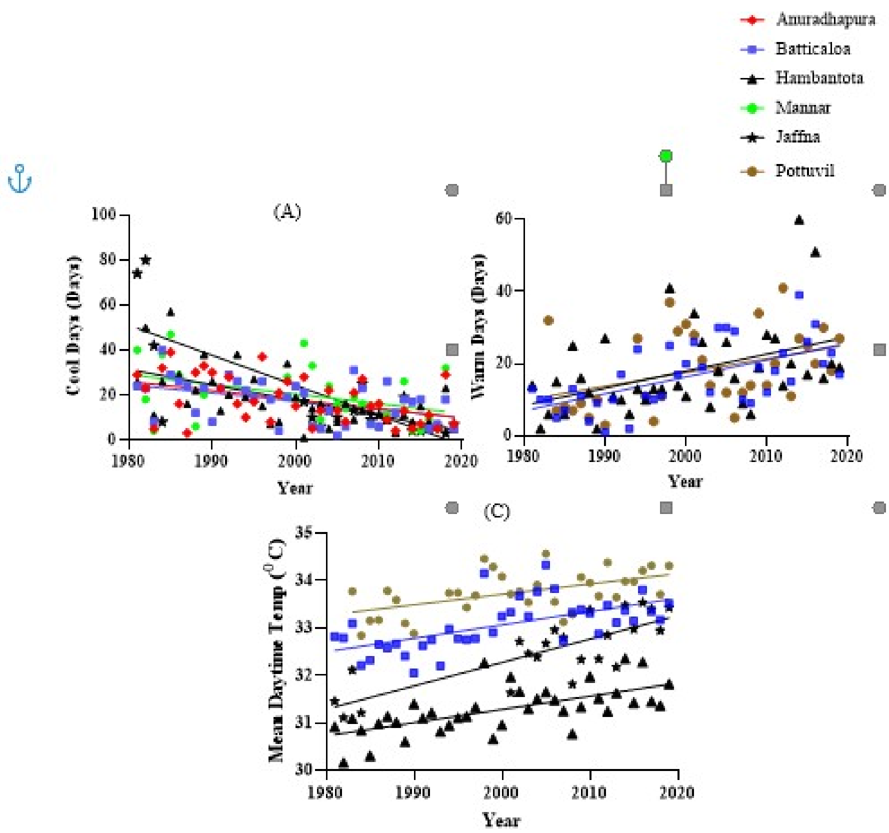

Figure 5: Locations with significant trends for (A) Cool days (B) Warm days and (C) Mean of daytime temperature (lines indicate linear trends of regression)

Northern and Eastern locations (Anuradhapura, Batticaloa, Mannar and Jaffna) showed a significant decreasing trend in cool days (TX10p) during the *Yala* season. A significant decline in cool days was reported in Hambantota, which is located towards the most southern part of the dry zone (Figure 05A). In contrast to cool days, Batticaloa, Hambantota and Pottuvil showed an increasing trend for warm days (TX90p), which is significant (Figure 05B). This is further verified by the significant rise of the seasonal mean daytime temperature (TMAXMEAN) of those locations (Figure 05C). Apart from those locations, Jaffna also showed an increasing trend, which is significant for the seasonal mean daytime temperature during the *Yala* season.

When summarizing the behaviors of the daytime temperature indices in the *Yala* season, a warming trend could be observed in most of the locations except Mahailuppallama. However, the decreasing trends observed in Mahailuppallama are not significant. Batticaloa, Hambantota, and Puttalam showed significant increasing trends for most indices, which explain the behavior of daytime temperature within the *Yala* season.Regarding the seasonal maximum temperature, the study done by Navendrakumar *et al.* (2018) indicated that statistically significant increases were seen at least in 45% of the locations within the *Yala* season followed by 55% during the *Maha* season.

Nighttime temperature:

Generally, the minimum temperature of a day in a certain place occurs at night and is considered the nighttime temperature. When the daily nighttime temperature is above 20 °C, it is explained by Tropical Nights (TR) and estimated as the count of days per annum or season. In the present analysis, all the locations showed an increasing trend for TR during the *Yala* season, while the trends of Vavuniya, Trincomalee, and Jaffna were significant. Interestingly, all the locations showed an increasing trend for the seasonal minimum nighttime temperature (TNn) except Jaffna. The trend shown by the Jaffna station for TNn is significantly negative. The increasing trends of Anuradhapura, Batticaloa, Puttalam, Vavuniya, and Hambantota (Figure 06A) were significant. Similar behavior could be observed in maximum nighttime temperature (TNx) as well. Locations that showed a significantly increasing trend for TNn also showed a significantly increasing trend for TNx. However, the negative trend observed in Jaffna for TNx was not significant. Warm nights (TN90p) showed an increasing pattern throughout the entire dry zone during the *Yala* season, while the trends at Anuradhapura, Hambantota, Batticaloa, and Puttalam (Figure 06B) were significant. Confirming the above results, the seasonal mean nighttime temperature (TMINMEAN) of all locations showed an increasing trend except Jaffna. Anuradhapura, Hambantota, Batticaloa, Mannar, Vavuniya, and Puttalam (Figure 06C) showed significant positive trends for TMINMEAN.Similar to the annual changes observed in nighttime temperature, Anuradhapura, Hambantota, and Batticaloa showed clearly defined significant increasing trends during the study period in the *Yala* season. Jaffna, on the other hand, showed a significant decreasing trend in nighttime temperatures clearly.

Similar findings were reported by (Naveendrakumar *et al.*, 2019) by analyzing the temperature indices for the period of 1961-2015. The study revealed that statistically significant increases were in 80% of the stations for nighttime temperature during the *Yala* season over the entire study period (in June and July).

Diurnal Temperature Range (DTR):

Similar to the annual results, different locations showed different results for the DTR during the *Yala* season. Puttalam showed a significant decreasing trend, while Jaffna showed a significant increasing trend. The increasing trend of the nighttime temperature led to a reduction in the DTR at Puttalam, and the decreasing trend of nighttime temperature led to an increase in DTR at Jaffna.

Drought Index:

The occurrence of drought can be explained by the indices of Warm Spell Duration Indicator (WSDI) and maximum daytime temperature (TXx). Both increasing and decreasing trends for WSDI were observed, while only Jaffna showed a significant increasing trend, indicating the risk of drought in the dry zone during the *Yala* season. This is further verified by a significant increasing trend in TXx at Jaffna. Batticaloa and Hambantota also showed significant increasing trends in maximum daytime temperature (TXx) during the *Yala* season, indicating the possibility of drought. The results of the present study align with the findings of Chithranayana and Punyawardena (2008), stating that, “Regardless of their geographic position, during the Yala seasons, all Agro-Ecological Regions in Sri Lanka’s dry Zone are vulnerable to severe drought conditions.”

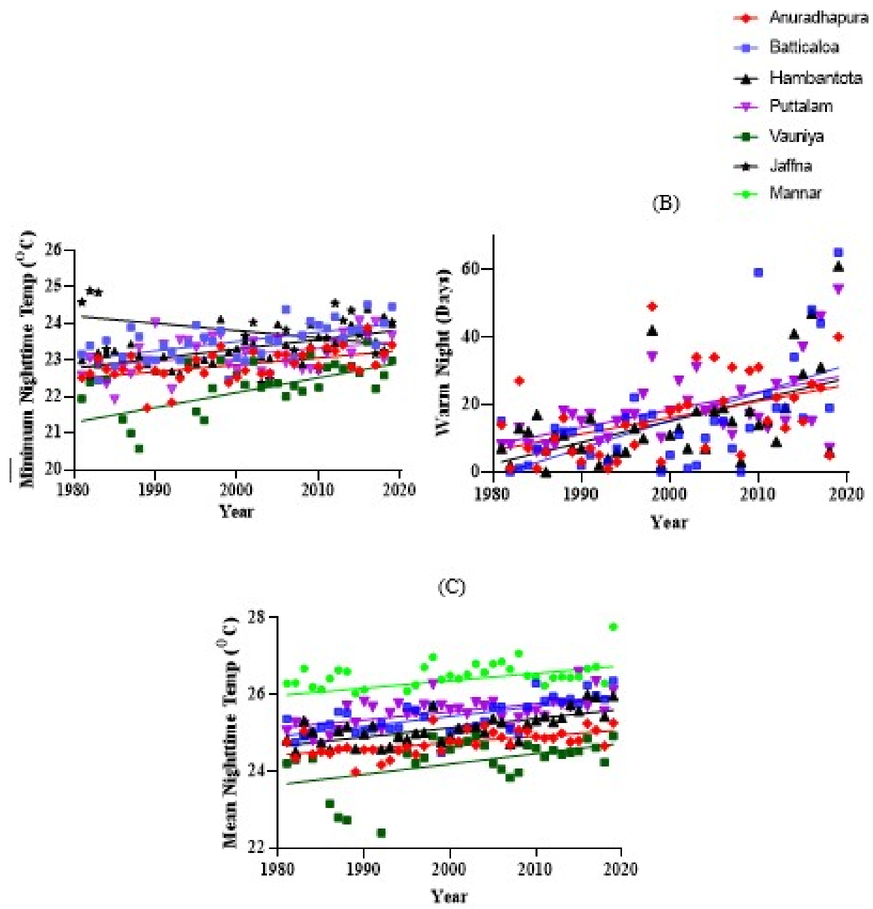

Figure 6: Locations with significant trends for (A) Minimum of minimum temperature (B) Warm night and (C) Mean of minimum temperature. (lines indicate linear trends of regression)

Seasonal Trend Analysis of Extreme Temperature Indices – *Maha* Season

Daytime Temperature:

In contrast to the *Yala* season, no significant trends were observed for the summer days (SU) and minimum daytime temperature (TXn) during the *Maha* season. Most of the locations showed a decreasing trend for the cool days (TX10p), while the decreasing trend observed in Hambantota was significant. Both increasing and decreasing trends were displayed by warm days (TX90p); however, most locations showed decreasing trends. Batticaloa, Hambantota, and Jaffna (Figure 07A) showed significant increasing trends. Batticaloa, Hambantota, and Jaffna stations (Figure 07 B) also showed significantly increasing trends for the seasonal mean of daytime temperature (TMAXMEAN).

When comparing the two cropping seasons, the *Yala* season showed more considerable changes than the *Maha* season in the variation of daytime temperature within the study period.

Nighttime Temperature:

Almost all the locations showed an increasing pattern of Tropical Nights (TR), with the patterns being significant in Batticaloa, Pottuvil, and Mannar. Most of the locations showed an increasing trend for minimum nighttime temperature (TNn) except Jaffna. The TNn of Jaffna was significantly decreasing, which corresponds with the annual and *Yala* season trend results. Batticaloa and Hambantota showed a significant increasing trend for TNn.Similarly, maximum nighttime temperature (TNx) also showed an increasing trend in all locations except Jaffna. However, the decreasing trend observed in Jaffna was not significant, while Anuradhapura, Mahailuppallama, Batticaloa, Hambantota, Puttalam, and Vavuniya showed a significant increasing trend (Figure 08A). Similar to the other indices, warm nights (TN90p) displayed an increasing trend throughout the dry zone during the *Maha* season. The trends in Anuradhapura, Batticaloa, Hambantota, and Puttalam were significant (Figure 08B). Confirming the behavior of the nighttime temperature indices, the seasonal mean nighttime temperature (TMINMEAN) showed a very clear increasing trend during the *Maha*

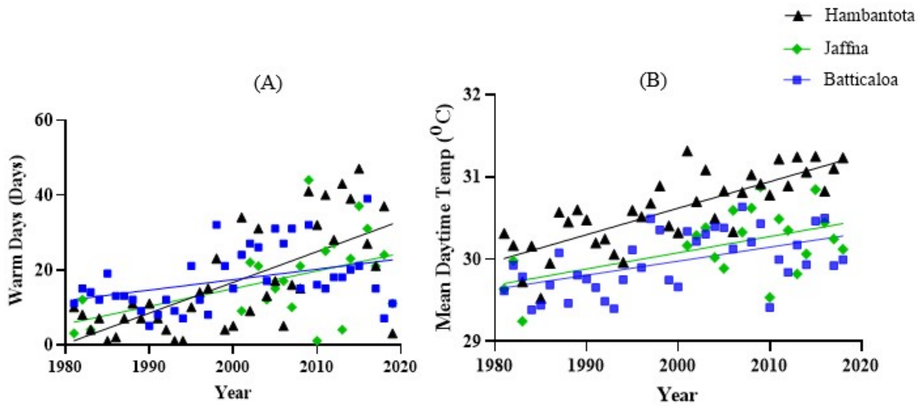

Figure 7: Locations with significant trends for (A) Warm days and (B) Mean of maximum temperature. (Lines indicate linear trends of regression)

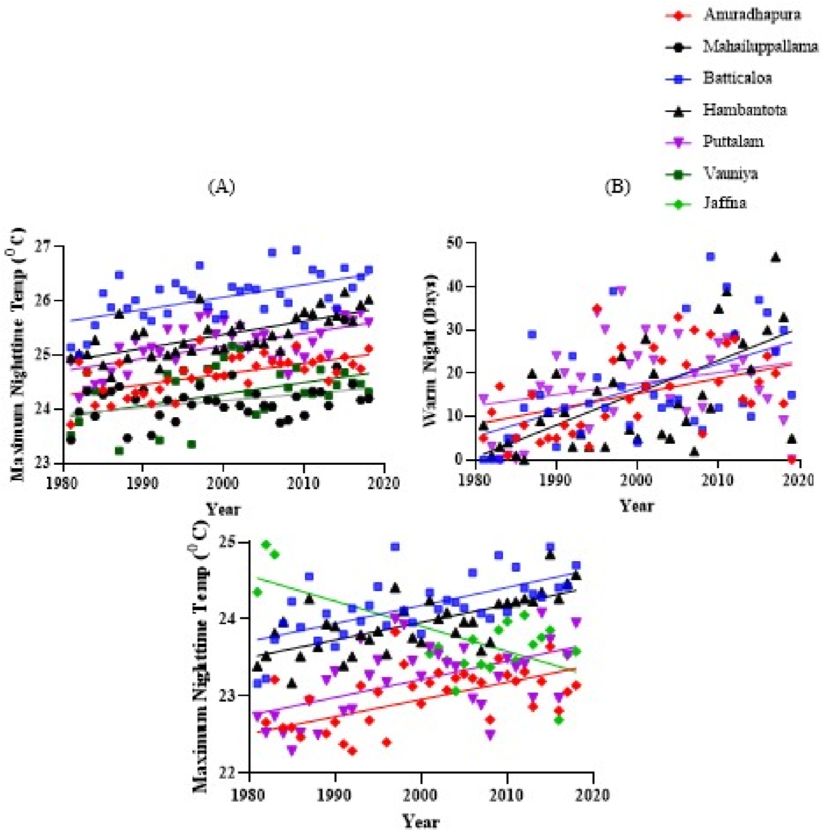

Figure 8: Locations with significant trends for (A) Maximum of minimum temperature (B) Warm night and (C) Mean of minimum temperature. (Lines indicate linear trends of regression)

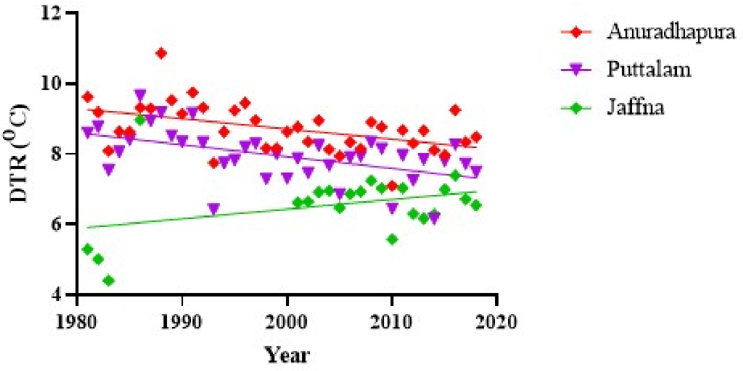

Figure 9: Locations with significant trends for Diurnal temperature range (lines indicate linear trends of regression)

season. Anuradhapura, Batticaloa, Hambantota, and Puttalam showed significant positive trends (Figure 08C). However, Jaffna showed a significant decreasing trend. A considerable number of indices have shown significant trends in Anuradhapura, Batticaloa, Hambantota, and Puttalam within the *Maha* season. As seen in the annual and *Yala* season results, Jaffna consistently showed a significant decreasing trend for nighttime temperatures. The trends of DTR of the Maha season are on par with the annual and Yala season results. Anuradhapura and Puttalam showed a significantly decreasing trend for DTR while Jaffna showed a significantly increasing trend (Figure 09).

Drought indices:

Drought indices showed both increasing and decreasing patterns during the *Maha* season within the study period. Hambantota and Jaffna showed a significantly increasing trend for WSDI indicating a risk of having a drought while Puttalam showed a significantly less risk. Considering the maximum daytime temperature (TXx), increasing trends of Batticaloa and Hambantota were significant. It indicates the possibility of developing drought conditions around Batticaloa during the *Maha* seasons. Chithranayana and Punyawardene (2008) also verified this as the extreme northern and southern areas of the island often receive less rain during the northeast monsoon, making those regions more susceptible to drought conditions throughout the *Maha* season.

CONCLUSION

This study attempted to investigate annual and seasonal trends in temperature extreme events in the dry zone of Sri Lanka. Accordingly, dynamic trends, both increasing and decreasing patterns were observed for the period of 1981-2019.

Most of the observed locations showed a significantly increasing trend in daytime temperature. Among them, Jaffna, Batticaloa, Trincomalee and Hambantota are prominent. Considering the nighttime temperature, Anuradhapura, Batticaloa, Puttalam, Mannar and Hambantota showed significant increasing trends. However, the Jaffna location showed opposite trends by decreasing trends of nighttime temperature, cool nights and the annual mean nighttime temperature. In locations where there were positive trends, the increasing rate of nighttime temperature is greater than the increasing rate of daytime temperature. Jaffna and Trincomalee locations showed an increasing trend for the diurnal temperature range while Anuradhapura, Puttalam and Mannar showed a decreasing trend. Decreasing the diurnal temperature range was mainly driven by the increasing trend of nighttime temperature. An increasing trend was observed for the occurrence of drought in Jaffna and Hambantota.

The analysis revealed a distinct warming trend in Anuradhapura, Vavuniya, Mannar, Pottuvil, Batticaloa and Hambantota regions by showing significant trends both for most of day time and night time temperature indices. In contrast, findings for Jaffna location were different, as they showed warming trends for daytime temperature indices and cooling trends for nighttime temperature indices. Significant changes were observed for the diurnal temperature range of Puttalam and Jaffna. Increasing trend of nighttime temperature was led to increase the DTR in Puttalam while decreasing trend of nighttime temperature was led to reduce the DTR in Jaffna. There is a probability of occur droughts during the *Yala* seasons in Jaffna, Batticaloa and Hambantota regions.

During the *Maha* season, variation of daytime temperature indices are less compared to the *Yala* season. However, Batticaloa and Hambantota locations showed clear daytime warming. The nighttime temperature of both locations also shows an increasing trend. Nighttime temperature of Anuradhapura, Mahailluppallama, Puttalam and Vavuniya also show an increasing trend. There is a decreasing trend of nighttime temperature in the Jaffna region. The diurnal temperature range in Anuradhapura and Puttalam is decreasing, whereas in Jaffna, it is increasing. Similar to the *Yala* season, Jaffna, Batticaloa and Hambantota regions may have a chance to occur droughts during the *Maha* season. Puttalam may have a chance in decreasing the drought occurrence.

Conflicts of Interest The authors declare that there is no conflict of interest regarding the publication of this paper.

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Table 4: Kendall's tau and correlation coefficient values of annual trend analysis

Location	SU	TR	DTR	TN90p	TX90p	TXX	TNX	TXN	TNN	TN10p	TX10p	WSDI	TX10p*	TX90p*	TN90p*	*Tmaxmean*	*Tminmean*
Anuradhapura	0.191	**0.258**	**-0.514**	**0.45**	-0.095	**<0.0001**	-0.012	0.054	**0.323**	**-0.367**	-0.118	-0.1	0.143	-0.069	**0.418**	-0.034	**0.689**
Mahailuppallama	-0.096	0.02	-0.099	0.164	-0.092	-0.072	0.072	-0.115	0.095	0.006	-0.06	-0.045	**-0.166**	-0.017	0.202	0.017	0.204
Batticaloa	0.017	**0.343**	0.042	**0.637**	**0.5**	**0.369**	**0.346**	-0.270	0.226	**-0.609**	**-0.511**	0.048	**-0.327**	0.3	**0.494**	**0.636**	**0.717**
Hambantota	0.131	-0.062	0.305	**0.64**	**0.613**	0.142	0.203	-0.052	**0.284**	**-0.685**	**-0.486**	**0.255**	**-0.46**	**0.453**	**0.484**	**0.751**	**0.744**
Puttalam	0.071	-0.015	**-0.606**	**0.622**	-0.256	-0.148	**0.316**	-0.093	0.086	**-0.481**	0.114	-0.173	0.165	-0.144	**0.455**	-0.18	**0.606**
Pottuvil	-0.123	0.218	-0.179	0.244	0.33	-0.18	0.043	-0.338	0.275	-0.246	-0.017	0.026	0.082	0.227	0.206	0.327	0.31
Mannar	0.079	0.142	**-0.405**	0.321	-0.092	-0.124	-0.142	-0.08	0.201	**-0.388**	0.05	-0.052	0.076	-0.074	0.187	-0.038	0.397
Vauniya	0.319	**0.222**	-0.111	0.081	0.167	0.279	**0.376**	-0.297	0.157	-0.315	-0.068	-0.087	-0.192	0.022	0.109	0.215	0.273
Trincomalee	0.291	0.083	**0.641**	-0.12	0.196	0.146	-0.091	0.169	**-0.59**	0.206	**-0.424**	0.158	**-0.281**	0.125	0.031	**0.463**	-0.194
Jaffna	0.18	-0.185	**0.861**	0.099	**0.483**	0.116	0.025	-0.115	**-0.864**	**0.754**	-0.236	0.335	-0.106	**0.377**	-0.178	**0.82**	**-0.599**

Locations and indices with significant trends were in bold numbers.

Table 5: Kendall's tau and correlation coefficient values of *Yala* seasonal trend analysis

Location	*Indices*												
	SU	**TR**	**DTR**	**TN90p**	**TX90p**	**TXX**	**TNX**	**TXN**	**TNN**	**TX10p**	**WSDI**	**Tmaxmean**	**Tminmean**
Anuradhapura	0.101	0.136	-0.281	0.349	-0.166	-0.293	0.331	0.399	0.521	-0.349	-0.114	0.100	0.592
Mahailuppallama	-0.123	-0.044	-0.200	0.162	-0.068	-0.153	0.160	-0.027	0.152	-0.179	-0.096	-0.057	0.264
Batticaloa	0.152	0.229	0.010	0.440	0.427	0.548	0.563	0.427	0.586	-0.346	0.030	0.609	0.672
Hambantota	0.275	-0.153	0.138	0.379	0.341	0.154	0.597	0.263	0.655	-0.467	0.228	0.641	0.696
Puttalam	0.003	-0.082	-0.584	0.401	-0.149	-0.153	0.369	-0.173	0.393	-0.058	-0.213	-0.141	0.608
Pottuvil	0.128	0.247	-0.093	0.168	0.269	-0.083	0.229	0.202	0.350	-0.239	-0.140	0.523	0.282
Mannar	0.074	0.139	-0.193	-0.022	-0.018	-0.101	0.027	0.167	0.291	-0.287	-0.118	0.083	0.382
Vauniya	0.350	0.357	-0.186	0.107	0.069	-0.155	0.301	0.073	0.461	-0.124	0.159	0.140	0.358
Trincomalee	0.225	0.392	0.556	0.191	0.043	0.016	0.222	0.306	0.246	-0.145	0.028	0.389	0.225
Jaffna	0.289	0.398	0.804	0.144	0.294	0.290	-0.001	0.555	-0.434	-0.439	0.519	0.778	-0.357

Note: Locations and indices with significant trends are in bold numbers.

Table 6: Kendall's tau and correlation coefficient values of *Maha* seasonal trend analysis

Location	*Indices*												
	SU	**TR**	**DTR**	**TN90p**	**TX90p**	**TXX**	**TNX**	**TXN**	**TNN**	**TX10p**	**WSDI**	**Tmaxmean**	**Tminmean**
Anuradhapura	0.108	0.101	-0.473	0.384	-0.024	-0.292	0.618	-0.016	0.288	0.064	0.031	-0.178	0.576
Mahailuppallama	0.051	0.063	0.025	-0.017	-0.120	-0.058	0.334	-0.103	-0.057	-0.074	-0.066	0.085	0.077
Batticaloa	-0.174	0.343	-0.258	0.391	0.302	0.338	0.568	-0.095	0.513	-0.156	0.139	0.526	0.647
Hambantota	0.169	0.174	0.245	0.493	0.537	0.428	0.701	0.272	0.519	-0.258	0.411	0.794	0.695
Puttalam	0.056	-0.017	-0.502	0.234	-0.182	-0.179	0.605	-0.186	0.281	0.158	-0.309	-0.200	0.548
Pottuvil	0.030	0.261	-0.192	0.249	0.108	0.109	0.229	-0.274	0.302	-0.049	-0.019	0.171	0.293
Mannar	0.124	0.302	-0.263	0.133	-0.124	0.141	0.191	-0.077	0.302	0.026	-0.064	0.076	0.334
Vauniya	0.221	-0.017	-0.101	-0.061	-0.135	0.074	0.399	0.135	0.148	-0.055	-0.051	0.132	0.256
Trincomalee	0.116	0.145	0.408	0.099	0.140	-0.082	0.195	0.156	0.061	-0.196	0.183	0.282	0.168
Jaffna	-0.085	-0.190	0.725	0.068	0.410	-0.018	-0.147	0.168	-0.751	-0.049	0.334	0.523	-0.692

*Note: Locations and indices with significant trends are shown in **bold** numbers.*