Meeting the Climate Challenge:
Climate Data Analysis of Thirappane and Palugaswewa areas in the North Central Province in Sri Lanka

Healthy Landscapes Project

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Final Report

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Meeting the Climate Challenge - Climate Data Analysis of Thirappane and Palugaswewa areas in the North Central Province (NCP) in Sri Lanka

Executive Summary

- Climate change is a fact, not a myth.
- There was no discernible trend in the total annual cumulative rainfall, decadal rainfall, and the annual average maximum and minimum temperatures during the study period 1981-2022 in the Anuradhapura area in the agro-ecological region DL1.
- Extreme rainfall events did occur during the study period 1981 to 2022, however, there was no clear linear trend to provide any short term predictions on the occurrence of extremely rain fall events.
- Though the diurnal temperature variations did not show a discernible linear trend during the study period, the night temperatures (minimum) increase at a faster rate than the day temperatures (Maximum) alarming of future threats to agriculture and less number of comfortable nights. Increasing night temperatures will increase plant respiration thus reducing the final economic yield.
- There was evidence of heat stress where it can lead to an imbalance in plant hormones, impairing plant growth, photosynthesis, pollen development, and reproduction, and also human health concerns.
- The onset of rainfall have deviated significantly from the known standards. The analysis revealed that the 13th week as the date of onset of rainfall for the DL1 regions for *Yala* season (current standard: 9th week) and 39th week for the *Maha* season (current standard: 35th week). The mean duration of the growing season is 14.7 ± 3.4 weeks.

Summary Recommendations:

- Availability and access to long-term and reliable weather data at least for a 30 year period as identified by the Intergovernmental panel on climate change (IPCC) helps in providing more accurate analysis of climate change at national and regional (or specific location) level-term data availability
- Establishment of automated weathers stations is a must to obtain reliable weather data for analysis of the climate change in the future.
- Regional and location specific analysis of climate change provide a better understanding of the issue and to find and implement pragmatic solutions.
- Continuous capacity building of the regional officers is important for location-specific and scientifically-based climate analysis to make informed decisions by the policy makers and the farming community.
- Development of knowledge products on all aspects of climate change in both local languages (Sinhala and Tamil) would immensely help the officers and farming community to learn more of regional focus on climate change and find and adopt pragmatic solutions to build resilience.

Introduction

(1) Sri Lanka shows a typical tropical monsoonal climate, hot and humid all year round with distinct wet and dry seasons. Rainfall of Sri Lanka is of multiple origins. Monsoonal, convectional, and synoptic-scale “weather systems” formed in the Bay of Bengal account for a major share of the annual rainfall, varying from 900 mm (southeastern lowlands) to over 5,500 mm (southwestern slopes of the Central Highlands).

(2) The rainfall experienced during a 12-month period in Sri Lanka can be characterized into four rainfall seasons, namely, first inter-monsoon (March–April; FIM), southwest monsoon (May–September; SWM), second inter-monsoon (October–November; SIM), and northeast monsoon (December–February; NEM). The minor cultivating season (*Yala* season) receives rainfall from the FIM and SWM, while the main cultivating season (*Maha* season) receives rainfall from the SIM and NEM.

(3) On the basis of average annual rainfall along with some other biophysical parameters, Sri Lanka has been generalized into three major climatic zones in terms of “Wet Zone” in the southwestern region including Central Highlands country, “Dry Zone” covering predominantly, northern and eastern part of the country, and being separated by an “Intermediate zone,” skirting the Central Highlands except in the south and the west.

(4) The spatial differences in temperature in Sri Lanka are due to altitude; there is no temperature variation due to latitude. The mean monthly temperatures differ slightly depending on the seasonal movement of the sun, with some modifying influence caused by rainfall. In the lowlands, the mean annual temperature is 27 °C and the mean daily range is 6 °C. In the Central Highlands with altitudes up to 2,400 m a cooler climate is experienced**.**

Climate Change in Sri Lanka

(5) Climate change impacts our society by disrupting the natural, economic and social systems. A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes (TNC 2022), with a higher exposure of people and economic assets resulting in long-term increases in economic losses from climate-induced disasters. The intensity and frequency of extreme events relating to rainfall (e.g. heavy rainfall events and the absence of rainfall over a lengthy period) are increasing in Sri Lanka (Marambe et al. 2015).

(6) The extreme rainfall events could affect the biodiversity, increase the number of warm days and nights, decrease the number of cold days and nights, and decrease the diurnal temperature range over most regions of the country. Analysis carried out by scientists have clearly indicated that the wet zone in Sri Lanka would become wetter and the dry zone become drier in the future climate scenarios (TNC 2022).

(7) In terms of future rainfall climatology of Sri Lanka, projections with A2 scenario reveal that Dry zone will become more drier while the Wet and Intermediate zones to become more

wetter than at present as we reach the end of century. Meanwhile, B2 scenario uncovers a relatively complex situation of both Dry zone and Central highlands of Sri Lanka to become drier than today as time progresses while the wetter parts of Sri Lanka to become further wet, but at a lesser rate compared to the A2 scenario (Premalal and Punyawardena 2013; Marambe et al. 2015).

Climate Vulnerability

(8) Sri Lanka's vulnerability to climate change is exacerbated further by the fact that the majority of its population live in rural areas and continue to engage in small- scale farming, fisheries or are employed in the agricultural value chain. Sri Lanka's low urbanization has contributed in no small measure to its overall low-emission growth trajectory. However, this rural lifestyle is increasingly threatened by extreme weather events and anomalies related to the regular monsoon pattern around which the rural economy is organized.

(9) Though Sri Lanka is a negligible contributor to global warming compared to developed countries, but it is highly vulnerable to the impacts of global climate change. The Climate Risk Index (CRI) developed by the Germanwatch (2022) ranked Sri Lanka at 4^{th} (2016), 2^{nd} (2017), 6^{th} (2018) and 30^{th} (2019) most affected country owing to its increasing climate-related natural hazards such as floods, landslides, droughts and extreme weather events resulting in loss of lives and property. Over one million farmers were impacted by flood events in 2016 and 2017.

(10) Sri Lanka is recognized as vulnerable to climate change impacts, ranked 103 out of 181 countries in the ND-GAIN Index (University of Notre Dame 2020). The climate change impacts on different adaptation sectors, as identified in the NDCs, are well documented. Hence, sub-sections below comprise extracts of the information presented in the published literature with respect to climate change impacts on the NDC adaptation sectors.

Climate Impact on Food Crop Production Sector – with a special focus on paddy crop

(11) Sri Lanka is predominantly rural and agriculture-based country. It boasts a world-renowned hydraulic civilization spanning over two millennia. Approximately 2.6 million ha, equivalent to 42% of the country's total terrain, is in crop production. Much of this land is owned by 1,650,000 smallholder farmers. Agriculture in Sri Lanka is considered to be the sector that is the most vulnerable to the adverse impacts of climate change. Moreover, Sri Lanka have experienced a severe food insecurity situation with a number of associated issues mainly owing to climate change (Marambe et al. 2015).

(12) At present, climate change impacts are threatening the entire life cycle of food production and food security in Sri Lanka. The major climatic parameters such as temperature, CO_2 and precipitation are the most influencing factors for crop growth (Jayatillake and Droogers

2004) and the farming districts of Nuwara Eliya, Badulla, Moneragala, Ratnapura, and **Anuradhapura** are more sensitive to climate change (Eriyagama et al. 2010).

(13) Moreover, Sri Lankan farming communities have faced frequent and severe droughts since 1974 having a negative impact on agriculture (Berundharshani and Munasinghe 2015) and livelihoods and the socio-economic condition of farmers. Increased temperatures and decreased daytime and night time temperature differences have negatively affected high value crops, especially vegetable and potato cultivation (De Zoysa and Inoue 2014). This trend will continue due to the reducing diurnal temperature variations (Shelton et al. 2013), largely due to a higher rate of increase in the nighttime temperature compared to that of the daytime temperature.

(14) Rice cultivation is highly vulnerable to climate shocks such as droughts, increasing temperature, and floods. Rainfed paddy farmers are highly exposed and sensitive to drought. Crop failures due to climate change impacts have resulted in loss of resilience among farmers. Due to the drought in 2009, 2012, and 2017, the total area of cultivation in main major paddy-growing districts in Sri Lanka, namely, Ampara, Kurunegala, Anuradhapura, and Polonnaruwa decreased by more than 35% (Alahacoon and Amaranath 2022). In RCP 8.5 scenario the paddy variety Bg300 and Bg359 would reduce by 11% in 2050 and 28% in 2100 (Amarasingha et al. 2018). Further, Basnayake et al. (2021) reported that the flood-water height 1 m height could cause 2.2% yield loss in paddy (i.e. 44,220 kg paddy output for 1 km^2 of paddy production area).

(15) The information generated through well designed scientific studies as stated above clearly indicate that ecosystems vary in their sensitivity and response to climate change because of complex interactions among organisms, disturbance and other stressors. Changes in natural ecosystems due to climate change threaten biodiversity worldwide, and have implications for global food production.

The Project Scope

(16) Healthy landscapes comprising trees, forests and agriculture are key to reducing carbon emissions and assisting countries like Sri Lanka in adapting to the adverse effects of climate change. To achieve the Paris Agreement and meet major climate-related challenges, maintenance of productive multi-functional landscapes becomes crucial. Hence, a scientific analysis of the long-term climate parameters to identify the level at which climate change has occurred in the given location will assist in informed decision making in respect to climate smart practices.

(17) This assessment is focused on identifying the changes in the climate of two locations of the Healthy Landscape Project, namely, Thirappane and Palugaswewa, both belongs to the Agro-ecological region DL_{1b} and will probably have similar changes in weather in the long run.

(18) The study was thus designed to analyze the climate data obtained from the Mahailuppallama Weather Station managed by the Department of Meteorology located in the DL_1 over the period of 30 years (1991-2020) or longer based on the data availability collecting daily weather parameters

Project Activities

(19) The main tasks performed under project activities are as follows:

(a) Collection of daily rainfall, maximum and minimum temperature, sunshine, relative humidity, and evaporation data for a 30 year period (1991-2020) from the Mahailuppallama Weather Station.
(b) Develop a clean dataset considering the missing values and outliers. Missing values to be computed by the normal ratio method.
(c) Conduct an annual trend analysis of the weather parameters collected using standard procedures
(d) Conduct a seasonal trend analysis of rainfall (*Yala* and *Maha* seasons, separately) considering the inter-monsoon and monsoon rains, and other weather parameters as available
(e) Analyze the onset of the monsoon rainfall (early, normal and late) separately for the *Yala* and *Maha* seasons
(f) Conduct an analysis of changes in the day and night temperatures, and the diurnal changes of the temperature
(g) Conduct an analysis of the occurrence of extreme rainfall events during the 30 year period from 1991-2020
(h) Prepare and submit the climate analysis report combining all analysis and providing inter-relations among the parameters tested.

Note*: Due to unavailability of long-term data, the trends were not compared with the 30-year period of the climate data from 1961-1990, which is the standard practice recommended by the Intergovernmental Panel on Climate Change (IPCC).*

Scientific Methodology:

(20) The scientific methodology adopted in the analysis is given below:

(a) Weather data were collected from Mahailluppallama meteorological observation Station.
(b) The weather data collected included daily rainfall (mm), daily maximum and minimum temperatures (^{o}C), daily pan evaporation (mm), daily sunshine hours (hr), daily relative humidity (%) and daily wind velocity (km/hr) for a 42-year period (1981-2022) from the Mahailluppallama Agro-met Station.
(c) The set of data was quality controlled considering the missing values and outliers (Meteorological station at Anuradhapura was considered for missing data and outliers for rainfall and temperature).
(d) The annual trend analysis of the weather parameters collected was conducted using standard procedures, and the parameter were also analyzed for the seasonal trends of change during *Yala* and *Maha* seasons considering the inter-monsoon and monsoon rain periods, where applicable.
(e) Frequency of occurrence of extreme rainfall events was estimated considering the 90^{th} percentile of rainfall data to obtain a threshold value and average of the counts on percentiles events.
(f) Linear regression analysis was conducted, providing the regression co-efficient and the probability levels of significance to provide inference on the changes in meteorological data.

(g) In the case of estimating the onset of monsoonal rains, the methodology proposed by Punyawardena (2002) was adopted where standard week of rainfall onset was estimated when a spell of at least 30 mm of rain per week received in three consecutive weeks after a pre-specified week. Thus, the standard onset week for the *Maha* was considered as the 35^{th} week of the years, while that for *Yala* season was considered as the 9^{th} week of the year. If a three weeks criterion was not satisfied, the condition was relaxed up to two consecutive weeks with a rainfall equal to or greater than 30 mm. This leniency, where necessary, is particularly important for the *Yala* season where the continuity of the rains is always uncertain. The methodology proposed by Sonnadara (2015) based on cumulative rainy days was utilized in the determination of the onset and retreat dates.

Results and Discussion

(1) Annual Trend Analysis

1.1. Trend in Annual Cumulative Rainfall

The trend in annual cumulative rainfall data is illustrated in Figure 1. Though there was an apparent trend of increase in annual cumulative rainfall at the rate of 6 mm per year, with considerable fluctuations among years, the linear regression analysis showed a non-significant (P>0.05) relationship in increase of annual rain fall over the 42 year period from 1981 to 2022. The highest annual rainfall recorded during the study period was in 1984 (2,143 mm) and the lowest in 1988 (833 mm).

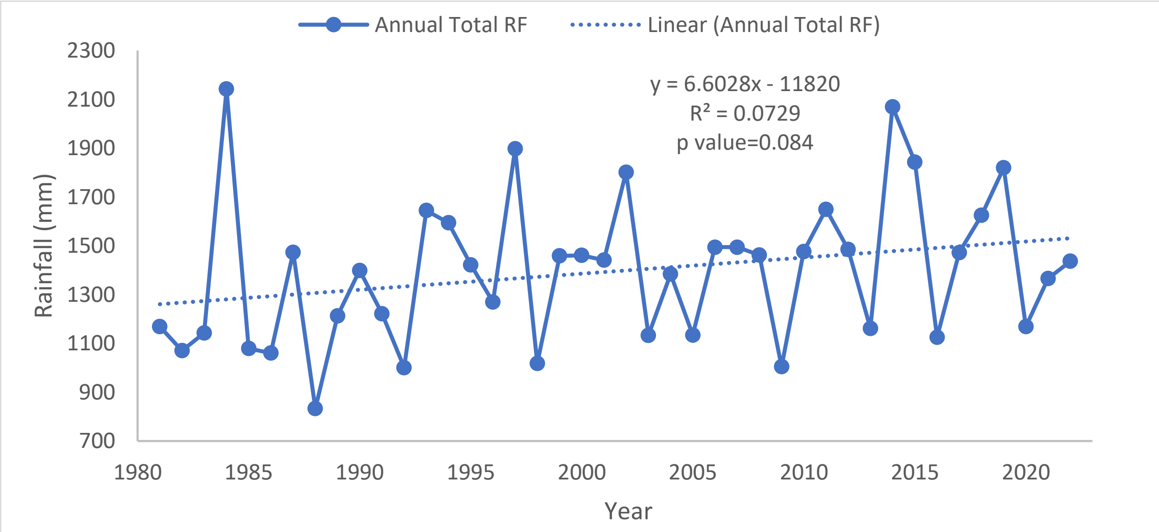


Figure 1. Changes in annual rainfall in the study sites from 1981 to 2022

1.2. Trend in Annual Average Maximum Temperature

Interestingly, the annual average maximum (day) temperature (Figure 2) showed an apparent declining trend from 1981 to 2022 (0.001 °C per year), though the linear regression co-efficient is not statistically significant (P>0.05). The highest temperature was recorded in 1983 (33.6 °C) and the lowest in 1999 (31.5 °C).

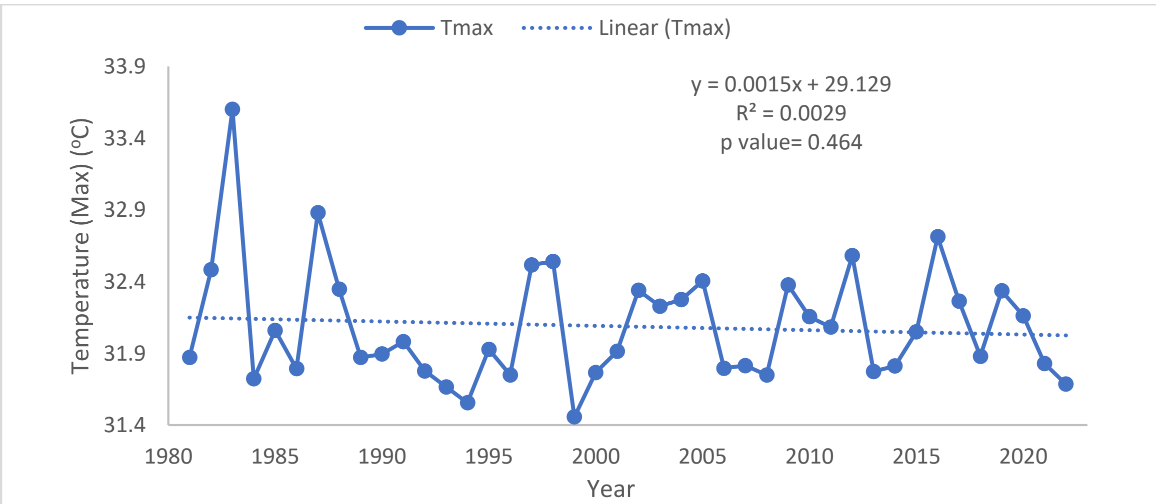


Figure 2. Changes in the annual maximum (day) temperatures in the study sites from 1981 to 2022

1.3. Trend in Annual Average Minimum Temperature

In contrary to the outcome of the analysis of annual maximum temperature, the annual minimum (night) temperature of the study sites (Figure 3) an apparent increasing trend (at 0.006 °C per year) during the 42-year period considered from 1981 to 2022. During the study period, the highest nighttime temperature was recorded in 2015 (24.1 °C) and lowest in 1992 (22.7 °C).

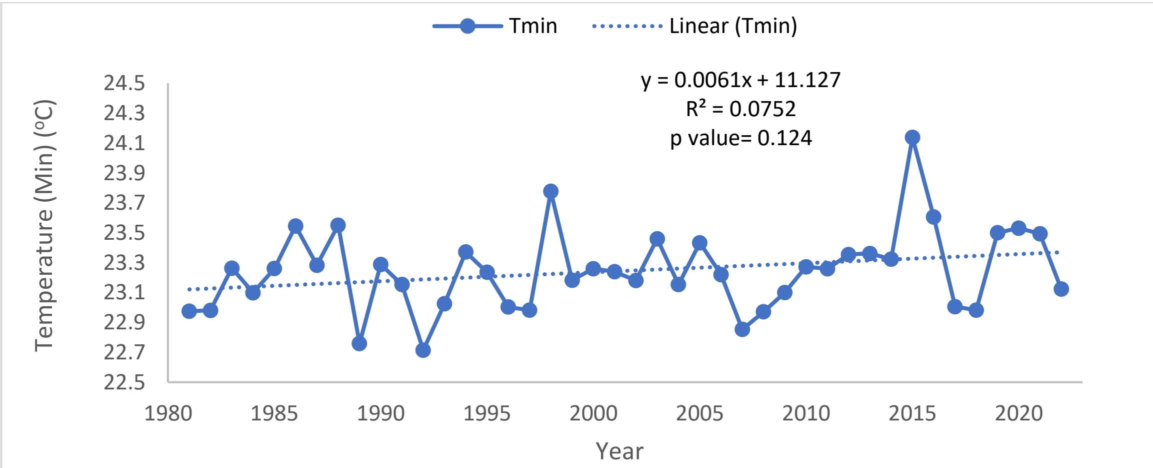


Figure 3. Changes in annual minimum (night) temperatures in the study sites from 1981 to 2022

1.4. Trend in Annual Average Daily Pan Evaporation

The average daily pan evaporation has decreased annually at a rate of 0.35 mm per year over the 42-year study period as illustrated in Figure 4, with a statistically significant ($P<0.05$) Linear Regression Coefficient of 0.59 (Correlation Coefficient = 0.77). The results coincides well with the average daily maximum temperature trend recorded (see Figure 2). The highest daily average pan evaporation was reported in 1983 (5.19 mm) and the lowest in 2010 (2.99 mm).

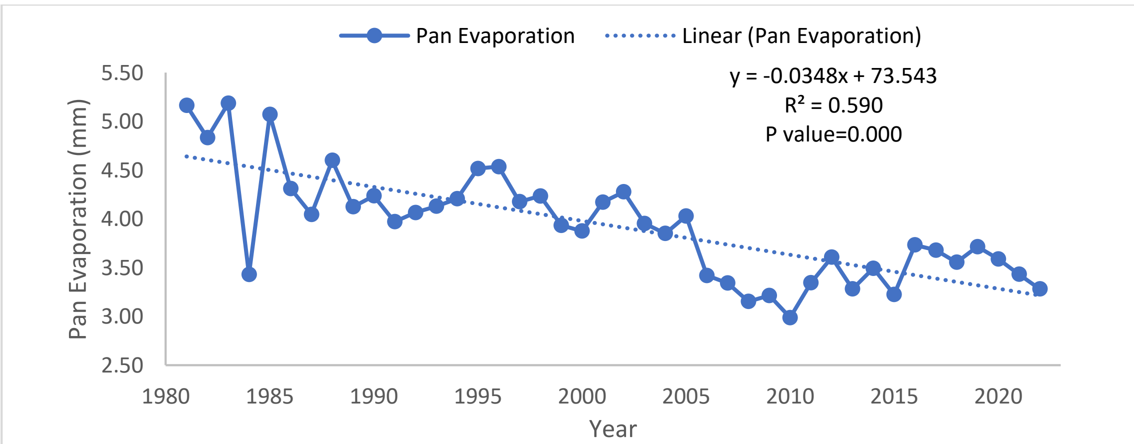


Figure 4. Annual trend of change in Average Daily Pan Evaporation from 1981 to 2022

1.5. Trend in Annual Average Daily Sunshine hours

The sunshine hours (Figure 5) showed a significant decline ($P<0.05$) in the annual trend analysis at a rate of 0.2 hrs per year, with a Linear Regression Coefficient of 0.23 (Correlation Coefficient = 0.48). The longest sunshine hours was reported in 2017.

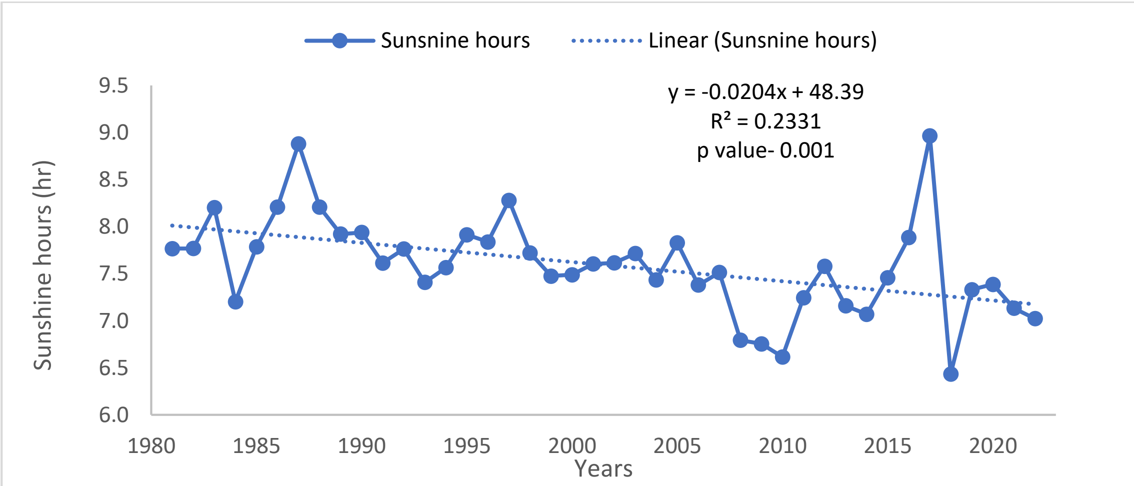


Figure 5. Annual trend of change in Average Daily Sun Shine Hours from 1981 to 2022

1.6. Trend of change in Annual Average Daily Wind Velocity

The significant change was observed in the average daily wind velocity in the annual trend analysis (Figure 6) at a rate of 0.9 km per hr, with a Linear Regression Coefficient of 0.66 (Correlation Coefficient = 0.81). The study period was 1988-2022 due to the data availability. The highest average daily wind velocity was recorded in 2003 (8.24 km per hour) and the lowest in 2018 (4.37 km per hour).

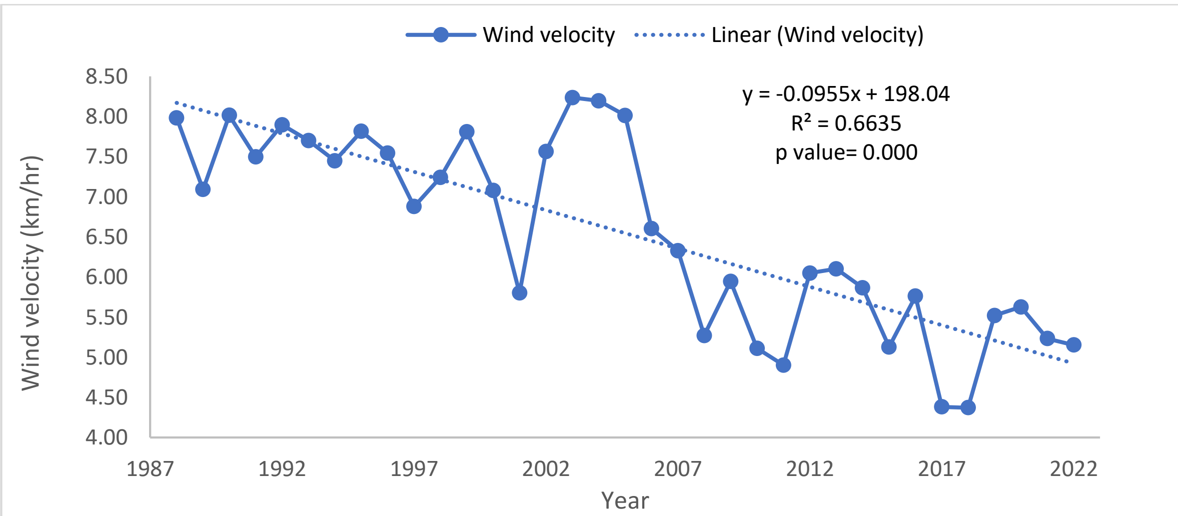


Figure 6. Annual trend of change in Average Wind Velocity from 1988 to 2022

1.7. Trend in Annual Average Daily Relative Humidity (Morning)

The Average Daily Relative Humidity (RH) in the morning hours showed a significant annual increase at a rate of 0.03%, however, the linear regression coefficient (R^2=0.07) was not statistically significant (P>0.05). The highest Average Daily RH in the morning hours was reported in 2010 (86%) and the lowest in 1989 (81%).

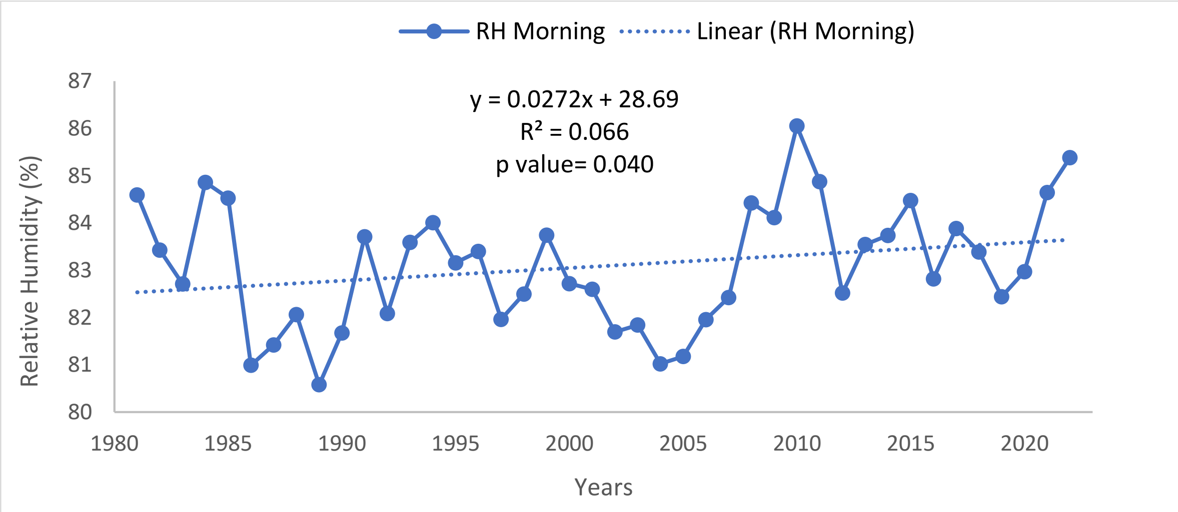


Figure 6. Annual trend of change in Average Daily Relative Humidity (morning hours) from 1981 to 2022

1.8. Trend in Annual Average Daily Relative Humidity (Evening)

In contrary to the RH in the morning hours, the Average Daily Relative Humidity (RH) in the evening hours showed a significant annual increase at a rate of 0.26%, a Linear Regression Coefficient (R^2=0.57; P<0.05). The Correlation Coefficient is 0.75. The highest Average Evening RH was reported in 1984 (76%) and the lowest in 2016 (60%).

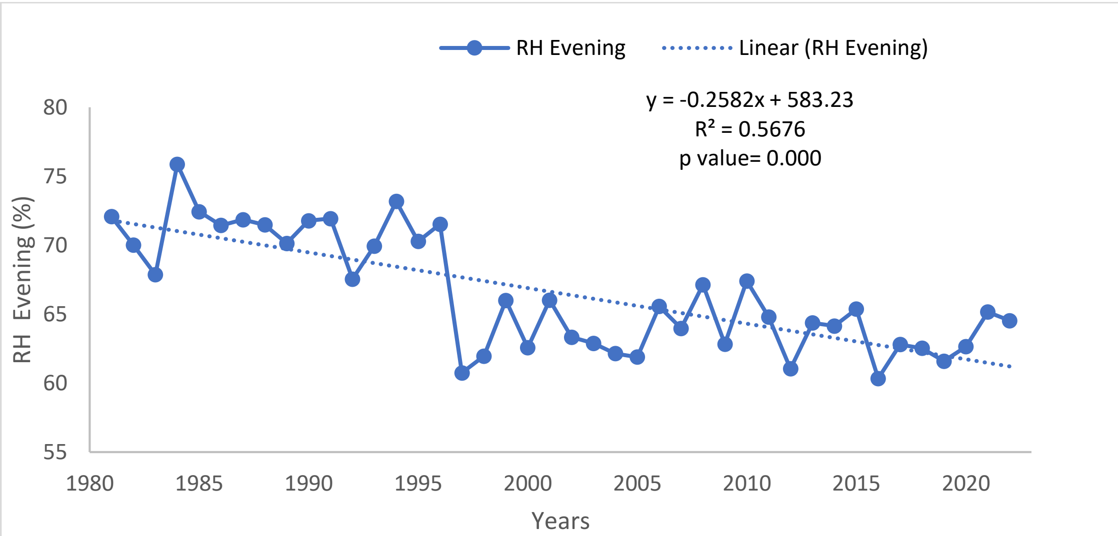


Figure 6. Annual trend of change in Average Daily Relative Humidity (evening hours) from 1981 to 2022

An island wide study done by Jayawardena et al (2018) reported that there is an increasing trend in the annual total rainfall in Sri Lanka during the period 1980-2015, where 65% of rain-gauge stations have shown a significant increasing trend. However, the present study, though a trend in increase in rainfall was evident, there was no statistically significant increase of total rainfall

(P>0.05) during the study period 1981-2022. According to Jayawardena et al. (2018) the Simple Daily Intensity of Rainfall (SDII) in Anuradhapura has shown an increasing trend as observed in this analysis for the period 1981-2022. The increasing annual temperature also did not show any discernible trends in the study regions for the same period.

The decreasing wind velocity and increasing day-time humidity levels in the regions as observed in this study, further supported by decreasing pan evaporation trend, would increase the heat stress in the regions negatively affecting crop productivity. Heat stress leads to an imbalance in plant hormones, impairing plant growth, photosynthesis, pollen development, and reproduction. The lower annual sun light intensities would further aggravate the problem of crop productivity due to reduced photosynthetic efficiency.

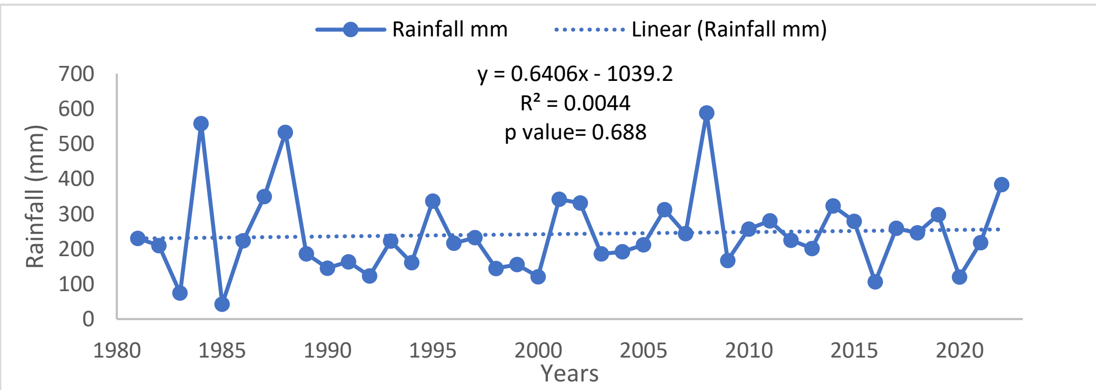
(2) Seasonal Analysis – Cumulative Rainfall

2.1. Cumulative Rainfall – four rainfall seasons

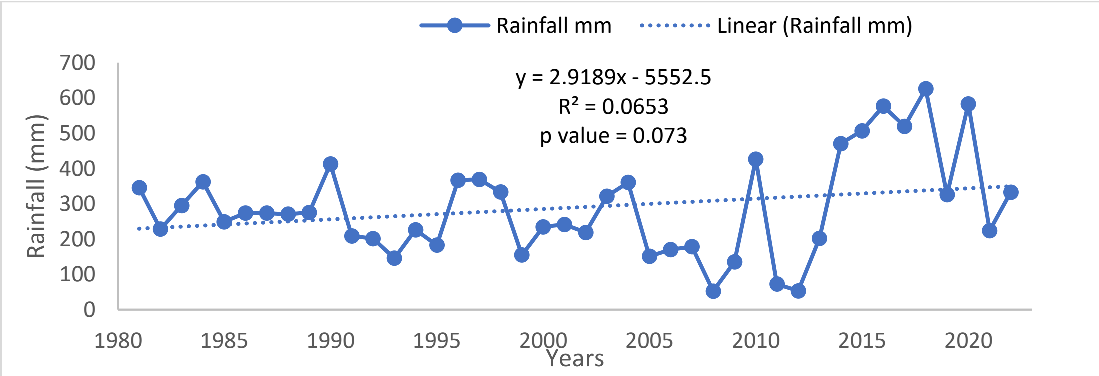
The separate analysis done for the change on the total cumulative rainfall in the First Inter-monsoon (March-April), South West Monsoon (May- September), Second Inter-monsoon (October-November) and North East Monsoon (December-February) did not show a discernible linear trend, except during SWM (though not statistically significant; P>0.05) but showed a wider variability across the years studied (Figure 7).

The maximum and minimum cumulative rainfall during the FIM was recorded in 2008 (582 mm) and 1985 (42.8 mm), respectively; during SWM in 2018 (625.7 mm) and 2012 (53.3. mm) =, respectively; during SIM in 1997 (903.6 mm) and 2020 (208.5); during NEM in 1983/1984 (1133.8 mm) and 1988 (75.5 mm).

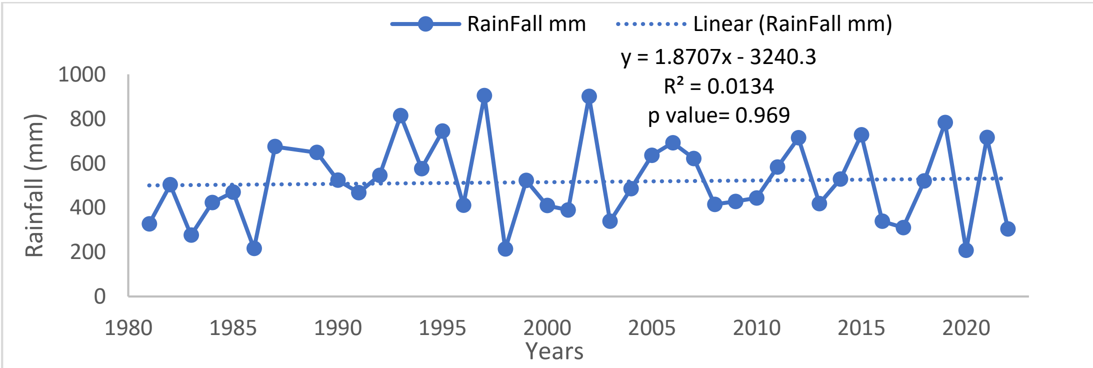
First Inter-monsoon (FIM)



South-west Monsoon (SWM) season



Second Inter-monsoon (SIM) season



North-east Monsoon (NEM) season

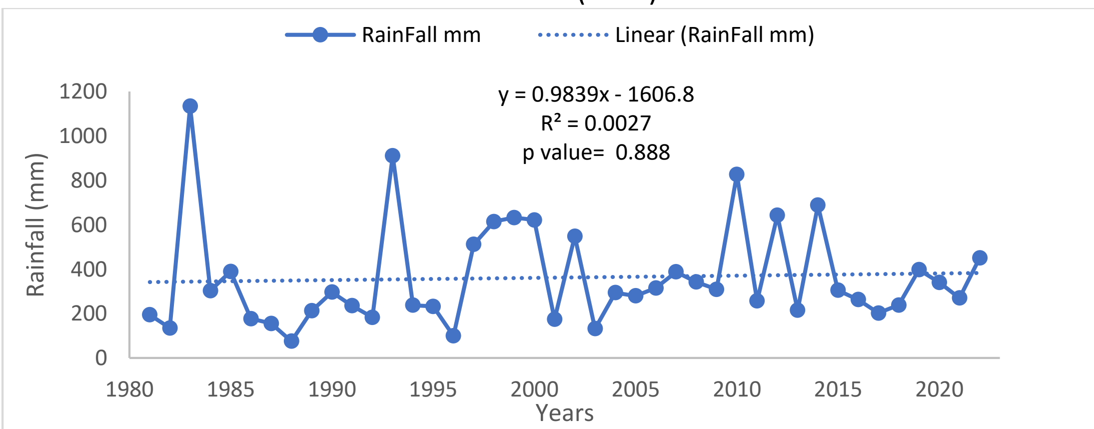


Figure 7. The trend in Average Cumulative Rainfall of four rainfall seasons from 1981 to 2022

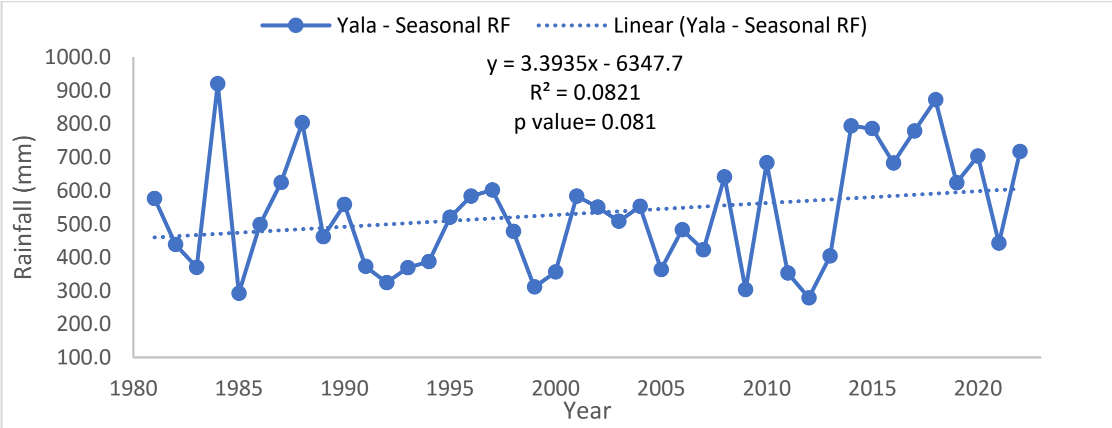
Jayawardena et al. (2018) further reported of a 60% and 50% increase in the maximal one-day and 5-day precipitation amounts, respectively, at Anuradhapura during the period from 2010 to 2015, which was supported by the analysis in the present study due to higher rainfall observed in the SIM and NEM during the said period (*Maha* season). Further, of the four rainfall seasons in the study area, the SWM has shown a considerable increase during the period 2015-2020 despite that fact that 2016-2017 were relatively dry years owing ENSO events that took place, highlighting regional disparities among the rain fall distribution in Sri Lanka. Apart from this, there were no discernible linear trends in the four rainfall seasons in the study regions.

This short term increase in cumulative annual rainfall is alarming and special consideration should be given in the future to assess such trends in the short time intervals to provide short-term predictions to support decision making in the agricultural as well as livelihood activities in the Anuradhapura region.

2.2. Cumulative Rainfall – Two Cultivating Seasons

The cumulative rainfall in the *Yala* (FIM+SWM) and *Maha* (SIM+NEM) seasons, respectively, across 42 years have shown a wider variability but did not a discernible linear trend as illustrated in Figure 8. In the concerned study period, the highest cumulative rainfall in a *Yala* season was recorded in 1984 (920.4 mm) and lowest in 2012 (278.5 mm). In the case of *Maha* seasons, the highest cumulative rainfall was recorded in 1994/1994 (1725 mm) and the lowest in 1988 (75.5 mm).

Cumulative Rainfall in the *Yala* season



Cumulative Rainfall in the *Maha* season

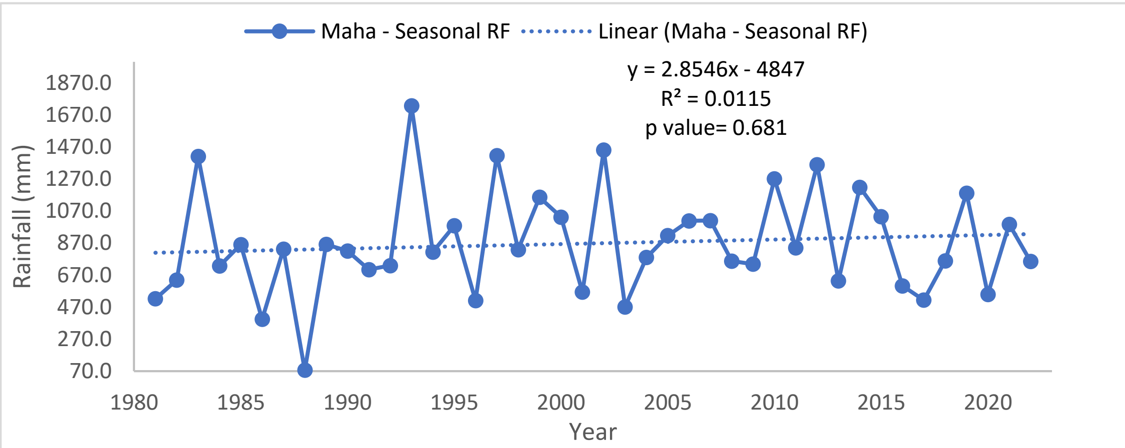


Figure 8. Cumulative rainfall in two cultivating seasons during 1981-2022

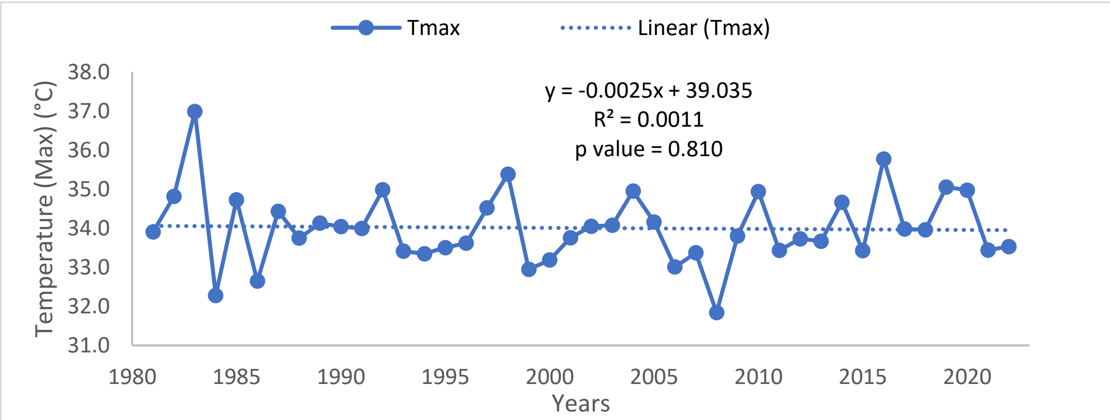
Though the cumulative rainfall for *Maha* season is higher than that of the *Yala* seasons, as expected and with ample evidence for the same over decades, the analysis clearly show the need to analysis short term and long term variations in the future and to develop stronger statistical models to predict the changes in rainfall in different RCP scenarios to support informed decision making to assist the livelihood activities of the people.

(3) Seasonal Analysis – Average Seasonal Temperature

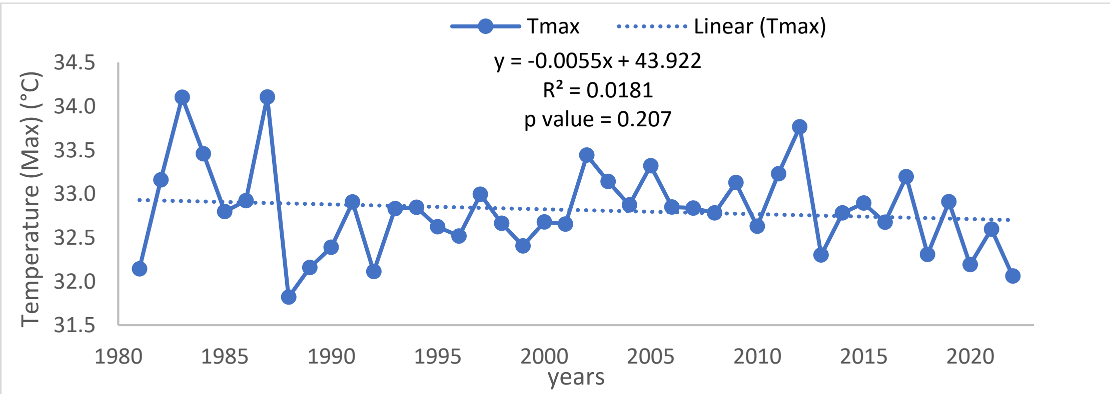
3.1. Average Maximum Temperature – four rainfall seasons

Similar to the results of the cumulative rainfall analysis, the average maximum day temperature in each of the four rainfall seasons did not show a statistically significant change (Figure 9). During the focus period of the study, the highest maximum and the lowest seasonal daytime temperature in FIM was reported in 1983 (37 °C) and the lowest in 2008 (31.8 °C), respectively; the maximum and the minimum daytime temperature during SWM in 1987 (34.1 °C) and 1988 (31.8 °C), respectively, the maximum and the lowest daytime temperature during SIM in 1983 (32.7 °C) and 1993 (30.0 °C), respectively; and during NEM in 2003 (31.2 °C) and 2010 (28.7 °C), respectively

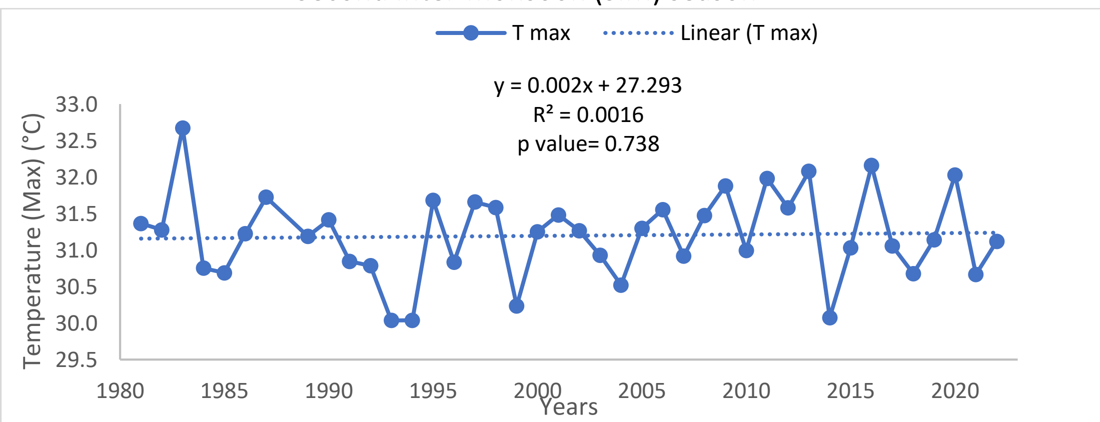
First Inter-monsoon (FIM) season



South-west Monsoon (SWM) season



Second Inter-monsoon (SIM) season



North-east Monsoon (NEM) season

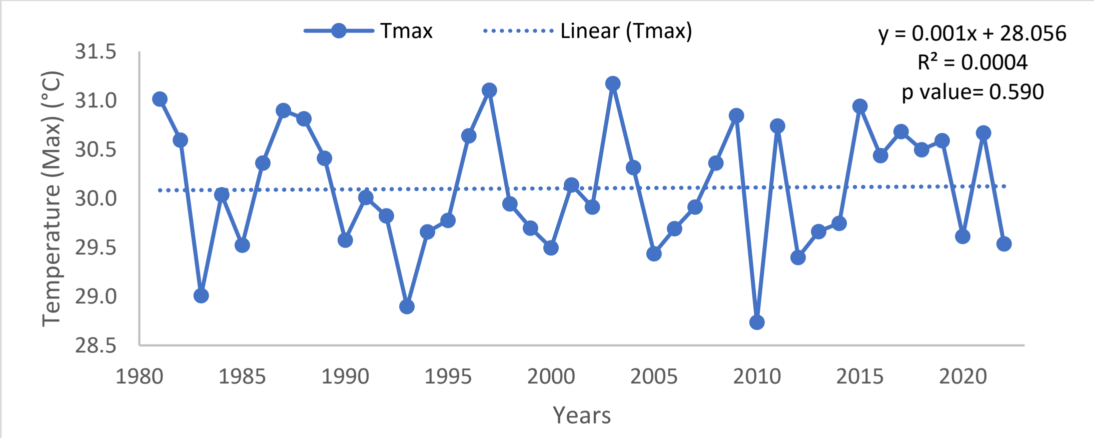


Figure 9. The trend in Average Maximum Temperature of four rainfall seasons from 1981 to 2022

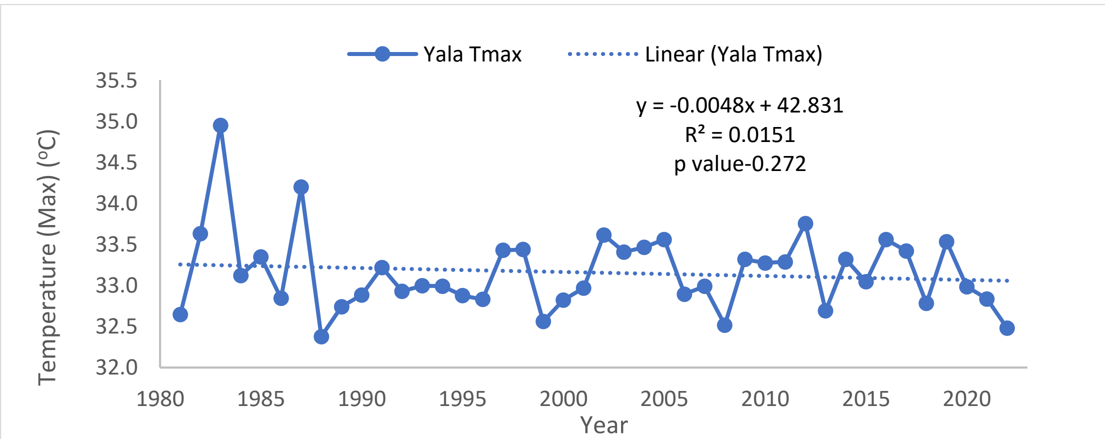
In general, the FIM recorded the highest seasonal temperature during the 42 year period. In the cultivating seasons, the maximum daytime temperature in *Yala* season was higher than that of the *Maha* season through the study period. Overall, though a rise in the mean maximum temperature can be seen in most of the stations, the trend is not significant as explained by Jayawardena et al. (2018).

3.2. The Maximum Seasonal Daytime Temperature – Two cultivating seasons

The maximum seasonal daytime temperature from 1981 to 2022 did not show any significant increase or a decrease (P>0.05; Figure 10). However, the maximum daytime temperature in the *Yala* season was higher than that of the *Maha* seasons throughout the concerned study period.

The maximum daytime temperature reported in a *Yala* season was in 1983 (34.9 °C) and the lowest in 1988 (32.4 °C), while the highest maximum daytime temperature reported in a *Maha* season was in 1988/1989 (32.0 °C) and the lowest in 1993.1994 (29.4 °C).

Trend in the Maximum Seasonal Daytime Temperature - *Yala* season



Trend in the Maximum Seasonal Daytime Temperature - *Maha* season

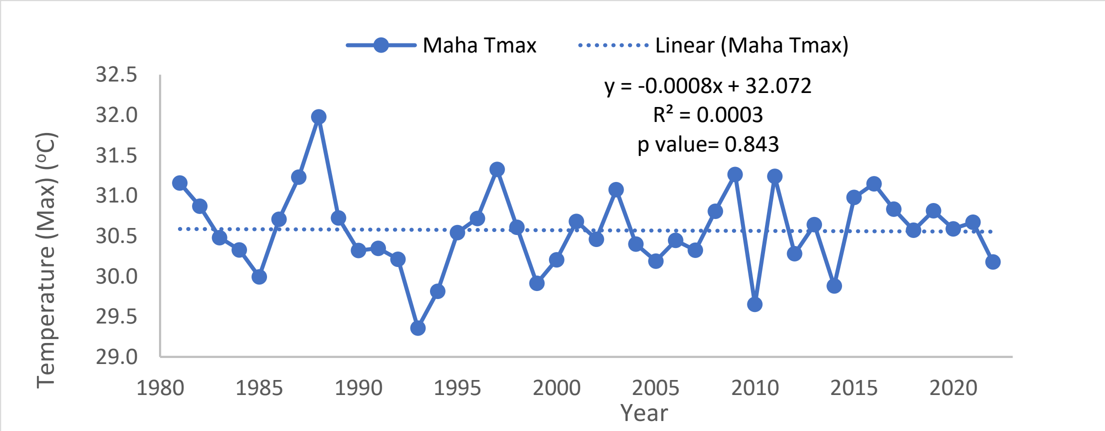
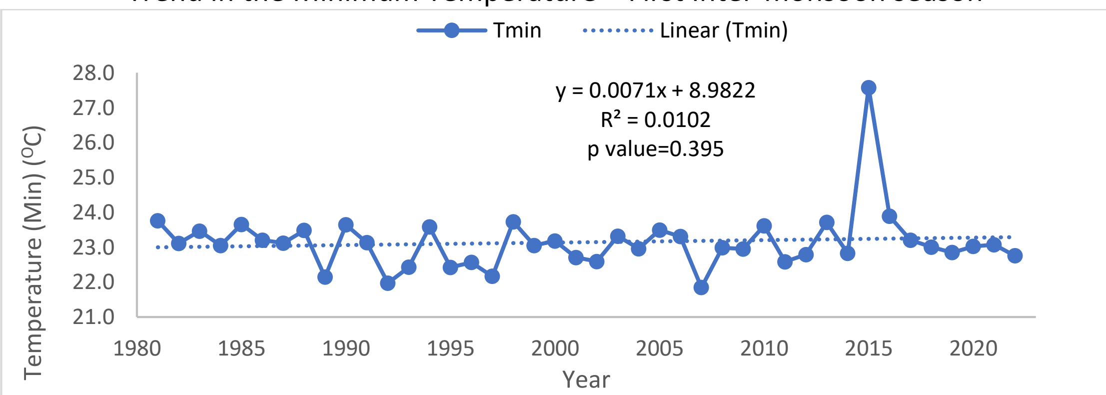


Figure 10. The trend in Average Seasonal Maximum Temperature in two cultivating seasons from 1981 to 2022

3.3. The Average Minimum (nighttime) Temperature – Four rainfall seasons

The average maximum nighttime temperature in each of the four rainfall seasons did not show a statistically significant change (P>0.05) during FIM, SIM and NEM, however, a significant increase was reported during the SWM from 2018 to 2022 (Figure 11). During the SWM, the daily minimum seasonal temperature during the period 1981-2022 has increased at a rate of 0.006 °C) per year. During the concerned study period, the highest maximum and the lowest seasonal nighttime temperature in FIM was reported in 2015 (27.6 °C) and the lowest in 2007 (21.8 °C); the maximum and the minimum nighttime temperature during SWM in 1986 (25.0 °C) and 1984 (24.1 °C), respectively, the maximum and the lowest minimum temperature during SIM was reported in 2020 (23.7 °C) and 2008 (22.3 °C), respectively; and the maximum and the minimum of the nighttime temperature during NEM was reported in 1997 (22.6 °C) and 1981 and 2008 (19.9 °C), respectively.

Trend in the Minimum Temperature – First Inter-monsoon season



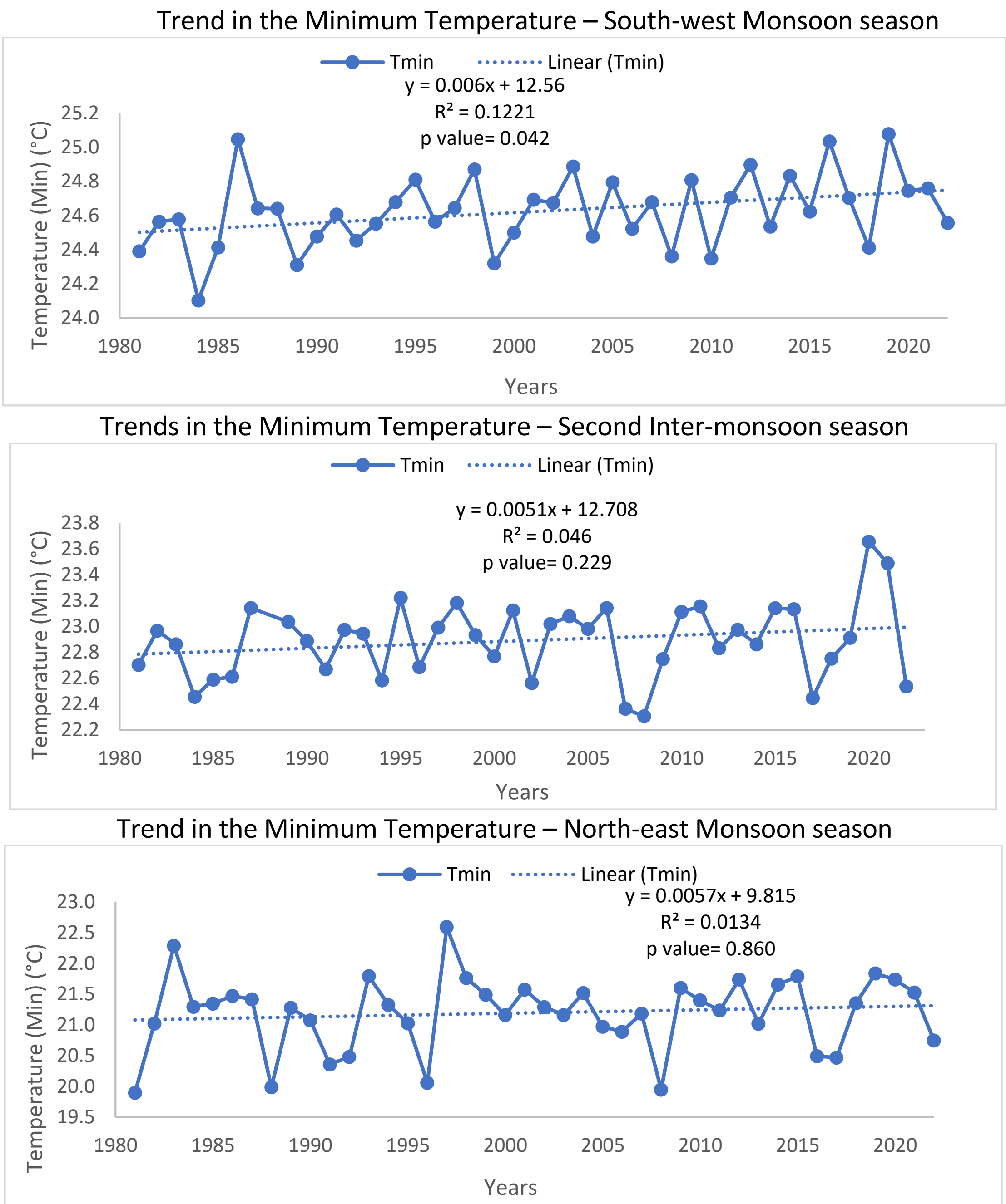
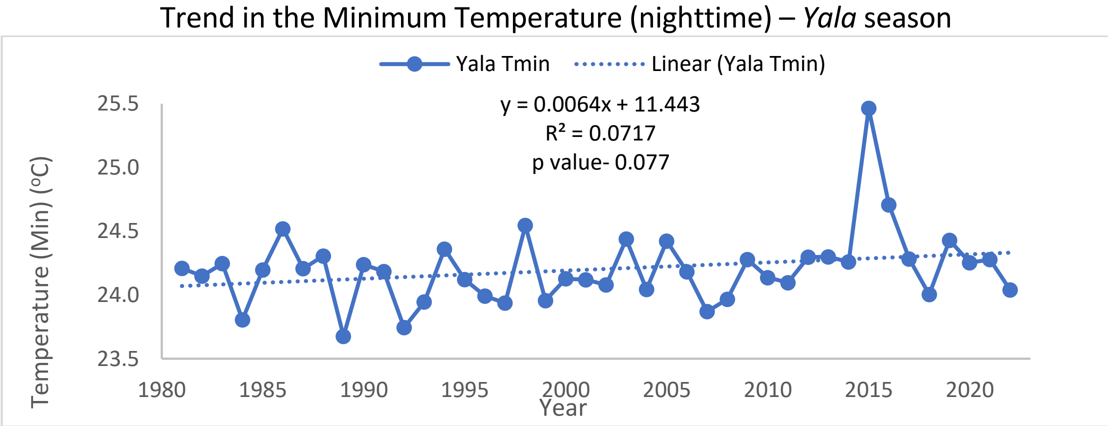


Figure 11. Trend in Average Minimum Temperature of four rainfall seasons (1981-2022)

3.4. The Average Minimum (nighttime) Temperature – Two cultivating seasons

The minimum seasonal nighttime temperature from 1981 to 2022 did not show a significant linear trend (P>0.05; Figure 12) during the period 1981-2022. However, similar to what observed in the maximum daytime temperature, the nighttime temperature was higher in the *Yala* season than that of the *Maha* seasons throughout the concerned study period. The maximum nighttime temperature reported in a *Yala* season was in 2015 (25.5 °C) and the lowest in 1989 (23.7 °C), while the highest nighttime temperature reported in a *Maha* season was in 1992/1993 (22.7 °C) and the lowest in 1988/1989 (20.0 °C).



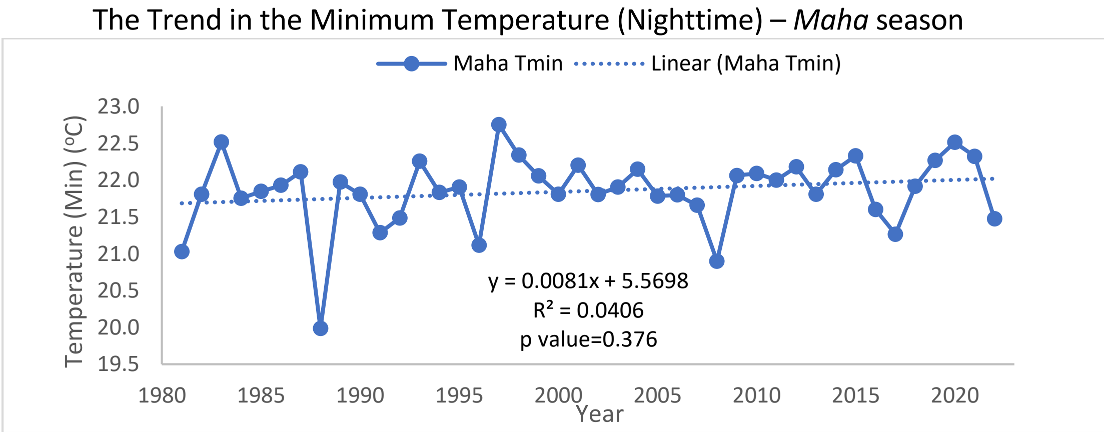
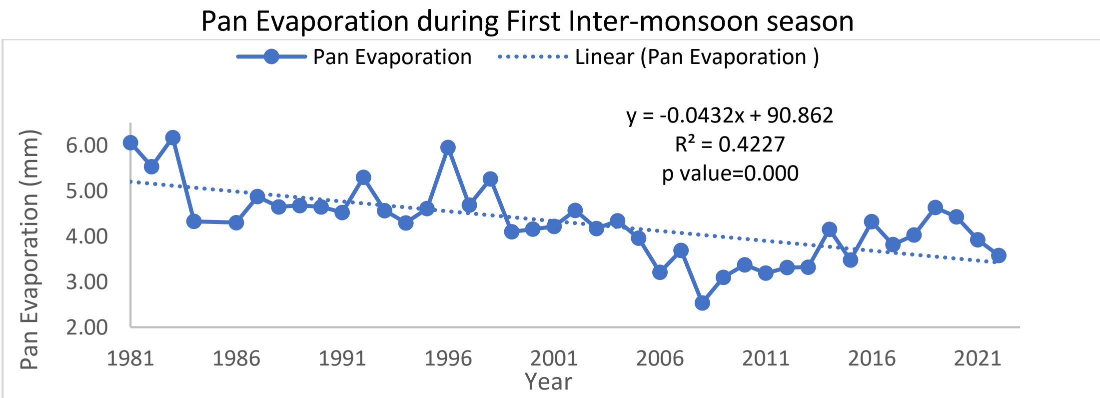


Figure 12. Trend in Average Minimum Temperature of two cultivating seasons (1981-2022)

(4) Average Daily Pan Evaporation – Four Rainfall Seasons

The average daily pan evaporation during the four rainfall seasons showed statistically significant declining trend ($P<0.05$) during the period 1981-2022 (Figure 13). The FIM showed the highest pan evaporation (0.04 mm per day) followed by SIM, SWM and NEM.



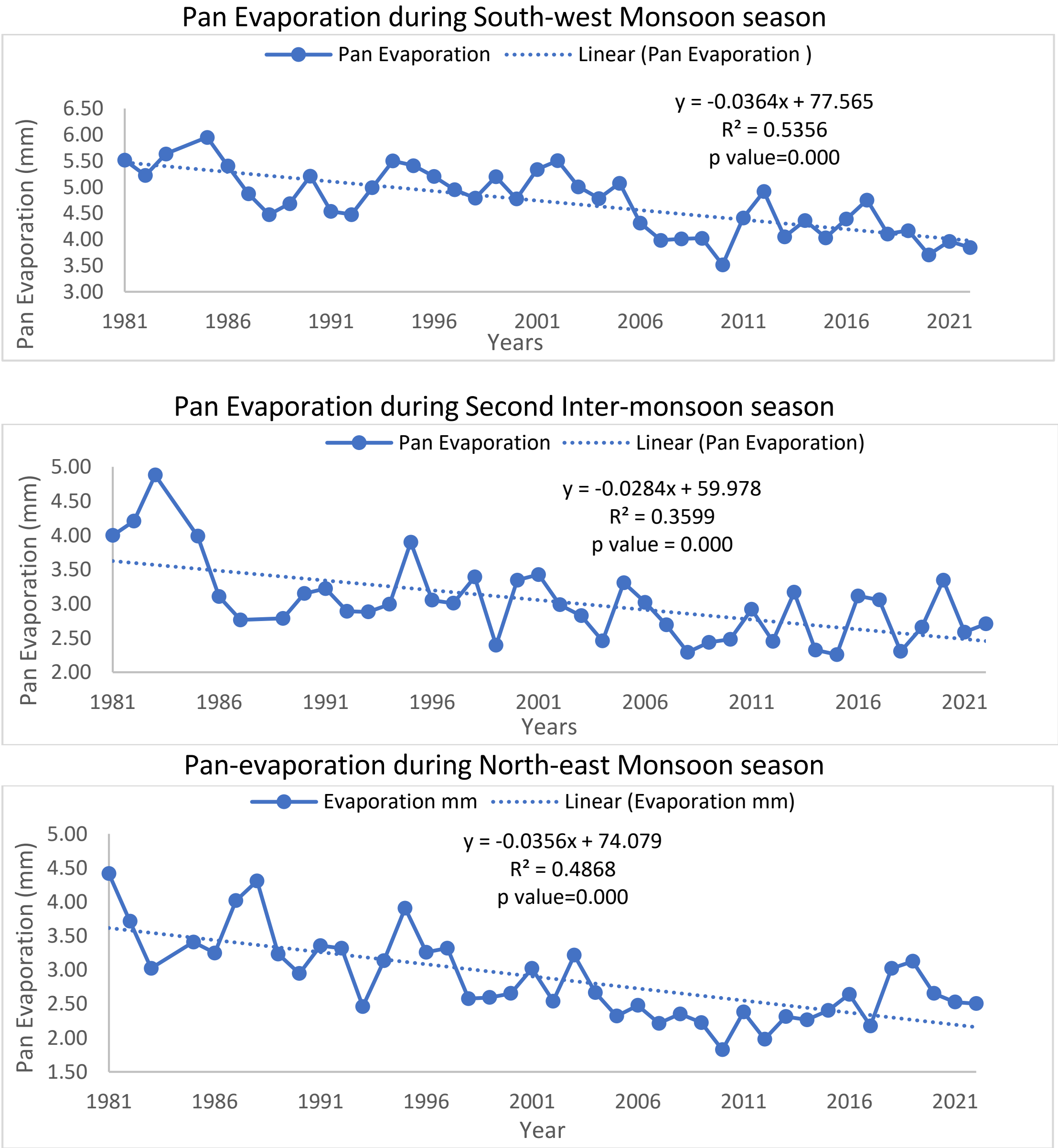


Figure 13. Average Daily Pan Evaporation during the four rainfall seasons

4.1. Average Daily Pan Evaporation – Two Cultivating Seasons

During the period from 1981 to 2022, the average pan evaporation in *Yala* and *Maha* seasons showed a significant reduction ($P<0.05$; Figure 14), with the *Yala* seasons showing a marginally higher daily average pan evaporation compared to that of the *Maha* season.

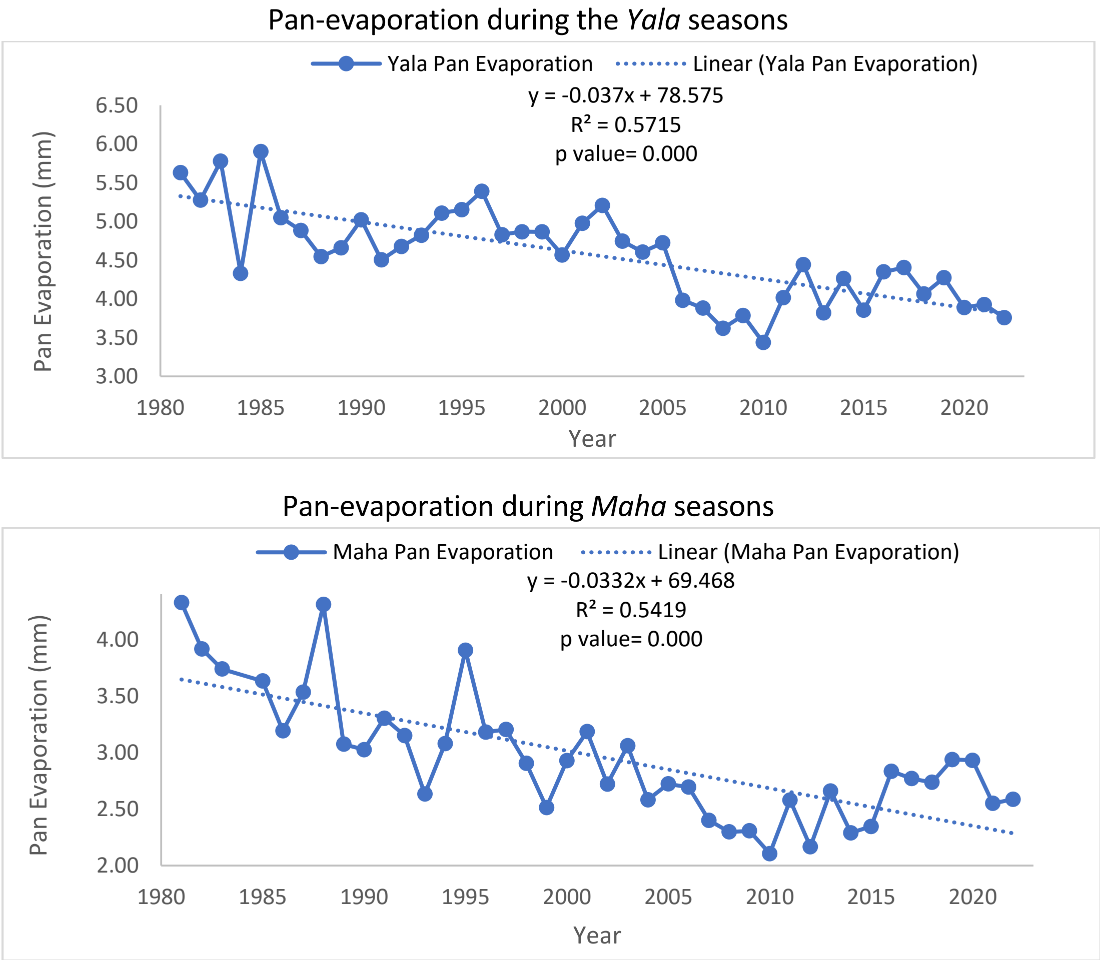


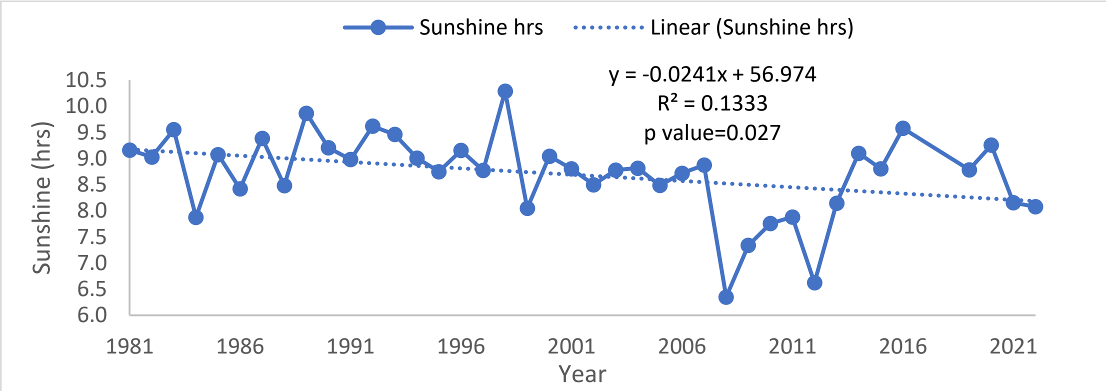
Figure 14. Average Daily Pan Evaporation during the two cultivation seasons

(5) Average Sunshine Hours – Four Rainfall Seasons

The average sunshine hours showed a significant declining trend (P<0.05) in FIM, SIM and NEM, nut not in SWM (Figure 15). During the period 1981 to 2022, the annual average daily sunshine hours in SIM decreased at a rate of 0.02 hrs, in SIM by 0.03 hrs and in NEM by 0.03 hrs.

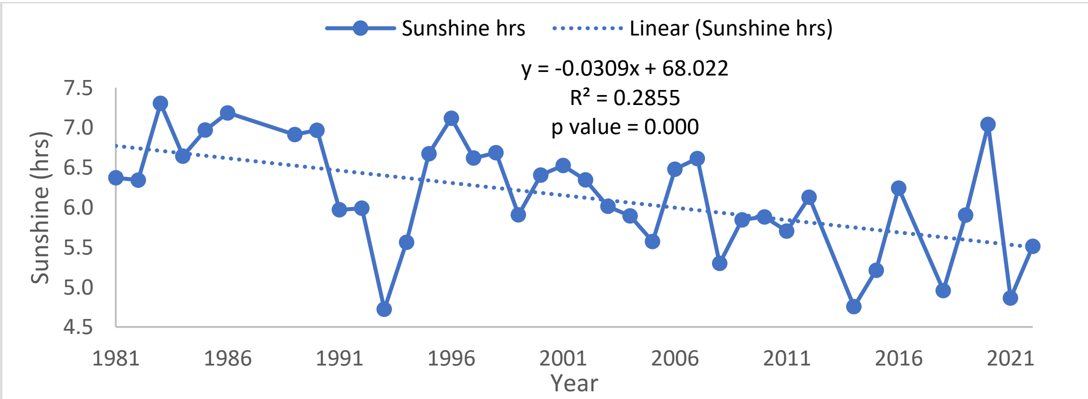
The longest sunshine hrs per day (average annual) in FIM was reported in 1998 (10.3 hrs) and the shortest in 2008 (6.3 hrs); the longest and the shortest sunshine duration in SWM was in 1987 (9.4 hrs) and 2010 & 2020 (7 hrs), respectively, in SIM was in 1983 (7.3 hrs) and 1993 (4.7), respectively; and in NEM in 1989 & 1996 (8.4 hrs) and 2010 (3.9 hrs), respectively.

Trend in the Sunshine hours – First Inter-monsoon season



Trend in the Sunshine hours – South-west Monsoon season

Trend in the Sunshine hours – Second Inter-monsoon season



Trend in the Sunshine hours – North-east Monsoon season

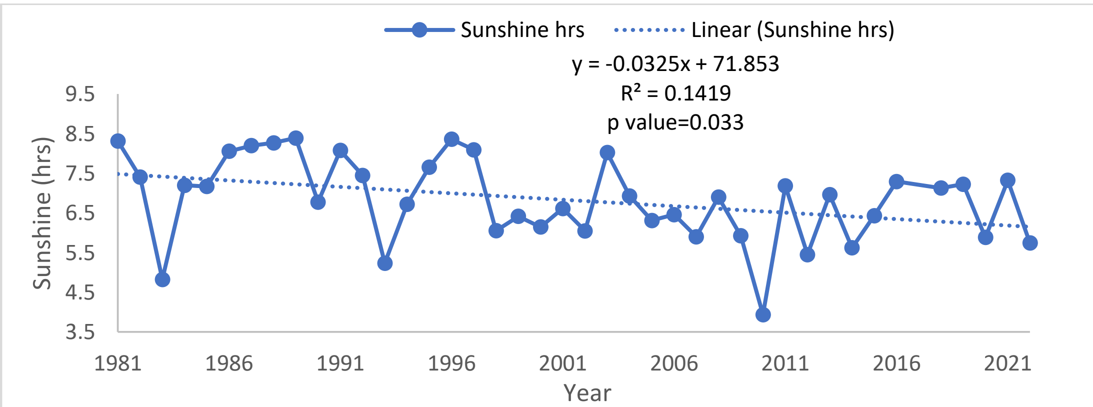
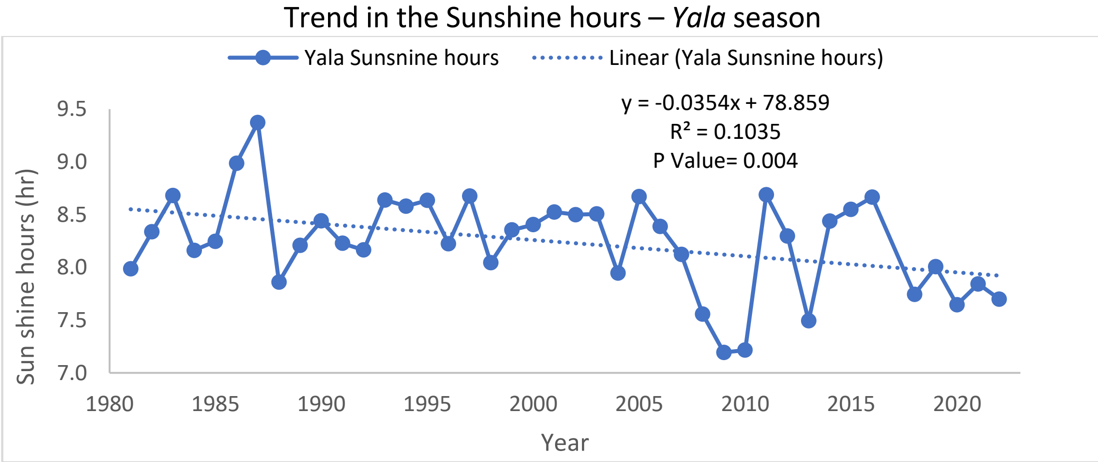


Figure 15. The average daily sunshine hours of the four rainfall seasons from 1981 to 2022

5.1. The Average Sunshine Hours – Two cultivating seasons

The sunshine hours in both *Yala* and *Maha* seasons have reduced significantly ($P<0.05$) from 1981 to 2012 (Figure 16) during the period 1981-2022. The sunshine hours per day were generally longer in the *Yala* season throughout the concerned study period compared to the *Maha* season, owing to heavy rainfall and cloud cover prevailed during the season.

The longest and shortest sunshine duration reported in the *Yala* seasons from 1981 to 2022 was in 1987 (9.4 hrs) and 2009 (7.2 hrs), while that of *Maha* season was in 1998/199 (8.3 hrs) and 2010/2011 (4.7 hrs).



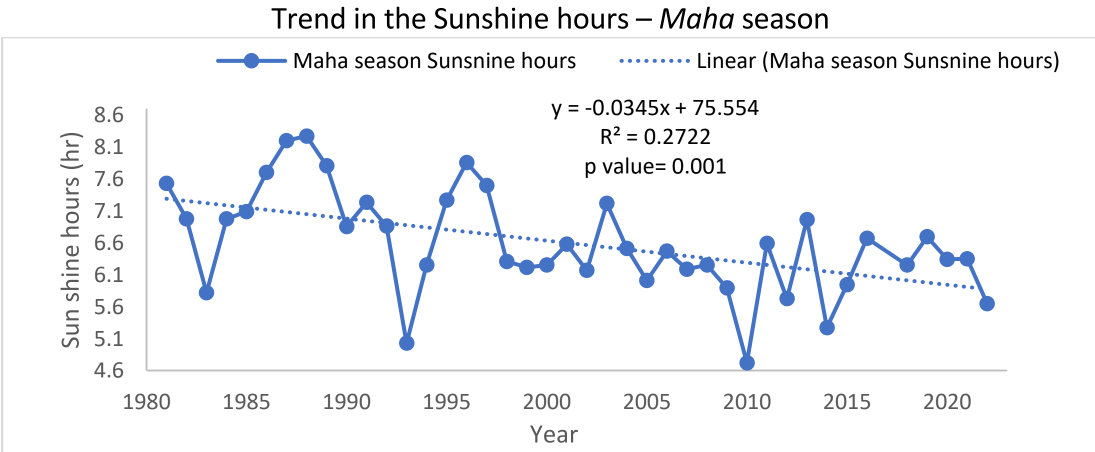


Figure 16. The sunshine hours of two cultivating seasons from 1981 to 2022

(6) Average Wind Velocity – Four Rainfall Seasons

The average daily wind velocity in the FIM, SWM and SIM showed a significant linear reduction in the wind velocity ($P<0.05$) during the period 1981-2022 (Figure 17). The wind velocity during the NEM did not show a discernible linear trend during the same period.

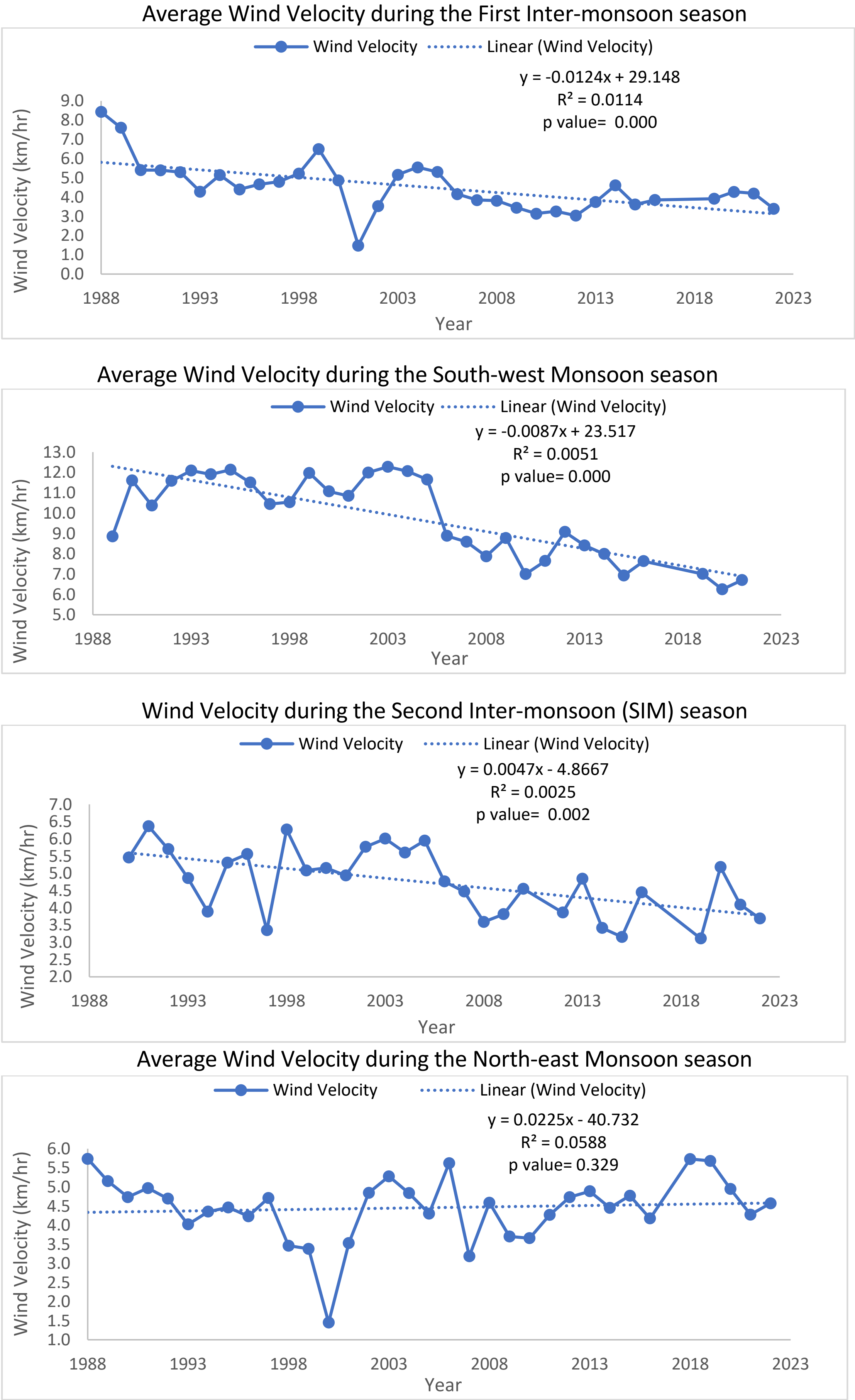


Figure 17. The average daily wind velocity during the four rainfall seasons from 1981 to 2022

6.1. Average Wind Velocity – Two Cultivating Seasons

The average wind velocity during the *Yala* season showed a significant decreasing trend during the period 1981-2022, aligning with the wind velocity data presented in Figure 17 for the FIM and SWM. The *Maha* season did not show a discernible linear trend in the wind velocity. Similar observation recorded for NEM during the study period would have contributed the similar trend in wind velocity as reported in the *Maha* season.

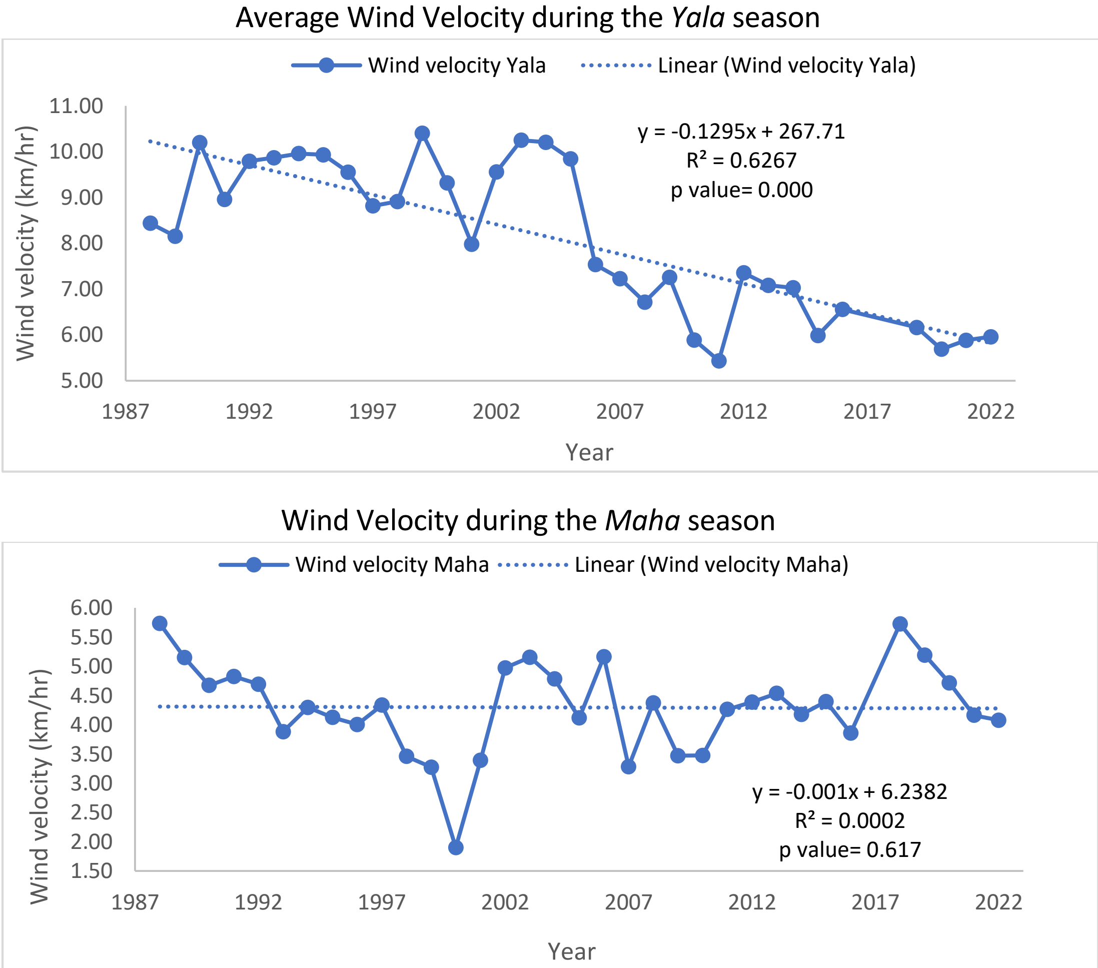


Figure 18. The average daily wind velocity during the two cultivating seasons from 1981 to 2022

(7) Average RH (morning) – Four Rainfall Seasons

The average RH (morning) did not show any discernible linear trend during the FIM, SWM and SIM, however, the RH showed a significant linear increasing trend in NEM ($P<0.05$) during the period 1981-2022 (Figure 19).

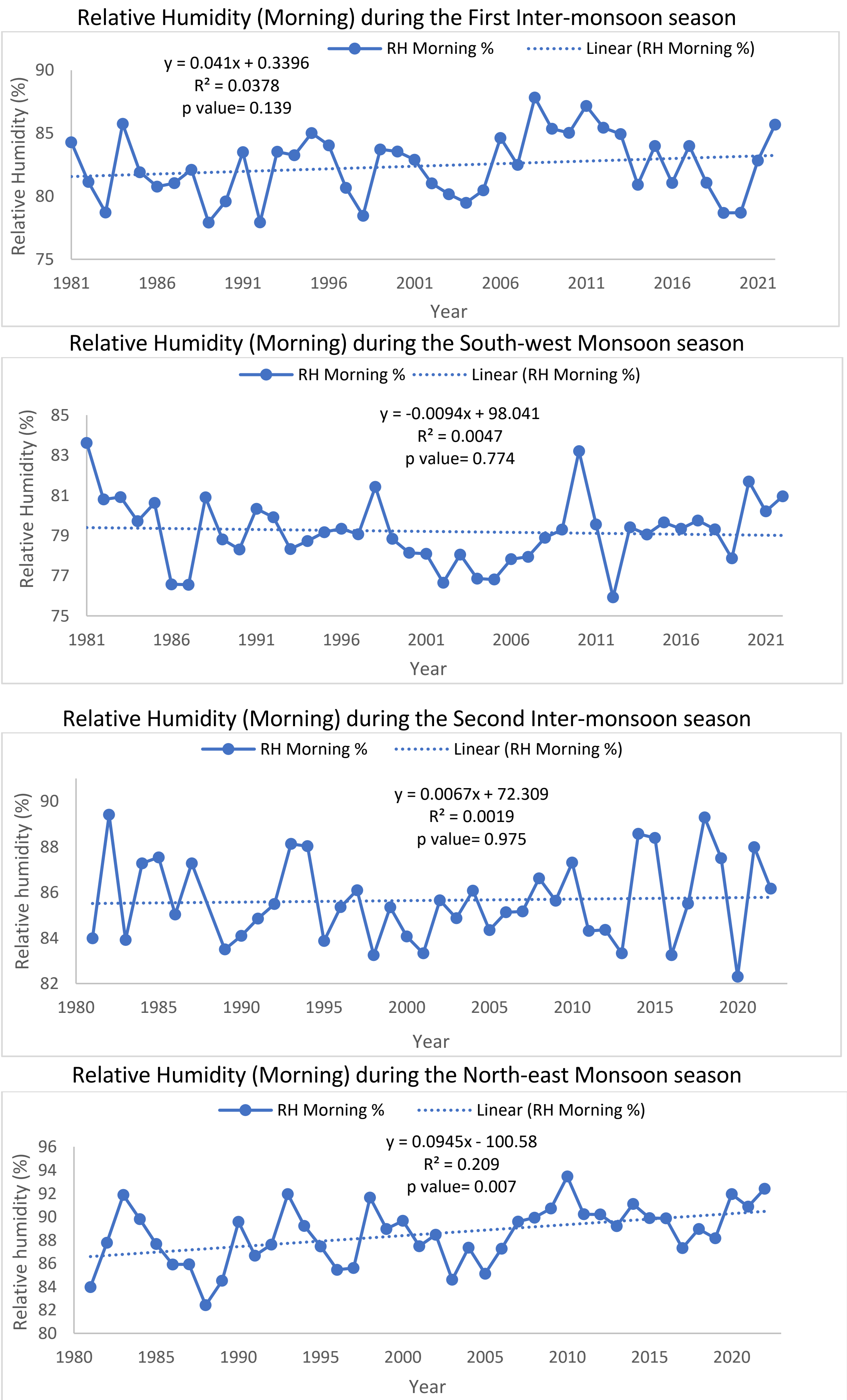
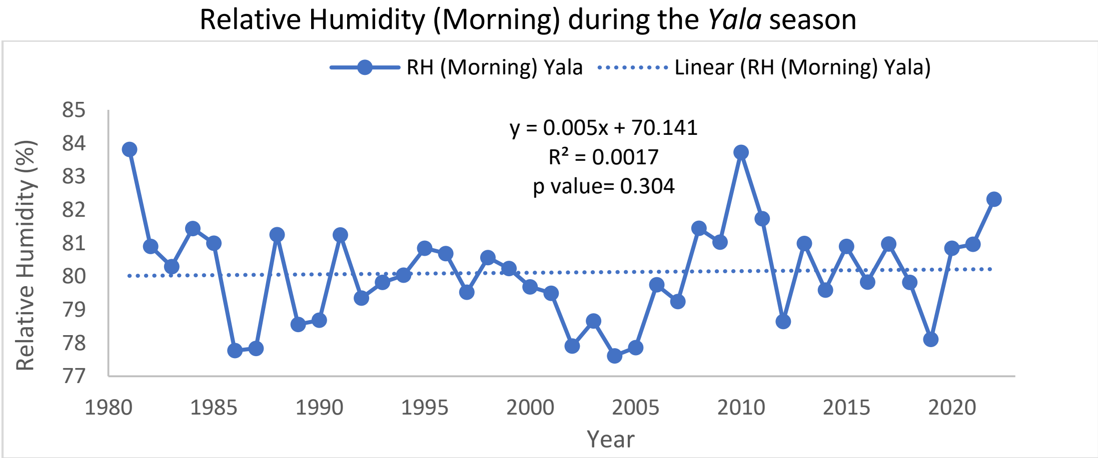


Figure 19. The average daily RH (morning) during the four rainfall seasons from 1981 to 2022

7.1. Average RH (morning) – Two Cultivating Seasons

The RH (morning) in the *Yala* season did not show any significant linear trend during the period 1981-2022 (Figure 20) However, the RH in the *Maha* season during the same study period shows a significant linear increase (P<0.05), with the main contribution coming from the significant increase in RH observed during the NEM (see Figure 19).



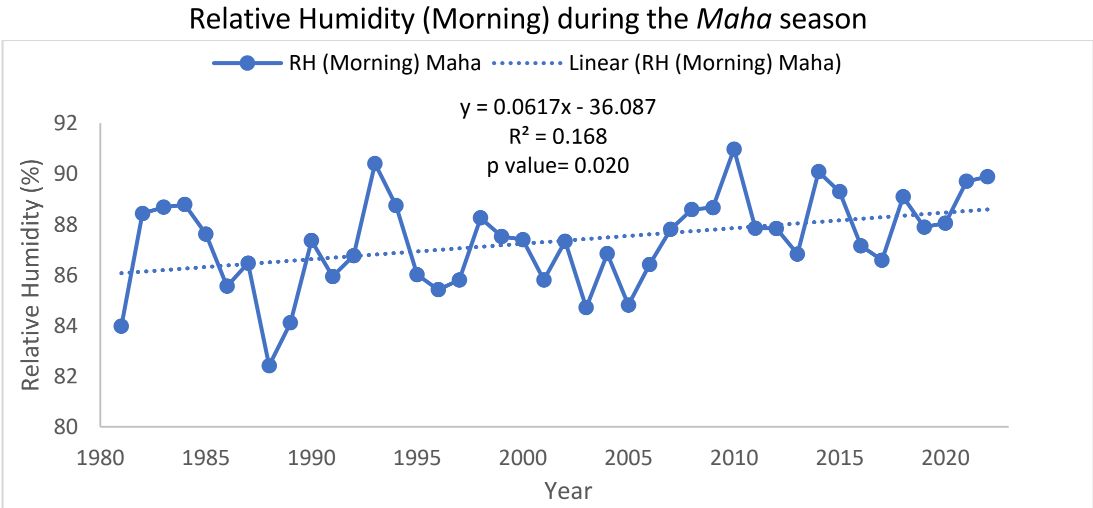


Figure 20. The average daily RH (morning) during the two cultivating seasons from 1981 to 2022

7.2. Average RH (evening) – Four Rainfall Seasons

In contrary to the average RH (morning) presented in Figure 19 above, the RH (evening) showed a significant decline over the period 1981-2022 during the FIM, SWM, SIM, and NEM.

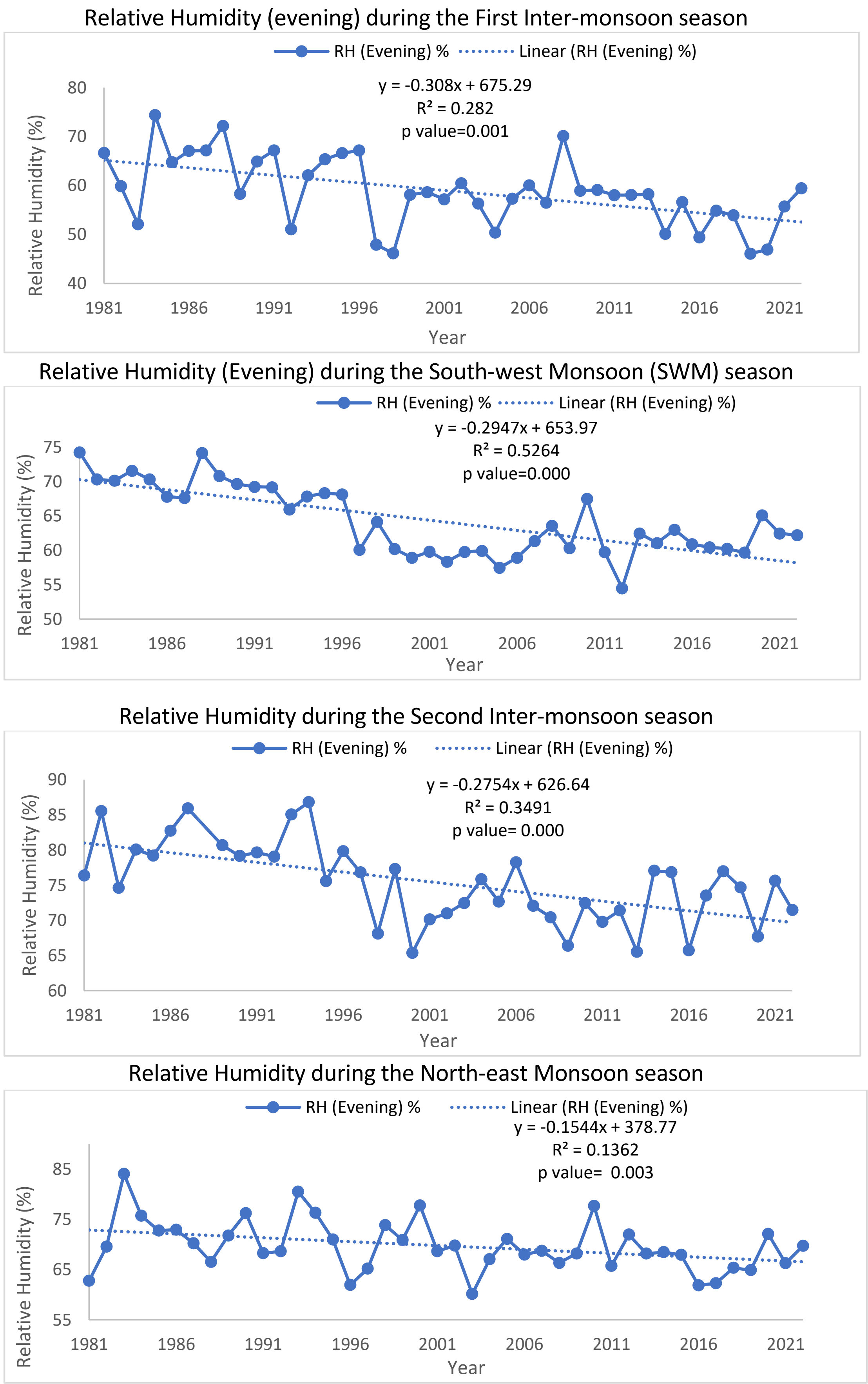
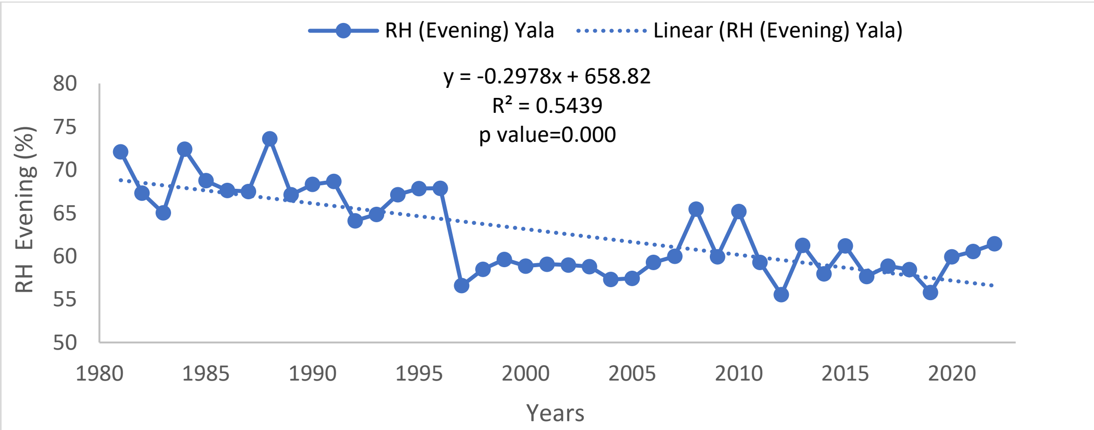


Figure 21. The average daily RH (evening) during the four rainfall seasons from 1981 to 2022

7.3. Average RH (evening) – Two Cultivating Seasons

The average RH (evening) in both *Yala* and *Maha* seasons showed a significant linear decline (P<0.05) during the period 1981-2022 (Figure 22). This is in contrary to the linear increasing trend that was observed in the RH (morning) as illustrated in Figure 20.

Relative Humidity during the *Yala* season



Relative Humidity during the *Maha* season

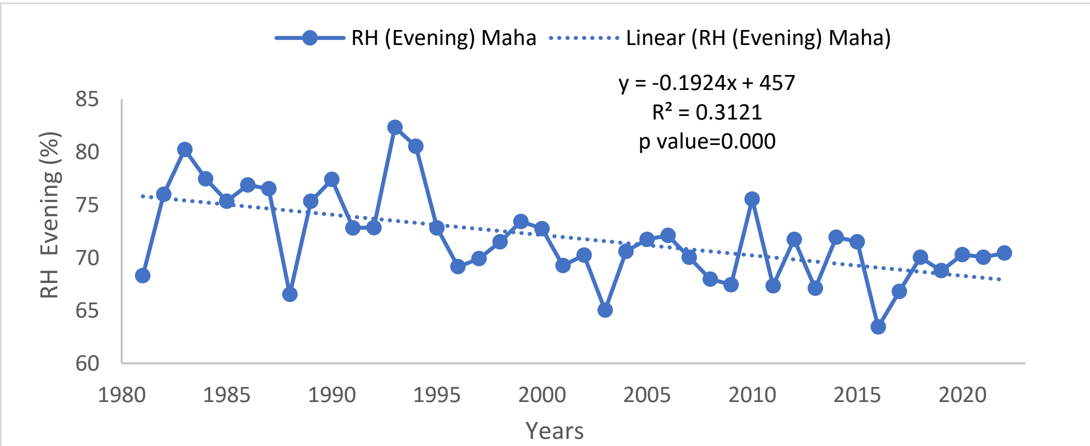


Figure 20. The average daily RH (evening) during the two cultivating seasons from 1981 to 2022

Discussion on the Trends of Climatic Parameters

The seasonal variations in climate showed a similar as well as opposite trends trend to the annual cumulative values, indicating the need for more decomposed studies in terms of climate analysis. The study clearly reported the changes observed in the RH in morning and evening hours which is a clear indication for deciding on the agricultural operations.

Analysis of rainfall in Sri Lanka also revealed that there is no significant trend over the time, but short term duration of heavy or extreme rainfall events have observed during the recent past leading to flash floods in low-lying areas. Frequent, short term and intense drought periods have also become a common feature in most parts of the country with significant damage to annual crop and plantation agriculture. Premalal and Punyawardena (2013) reported that this trend could be attributed to the failure of southwest monsoon rains. Though this was not evident in the present analysis, further studies are required before a generalized conclusions are made. Change of precipitation (rainfall) is not only depending on the radiative force, which alter the heating capacity of the atmosphere. The amount of precipitation depends on the moisture holding capacity of the atmosphere, but atmospheric circulation play a vital role for changing the amount of precipitation. El Nino Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) and Indian Ocean Dipole (IOD) are some of the phenomena which change the general atmospheric circulation.

Hence, periodic analysis of such changes in the atmosphere is a necessity prior to drawing any conclusions on this aspect. The analysis done in this study used data collected from the Mahailuppallama (MI) Weather Station. In an island wide study done by Jayawardena et al. (2018) reported that the annual total precipitation (PRCPTOT) has indicated a significant increasing over 1980-2015 in more than 80% of the weather stations. However, data from the MI weather station does not represent a significant increase in the total cumulative rainfall. Both the present study and that done by Jayawardene et al. (2018) thus indicate the necessity for regional and location-specific analysis to provide precise information to the farming community and the rest of the people in the regions to take more informed decision regarding their livelihood activities. It is also important to note that compared with temperature changes, less spatially coherent pattern of change and a lower level of statistical significance were observed in precipitation indices.

Previous trend analysis carried out on temperature in Sri Lanka reveals that both daytime maximum and nighttime minimum temperature are significantly increasing at a rate of 0.01 to 0.03 °C per year with a few exceptions (Premalal and Punyawardena 2013; Marambe et al. 2015). Contrary to the mean maximum temperatures, significant increasing trends can be observed in the mean minimum temperatures. In the major agricultural area in the dry zone, Anuradhapura, the rate of increase in air temperature has been around 0.0078 °C per year (De Costa, 2008). However, the present analysis shows that the day temperature in the Anuradhapura area has increased at a lower rate (0.0015 °C per year). Though the rate at which the maximum temperature increase has slowed down

In addition, number of days with higher temperature values has also been reported during recent years. Compared to the global trend of increasing temperature (0.74°C), the increasing trend in Sri Lanka is very significant. The present study also reveals the increasing the day and night time temperatures in the study region. Increasing trend of temperature as well as extreme temperatures has resulted many negative sectoral impacts such as agriculture, health, water etc.

It is well established that high temperature injuries in rice are inevitable if the plant is exposed to an ambient temperature that exceeds 35° C just for 60-90 minutes at the anthesis stage (flowering). Even though, it was used to be a rare event to experience such an environmental temperature regime in major rice growing regions of the country, recent agro-meteorological observations have confirmed that frequency of such temperature events has increased significantly in both Dry and Intermediate zones, especially during dry (*Yala*) seasons resulting high rate of un-filled grains due to increased spikelet sterility. High temperature regime will also increase the evapotranspiration losses leading to frequent soil moisture stress conditions in upland crops.

8. Extreme Rainfall Events (1981-2022)

The frequency of occurrence of extreme rainfall events in the regions showed a discernible linear trend of increasing over the past 42 years (Figure 21). However, the linear regressions analysis did not show a significant difference (P>0.05).

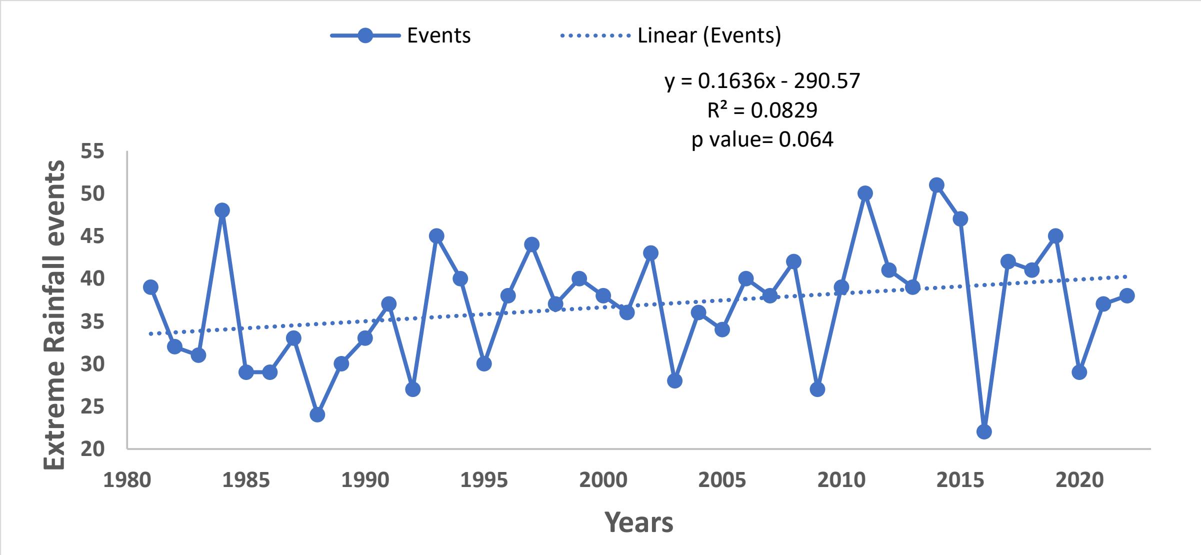


Figure 21. Frequency of occurrence of extreme rainfall events over the period 1981-2022

It is important to note that the extreme rainfall events are often related to different physical processes than those that govern long-term means. While an average change in rainfall is primarily due to circulation changes, extremes are much more sensitive to the thermodynamic state and conditions during specific days. Therefore, it is important to compare and contrast trends and projections in means against those of rare events. The results of the present study also support the findings of Premalal and Punyawardena (2013) reported that there is no significant trend over the time, but short term duration of heavy or extreme rainfall events have observed during the recent past leading to flash floods in low-lying areas. Moreover, although we did not analysis the impact of drought in this analysis, frequent, short term and intense drought periods have also become a common feature in most parts of Sri Lanka with significant damage to annual crop and plantation agriculture.

Previous studies have shown that the trends in extreme precipitation events such as maximal one-day precipitation, maximal five-day precipitation, and total precipitation on extreme rainfall days are increasing at most locations in Sri Lanka (Jayawardene et al 2018), indicating that the intensity of the rainfall is increasing. Increase of precipitation extreme trends indicate that occurrence of extreme rainfall events notably influence total annual precipitation in Sri Lanka. Therefore, the observed increases in total rainfall observed in many locations may be due in part to an increase in of extreme rainfall events. Patterns of change in precipitation extremes are more heavily influencing the climate variability by aggravating the variability, significantly influencing climate sensitive sectors such as agriculture and water resource management.

9. Changes in the onset of rainfall

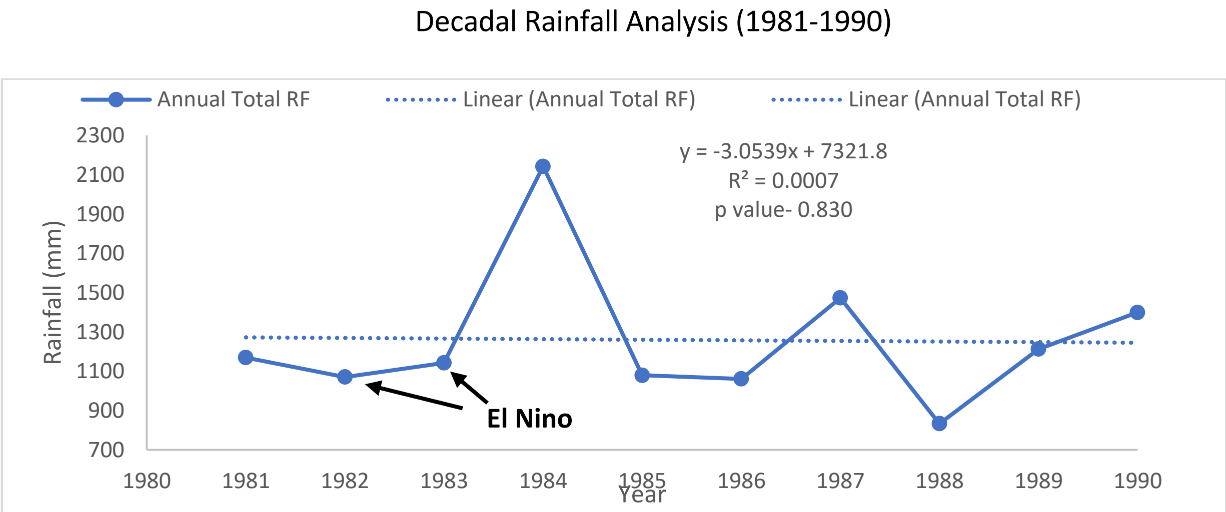
The onset of the monsoon rainfall (early, normal and late) separately for the *Yala* and *Maha* seasons were analyzed based on the data presented previously. The standard weeks of onset were considered based on the studies carried out by Punyawardena (2002) and Sonnadara (2015) to determine the onset and retreat dates.

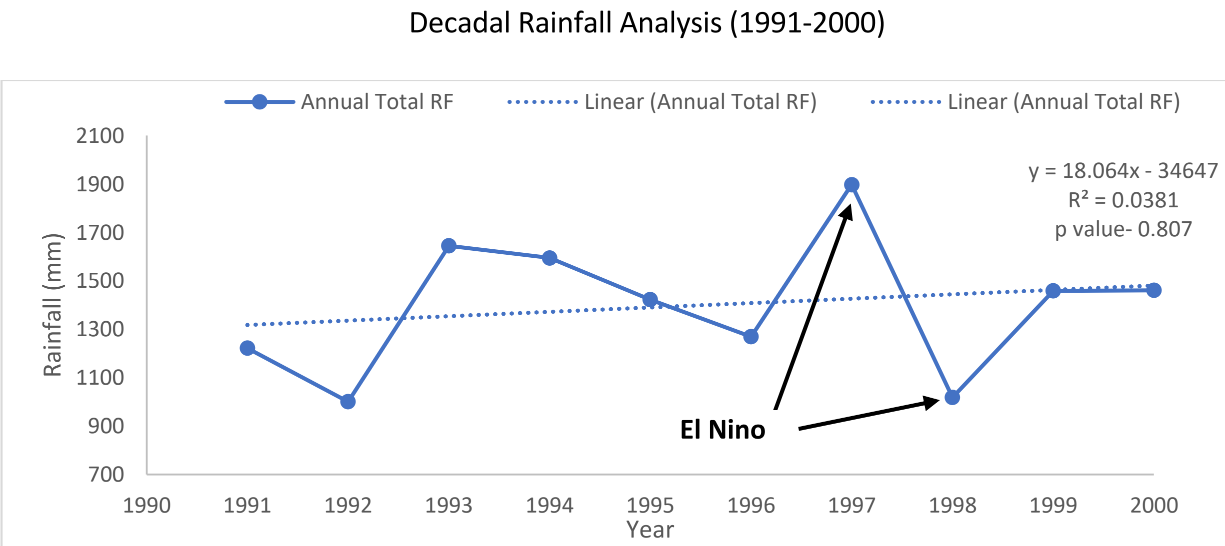
There has been no significant trend in the onset dates during the last 40 years in the MI region of Sri Lanka. However, the analysis revealed that there is substantial inter-annual variability in onset and retreat dates. The mean onset and retreat dates fall on the standard week 38.3 ± 2.7 and 53.0 ± 2.9, respectively. The mean duration of the growing season is 14.7 ± 3.4 weeks. Hence the analysis of rainfall data proposed the 13th week as the date of onset of rainfall for the DL1 regions for *Yala* season and 39th week for *Maha* season.

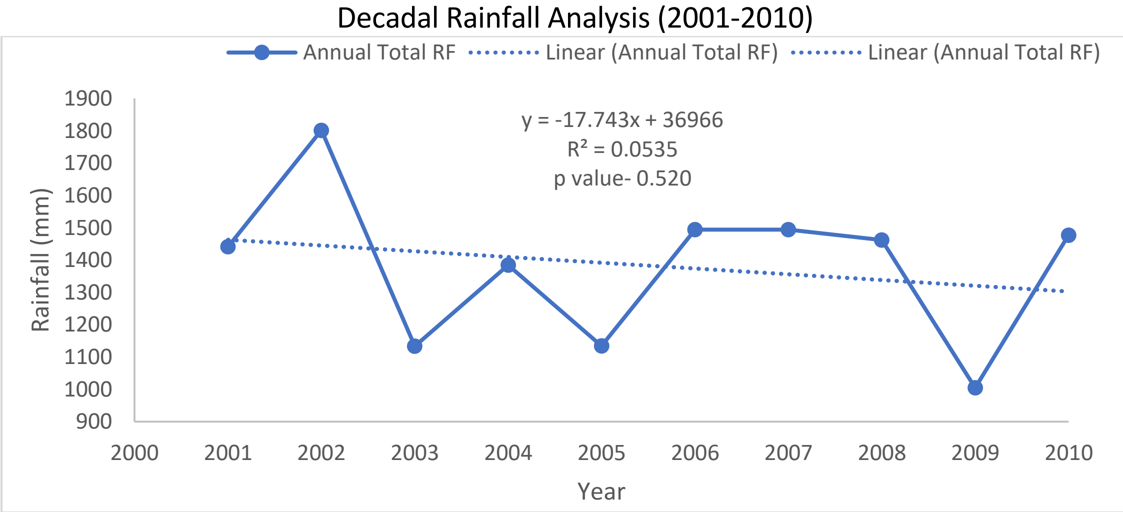
10. Decadal changes in rainfall

The decadal rainfall trend analysis conducted using standard procedures showed that there is no discernible linear trends in rainfall intensities during all four decades (Figure 22). There is a need to conduct further analysis in the future to confirm whether there is any significant trend in the rainfall intensities Anuradhapura area within short time spans, as it is important for agriculture that has played an important role in the Anuradhapura area considering the country's agricultural economy.

The analysis further confirms that El Nino Southern Oscillation (ENSO) has impacted the rainfall intensities at different levels in each decade. This indicates the difficulty in pre-determining the impacts of El Nino events, and the challenge to prepare for such an event. Though there is no direct link with the climate change, the ENSO affects many parts of the globe, but most intensely impacts the tropics, including countries and areas in Africa, Latin America and South and South-East Asia that are particularly vulnerable to natural hazards.







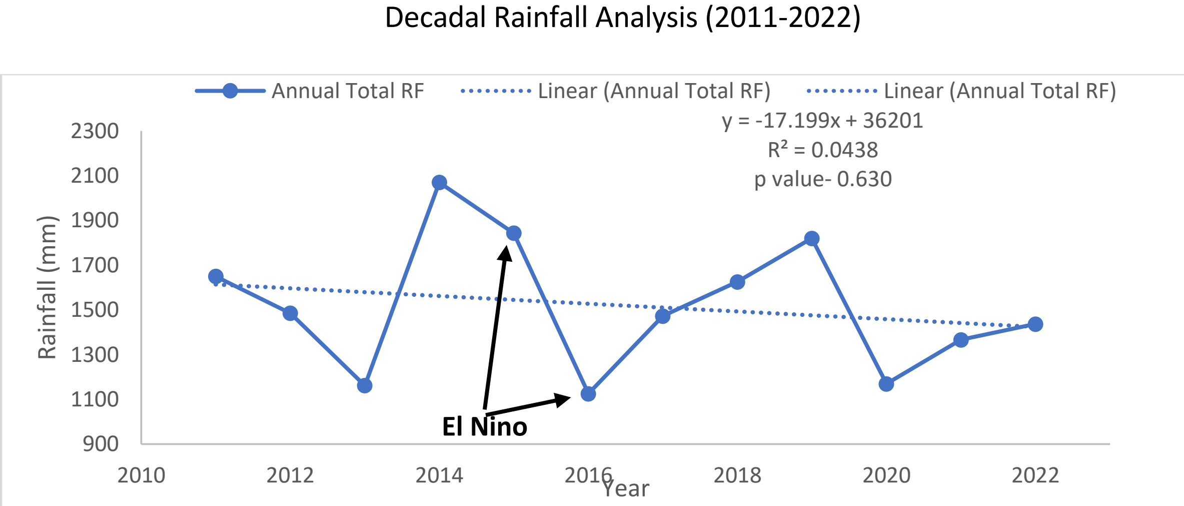


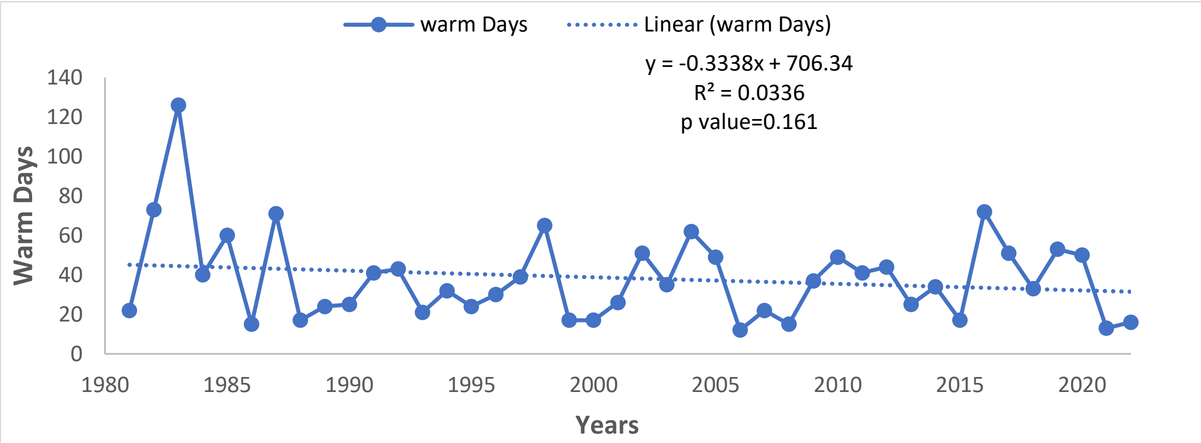
Figure 22. Decadal changes in the rainfall and changes in the rainfall pattern during El Nino years.

The ENSO is one of the most important sources of annual global climate variability, second only to the earth–Sun relationship that drives the seasons. *El Niño* and its counterpart *La Niña* are associated with characteristic patterns of rainfall and temperature, which can include extreme events such as flooding and drought. The ENSO is also associated with altered transmission patterns of vector-borne, rodent-borne and waterborne diseases, as well as fish and shellfish poisoning. Early warning systems and anticipatory action can help reduce the impacts of extreme weather conditions exacerbated by ENSO. The effects of each El Niño/La Niña event vary depending on the intensity, duration, time of year when it develops, and the interaction with other modes of climate variability. Not all regions of the world are affected, and even within a region, impacts can be different.

11. Trend in changes in the maximum and minimum temperatures during days and nights

Figure 23 illustrates that the annual number of warm and cold day temperatures have not shown a discernible linear trend (P>0.05) over the study period.

Number of warm Days in the Study Area in a Year



Number of Cold Days in the Study Area in a Year

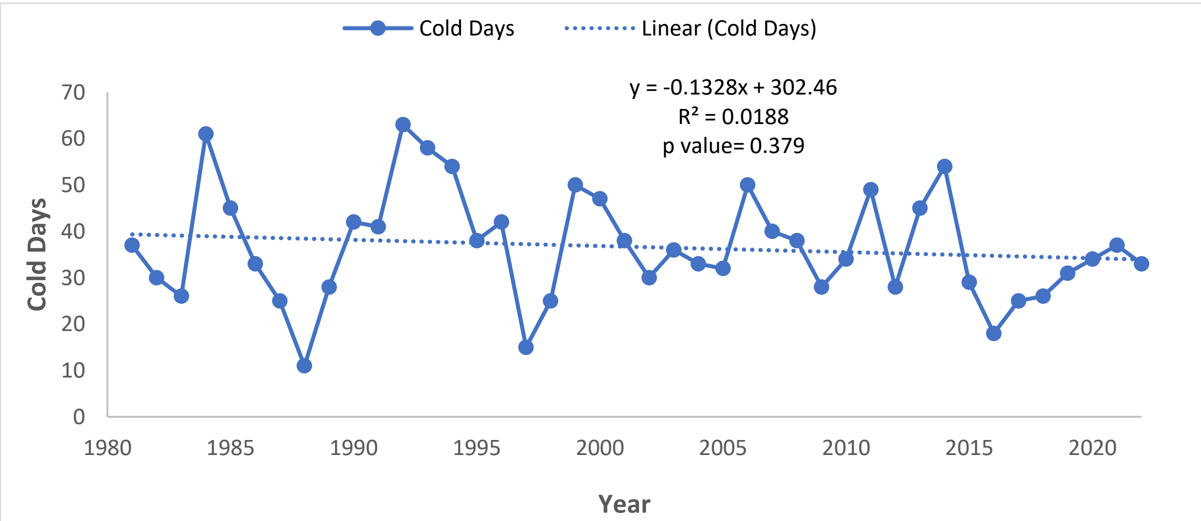
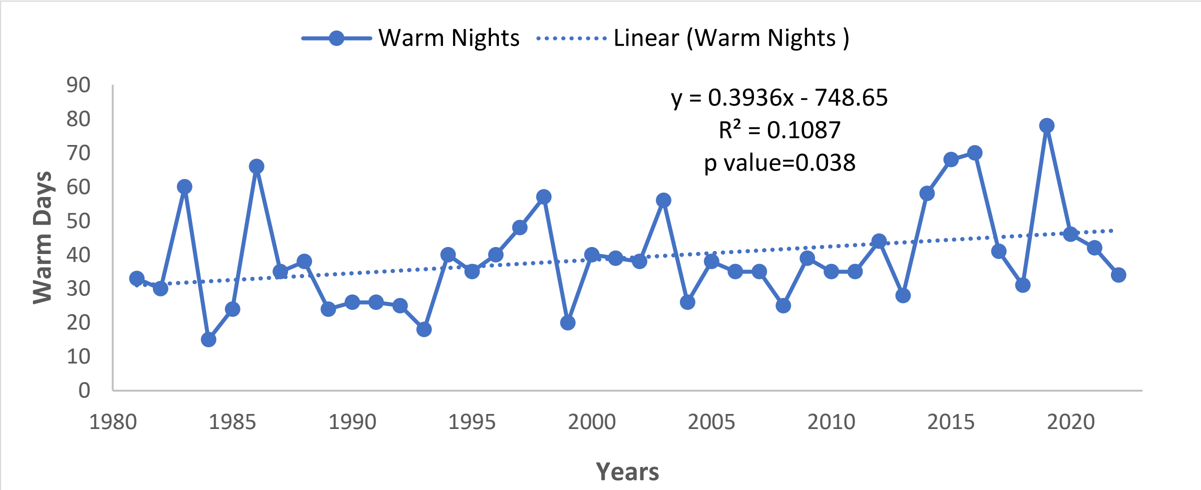


Figure 23. The number of warm and cool days in a given year over a period from 1981 to 2022

Interestingly the number of warm nights in the study locations have significantly increased (P<0.05) over the study period (Figure 24) while the number of cold nights have shown a decreasing trend, though statistically not significant (P>0.05) over the same period.

Over 60% of the stations show significant increasing trends in the percentage of warm nights (Jayawardene et al. 2018) and 70% of the stations show significant decreasing trends in the percentage of cold nights in Sri Lanka. This means that many stations have seen fewer cold nights and more warm nights during the past 3 - 4 decades, which was also confirmed in this study. Alexander et al. () also reported that over 70% of the land area globally has shown a significant increase in the annual occurrence of warm nights while the occurrence of cold nights showed a similar proportion of significant decrease.

Number of Warm Nights in the Study Area



Number of Cold Nights in Study Area

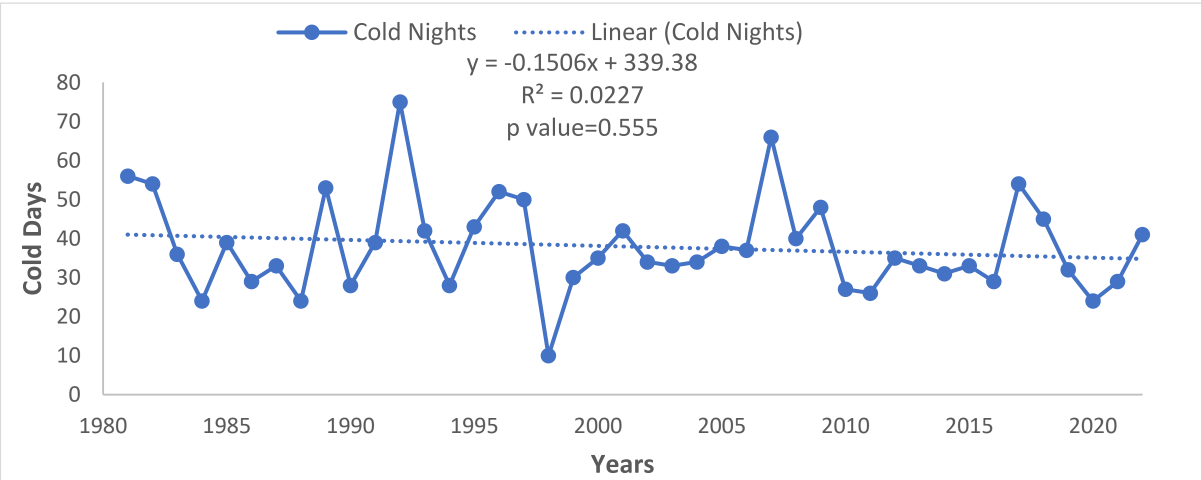
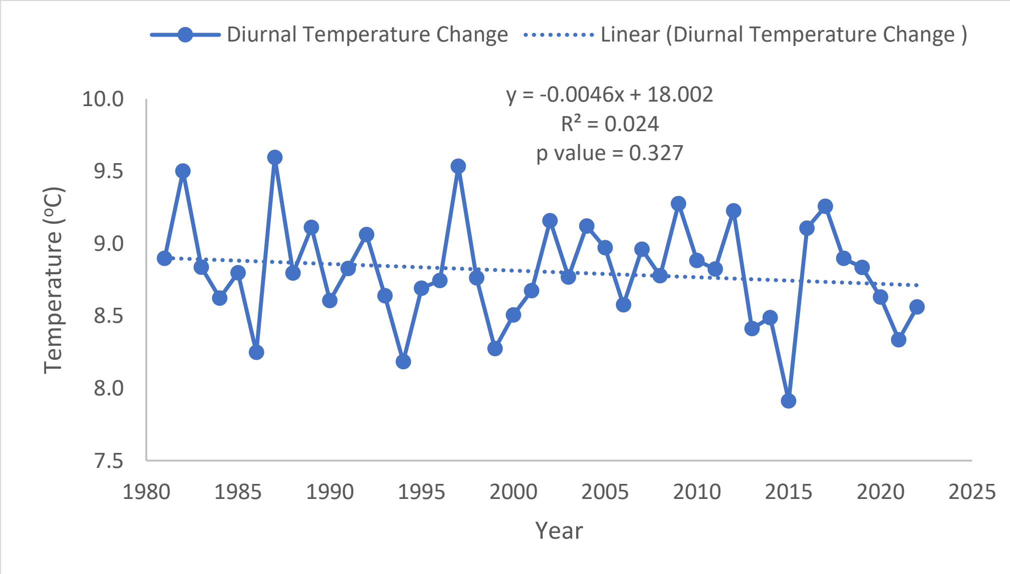


Figure 24. The number of warm and cool nights in the study regions from 1981 to2022.

In terms of human health and comfort of human beings, hot days and hot nights do not allow the human body to cool down, leading to increased heat stress. The combined effect of a warm day and warm night is detrimental to human health. The relative mortality risk on days with hot nights could be 50% higher than on days with non-hot night (Deshpande 2023). Night-time warming in the field reduces nocturnal stomatal conductance and grain yield (Bakum 2023). Paddy grain yield has shown a decline by 7% and 6% for each 1 °C increase in night time temperature and day time temperature, respectively, when exceeded the optimum temperatures. Increasing grain sterility has been reported from several rice-growing districts in the dry zone of Sri Lanka, especially during the warmer, minor rainfall season (locally known as the *Yala* season) during which temperatures are highly likely to exceed the upper threshold of 34 °C. Weerakoon et al. (2008) showed that high temperature-induced grain sterility in rice is exacerbated at high humidity. In contrast maize as a C4 crop could tolerate high temperature stress than other C3 species grown in Sri Lanka. However the reported optimum temperatures for different crops are; maize 28 °C, soybean 30 °C and cotton 31 °C.

12. Diurnal Temperature Changes in the Study Sites

The diurnal temperature changes in the study region did not show a discernible linear trend during the period 1981 to 2022 (Figure 25).



Diurnal Temperature Range (DTR), is defined as the difference of daytime maximum temperature and night time minimum temperature. The change in DTR is regional rather than to be global. Many studies have revealed that there is a decrease in DTR since the mid-20th century. Recent research has suggested that on an annual basis, results indicate that the DTR significantly decreased per decade by −0.14 °C, −0.16 °C, and −0.18 °C, over the high elevation temperature zone (HT), low-elevation temperature zone one (LT-2), and low elevation temperature zone two (LT-2), respectively. The annual decreasing trend of DTR in three temperature zones is mainly due to the larger increase in minimum temperature (Shelton et al. 2022). However, results of the present analysis was not in favour of that reported by Shelton et al. (2022) thus, indicating the regional disparities which is worth studying further in detail to provide more precise information for informed-decision making by policy makers and practitioners.

The larger temperature difference between day and night could potentially affect crop yields, plant growth, animal well-being and human health. For example, an increased temperature difference between daytime and nighttime is recognized as one of the environmental stressors that could lead to elevated heart rate and blood pressure, consequently increasing cardiac workload and the mortality and morbidity of cardiovascular and respiratory diseases. This indicates the need to adjust strategies in different areas affected by temperature variations between day and night, such as agriculture, public health, and forestry management, to address the challenges posed by this climate change,

13. Conclusions

Based on the analysis done using meteorological data obtained from the Mahailuppallama weather station for the period 1981-2022, the following conclusions can be drawn.

- **Annual Cumulative Rainfall, and Daily Maximum and Minimum Temperatures**:

  In the present study, though a trend in increase in rainfall was evident, there was no statistically significant increase of total annual cumulative rainfall, and the annual average maximum and minimum temperatures ($P>0.05$) during the study period 1981-2022.

- **Seasonal Cumulative Rainfall (Rainfall periods and Cultivating seasons)**

  In the four rainfall seasons in the study area, the SWM has shown a considerable increase in the intensity during the period 2015-2020 despite that fact that 2016-2017 were relatively dry years owing ENSO events that took place, highlighting regional disparities among the rain fall distribution in Sri Lanka. Apart from this, there were no discernible linear trends in the four rainfall seasons in the study regions. The extreme rainfall events in the regions did not show a statistically significant increasing trend during the period 1981-2022.

  This short term increase in cumulative annual rainfall is alarming and special consideration should be given in the future to assess such trends in the short time intervals to provide short-term predictions to support decision making in the agricultural as well as livelihood activities in the Anuradhapura region.

- **Seasonal Maximum and Minimum Temperatures (Rainfall periods and Cultivating seasons):**

  The daily maximum temperatures did not also show any discernible linear trend in the four rainfall period and the *Yala* and *Maha* seasons ($P>0.05$). However, the average daily minimum temperature showed a statistically significant increase in the SWM period (0.006 °C per year from 1981 to 2022). The SWM provide rainfall during the *Yala* cultivating season (coupled with the FIM), however, there was no overall statistically significant increasing trend of the daily minimum temperatures in *Yala* or *Maha* seasons during the same study period.

- **The average pan Evaporation:**

  The annual average pan evaporation showed a statistically significant reduction ($P<0.05$) at 0.035 mm per year. The pan evaporation in all four rainfall seasons has also decreased significantly (P<0.05) during the period 1981 to 2022; in the FIM by 0.043 mm per year, SWM by 0.036 mm per year, SIM by 0.028 mm per year, and NEM by 0.035 mm per year. Further, the Pan Evaporation showed a significant decreasing trend in both seasons during the period 1981-2022; *Yala* season by 0.037 mm per year and in the *Maha* season by 0.033 mm per year.

- **The average daily sunshine hours**

In the study regions, the average daily sunshine hours decreased significantly over the study period by 0.02 hours per year and the annual wind velocity was decreased by 0.09 km per hour per year.

The average sunshine hours was also decreased in the First Inter-monsoon (FIM) by 0.04 hours per year, Second Inter-monsoon (SIM) by 0.031 hours per year, and North East Monsoon (NEM) by 0.033 hours per year. There was no discernible trend of the average daily sunshine in the South West Monsoon (SWM).

The average daily sunshine hours also decrease significantly during the same study period in *Yala* seasons 0.035 hours per year and in the *Maha* season by 0.0345 hours per year. The crop production efficiency would thus be in trouble owing to the reduced sunshine in the past and future owing lower sun light intensity reducing the photosynthetic efficiency.

- **The average daily wind velocity and the Relative Humidity**

The average annual wind velocity was significantly reduced by 0.096 km per hour. The Daily average relative humidity (RH) in the morning was increased by 0.027% annually while the average RH in the evening was reduced by 0.26% between 1981 and 2022.

The average wind velocity was reduced by 0.0124 km per hour in the FIM, 0.008 lm per hour in the SWM, and 0.0047 km per hour in the SIM. Among the four rainfall seasons, the daily morning RH increased significantly only during the NEM period (0.095% per year’ P<0.05).

The average wind velocity in the *Yala* season was reduced by 0.129 lm per hour per year. This coupled with the annual average daily relative humidity (RH) in the morning increased by 0.027% per year, 0.94% per year during the NEM period and 0.062% per year in the *Maha* season during the period 1981-2022, would have significant impact on crop livelihood of people due to build-up of heat leading to heat stress at work during the day time. Heat stress leads to an imbalance in plant hormones, impairing plant growth, photosynthesis, pollen development, and reproduction

The evening daily RH, in contrast, showed a reduction by 0.026% annually, and in four rainfall seasons (0.31% in the FIM, 0.295% in the SWM, 0.275% in the SIM, 0.154% in the NEM) and in two cultivating seasons (*Yala* season by 0.297% and *Maha* season by 0.192%).

- **Change in the Onset of Rains**

The mean onset and retreat dates deviated from the current standard weeks. The analysis of rainfall data conducted in the study region for the period 1981 to 2022, the 13th week is proposed as the date of onset of rainfall for the DL1 regions for *Yala* season (as against the 9th week) and 39th week for *Maha* season (as against 35th week) based on the analysis conducted. The mean duration of the growing season is 14.7 ± 3.4 weeks.

Mechanisms should thus be adopted to disseminate this information effectively among the farming community in the study region to harness maximum benefits with respect to agriculture.

- **Decadal Changes in the Rainfall Intensity**

There was no discernible linear trends in annual cumulative rainfall intensities during 1981-1990, 1991-2000, and 2001-2010 and the last 12 year period from 2100 to 2022.

El Nino Southern Oscillation (ENSO) has impacted the rainfall intensities at different levels in each decade, but showed the difficulty in pre-determining the impacts of El Nino events, and the challenge to prepare to overcome the damages caused by a natural event.

- **Diurnal Temperature Change**

There was no discernible linear trend in the diurnal temperature difference during the period 1981 to 2022

Recommendations:

1. The policy makers and farming community to be educated on the latest finding of the study to support their decision making to enhance agricultural productivity and sustainable development, livelihood activities and resilience.

2. Establishment of automated weathers stations is a must to obtain reliable weather data for analysis of the climate change in the future.

3. Build capacity of the regional officers across Sri Lanka to conduct location-specific and scientifically-based climate data analysis to support regional agriculture development.

4. Establishment of automated weathers stations is a must to obtain reliable weather data for analysis of the climate change in the future.

5. Ensure incorporation of regional climate analysis in the provincial level planning, including provincial adaptation plans to support decision making and plan implementation.

6. Develop knowledge products in local languages (Sinhala and Tamil) to provide details of climate change at national and regional levels with appropriate solutions to overcome the impact and build resilience.

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