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# Recent trends of extreme weather events in Sri Lanka

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## Abstract

**The impacts of climate change of a particular region depend on several factors such as geographical settings, weather factors and socio-economic situation. Therefore, it is important to keep timely records on changing weather parameters across all geographical regions in a country to implement appropriate mitigation and adaptation interventions accordingly. This study was carried out using daily rainfall and temperature time series for more than 30 years ranging from 1961 to 1984 up to 2019. Possible climatological trends were analyzed for 17 agro-meteorological observation stations scattered throughout the island. Eight temperature indices and six rainfall indices were analyzed using ClimPACT2 software to determine the extreme climatic events of time series data. Results have revealed that annual mean daily temperature, maximum and minimum temperatures have shown a significant increasing trend in all three climatic zones. Decreasing of cold days and cold nights and increasing of warm days and warm nights were also significant in Dry Zone (DZ). Annual total rainfall, consecutive dry days and consecutive wet days have not shown a significant increasing or decreasing trend. However, heavy rainfall events and simple daily intensity index indicated an apparent increasing trend in the DZ. Since DZ is the major agricultural region of the country, increasing trends of ambient temperature and heavy rainfall event there in likely to influence the agricultural production of the country in a negative manner.**

**Keywords: Climate indices, Extreme weather events, Rainfall, Temperature**

## Introduction

The year 2019 was ranked as the second warmest year on record and it is just behind the year 2016 (WMO, 2020; NOAA, 2020). The National Oceanic and Atmospheric Administration (NOAA) declared that 2010-2019 was the hottest decade ever recorded. Furthermore, the world's five warmest years have all occurred since 2015 (NOAA, 2020). The year 2019 was also the 43 consecutive year with global land and ocean temperatures, at least nominally, above average. The average temperature across the globe in 2019 was 1.71 $^{o}$F (0.95 $^{o}$C) above the 20$^{th}$ century average and just 0.07 $^{o}$F (0.04 $^{o}$C) cooler than the 2016 record (NOAA, 2020).

The impacts of global warming situation are mainly the increasing both ocean and atmospheric temperatures, increasing $CO_2$ concentration, erratic rainfall, increasing lightning and tornado type winds, frequent cyclonic storms, heat waves and sea level rise (IPCC, 2013). Annual GHG emissions grew on average by 1.0 gigatonne carbon dioxide equivalent (GtCO2eq) (2.2%) per year from 2000 to 2010 compared to 0.4 GtCO2eq (1.3%) per year from 1970 to 2000 (IPCC, 2014).

Several studies have been carried out, in different regions of the world to find the occurrence of extreme climatic events. A variation of the increasing and decreasing trends of rainfall and temperature can be observed, depending on the geographical locations (Melo *et al*., 2015; Marigi *et al*., 2016; Hafez, 2018; Rahimi *et al*., 2018).

Climate change and its consequences in Sri Lanka also can be proven, considering the recent studies carried out. According to the recent rainfall observations, the total annual and seasonal rainfall has not showed a significant change. However, the heavy rainfall events, that is intense rains after prolonged dry periods has shown an increasing trend (Nissanka *et al*., 2011; Punyawardena and Premalal, 2013; Abeysekera *et al*., 2015; Nisansala *et al*., 2019). Jayawardena *et al.* (2018) revealed that 75% of main meteorological stations show significant increasing trend for annual precipitation (1980-2015). The trends in extreme precipitation events such as maximal one-day precipitation, maximal five-day precipitation and total precipitation on extreme rainfall days (R95p and R99p) are increasing in most of the locations, indicating an increase in the intensity of rainfall. Furthermore, the occurrence of extreme rainfall events notably influenced

total annual precipitation in Sri Lanka (Jayawardena *et al*., 2018). A decrease of rainfall in higher elevations and increase of rainfall in lowlands in the south western sector of Sri Lanka during southwest monsoon season has also been observed (Malmgren *et al*., 2003). Therefore, further studies are needed to explore spatial and temporal variations of rainfall. Moreover, both daytime maximum and night-time minimum temperatures are significantly increasing at a rate of 0.01 °C to 0.03 °C per year with a few exceptions (Premalal and Punyawardena, 2013).

Climate change influence the biophysical factors, such as plant and animal growth, water cycles, biodiversity and nutrient cycling, thereby the food security of a country. Agriculture is important for food security in two ways: it produces the food people eat; and it provides the primary source of livelihood for 36% of the world's total workforce (FAO, 2018). Physiology of plant; the growth and developmental stages of a plant highly depends on the climatic parameters. Therefore, it is important to study and update the changing situation of weather parameters or current trends of climate of a country. The objective of this study was to identify recent trends of temperature and rainfall events in the country. Investigating the increasing or decreasing ranges of weather indices will be useful to find their impact on crop physiology. Furthermore, it can be taken as an agricultural decision making tool for planning cultivation seasons, adjusting cropping calendar and developing new crop varieties to improve the agricultural production of the country.



## Materials and Methods

Daily rainfall and temperature data from 17 meteorological observation stations were collected.The agro-ecological regions of the meteorological observation stations used in the study, their latitude, longitude, altitude and the study period taken into consideration are shown in Table 1.

**Table 1. Geographical details and study period of meteorological observation stations used in the study**

| Station | AER | Latitude (N) | Longitude (E) | Altitude (m) | Study period |
|---|---|---|---|---|---|
| Sita Eliya | WU 3 | 6° 58’ | 80° 46’ | 1860.0 | 1976 - 2019 |
| Peradeniya | WM 2b | 7° 25’ | 80° 60’ | 487.6 | 1976 - 2019 |
| Ratnapura | WL 1a | 6° 68’ | 80° 40’ | 34.4 | 1976 - 2019 |
| Bombuwela | WL 1b | 6° 57’ | 80° 02’ | 3.0 | 1976 - 2019 |
| Colombo | WL 3 | 6° 90’ | 79° 87’ | 7.3 | 1961 - 2019 |
| Bandarawela | IU 3c | 6° 83’ | 80° 98’ | 1219.0 | 1976 - 2019 |
| Kundasale | IM 3a | 7° 27’ | 80° 68’ | 492.0 | 1983 - 2019 |
| Batalagoda | IL 1a | 7° 52’ | 80° 45’ | 100.0 | 1976 - 2019 |
| Makandura | IL 1a | 7° 32’ | 79° 97’ | 25.0 | 1983 - 2019 |
| Girandurukotte | IL 2 | 7° 40’ | 81° 08’ | 292.0 | 1976 - 2019 |
| Angunakolapelessa | DL 1b | 6° 17’ | 80° 88’ | 23.0 | 1977 - 2019 |
| Anuradhapura | DL 1b | 8° 35’ | 80° 38’ | 92.5 | 1961 - 2019 |
| MahaIlluppallama | DL 1b | 8° 12’ | 80° 47’ | 137.8 | 1976 - 2019 |
| Aralaganwila | DL 2b | 7° 68’ | 81° 18’ | 230.0 | 1984 - 2019 |
| Batticaloa | DL 2b | 7° 72’ | 81° 70’ | 2.7 | 1961 - 2019 |
| Jaffna | DL 3 | 9° 68’ | 80° 03’ | 3.0 | 1961 - 2019 |
| Mannar | DL 4 | 8° 59’ | 79° 55’ | 3.6 | 1961 - 2019 |

*AER: Agro Ecological Region*



This study was carried out as an update of the paper published by Premalal and Punyawardena using the statistical software, RClimDex in 2013 (Premalal and Punyawardena, 2013). For this study ClimPACT2 softwarewas used to calculate indices of climate extremes (Herold and Alexander, 2016). It can be used to calculate 115 climate indices under the free “R” statistical package. For the study, 14 indices were selected considering the country specific factors (Tables 2 and 3).

**Table 2. Temperature indices and their definitions used for the analysis**

| Index | Definition |
|---|---|
| Trend of annual temperature | Annual mean daily mean temperature |
| Trend of maximum temperature | Annual mean daily maximum temperature |
| Trend of minimum temperature | Annual mean daily minimum temperature |
| Number of cold days | Annual percentage of days when TX<10th percentile |
| Number of warm days | Annual percentage of days when TX>90th percentile |
| Number of cold nights | Annual percentage of days when TN<10th percentile |
| Number of warm nights | Annual percentage of days when TN>90th percentile |
| Warm Spell Duration Indices (WSDI) | Annual number of days contributing to events where 6 or more consecutive days experience TX > 90th percentile |

**Table 3. Rainfall indices and their definitions used for the analysis**

| Index | Definition |
|---|---|
| Trend of total precipitation | Annual sum of daily precipitation |
| Trends in consecutive dry days | Maximum annual number of consecutive dry days (when precipitation < 1.0 mm) |
| Trends in consecutive wet days | Maximum annual number of consecutive wet days (when precipitation >= 1.0 mm) |
| Trend of one day heavy rainfall | Maximum annual 1-day precipitation total |
| Trend of five day heavy rainfall | Maximum annual 5-day precipitation total |
| Trend of simple daily intensity index (SDII) | Annual total precipitation divided by the number of wet days (when total precipitation >= 1.0 mm) |



## Results and Discussion

### Trends of temperature

#### Trends of annual temperature

Annual mean daily mean temperature has shown a statistically significant (65% of stations) increasing trend (Table 4). Two locations, namely Batalagoda and Aralaganwila have shown a decreasing trend. Temperature increase was ranged from 0.003 $^{O}$C to 0.025 $^{O}$C per year. Out of seven, five locations in the DZ have shown a significant increasing trend. This increasing trend was further proven by annual mean daily maximum and minimum temperature values. Eight stations showed an increasing trend of maximum temperature. No trend was observed at Batalagoda. Increase in maximum temperature ranged from 0.002 $^{O}$C to 0.032 $^{O}$C per year. Increasing trend of minimum temperature was observed in eight locations and ranged from 0.001 $^{O}$C to 0.041 $^{O}$C per year.

**Table 4. Trends of annual mean daily mean temperature, mean daily maximum and minimum temperature**

| Station | AER | Trend (Mean temperature) | Trend (Maximum temperature) | Trend (Minimum temperature) |
|---|---|---|---|---|
| Sita Eliya | WU 3 | 0.010ns | 0.011ns | 0.010ns |
| Peradeniya | WM 2b | 0.025*** | 0.019ns | 0.041*** |
| Ratnapura | WL 1a | 0.003ns | 0.007ns | 0.000ns |
| Bombuwela | WL 1b | 0.018ns | 0.018*** | 0.015ns |
| Colombo | WL 3 | 0.018*** | 0.011*** | 0.025*** |
| Bandarawela | IU 3c | 0.010* | 0.020** | 0.001ns |
| Kundasale | IM 3a | 0.004ns | 0.012ns | 0.006ns |
| Batalagoda | IL 1a | –0.009* | –0.005ns | –0.015** |
| Makandura | IL 1a | 0.022* | 0.007ns | 0.034*** |
| Girandurukotte | IL 2 | 0.018ns | 0.007ns | 0.030** |
| Angunakolapelessa | DL 1b | 0.021*** | 0.018*** | 0.036*** |
| Anuradhapura | DL 1b | 0.023*** | 0.021*** | 0.022*** |
| MahaIlluppallama | DL 1b | 0.003ns | 0.002ns | 0.006ns |
| Aralaganwila | DL 2b | –0.028* | 0.002ns | –0.059*** |
| Batticaloa | DL 2b | 0.017*** | 0.020*** | 0.014*** |
| Jaffna | DL 3 | 0.013*** | 0.032*** | –0.007** |
| Mannar | DL 4 | 0.011*** | 0.015*** | 0.011*** |

*AER: Agro Ecological Region; trends followed by 'ns' are not significantly different, trends followed by '*' are significantly different at p=0.05, trends followed by '**' are significantly different at p=0.01 and trends followed by '***' are significantly different, at p=0.001*



The study conducted by Naveendrakumar *et al*. (2018) also reported notable increases in minimum and maximum temperatures at 70% and 55% of the stations out of 20 in Sri Lanka, respectively. Several food crops, including paddy are highly sensitive to the temperature variations. Grain development of rice is mainly impact on high temperature during its reproductive stage, with significant increases in grain sterility occurring when temperature increases beyond 34 $^{o}$C even for a few hours (Horie *et al*., 2000). Increasing grain sterility has been reported from several rice-growing districts in the DZ of Sri Lanka, especially during the warmer, minor rainfall season (i.e. *Yala* season) during which temperatures were likely to exceed the upper threshold of 34 $^{o}$C

(Costa, 2010). Therefore, if the investigated temperature increment is continued yearly, it can impact on the paddy production.

## Trends of cold days, cold nights, warm days and warm nights

Ten locations out of 17 have shown a decreasing trend of cold days (Table 5). The two locations, namely Rathnapura and Batalagoda showed no change of cold days. Five locations in the DZ showed a reduction of cold days. Out of 17 locations nine have shown a decreasing trend in cold nights (Table 5). The observed results are closely related to the findings of Jayawardena *et al*. (2018). Decreasing of cold nights causes to decrease the diurnal temperature change which affects the yield of certain crops such as potato.

**Table 5. Trend of cold days, cold nights, warm days and warm nights**

| Station | AER | Trend (Cold days) | Trend (Cold nights) | Trend (Warm days) | Trend (Warm nights) |
|---|---|---|---|---|---|
| Sita Eliya | WU 3 | –0.046ns | –0.188ns | 0.116ns | –0.066ns |
| Peradeniya | WM 2b | –0.340*** | –0.367** | 0.112ns | 0.529*** |
| Ratnapura | WL 1a | 0.074ns | 0.057ns | 0.306*** | –0.214ns |
| Bombuwela | WL 1b | –0.155ns | –0.081ns | 0.431*** | 0.066ns |
| Colombo | WL 3 | –0.150*** | –0.291*** | 0.178*** | 0.400*** |
| Bandarawela | IU 3c | –0.206*** | –0.160*** | 0.139ns | –0.069ns |
| Kundasale | IM 3a | –0.203* | –0.051ns | –0.006ns | –0.170ns |
| Batalagoda | IL 1a | 0.019ns | 0.167* | –0.081ns | –0.344*** |
| Makandura | IL 1a | –0.384* | –0.492*** | –0.014ns | 0.496*** |
| Girandurukotte | IL 2 | –0.143ns | –0.505** | 0.009ns | 0.249ns |
| Angunakolapelessa | DL 1b | –0.152** | –0.595*** | 0.309** | 0.437*** |
| Anuradhapura | DL 1b | –0.207*** | –0.338*** | 0.204*** | 0.373*** |
| MahaIlluppallama | DL 1b | –0.015ns | –0.067ns | 0.007ns | 0.083ns |
| Aralaganwila | DL 2b | –0.073ns | 0.950** | –0.041ns | –0.468* |
| Batticaloa | DL 2b | –0.251*** | –0.177*** | 0.268*** | 0.286*** |
| Jaffna | DL 3 | –0.287*** | 0.099* | 0.369*** | 0.065ns |
| Mannar | DL 4 | –0.205*** | –0.123*** | 0.175ns | 0.223*** |

*AER: Agro Ecological Region; trends followed by 'ns' are not significantly different, trends followed by '*' are significantly different at p=0.05, trends followed by '**' are significantly different at p=0.01 and trends followed by '***' are significantly different at p=0.001*

Except some locations in the Intermediate Zone (IZ), almost all locations have shown an increasing trend of warm days (Table 5). Among them, 54% of incidents are statistically significant. None of the four instances which have shown a decreasing trend were statistically significant. Seven locations have shown increasing trends in warm nights (Table 5). From the previous study of Premalal and Punyawardena (2013) also proven an increasing trend of warm days and warm nights. Many important physiological processes of plants such as panicle initiation, formation of reprodutive organs and grain filling are highly sensitive to increasing day time and night time temperatures. Therefore, when incresing temperature reaches the threshhold values, it leads to yield losses in many food crops.

## Trends of warm spell duration index (WSDI)

Out of 17, four stations have shown an increasing trend of WSDI (Table 6). None of the locations showed statistically significant decreasing trend.When temperature has increased up to the optimal or sub optimal range of a plant, many yield determining physiological processes are affected. WSDI is a good indicator of consecutive dry periods when temperature exceeds the cardinal temperatures ranges.

**Table 6. Trends of warm spell duration index (WSDI)**

| Station | AER | Trend of WSDI |
|---|---|---|
| Sita Eliya | WU 3 | −0.136ns |
| Peradeniya | WM 2b | 0.017ns |
| Ratnapura | WL 1a | 0.169* |
| Bombuwela | WL 1b | 0.199** |
| Colombo | WL 3 | 0.135ns |
| Bandarawela | IU 3c | 0.013ns |
| Kundasale | IM 3a | –0.257ns |
| Batalagoda | IL 1a | –0.180ns |
| Makandura | IL 1a | –0.042ns |
| Girandurukotte | IL 2 | –0.005ns |

| Station | AER | Trend of WSDI |
|---|---|---|
| Angunakolapelessa | DL 1b | 0.407* |
| Anuradhapura | DL 1b | 0.222ns |
| MahaIlluppallama | DL 1b | –0.014ns |
| Aralaganwila | DL 2b | –0.063ns |
| Batticaloa | DL 2b | 0.172ns |
| Jaffna | DL 3 | 0.316*** |
| Mannar | DL 4 | 0.295ns |

*AER: Agro Ecological Region; trends followed by 'ns' are not significantly different, trends followed by '*' are significantly different at p=0.05, trends followed by '**' are significantly different at p=0.01 and trends followed by '***' are significantly different at p=0.001*

## Trends of rainfall

### Annual total rainfall, number of consecutive dry days (CDD) and consecutive wet days (CWD)

Table 7 shows linear trends of annual total rainfall in the selected locations of the study. Despite the findings of the base study of Premalal and Punyawardena (2013) the results have shown a positive anomaly of annual total rainfall. Bandarawela has shown a significant increasing trend. Only two stations, which are located in the Wet Zone (WZ) have shown no trend, namely Sita Eliya and Colombo. Naveendrakumar *et al*. (2018) revealed thatout of 20 stations considered only two stations showed significant trends in annual total rainfall, Katunayaka (decreasing) and Bandarawela (increasing), which was closely related to the results of present study. Another recent studies carried out by Jayawardena *et al*.(2018) and Nisansala *et al*.(2019) also observed similar results. Although the country has experience prolonged dry periods, since the occurrence of intense heavy rainfall events, the increasing rainfall pattern might have observed.

According to the Table 7, decreasing trend of CDD have shown in 11 stations. Sita Eliya has shown a significant decreasing trend. Nine locations out of 17 have shown an increasing trend of CWD. Aralaganwila has shown a significant increase. Similar results were observed by Jayawardena *et al*. (2018).

**Table 7. Trend of annual total rainfall,consecutive dry days (CDD) and consecutive wet days (CWD)**

| Station | AER | Trend of annual total rainfall | Trend of CDD | Trend of CWD |
|---|---|---|---|---|
| Sita Eliya | WU 3 | –1.046ns | –0.500** | –0.069ns |
| Peradeniya | WM 2b | 5.204ns | –0.129ns | 0.102ns |
| Ratnapura | WL 1a | 0.218ns | –0.125ns | 0.075ns |
| Bombuwela | WL 1b | 0.734ns | –0.169ns | –0.026ns |
| Colombo | WL 3 | –4.274ns | 0.009ns | –0.031ns |
| Bandarawela | IU 3c | 9.031** | –0.146ns | 0.048ns |
| Kundasale | IM 3a | 3.862ns | 0.016ns | 0.024ns |
| Batalagoda | IL 1a | 2.757ns | –0.220ns | –0.058ns |
| Makandura | IL 1a | 5.918ns | –0.393ns | –0.007ns |
| Girandurukotte | IL 2 | 0.367ns | 0.113ns | –0.057ns |
| Angunakolapelessa | DL 1b | 5.834ns | –0.216ns | 0.001ns |
| Anuradhapura | DL 1b | 3.908ns | 0.264ns | 0.019ns |
| MahaIlluppallama | DL 1b | 5.549ns | –0.053ns | –0.053ns |
| Aralaganwila | DL 2b | 8.034ns | 0.078ns | 0.205** |
| Batticaloa | DL 2b | 3.924ns | –0.007ns | 0.024ns |
| Jaffna | DL 3 | 3.571ns | –0.100ns | 0.034ns |
| Mannar | DL 4 | 0.305ns | 0.127ns | –0.005ns |

*AER: Agro Ecological Region; trends followed by 'ns' are not significantly different and trends followed by '**' are significantly different, at p=0.01*

## One day and five day heavy rainfall and simple daily intensity index (SDII)

Despite from the base study (Premalal and Punyawardena, 2013), the results have shown an increasing trend of heavy rainfall (Table 8). Anuradhapura has shown a significant increasing one day heavy rainfall. Angunakolapelessa and Anuradhapura have shown significant increasing trend of five day rainfall (Table 8). Furthermore, Anuradhapura and Batticaloa showed a significant positive trend of SDII (Table 8). These findings are closely related to the findings of Jayawardena *et al*. (2018) and Naveendrakumar *et al*. (2018). According to the study carried out by Nisansala *et al*.(2019), an increasing trend of rainfall at 86% of stations during North East Monsoon (NEM) season was reported. A study conducted by Abeysekera *et al*. (2015) to ascertain the recent trends of extreme positive rainfall anomalies in the DZ of Sri Lanka during

the period of 1990-2014 has shown that there is an apparent increasing trend of heavy and very heavy rainfall anomalies during NEM season. This trend has been clearly evident during the last pentad of 2010-2014. The present study has further supported to these findings. NEM rain is the most important rainfall season to the country as the reproductive phase of most of the crops grown in the major cultivation season; *Maha* is coinciding with NEM rains.

**Table 8. One day and five day heavy rainfall and simple daily intensity index (SDII)**

| Station | AER | Trend of one day rainfall | Trend of five day rainfall | Trend of SDII |
|---|---|---|---|---|
| Sita Eliya | WU 3 | –1.007ns | –1.164ns | –0.001ns |
| Peradeniya | WM 2b | 0.654ns | 1.525ns | 0.017ns |
| Ratnapura | WL 1a | –0.326ns | –0.207ns | –0.006ns |
| Bombuwela | WL 1b | 0.181ns | –0.428ns | 0.006ns |
| Colombo | WL 3 | 0.007ns | –0.809ns | 0.012ns |
| Bandarawela | IU 3c | 0.556ns | 1.008ns | 0.045ns |
| Kundasale | IM 3a | 0.182ns | 1.304ns | 0.034ns |
| Batalagoda | IL 1a | 0.549ns | 0.630ns | 0.030ns |
| Makandura | IL 1a | 0.426ns | –0.359ns | 0.042ns |
| Girandurukotte | IL 2 | –0.205ns | 0.315ns | 0.039ns |
| **Table 8. cont.** | | | | |
| Angunakolapelessa | DL 1b | 0.424ns | 1.157** | 0.028ns |
| Anuradhapura | DL 1b | 0.525* | 1.202** | 0.077*** |
| MahaIlluppallama | DL 1b | 0.301ns | 1.496ns | 0.041ns |
| Batticaloa | DL 2b | 0.089ns | 1.348ns | 0.092** |
| Jaffna | DL 3 | 0.088ns | 0.390ns | 0.007ns |
| Mannar | DL 4 | 0.016ns | 0.559ns | 0.019ns |

*AER: Agro Ecological Region; trends followed by 'ns' are not significantly different, trends followed by '*' are significantly different at p=0.05, trends followed by '**' are significantly different at p=0.01, and trends followed by '***' are significantly different, at p=0.001*

## Conclusion

This study was carried out to ascertain the recent possible rainfall and temperature trends of Sri Lanka. Eight temperature indices and six rainfall indices were analyzed using ClimPACT2 software. Mean annual temperature, maximum and minimum temperatures have shown a significant increasing trend. Increase in temperature ranged from 0.003 $^{O}$C to 0.025 $^{O}$C per year. Decreasing trend of cold days and cold nights and increasing trend of warm days and warm nights were prominent in DZ. However, annual total rainfall has not shown asignificant increasing or decreasing trend. Heavy rainfall events and SDII has shown an increasing trend in DZ with significant positive anomaly at Anuradhapura.

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