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RESEARCH ARTICLE

Environmental Science

Annual and seasonal trends in extreme precipitation events in the dry zone of Sri Lanka

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Abstract: Extreme precipitation events can be devastating, especially in countries heavily reliant on agriculture. In Sri Lanka, where agriculture is predominantly influenced by the dry zone, studying trends in precipitation extremes is crucial for enhancing resilience and mitigating adverse impacts. The objective of this study is to examine the annual and seasonal trends in extreme precipitation events within the dry zone of Sri Lanka. Daily precipitation data from 19 selected locations within the dry zone, spanning 38 years from 1981 to 2019, were analyzed. Thirteen extreme precipitation indices were computed using the RClimDex software package and Microsoft Excel, following the guidelines established by the expert team on climate change detection and indices (ETCCDI). Regression analysis and Mann-Kendall tests were conducted to assess trends in annual and seasonal extreme precipitation events. This study, which utilized more recent data, identified significant ($p < 0.05$) trends in both annual and seasonal precipitation indices. Seven locations exhibited a significant ($p < 0.05$) positive trend in annual total precipitation (PRCPTOT), mainly attributed to variations in the number of rainy days. While precipitation during the *Yala* season remained consistent in many locations, a decrease in drought events was observed. During the *Maha* season, Anuradhapura, Batticaloa, Okkampitiya, Wellawaya Trincomalee and Polonnaruwa showed significant positive trends for flood-related indices indicating a decrease in drought occurences during the season.

Keywords: Dry zone of Sri Lanka, extreme precipitation, *Maha* season, Mann Kendal, RClimDex, *Yala* season.

INTRODUCTION

Climate change (CC) refers to a change in the state of the climate that can be identified by changes in the long-term mean or the short-term variability of its properties and that persists for an extended period, typically decades or longer (IPCC, 2014). It has caused changes in the frequency and severity of climate extremes such as heat waves, droughts, floods, and tropical cyclones (Jayadas & Ambujam, 2019). Therefore, CC has been identified as a significant threat to both natural and human ecosystems in the 21st century (De Costa, 2008). The impacts of climate change can either be beneficial or detrimental to natural and man-made ecosystems, particularly affecting ecosystem services and human well-being (Solomon, 2007). Changes in the frequency, intensity, spatial extent, duration, and timing of weather attributes can result in climate-related disasters (IPCC, 2014). The occurrence of weather attributes beyond their threshold limits is known as 'climate extremes' (Field *et al*., 2012).

Numerous studies conducted in the recent past have shown a growing tendency of precipitation variability at sub-regional, regional, and global scales (Collins *et al*., 2000, Zhang *et al*., 2000, Groisman *et al*., 2005, Griffiths & Bradley, 2007, Pendergrass *et al*., 2017). In

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the last few decades, the Asian region has experienced significant changes in the occurrence of extreme climate events (Griffiths *et al*., 2005, Choi *et al*., 2009, Caesar *et al*., 2011). Many Asian countries are classified as highly vulnerable to extreme climate events based on their economic status and other related limiting factors. A study by Sheikh *et al*. (2015) in South Asia revealed that changes in extreme precipitation indices are less coherent. However, on average, most extreme precipitation indices show increases in South Asia.

Sri Lanka, a South Asian island, has a diverse geography, including mountains rising up to 2500 m amidst flat terrain. The country's altitude delineates three zones: low country (< 300m), mid country (300-900m), and up country (> 900m). Sri Lanka experiences Southwest (SWM) and Northeast (NEM) monsoons, which determine its precipitation patterns leading to two main seasons (SWM: May-Sept, NEM: Dec-Feb) and two inter-monsoon periods [first inter-monsoon (FIM): Mar-Apr, second inter-monsoon (SIM): Oct-Dec] (Domroes 1974; Suppiah, 1996). Based on the precipitation climate, the country has traditionally been classified into Dry (<1750mm), Intermediate (1750-2500mm), and Wet (>2500mm) zones. The seasonal variation of monsoon precipitation delineates two distinct agricultural (cropping) seasons, the major *Maha* and the minor *Yala* across the dry zone of the country.

Climate change has caused significant changes in precipitation trends in Sri Lanka over the last few decades (Naveendrakumar *et al*., 2018). Studies in Sri Lanka have documented numerous extreme precipitation events, resulting in catastrophic floods, and droughts (Jayawardena *et al*., 2018, Naveendrakumar *et al*., 2019, Thevakaran *et al*., 2019). Moreover, it has been reported that high-intensity precipitation-driven flash floods in urban areas are becoming more frequent in recent years. The number of deaths due to flash floods has increased during the past decade in Sri Lanka (Ministry of Disaster Management, 2016). In addition, about five million people were affected between 2000 and 2013 due to 25 large-scale floods in Sri Lanka (Ministry of Disaster Management, 2018).

An increasing trend in annual total precipitation was reported from 1980 to 2015 (Karunathilaka *et al*., 2017, Sanjeewani & Manawadu, 2017, Jayawardene *et al*., 2018). Sanjeewani & Manawadu (2017) emphasized that extraordinary precipitation extremes are mainly concentrated in the southwestern part of Sri Lanka. In contrast, Thevakaran et al. (2019) reported that in the last 50 years, large-scale climate change resulted in increasing trends in the number of dry days in the wet zone.

Previous studies on the long-term trends of most precipitation indices in Sri Lanka, covering various periods from 1870 to 2007, have shown spatially and temporally variable trends - both positive and negative (Suppiah, 1986; 1996; Senevirathna *et al*., 1997, Wickramagamage, 1998, Malmgren *et al*., 2003, Madduma & Wickramagamage, 2004, Eriyagama & Smakhtin, 2006, Ampitiyawatta & Guo 2009). Malmgren *et al*. (2003) found a decrease in the average monthly precipitation at higher elevations and an increase in precipitation in the lowlands in the southwestern sector of Sri Lanka during the southwest monsoon. According to Sanjeewani & Manawadu (2014), some of the dry zone locations (Batticaloa, Hambantota, and Trincomalee) showed a significant increase in annual maximum consecutive five-day precipitation events. Sheikh *et al*. (2015) found declining precipitation trends in the southern part of Sri Lanka from 1961 to 2000. Owing to these contradictory findings Jayawardena *et al.*, (2005) concluded that a coherent increase or decrease in precipitation in the wet or dry zones is apparent in the last 100 years (1895-1996).

Extreme climate events such as high intensity precipitation and long duration droughts are more significant and cause more catastrophic disasters than small changes in the climate. Understanding climate change and how these changes can impact extreme climate events would provide insights into future courses of action. Therefore, analyzing extreme precipitation events in different climatic regions and seasons in Sri Lanka is crucial for policymakers to plan adaptation strategies and minimize the impact from extreme events such as flash floods and droughts. Additionally, it will provide valuable information for the planning and management of water resources to ensure peoples livelihoods and food security. Although many research studies are available on climate change and climate variability in Sri Lanka, less attention has been given to the study of extreme climate events, especially in various climatic zones and monsoon seasons. Since the different climatic zones are not uniform, distinct studies are necessary. Therefore, the objective of this study is to identify annual and seasonal trends in precipitation extremes in the dry zone of Sri Lanka.

The dry zone covers almost three-quarters of the island's land surface (Punyawardena *et al*., 2003). This area receives less than 1750 mm of annual precipitation and the main agricultural practices in this region are rain-fed. The dry zone contributes the most to the national paddy production, which is the major food crop in Sri Lanka. Therefore, identifying precipitation extremes over the dry zone of Sri Lanka will be beneficial for planning adaptation strategies and sustaining agriculture in the future.

MATERIALS AND METHODS

Data and study Area

From the long-term daily precipitation records available at the Department of Meteorology in Sri Lanka, 19 gauging stations were selected to cover geographical areas in the dry zone. The locations (Figure 1) and elevation details of all selected stations are given in Table 01.

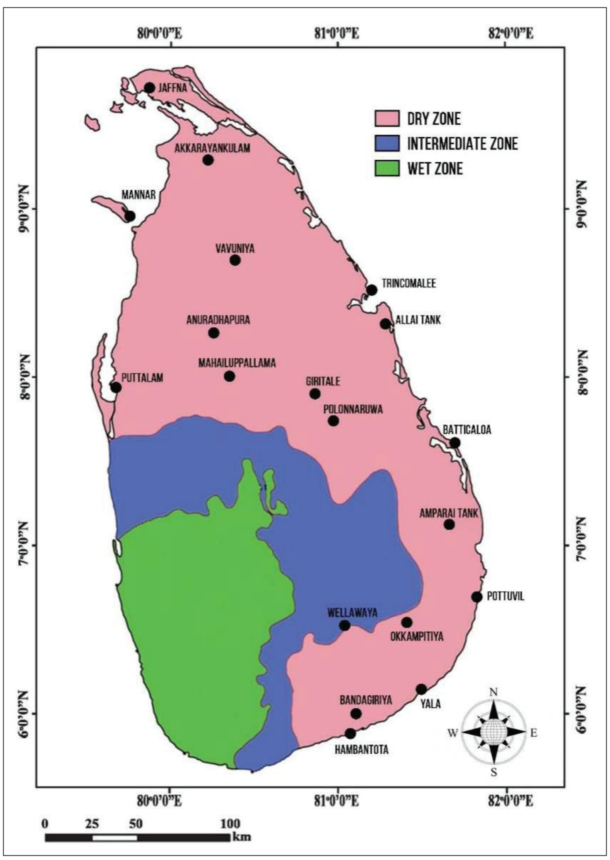

Figure 1: Selected gauging stations in the Dry Zone, Sri Lanka

Table 1: Latitude, longitude and altitude of selected locations

Location	Latitude	Longitude	Altitude(m)
Batticaloa	7.72	81.70	5
Jaffna	9.68	80.03	5
Puttalam	8.03	79.83	6
Pottuvil	6.88	81.83	7
Mannar	8.98	79.92	8
Trincomalee	8.58	81.25	8
Allai tank	8.40	81.32	9
Hambantota	6.12	81.13	16
Akkarayankulam	9.30	80.35	28
Amparai tank	7.28	81.67	40
Polonnaruwa	7.87	81.05	51
Yala	6.37	81.53	67
Giritale	8.00	80.93	77
Anuradhapura	8.35	80.38	81
Vavuniya	8.75	80.50	99
Bandagiriya	6.23	81.15	100
Okkampitiya	81.3	6.75	100
Mahailuppallama	8.12	80.46	113
Wellawaya	6.73	81.10	189

Long-term data records are essential for detecting trends (Westmacott & Burn, 1997). Therefore, daily observed precipitation data from all selected locations were collected from 1981 to 2019. According to Keggenhoff *et al*. (2014), trends can be successfully observed when missing values are less than 20%. All selected stations satisfied this condition and had a minimum of 30 years of data. The length of the data set meets the minimum requirement to investigate evidence of climate change in hydro-climatic time series as proposed by Burn and Elnur (2002) and Kahya and Kalayci (2004). The annual data was rearranged into the two cultivation seasons (*Yala* and *Maha*), considering the two monsoons (SWM and NEM). Data covering six months from March to August (*Yala* season), and six months from September to February (*Maha* season) were analyzed seasonally (Chithranayana and Punyawardene, 2008).

Data and quality control

Data quality control was done using the RClimDex (version 4.0.2.) software to identify missing and unrealistic values. During this process, all user-defined missing and unrealistic values were replaced by a default missing marker. Since the focus of the study is on extreme events, no attempt was made to reconstruct the missing daily precipitation records.

Selection of extreme indices

Researchers have utilized various threshold values and indices to study extreme climate events, depending on the region of interest and the season (Sanjeewani and Manawadu, 2017, Mekonen and Berlie, 2020, Huo *et al*., 2021). In this study, extreme precipitation indices defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) (Table 2) were used. The RClimDex software calculates 27 extreme climate indices as described by ETCCDI. For this study, 11 extreme precipitation indices were selected based on their relevance to the dry zone of Sri Lanka. Further, two indices, R95p* and R99p*, were defined by the authors (Table 3) to better explain the conditions in Sri Lanka according to the ETCCDI definitions.

Annual extreme precipitation events were calculated using the RClimDex software package (version 4.0.2.) while both the RClimDex software package (version 4.0.2.) and Excel software package were used for seasonal analysis.

Table 2: Precipitation indices recommended by Expert Team on Climate Change Detection and Indices

Index	Descriptive name	Definition	Unit
PRCPTOT	Annual total wet days precipitation	Annual/seasonal total precipitation on wet days (precipitation >=1 mm)	mm
R10	Heavy precipitation days	Annual/seasonal count of days when precipitation is greater than 10 mm	days
R20	Very heavy precipitation Days	Annual/seasonal count of days when precipitation is greater than 20 mm	days
R25	Extreme precipitation Days	Annual/seasonal count of days when PRCP >= 25 mm; 25 mm is the user-defined threshold	days
R95p	Very wet days	Annual/seasonal total precipitation when precipitation is greater than the 95th percentile	mm
R99p	Extremely wet days	Annual/seasonal total precipitation when precipitation is greater than the 99th percentile	mm
RX1day	Maximum 1-day precipitation amount	Annual/seasonal maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Annual/seasonal maximum of consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual/seasonal total precipitation divided by the number of wet days (defined as precipitation >= 1.0 mm) in the year	mm/day
CWD	Consecutive wet days	Annual/seasonal maximum number of consecutive days with precipitation >=1 mm	days
CDD	Consecutive dry days	Annual/seasonal maximum number of consecutive days with precipitation <1 mm	days

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

Index	Descriptive name	Definition	Units
R95p*	Number of very wet days	Annual/seasonal count of days when precipitation is greater than 95th percentile	days
R99p*	Number of extremely wet days	Annual/seasonal count of days when precipitation is greater than 99th percentile	days

Trend analysis

The annual and seasonal trends of extreme events were detected by the Mann-Kendall (MK) test and regression analysis. The Mann-Kendall test is widely used in climatological and hydrological time series trend analysis because it is a non-parametric test and does not require the data to be normally distributed (Mann, 1945, Kendall, 1975).

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

In which,

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

Where Z_{mk}, is the Mann-Kendall statistic, x_k, and x_i are the sequential data values, n is the length of the data set, and sgn (x_k - x_i) is equal to 1,0, -1. If (x_k−x_i) is greater than, equal to, or less than zero, respectively. e_i is the extent of any given tie and ∑ denotes the summation of all ties. The null hypothesis, H_o, of no trend is accepted if the computed p-value is greater than the significance level (α =0.05). A positive value of Kendall's tau indicates an 'upward trend' while a negative value indicates a 'downward trend'.

RESULTS AND DISCUSSION

This study analyzes the trend of annual and seasonal extreme precipitation over the past 38 years (from 1981 to 2019) in the dry zone of Sri Lanka. Annual and seasonal (*Yala* and *Maha*) trends of extreme precipitation indices are described separately within this section. The significance of the trends was determined at the 95% confidence level.

Annual trends of the precipitation extremes in the dry zone

Annual total precipitation

During the study period, the dry zone received an average of 1359±188 mm of annual precipitation. The highest (1871±149 mm) and lowest (902±96mm) mean values were observed in Wellawaya and Bandagiriya, respectively. The highest variability of inter-annual precipitation was observed in Batticaloa (inter-quartile value of 652 mm) and the lowest in Mannar (inter-quartile value of 231 mm). The annual precipitation at seven locations (Anuradhapura, Akkarayankulam, Batticaloa, Mahailuppallama, Pottuvil, Polonnaruwa, and Wellawaya) showed significant positive trends (Figure 2), which is consistent with Jayawardene *et al.* (2018).

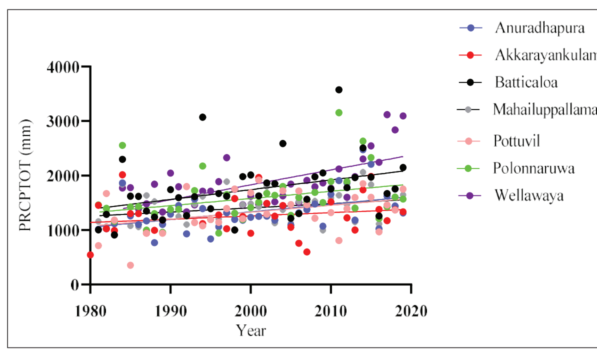

Figure 2: Locations with significant increasing trends for annual total wet days precipitation

Table 4: Correlation of total precipitation to higher intensity rainfall events R10, R20, R25, R99p, RX1day, RX5day in locations with positive precipitation trends

Location	R10	R20	R25	R95p	R99p	RX1day	RX5day
Anuradhapura	0.88	0.93	0.94	0.73	0.32	0.39	0.60
Akkarayankulam	0.77	0.88	0.90	0.30	-0.02	0.51	0.66
Batticaloa	0.94	0.93	0.93	0.81	0.74	0.67	0.72
Mahailuppallama	0.78	0.80	0.85	0.52	0.13	0.39	0.38
Pottuvil	0.81	0.88	0.89	0.34	0.01	0.46	0.58
Polonnaruwa	0.87	0.93	0.94	0.74	0.67	0.44	0.71
Wellawaya	0.85	0.93	0.96	0.66	0.39	0.16	0.47

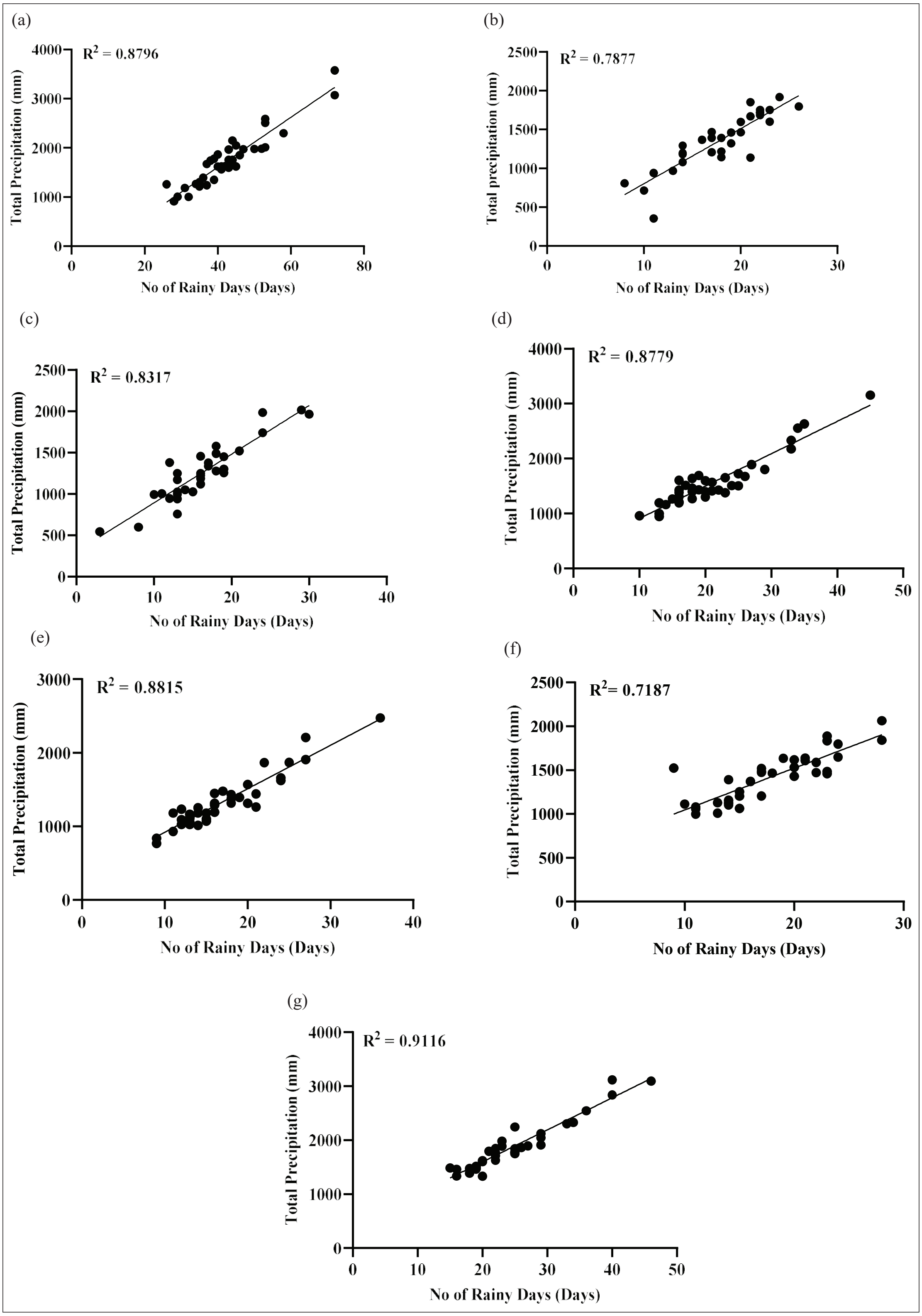

Figure 3: Correlations among the indices explaining number of rainy days (R10/R20/R25) with the total precipitation (PRCPTOT) at (a)Batticaloa (b) Pottuvil (c) Akkarayankulam (d)Polonnaruwa (e) Anuradhapura (f) Mahailuppallama and (g) Wellawaya.

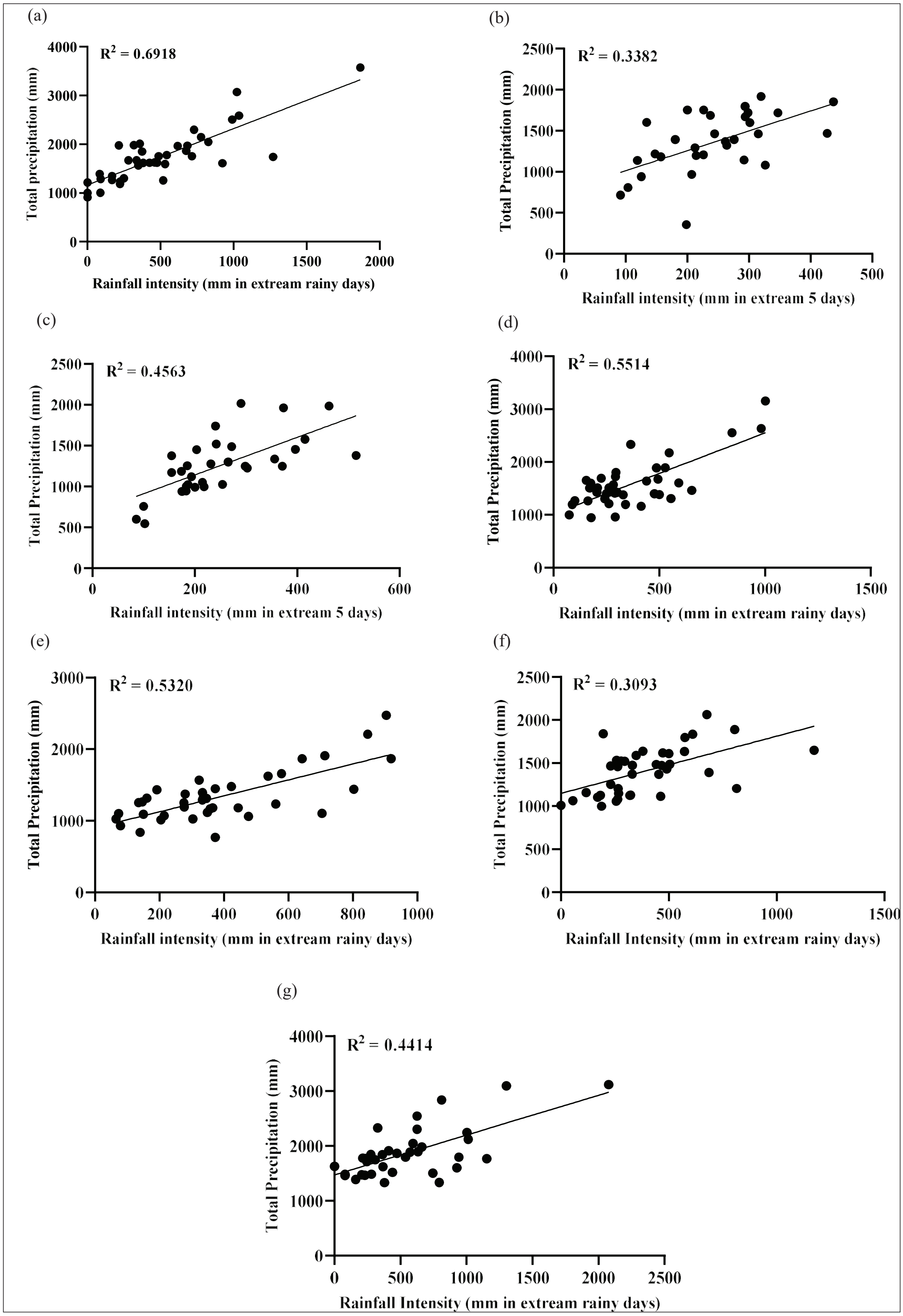

Figure 4: Correlations among the indices explaining rainfall intensity (R95p/Rx5day) with the total precipitation (PRCPTOT) at (a)Batticaloa (b) Pottuvil (c) Akkarayankulam (d)Polonnaruwa (e) Anuradhapura (f) Mahailuppallama and (g) Wellawaya.

The total precipitation is governed by two factors: the number of rainy days and the intensity of precipitation. In RClimDex, "extreme rainy days" are further classified into R10, R20 and R25 based on daily precipitation. The precipitation intensity is explained by the indices, R95p and R99p. The most extreme precipitation event for each calendar year is identified as RX1day and RX5day.

The locations that show positive annual precipitation trends are strongly correlated with R10, R20 and R25 indices (Figures). However, R95p, R99p, RX1day and RX5day did not show a strong correlation with variations in total precipitation. Furthermore, the Simple Daily Intensity Index (SDII) for Anuradhapura, Batticaloa, Mahailuppallama, Okkampitiya, Giritale and Wellawaya showed positive trends over the study period. Therefore, variations in total precipitation are primarily due to changes in extreme rainy days (i.e., R25 and SDII).

Variation in extreme precipitations

The fixed threshold base indices, R10, R20 and R25, represent the number of days with heavy (≥10 mm), very heavy (≥20 mm) and extreme (≥25 mm) daily precipitation, respectively. According to this study, the dry zone receives 13-20 days of very heavy precipitation per year. The highest median number of very heavy precipitation was recorded in the Amparai tank (25 days) and the lowest in Hambanthota, Bandagiriya and Yaala (12 days). The extreme precipitation index, R10, showed a significant positive trend at 4 locations (Anuradhapura, Batticoloa, Amparai tank, Polonnaruwa). The R20 index similarly showed significant positive trends at six locations (Anuradhapura, Mahailuppallama, Batticoloa, Amparai tank, Wellawaya, Okkampitiya), and the R25 index showed positive trends at seven locations (Anuradhapura, Mahailuppallama, Batticoloa, Amparai tank, Wellawaya, Polonnaruwa, Giritale). All three indices showed positive trends in Anuradhapura, Batticaloa and Amparai tank (Table 4). Both R20 and R25 showed positive trends in Mahailuppallama and Wellawaya, while Polonnaruwa showed positive trends for R10 and R25 indices. Okkampitiya and Giritale showed positive trends for R20 and R25, respectively. This is in agreement with Jayawardene et al., (2018) who reported increases of 10, 20 and 30 mm rainy days in Sri Lanka.

The absolute indices RX1day and RX5day (Annual maximum one day precipitation and Annual maximum five consecutive days precipitation) showed positive trends at three locations (Anuradhapura, Mahailuppallama, Giritale) and four locations (Anuradhapura, Mahailuppallama, Batticoloa, Wellawaya), respectively. Both indices had significant positive trends in Anuradhapura and Mahailuppallama, while Giritale showed a positive trend for RX1day precipitation. Batticaloa and Wellawaya showed positive trends for RX5day precipitation. The mean RX1day precipitation for the dry zone was 115±8mm and that for RX5day precipitation was 221±19mm.

The percentile indices, R95p and R99p (precipitation on very wet days and extremely wet days), exhibited positive trends in Anuradhapura, Mahailuppallama and Wellawaya. In contrast, Mannar showed a significant negative trend for R95p. The mean of the simple daily intensity index (SDII) for the dry zone was 19.1±1.6 mm/day. The highest mean SDII was recorded at the Allai Tank (23.8 mm/day) and the lowest at Hambanthota (12.4 mm/day). The SDII showed significant positive trends at six locations (Anuradhapura, Batticaloa, Mahailuppallama, Wellawaya, Okkampitiya and Giritale) and was negative at three locations (Mannar, Bandagiriya and Yaala).

The annual number of consecutive wet days (CWD) indicates the probability of floods. Five stations (Anuradhapura, Hambantota, Pottuvil, Trincomalee, and Polonnaruwa) showed significant positive trends for CWD (Figure 5). None of the stations showed significant negative trends for CWD. The probability of the occurrence of drought can be identified from consecutive dry days (CDD). The CDD decreased significantly at four locations (Pottuvil, Wellawaya, Bandagiriya, and Yaala). However, Mannar showed a significant increasing trend of CDD (Figure 6).

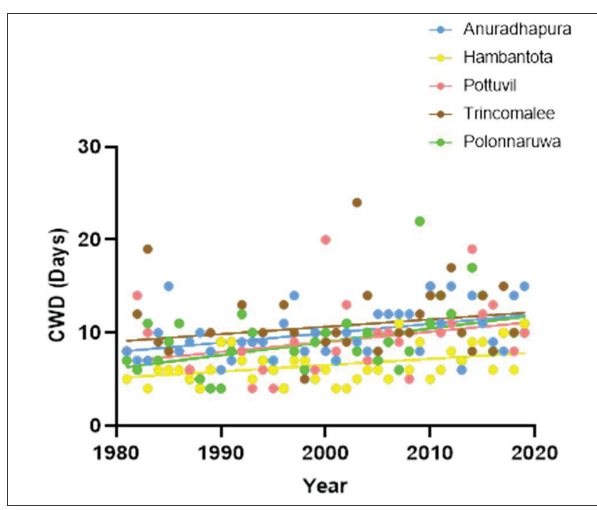

Figure 5: Locations with significant increasing trends for CWD

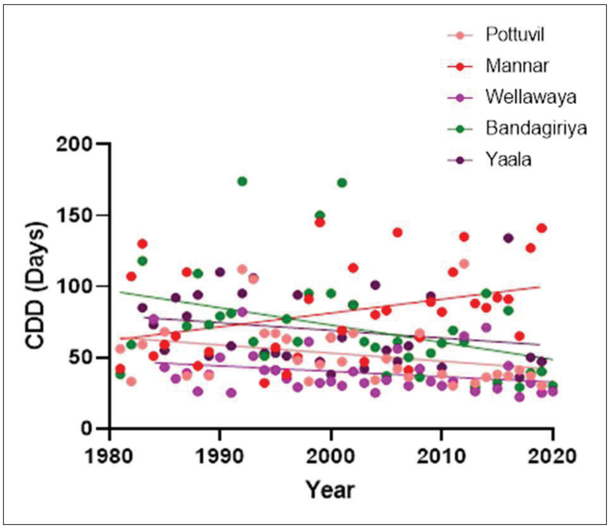

Figure 6: Locations with significant increasing trends for CDD

Extreme indices showed significant trends (positive or negative) at 12 locations: Anuradhapura (12 indices), Wellawaya (10 indices), Mahailuppallama (9 indices), Batticaloa (8 indices), Polonnaruwa (5 indices), Pottuvil (4 indices), Amparai tank (3 indices), Giritale (3 indices), Mannar (3 indices), Bandagiriya (2 indices), Okkampitiya (2 indices), and Yaala (2 indices).

Mannar, the trends were negative for R95p and SDII, and positive for CDD. The flood risk in Mannar decreased due to the reduced intense precipitation and increased CDDs. Further Bandagiriya and Yaala also showed negative trends for SDII. In contrast, all other locations showed positive trends for precipitation intensity, heavy precipitation and consecutive rainy days indicating a higher flood risk in those areas. Therefore, widespread areas of the dry zone are expeiencing increasing total annual precipitation, higher intensity of precipitation and flood risk. The probability of flood risks was higher in Anuradhapura, Mahailuppallama, Wellawaya and Batticaloa. Basnayake *et al*., (2002) and Malmgren *et al*., (2003) reported there was no clear trend or pattern in precipitation indices within Sri Lanka. However, present study, with more recent data, shows significant trends in annual precipitation indices.

Number of extreme rainy days

In the period 1981-2019, significant positive trends in the number of extreme rainy days were identified in Anuradhapura (R95p*, R99p*), Mahailuppallama (R95p*), Batticaloa (R95p*, R99p*), Pottuvil (R99p*), Wellawaya (R95p*, R99p*), Polonnaruwa (R95p*), and Giritale (R99p*) (Figure 7). Allai tank (R99p*) displayed a significant negative trend for number of extreme rainy days.

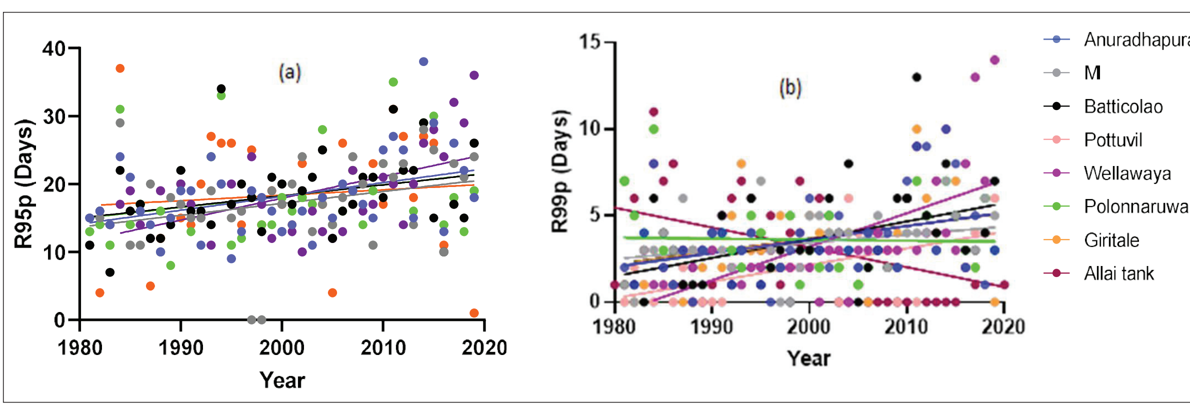

Figure 7: Locations with significant trends in (a) the number of very wet days (R95p), and (b) the number of extremely wet days (R99p)

Seasonal trend analysis - *Yala* season

Seasonal total precipitation

Yala is relatively a dry season in the dry zone of Sri Lanka. During the study period, the mean *Yala* precipitation in the dry zone was 350±25 mm. Precipitation was highest in Wellawaya (661±46 mm) and lowest in Yaala (223±16 mm). The highest variability in *Yala* precipitation was observed in Wellawaya (inter-quartile value 354 mm) and the lowest in Hambanthota (inter-quartile value 99 mm). Only Wellawaya showed a significant increase in precipitation during the study period. Based on mean values, Wellawaya recorded the highest values for nine indices including highest mean precipitation (661.5mm), maximum one day precipitation (RX1DAY, 83.9mm), maximum five consecutive days precipitation (RX5DAY, 156.1mm), very wet days precipitation (R95p, 430.1mm), extremely wet days precipitation (R99p, 160.9mm), number of heavy precipitations (R10, 18 days), number of very heavy precipitations (R20, 10 days), number of extreme precipitations (R25, 7 days) and consecutive wet days (CWD, 6days). In contrast Allai tank had the highest value for consecutive dry days (69 days) followed by Mannar (66 days). Most locations in the dry zone received 3 (1st Quartile) - 7 (3rd Quartile) extreme precipitations (R25) in the *Yala* season. *Yala* seasons with precipitation Beyond this range (i.e., greater than Q3) were considered extreme.

The mean maximum *Yala* season RX1day and RX5day precipitation were in the range 51-83 mm and 86-156 mm, respectively. These absolute indices RX1day and RX5day showed positive trends at two locations (Mahailuppallama and Wellawaya) and three locations (Anuradhapura, Mahailuppallama and Wellawaya) locations, respectively. The increasing trends of R25, RX1day and RX5day in Anuradhapura, Mahaillupplallama, Vauniya, Amparai tank and Wellawaya indicate a potential flood risk in these dry zone areas.

The percentile indices R95p had positive trends in Anuradhapura and Wellawaya, and R99p in Trincomalee and Wellawaya. The mean of the simple daily intensity index (SDII) for the dry zone was 17.1±1.1 mm/day. The highest mean for SDII was recorded in Mannar (33.5 mm/day) and the lowest in Hambanthota (10.5 mm/day).

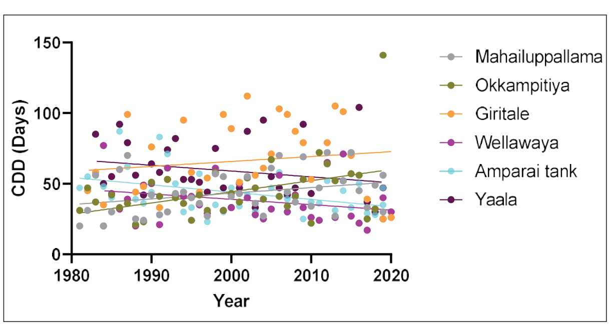

Figure 8: Locations with significant trends for CDD in the *Yala* season

SDII had significant positive trends at three locations (Mahailuppallama, Wellawaya and Okkampitiya) and was negative at two locations (Bandagiriya and Yaala). Wellawaya showed significant positive trends for CWD while Mahailuppallama, Okkampitiya and Giritale showed significant positive trends for CDD. The trend was negative for Wellawaya, Yaala and Amparai tank (Figure 8).

In conclusion, the precipitation during the *Yala* season did not change for many locations in the dry zone. However, Anuradhapura, Mahailluplallama, Vauniya, Amparai tank and Wellawaya showed significant positive trends for flood-related indices and negative trends for drought indices. Positive trends in drought indices suggest a potential for drought in Mahailuppallama, Okkampitiya and Giritale areas. This aligns with the findings of Thevakaran *et al*., (2019), on the behaviour of dry days during the *Yala* season. However, Chithranayana & Punyawardene (2008) concluded that all Agroecological regions of the dry zone are highly vulnerable to drought conditions during the *Yala* seasons. Therefore, the present study and that of Thevakaran *et al*., (2019) using more recent data concludes a reduction in drought events in the dry zone during the *Yala* season. In contrast to the present study, Wikramagamage (2015) reported a decrease in precipitation across Sri Lanka's dry zone regions during the *Yala* season from 1981 to 2010. The Southwest monsoon serves as the primary moisture source for the country during the *Yala* season. Karunathilaka *et al*., (2017) found a downward trend in precipitation records during the Southwest monsoon season across most parts of the country, based on data from 1966 to 2015.

Number of extreme rainy days - Yala Season

Both the R95p* and R99p* indices of Wellawaya showed significant positive trends in the number of extreme rainy days during the *Yala* season throughout the study period. Thevakaran *et al*., (2019) found no consistent statistically significant trends in heavy precipitation events during the two cropping seasons in Sri Lanka from 1961 to 2010. This study also detected a statistically significant upward trend in Jaffna, determined by the 99th percentile within the *Yala* season of the year. However, no significant trends were found in Jaffna for both indices (R95p*, R99p*) from our study using the most recent data for the *Yala* season.

Seasonal trend analysis - *Maha* season

Seasonal total precipitation

Maha is the major cropping season in Sri Lanka. During the study period the mean *Maha* seasonal precipitation in the dry zone was 1014±57 mm. The highest *Maha* seasonal precipitation was observed in Batticaloa (1441±88 mm) and the lowest in Bandagiriya (628±43 mm). The variability of the *Maha* seasonal precipitation was highest in Allai tank (inter-quartile value of 657 mm) and the lowest in Mannar (inter-quartile value of 188 mm). During the study period, the *Maha* seasonal precipitation increased significantly only in Wellawaya. Most locations in the dry zone received 9-16 (1st and 3rd Quartile) extremely heavy precipitation events (R25) in the *Maha* season. Beyond this range (greater than Q3) was considered an extreme M*aha* season. The R25 showed significant increasing trends in Wellawaya. Mean maximum *Maha* season RX1day and RX5days precipitation were in the range of 76-129 mm and 151-241 mm, respectively. The above absolute indices (RX1day and RX5days) showed positive trends in one (Anuradhapura) and two (Anuradhapura and Batticaloa) locations, respectively.

The percentile index R95p showed positive trends in Batticaloa and Wellawaya, and R99p in Wellawaya. The mean of the simple daily intensity index (SDII) for the dry zone was 19.1±1.0 mm/day. The highest mean SDII was recorded in Allai tank (24.9 mm/day) and the lowest in Hambanthota (6.1 mm/day). The SDII had significant positive trends at three locations (Anuradhapura, Okkampitiya and Giritale) and negative trends in Bandagiriya. Wellawaya, Trincomalee and Polonnaruwa showed significant positive trends for CWD (Figure 9) and Bandagiriya showed significant negative trends for CDD.

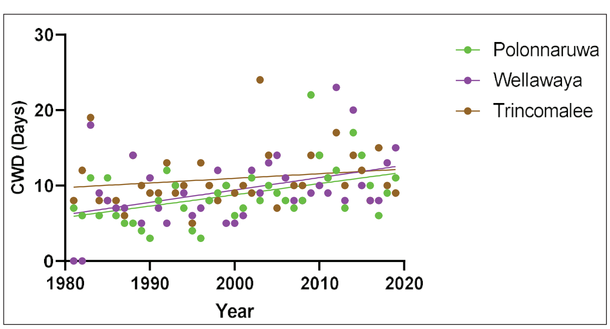

Figure 9: Locations with significant trends for CWD in the *Maha* season

In conclusion, precipitation in the *Maha* season did not change at many locations in the dry zone of Sri Lanka. However, Anuradhapura, Batticaloa, Okkampitiya, Wellawaya Trincomalee and Polonnaruwa had significant positive trends for flood related indices. This is in agreement with the findings of Chithranayana & Punyawardene (2008) that drought in dry zone is less likely to be experienced during the *Maha* season.

Number of extreme rainy days Maha season

A general increasing trend was detected in the number of extreme rainy days in the *Maha* season during the study period. Out of the 19 selected locations, 16 showed increasing trends for R95p* while 3 showed decreasing trends. The R99p* index showed increasing trends at 11 locations while 8 locations showed a decreasing trend. Most importantly the eastern coastal part of the country had a clear increasing pattern in the number of extreme rainy days; however, the trend was significant only in Batticaloa (R95*). All other trends were non-significant during the study period.

CONCLUSION

This study attempted to investigate annual and seasonal trends in the occurrence of extreme precipitation events in the dry zone of Sri Lanka. Trend analysis revealed significant positive trends in both annual and seasonal total precipitation within the dry zone throughout the study period. The rise in total precipitation was mainly driven by the number of rainy days. Moreover, an expanded area of the dry zone showed an increase in higher-intensity precipitation events, elevating the risk of floods. The probability of flood risk was greater in Anuradhapura, Mahailuppallama, Wellawaya and Batticaloa. Changes in atmospheric moisture resulting from warming oceans and intensified monsoonal circulation may contribute to an increased frequency of rain-bearing systems reaching the dry zone. Increases in atmospheric water vapor may lead to warming temperatures, which in turn fuels intense rainfall when condensation occurs.

Although some previous studies have concluded no significant changes in precipitation patterns within the dry zone, our study reveals significant changes in extreme precipitation indices, including both increasing and decreasing significant trends. Among the locations examined in this study, Wellawaya and Mannar showed significant deviations from the typical behavior of precipitation indices. Wellawaya demonstrated a significant positive trend in extreme precipitation, whereas Mannar exhibited a significant occurrence of extreme drought indices. Overall, the majority of locations within the dry zone displayed a wetting trend during the study period.

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