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Temporal Rainfall Trends in the Northern and Eastern Coastal Regions of Sri Lanka: An Analysis Spanning from 1981 to 2019

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ABSTRACT

The annual and seasonal rainfall trends and patterns along the Northern and Eastern coastal belt of Sri Lanka were analyzed by studying the daily rainfall records from 1981 to 2019 from five locations: Jaffna, Kanukkerny Tank, Trincomalee, Batticaloa, and Pottuvil, because no such pattern has been addressed previously. The Mann-Kendall test and Sen's slope estimator were used to detect the annual and seasonal rainfall trends and the magnitude of the trend, respectively. The findings indicate that the eastern coastal belt exhibits more consistent rainfall patterns both annually and seasonally. The rainfall pattern of Jaffna, situated in the Northern coastal region, differs from the aforementioned locations. The long-term mean annual rainfall of all locations was less than 1750 mm. The lowest seasonal rainfall occurs during the first inter-monsoon (FIM) season, amounting to less than 200 mm. During the second inter-monsoon (SIM) season, the entire area experiences its peak monthly rainfall, reaching up to 280 mm/month. The Northeast monsoon (NEM) is distinctly wet season for the entire Northern and Eastern coastal belt, with rainfall surpassing 100 mm/month. Trend investigations reveal that only the Batticaloa has a significantly increasing trend of 17.5 mm/year. This annual significant ($p < 0.05$) trend primarily stems from the noteworthy trend during the SIM, with an increase of 7.3 mm/season. Although converse trends are evident during other seasons across all locations, none of them are statistically significant ($p > 0.05$). In conclusion, the eastern coastal belt demonstrates a more consistent rainfall pattern both annually and seasonally, whereas the rainfall pattern of the northern region differs from it. Furthermore, only the Batticaloa region shows a statistically significant trend with an increment of 17.5 mm/year.

Keywords: Mann-Kendall, Northern and Eastern, Rainfall trend, Sri Lanka.

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INTRODUCTION

Sri Lanka, being an island, occupies a 1620 km long coastline, encircling the entirety of the country (Lakmali *et al*., 2016) and the Northern and Eastern coastal region encompasses one-third of it. The whole Northern and Eastern coastal region belongs to the dry zone of the country where the annual average rainfall is less than 1750 mm (Ampitiyawatta *et al*., 2022). The northeast monsoon which spans from December to February (Domrös, 1974; Suppiah, 1996; Thambyahpillay, 1954) is the main rainfall source and the season to the region while tropical depressions also bring substantial amounts of rainfall, especially during the second inter monsoon (from October to December) (Ampitiyawatta *et al*., 2022). Jaffna, Trincomalee, Batticaloa and Pottuvil are the main cities located in this region and are moderately populated. Agriculture and fisheries are the main income sources of dwellers in this region while business, tourism, and employment in public and private organizations are minor. Department of Census and Statistics (2022) of Sri Lanka reported that 13.4% of paddy harvested areas of the country were located in Jaffna, Trincomalee and Batticaloa districts and Wickramaarachchi *et al*. (2020) highlighted that the Eastern coastal line is a hub of fisheries and aquaculture. Jaffna is located in the northern parts of the country where there are no rivers, hence rainfall is the only source of water for all purposes which accounts for 67% of agriculture (Piratheeparajah *et al*., 2021). Being the main rainfall season in the Jaffna area, the northeast monsoon brings 935 – 1800 mm rainfall (Kandiah and Miyamoto, 2016) which accounts for 80% of annual rainfall (Gopalakrishnan *et al*., 2020). The eastern coastal belt, due to its geographical positioning, is directly exposed to the northeast monsoon and receives the highest percentage of annual rainfall from it (Partheepan *et al*., 2005).

Due to uncertainty and unexpected extreme rainfall events, rainfed agriculture, aquaculture and domestic water supply systems have faced unbearable difficulties in the recent past in the Northern and Eastern coastal regions. Drought susceptibilities emerged within the region due to the prolonged absence of rainfall, while flood vulnerabilities arose as a result of intense rainfall over a short period (Piratheeparajah *et al*., 2021). Partheepan *et al*. (2005) contend that higher damage to paddy production is caused by rainfall variability. Selvanayagam (2019) identified one of the serious problems faced by paddy farmers in the eastern region as adverse weather conditions. Furthermore, Selvanayagam (2019) provided elaboration on the 40% decline in paddy production observed during the *Yala* season in 2017 compared to 2016. This decrease was attributed to the insufficient water supply caused by the dry climate. The changes in the rainfall climate are also directly affecting the coastal aquaculture in the region. In their study on the impacts of climate change on shrimp aquaculture, Jayasinghe *et al*. (2019) summarized that farmers in shrimp farming have identified seasonal weather changes, heavy rains, floods, cyclones, high temperatures, low or unseasonal rainfall, and rising water levels in lagoons as significant environmental challenges.

Since rainfall serves as the primary source of water for agriculture and related industries in the region, its variations directly affect the success of agriculture and the well-being of the industries and the people of the region. The numerical measure of the rainfall amount of a region indicates whether the region is experiencing typical conditions or is at risk of drought or flooding. Hence, examining patterns in rainfall assists in recognizing the likelihood of floods or droughts in a specific area (Alahacoon and Edirisinghe, 2021).

Over the past thirty years, several investigations have been carried out both globally (Cui *et al*., 2017; Hussain *et al*., 2022; Salehi *et al*., 2020; Wang *et al*., 2020;) and within Sri Lanka (Ampitiyawatta and Guo, 2010; Bandara and Wickramagamage, 2004; Jayawardene *et al*., 2015; Kayane *et al*., 1998; Khaniya *et al*., 2019; Nisansala *et al*., 2020; Somaratne and Dhanapala, 1996) to examine rainfall trends. In Sri Lanka, studies have covered the entire island as well as specific regions, revealing distinct variations in rainfall patterns across the country. A recent study carried out by Nisansala *et al*. (2020) revealed that there is an increasing and decreasing trends in different regions of the country. They further elaborated that northern, north-central, eastern and southeastern parts of the country have experienced an increasing trend in rainfall over the past 31 years (1987 – 2017) and northwestern, western and central parts of the country have experienced a decreasing trend. Alahacoon and Edirisinghe (2021) found that the annual rainfall of all districts of Sri Lanka except four in the dry zone had a significant increase. Numerical findings of Piratheeparajah *et al*. (2021) indicated that the historical annual rainfall in Northern Sri Lanka has risen from 18.76 mm/decade to 37.68 mm/decade between 1970 and 2019. Nevertheless, no prior studies specifically addressing the identification of rainfall patterns and trends in the Northern and Eastern coastal areas have been discovered. Acknowledging the significance of the Northern and Eastern coastal region in relation to agriculture, fisheries, tourism, and the overall well-being of its residents, this research was conceived to delve into rainfall patterns and trends along the Northern and Eastern coastal belt of Sri Lanka. It was expected to investigate rainfall patterns and trends in the northern and eastern coastal belts on both an annual and seasonal basis.

MATERIALS AND METHODS

Data

For the study, five rain gauge sites (Jaffna, Kanukkerny Tank, Trincomalee, Batticaloa, and Pottuvil) were chosen along the Northern and Eastern coastal belt. The manually observed daily rainfall records spanning the past 39 years (1981 – 2019) for these locations were gathered from the Department of Meteorology, Sri Lanka. These locations distributed across the Northern and Eastern coastal belt, as illustrated in Figure 1 were strategically selected.

All the data series were validated for quality and homogeneity by the Department of Meteorology, Sri Lanka. Table 1 shows the geographical locations of the selected sites, their elevations, mean annual rainfall, and the estimated percentage of missing data. Accordingly, all the locations had less than 3% of missing data for the experimental period except Kanukkerny Tank.

In the detection of trends in time series, two fundamental principles are taken into consideration: the availability of long-term data and a minimal number of missing data. Long-term data should adhere to the criterion of no more than 10% missing data for a period of 30 years or longer (Ampitiyawatta and Guo, 2010). The stations at Kanukkerny Tank, Trincomalee, and Batticaloa comply

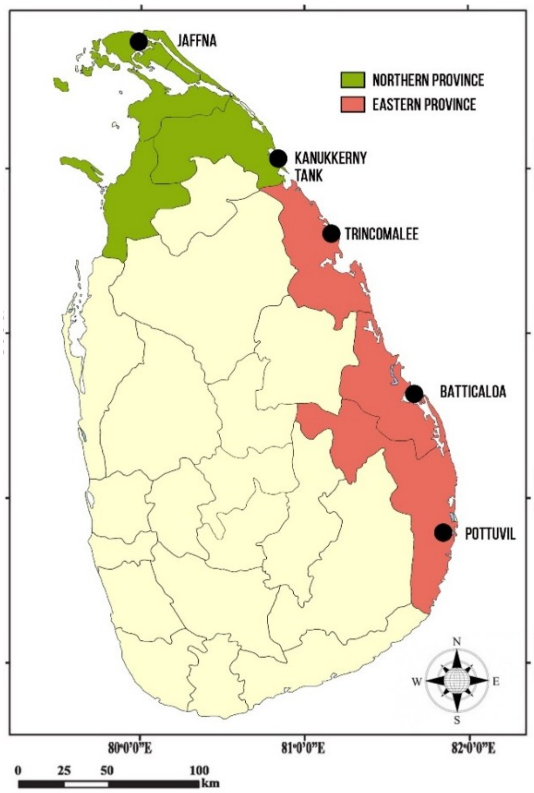


Figure 1. Geographical distribution of selected locations.

with this principle. However, owing to the civil war in the northern region during the specified time frame, rainfall records for Jaffna station are unavailable for an 11-year period (1991-2001), and this period was consequently omitted from the time series. Similarly, the rainfall records for Pottuvil were analyzed from 1992, omitting the years 2003 and 2009 due to the same reason.

Detection of Rainfall Pattern

Rainfall amounts of five locations were separately plotted against time on both an annual and seasonal basis. Subsequently, a five-point moving average window was applied to achieve a smoother curve for ease of pattern detection. The annual data series was split into four common rainy seasons based on monsoon behavior as first inter-monsoon (FIM) from March to April, southwest monsoon (SWM) from May to September, second inter-monsoon (SIM) from November to December and Northern and Eastern monsoon (NEM) from December to February (Domrös, 1974; Suppiah, 1996; Thambyahpillay, 1954).

Detection of Rainfall Trends

The Mann-Kendall (MK) test has found application in various research fields for trend detection in time series, and the trends identified by the Mann-Kendall statistics are not necessarily linear.

The MK test, originally proposed by Mann (1945) and further developed by Kendall, 1975, stands out as the most popular non-parametric method and has been endorsed by the World

Table 1. Geographical locations, elevation, mean annual rainfall and missing data percentage of selected sites.

Location	**Latitude (N°)**	**Longitude (E°)**	**Altitude (m)**	**Mean annual rainfall (mm)**	**Missing data %**
Jaffna	9.68	80.03	5	1325	2.5
Kanukkerny Tank	9.2	80.8	10	1285	3.3
Trincomalee	8.58	81.25	8	1528	2.6
Batticaloa	7.72	81.7	5	1749	0.84
Pottuvil	6.88	81.833	11	1442	1.8

Meteorological Organization (WMO) for the analysis of trends in hydro-meteorological time series. One notable feature of the MK test is its independence from the assumption of normality of the random variable. It indicates the general direction of trends whether increasing or decreasing statistically over a specific period, without providing information on the magnitude of the trends. Additionally, the Mann-Kendall test is robust against outliers due to its reliance on the sign of differences rather than directly on the values of the random variable. Owing to its wide applicability in rainfall trend detection (Aditya *et al.*, 2021; Ampitiyawatta and Guo, 2010; Karunathilaka *et al.*, 2017; Panda and Sahu, 2019; Salehi *et al.*, 2020; Wickramaarachchi *et al.*, 2020), this study also used the MK test for trend detection in the specified location of Sri Lanka. The Sen's slope estimator is frequently employed to quantify the magnitude of the trend, as the MK test primarily denotes the trend's direction. Hence, Sen's slope estimator was also used to detect the magnitude of the trend in this study.

Trend analysis was also carried out on the annual and seasonal basis. Since the annual rainfall does not evenly distribute throughout the year, the seasonal analysis was also performed for the common four rainy seasons as described above.

The Mann- Kendall test statistic is given in formula 1,

$$Z_{mk} = \begin{cases} \frac{(S-1)}{\sqrt{(Var(S))}} & S > 0 \\ 0 & S = 0 \\ \frac{(S+1)}{\sqrt{Var(S)}} & S < 0 \end{cases} \qquad \textbf{\textit{(1)}}$$

In which,

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} sgn(x_k - x_i) \qquad (2)$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_i ei(ei-1)(2e+5)}{18} \qquad (3)$$

Where, Z_{mk} gives the Mann-Kendal statistics, S denotes the mean, x_k and x_i are sequential data points, n is the number of data points and sgn (.) is the sign function. It returns -1 if the argument is negative, 0 if it is zero, and 1 if it is positive. The presence of a statistically significant trend is evaluated by using the Z_{mk} value. A positive value of Z_{mk} indicates an upward trend while negative value indicates a downward trend. The statistics Z_{mk} has a normal distribution. To test either an upward or downward monotone trend (a two-tailed test) at α level of significance, H0 is rejected if the absolute value of Z is greater than Z1-α/2, where Z1-α/2 is obtained from the standard normal cumulative distribution tables. The Z values were tested at 0.05 level of significance.

The Sen's slope estimator is given as,

$$Q_i = \frac{x_j - x_k}{j-k} \qquad (4)$$

For $i = 1,2, \ldots\ldots, n$

Where x_j *and* x_k are data values at time j and k (j>k), respectively. The median of these n values gives the Sen's estimator of slope (Q_i). The sign of the slope indicates the direction of the trend (positive for upward trend and negative for a downward trend), and the magnitude provides information about the steepness of the trend.

RESULTS AND DISCUSSION

Annual Rainfall Trend

Figure 2 (a – e) shows the general rainfall patterns observed in five locations studied, along with the representation of five-point moving average filters. The mean annual rainfall of these stations is shown in Table 1. Though there were slight variations in certain years, consequently, these findings support the earlier zonal classification of Sri Lanka based on the mean annual rainfall. Batticaloa recorded the highest mean annual rainfall (1749 mm/year) while it is observed that the long-term mean annual rainfall for all stations is below 1750 mm, categorizing them within the dry zone of the country. Kanukkerny Tank recorded the minimum rainfall of 1285 mm/year.

Considering the overall rainfall patterns of the five locations (Figure 2), Jaffna exhibits the least inter-annual rainfall variation. Further, the rainfall pattern of Jaffna differs from those observed in the other locations. The rainfall patterns in Kanukkerny Tank, Trincomalee, and Batticaloa exhibit a certain degree of similarity. This resemblance is attributed to their geographical locations along the eastern coastal belt of Sri Lanka, directly facing the Northern and Eastern monsoon, which contributes significantly to their annual rainfall.

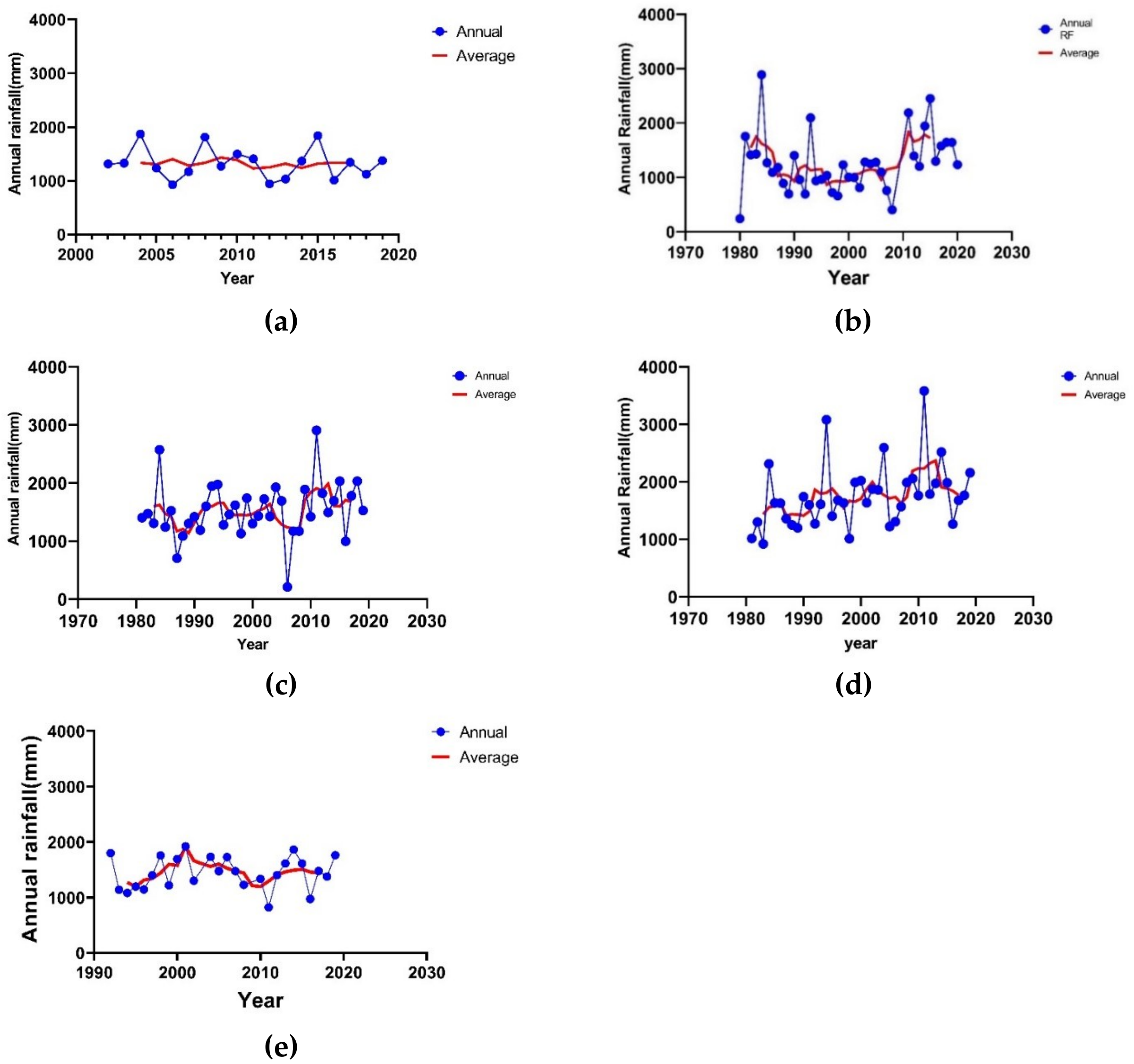


Figure 2. Long term annual rainfall pattern of (a) Jaffna, (b) Kanukkerny Tank, (c) Trincomalee, (d) Batticaloa, and (e) Pottuvil with moving average curves.

Hence, these results are deemed acceptable. Due to Pottuvil's marginal exposure to the Northern and Eastern monsoon, its rainfall pattern slightly differs from the aforementioned three locations. The years 1984, 1994, 2010, and 2014 stood out as exceptional rainfall years for Kanukkerny Tank (Figure 2-b), being the highest in 1984 during the analyzed period. This observation is verified by Nagamuthu, (2014), who confirms the occurrence of a severe flood in this area in 1984. In comparison, the Batticaloa area has experienced the highest mean annual rainfall, and during the years 1994 and 2011, the annual rainfall exceeded 3000 mm (Mathanraj and Kaleel (2017) and heavy floods also were documented during these two years, 1994 and 2011, resulting in significant agricultural damage.

Table 2 shows the Mann-Kendall statistics and Sen's slope estimator for both annual and seasonal time scales. In

Table 2. Annual and seasonal results for Mann-Kendall test and Sen's slope estimator.

Annual/ Season	**Test**	**Jaffna**	**Kanukkerny tank**	**Trincomalee**	**Batticaloa**	**Pottuvil**
Annual	MK-test	-0.033	0.108	0.192	0.325	0.120
	Sen's slope	-4.318	6.654	9.647	17.465*	6.933
FIM	MK-test	-0.255	-0.022	0.038	-0.012	0.179
	Sen's slope	-4.814	0	0.176	-0.371	2.747
SWM	MK-test	0.229	0.03	-0.003	0.078	0.162
	Sen's slope	10.440	1.266	-0.003	0.937	2.65
SIM	MK-test	-0.123	0.141	0.168	0.252	0.089
	Sen's slope	-4.581	5.987	6.19	7.343*	3.113
NEM	MK-test	-0.15	-0.006	0.077	0.127	-0.153
	Sen's slope	-11.055	-0.655	2.71	6.583	-6.988

FIM is First Inter Monsoon, SWM is Southwest Monsoon, SIM is Second Inter Monsoon and NEM is Northeast Monsoon. *Denotes the significant trend at 0.05 level.

the specified period of 1981-2019, every station exhibits an upward trend, except Jaffna. Despite Jaffna experiences a declining trend in rainfall, this trend is not deemed statistically significant. Due to its distinct location away from the Eastern coastal belt, the observed decline in rainfall in Jaffna can be reasonably accepted. In contrast, the other locations situated along the eastern coastal line demonstrate a similar pattern in rainfall behavior. On the contrary, Thevakaran *et al.*, (2019) reported divergent findings in their examination of trends in extreme rainfall events spanning from 1961 to 2010 in Sri Lanka. Their study identified significant increasing trends in heavy rainfall events (daily rainfall amount >10mm/day) specifically in Jaffna. This suggests a potential rise in intense rainfall occurrences, even as the overall trend in total rainfall indicates a decrease. Among the locations displaying upward trends, Batticaloa stands out with remarkable results demonstrating a statically significant trend. The increment is 17.46 mm/year which is a considerable value. Similar to the present study, Wickramaarachchi *et al.*, (2020) have observed upward trends for the locations of Trincomalee, Batticaloa and Pottuvil.

Seasonal Rainfall Trend

First Inter Monsoon (FIM)

Figure 3 (a – e) illustrates the long-term rainfall patterns observed during the first inter-monsoon (FIM) period (March – April) across five different locations. Notably, all these locations exhibit a consistent and similar pattern during the FIM season. It is evident from Table 3 that the mean seasonal rainfall during the first inter-monsoon is notably lower compared to other seasons. Across all locations, the seasonal mean rainfall consistently falls below 200 mm. In the majority of years, each location experiences rainfall below the 200 mm threshold, with only a few exceptions. Mathanraj and Kaleel, (2017) have also verified this observation by indicating that the rainfall in Batticaloa during FIM was consistently below 250 mm for many years. During the considered period, Kanukkerny Tank recorded the lowest rainfall (Table 3), as 59.6 mm. However, in 1984, the Kanukkerny Tank experienced the highest rainfall for that period, reaching 257.4 mm. This aligns with the findings of Nagamuthu, (2014), who reported significant flooding in the area during the year 1984. While there are both positive and negative rainfall trends during the FIM across locations, no station exhibits a significant trend (Table 2).

Southwest Monsoon (SWM)

Locations along the eastern coastal belt exhibit a somewhat similar rainfall pattern, as depicted in Figure 4, whereas the northern (Jaffna) and the southeast (Pottuvil) locations demonstrate dissimilar rainfall patterns during the SWM season. Pottuvil has experienced relatively low rainfall during the SWM season, while other locations have received a substantial amount of rainfall. However, the SWM season aligns with one of two main agricultural seasons of the country, the *Yala* season, spanning five months from May to September.

Thus, the average monthly rainfall across the entire area is approximately 50 mm. Further, the dry zone of the country has a higher evaporation rate of 6 mm/day (Punyawardena and Kulasiri, 1996). Given the agricultural significance of the country, this season might be a crucial dry period, underscoring the importance of selecting suitable dry crops for cultivation during this timeframe.

Nagamuthu, (2014) has also indicated that SWM gets a low amount of rainfall for the Northern region of Sri Lanka and it is no more than 75 mm. Further, he has noted that there are two or three consecutive dry months and generally this season is the driest in the northern region. Though positive and negative rainfall trends can be observed in different locations, none of them are statistically significant. However, the increasing trend slope shown by the Jaffna (10.4 mm/season) is a value that should be deeply considered. Similar

Table 3. Seasonal mean rainfall of observed locations.

Location	FIM	SWM	SIM	NEM
Jaffna	117.4	218.8	688.6	310.1
Kanukkerny Tank	59.6	268.3	527.5	519.6
Trincomalee	98.0	335.7	600.2	508.5
Batticaloa	134.7	234.0	562.1	824.2
Pottuvil	144.4	159.4	433.3	692.4

FIM is First Inter Monsoon, SWM is Southwest Monsoon, SIM is Second Inter Monsoon and NEM is Northeast Monsoon.

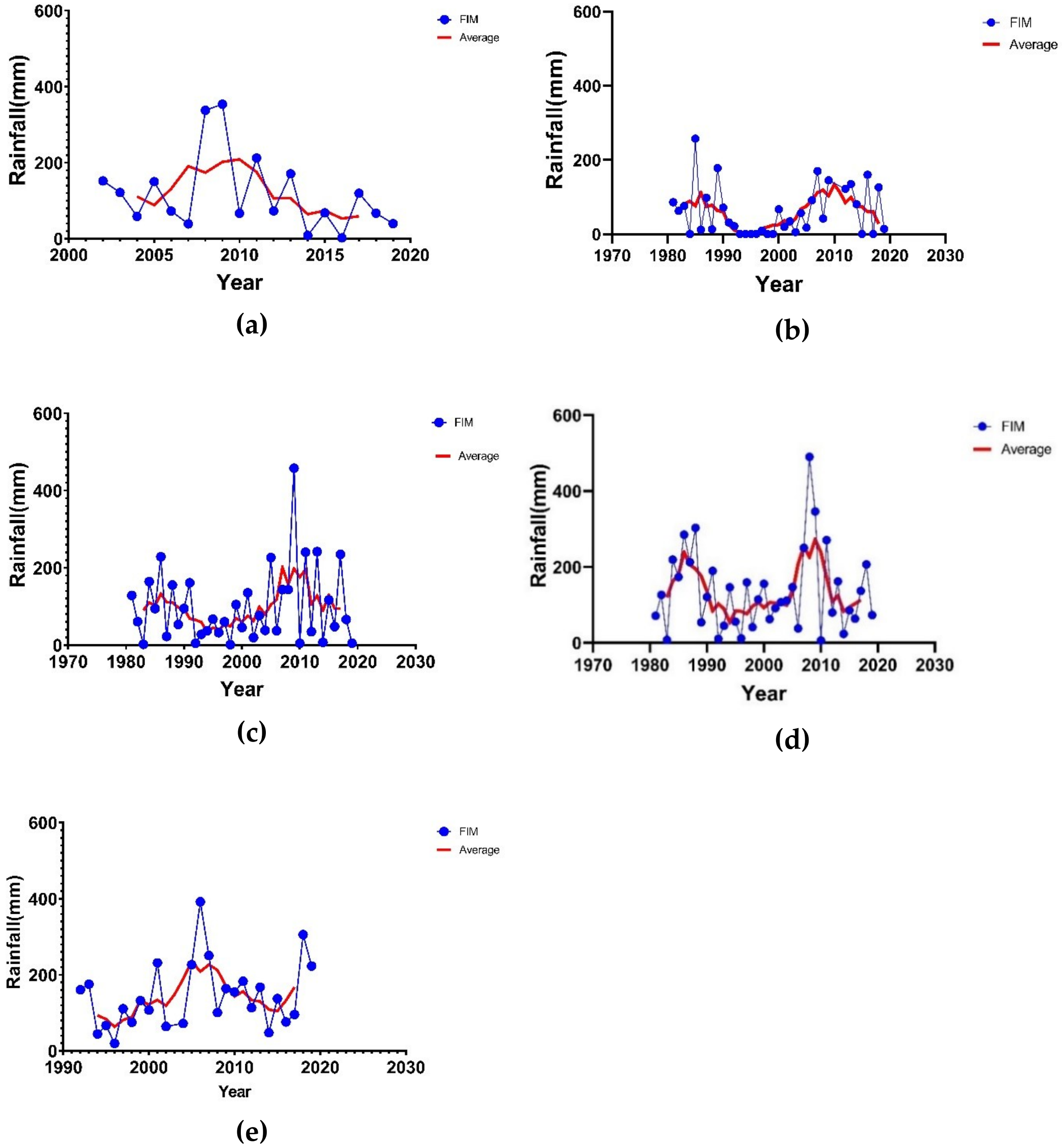


Figure 3. Long term seasonal (First Inter Monsson - FIM)) rainfall pattern of (a) Jaffna, (b) Kanukkerny Tank, (c) Trincomalee, (d) Batticaloa, and (e) Pottuvil with moving average curves.

results have been found by Wickramaarachchi *et al*. (2020) as positive trends in Batticaloa and Pottuvil and negative trends in Trincomalee during SWM.

Second Inter Monsoon (SIM)

General rainfall patterns of all analyzed locations follow a close pattern during the second inter-monsoon (SIM) season (Figure 5). Since the SIM prevails during October and November (2 months), SIM is the season that brings the highest monthly rainfall to the entire area rising up to 280 mm/month. Three locations receive the highest seasonal rainfall during the SIM and the other two locations also receive a considerable amount of rainfall. According to Zubair *et al*. (2006), the heavy rainfall experienced in SIM season is primarily attributed to large-scale cyclonic thunderstorms occurring over the northern and eastern regions of Sri Lanka during this time. This excess rainfall is crucial for storing in water resource structures within the region for irrigating purposes in off-season agriculture (Naveendrakumar *et al*. (2018). Except for Jaffna, all locations exhibited positive trends during the specified time frame. Interestingly, Batticaloa showed a significant positive trend of 7.34 mm/season. Although the positive trends observed at other stations lack statistical significance, their values have reached an alarming level.

Wickramaarachchi *et al*. (2020) also obtained comparable findings for Trincomalee, Batticaloa, and Pottuvil during the SIM season using Mann-Kendall statistics over a 30-year period (1986-2016).

Northeast Monsoon (NEM)

The rainfall patterns of Kanukkerny Tank, Trincomalee and Batticaloa bear a close resemblance (Figure 6). The interannual variation in the rainfall of Pottuvil during the observed period appears to be minimal. Although the Jaffna station also exhibits minimal interannual rainfall variation, its interpretation is hindered by data limitations.

The NEM is evidently a wet season for all locations, with rainfall exceeding 100 mm/month, and Batticaloa experiences particularly high precipitation, reaching 275mm/month. Batticaloa and Pottuvil have experienced the highest seasonal rainfall during the NEM, with Batticaloa notably recording 824.2 mm/season. Kanukkerny Tank experienced exceptional rainfall in the year 1984, reaching 2800 mm/season, which stands as the highest recorded during the analyzed period. This was confirmed by Nagamuthu, (2014), who referenced severe floods occurring at the Kanukkerny Tank station during the NEM season in 1984. Although converse trends are evident during the NEM, none of them are statistically significant. However, the situation in Jaffna has reached an alarming level which is -11.05 mm/season. Batticaloa exhibited a 6.5 mm/season upward trend, a finding corroborated by Wickramaarachchi *et al*. (2020).

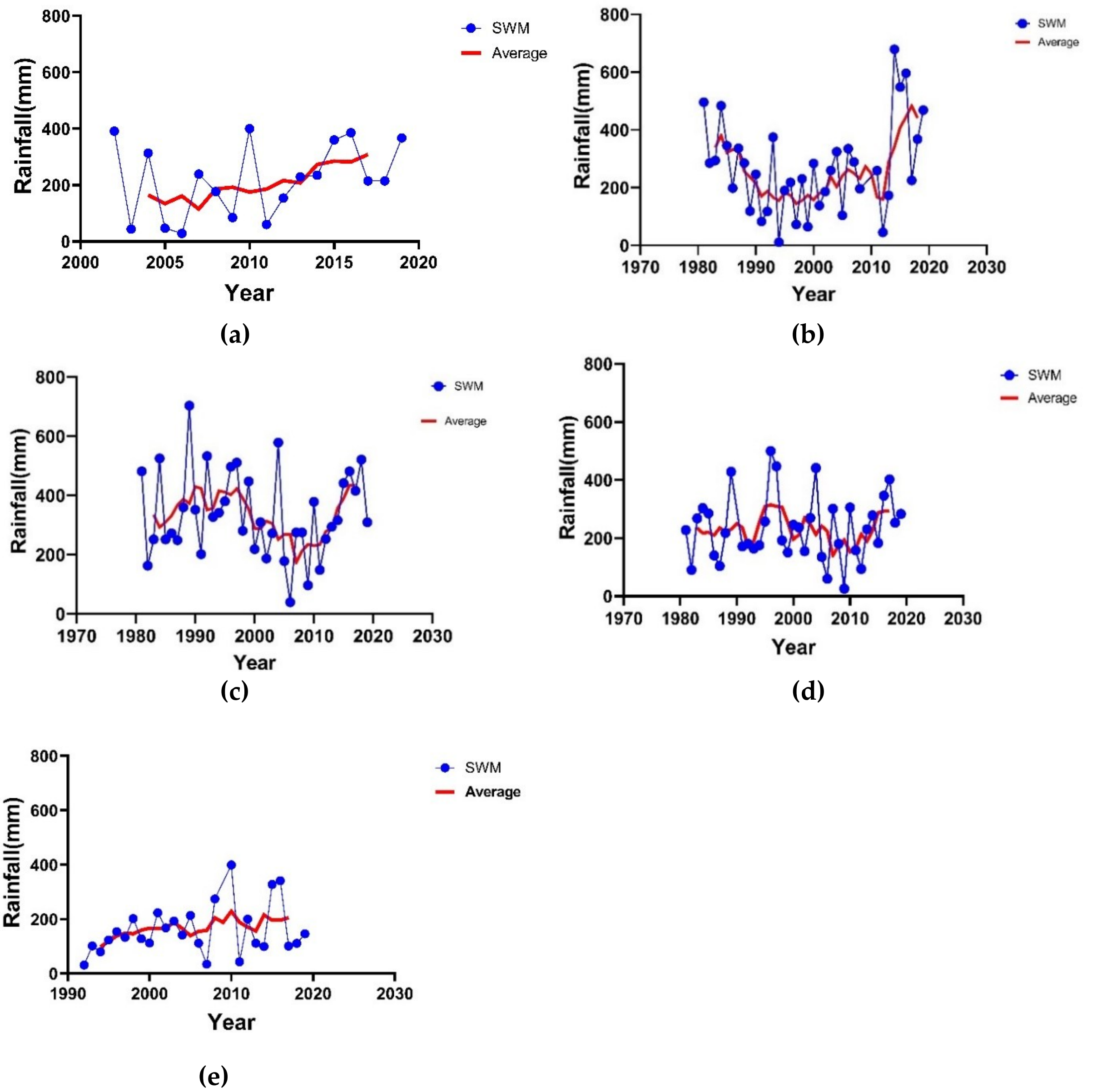


Figure 4. Long term seasonal (South West Monsson - SWM)) rainfall pattern of (a) Jaffna, (b) Kanukkerny Tank, (c) Trincomalee, (d) Batticaloa, and (e) Pottuvil with moving average curves.

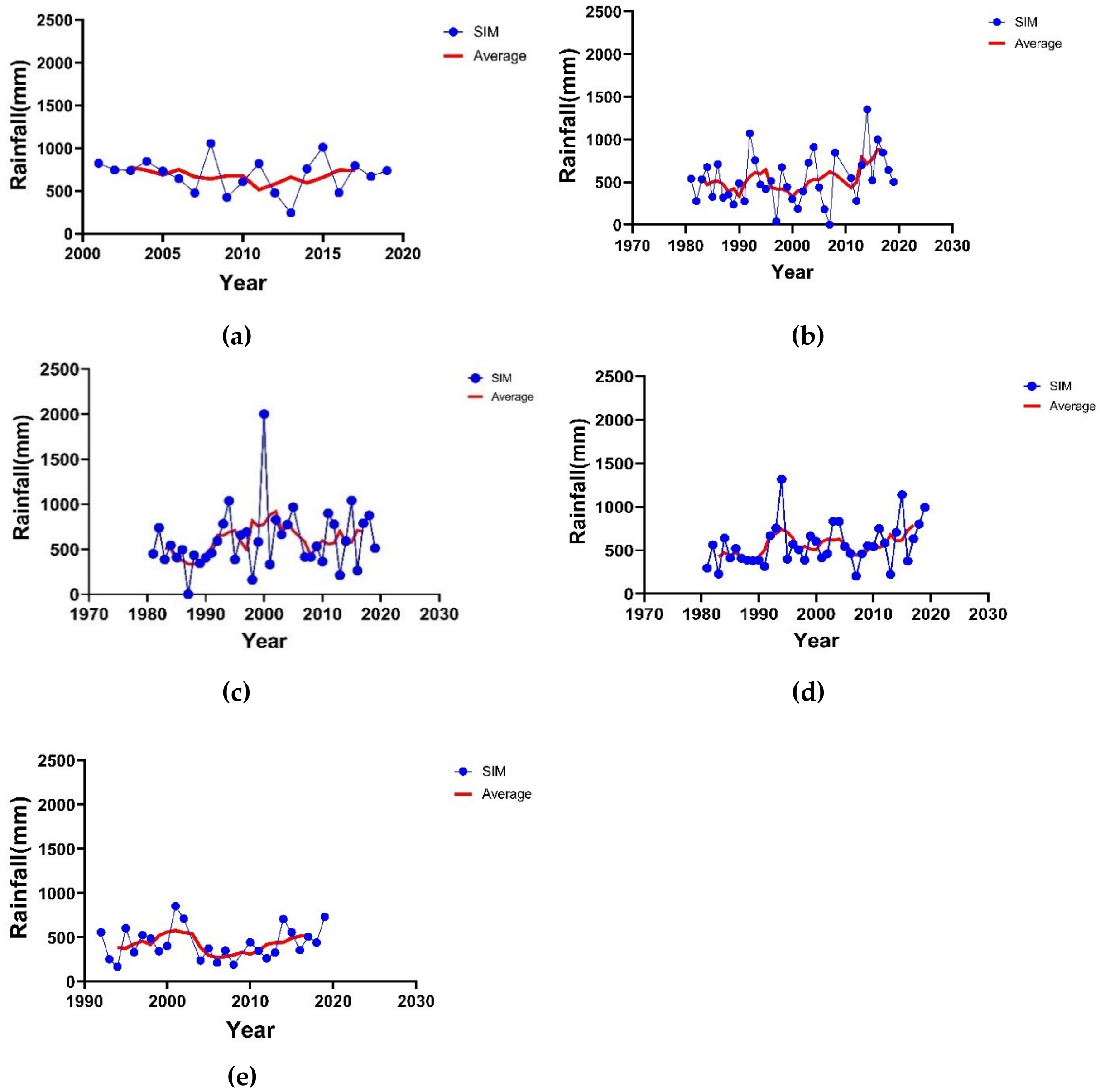
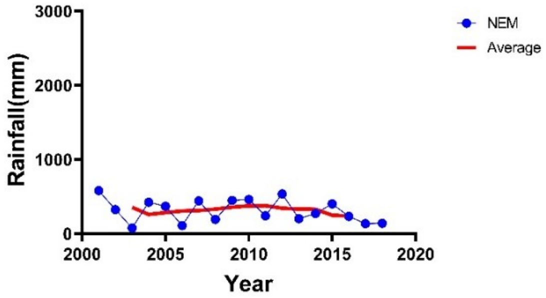
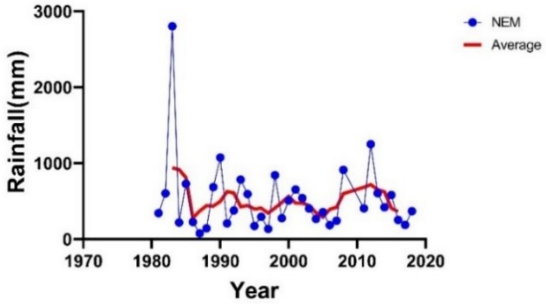


Figure 5. Long term seasonal (Second Inter Monsoon - SIM) rainfall pattern of (a) Jaffna, (b) Kanukkerny Tank, (c) Trincomalee, (d) Batticaloa, and (e) Pottuvil with moving average curves.



(a)



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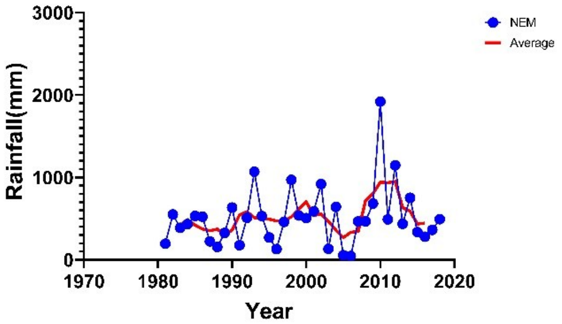

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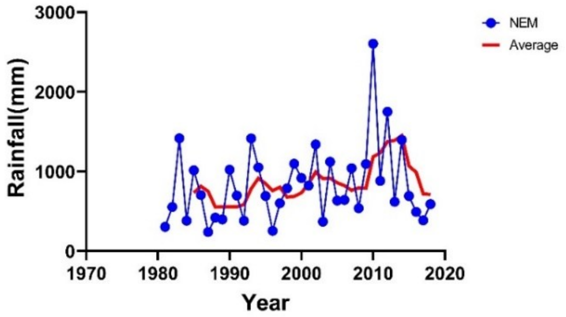
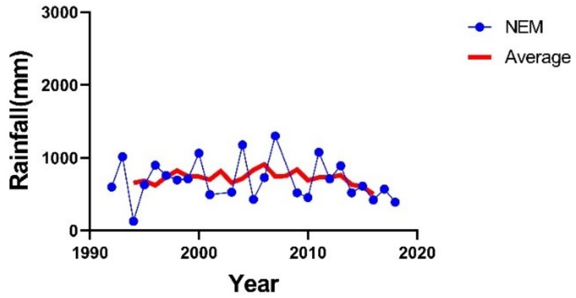


(d)



(e)

Figure 6. Long term seasonal (North East Monsoon - SIM) rainfall pattern of (a) Jaffna, (b) Kanukkerny Tank, (c) Trincomalee, (d) Batticaloa, and (e) Pottuvil with moving average curves.

CONCLUSION

The rain gauge stations situated along the eastern coastal belt, namely Kanukkerny Tank, Trincomalee, and Batticaloa, exhibit a more consistent rainfall pattern, affirming the uniform distribution of rainfall sources among them. The long-term mean annual rainfall for all stations is less than 1750 mm, confirming that the area further belongs to the dry zone of the country.

Out of the five locations studied, only Batticaloa has a significant trend, with an increase of 17.5 mm/year, which is considerable.

Throughout the first inter-monsoon (FIM) period, all locations display a consistent and similar rainfall pattern and none of the stations has a significant trend. The rainfall patterns of the locations along the eastern coastal belt resemble each other during the southwest monsoon (SWM) season. While positive and negative trends are evident in various locations, none of them are statistically significant. The second inter-monsoon (SIM) season brings the highest monthly rainfall to the entire area, rising up to 280 mm/month. Except for Jaffna, all other locations exhibit positive trends during SIM. The northeast monsoon (NEM) is more consistent and a wet season for the Northern and Eastern coastal belt, with rainfall exceeding 100 mm/month. While rainfall trends during the NEM are nonsignificant, the trend in Jaffna has reached an alarming decreasing level at 11.05 mm/season.

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