Trend Analysis of Rainfall in the Northern Region of Sri Lanka from 1970 to 2019

Analisis Tren Hujan di Wilayah Utara Sri Lanka dari tahun 1970 hingga 2019.

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ABSTRACT *Understanding the changes of long-term rainfall is vital for water resources management and climate mitigation strategies development. This study aims to evaluate the annual, seasonal, and monthly rainfall trends of the northern region of Sri Lanka from 1970 to 2019. The Mann-Kendall and Sen's slope tests have been used to analyze the trend and magnitude changes, respectively. The results show that the historical annual rainfall of Northern Sri Lanka has increased from 18.76 mm/decade to 37.68 mm/decade from 1970 to 2019. As per the seasonal pattern, the rainfall of the northeast monsoon has been reduced, while South west Monsoon rainfall has increased gradually in the Northern Region of Sri Lanka. There are fluctuating patterns in the monthly rainfall pattern, and November dominates in the monthly rainfall pattern, receiving more than 350 mm as the average. Changes in the rainfall pattern of the study area impact the physical and economic living environment.*

Keywords: Rainfall, Annual Changes, Seasonal Pattern, Sri Lanka, Climate Change

ABSTRAK *Memahami perubahan hujan jangka panjang sangat penting untuk pengurusan sumber air dan pengembangan strategi mitigasi iklim. Kajian ini bertujuan untuk menilai tren hujan tahunan, bermusim, dan bulanan di wilayah utara Sri Lanka dari tahun 1970 hingga 2019. Ujian lereng Mann-Kendall dan Sen telah digunakan untuk menganalisis perubahan trend dan magnitud, masing-masing. Hasilnya menunjukkan bahawa hujan tahunan bersejarah di Sri Lanka Utara meningkat dari 18.76mm/dekad menjadi 37.68 mm/dekad dari 1970 hingga 2019. Mengikut corak musiman, hujan Monsun Timur Laut telah berkurang, sementara Monsun Barat Daya curah hujan meningkat secara beransur-ansur di Wilayah Utara Sri Lanka. Terdapat corak turun naik dalam corak hujan bulanan, dan November mendominasi dalam pola hujan bulanan, menerima lebih dari 350mm sebagai rata-rata. Perubahan corak hujan di kawasan kajian mempengaruhi persekitaran hidup fizikal dan ekonomi.*

Kata kunci: Hujan, Perubahan Tahunan, Pola Musim, Sri Lanka, Perubahan Iklim

1. Introduction

Climate change has become a significant threat to the global economy and all countries, whereby its impacts are felt pervasively across all primary and sub-sectors of the development economy (Trenberth, 2011; Tan et al., 2019). Climate change is accompanied by an increase in occurrences frequency and intensity of extreme weather occurrences, including droughts, cyclones, floods, heatwaves, extreme rainfalls, cold and heat waves, all of which are projected in several parts of Asia. In recent decades, many countries have been giving high priorities to mitigate the climate change impacts, and they have extended their valuable support to other countries to adapt or reduce the climate change impacts in their respective countries (Stocker et al., 2013). As a result, projected future climate change variabilities globally and within the South Asian countries represents an intensification of present climatic variability rather than the mean climate state (Raswan, 2017).

Climate change is becoming a burning issue in Sri Lanka, impacting negatively on water resources, with the government of Sri Lanka facing considerable challenges to mitigate the impact of climate change on the water resources of Sri Lanka (Manawadu & Fernando, 2008). According to the ranking list for climate risk, the highest being the worse, Paparizou & Dirk Schindler (2017) ranked Sri Lanka in second place under the climate risk index in 2019 after Puerto Rico. As a result, the government finds incredible difficulties trying to provide solutions to people because people in one area face drought, but those in another area face floods in the same month. Due to so many areas being affected by such disasters simultaneously, the government finds difficulty providing relief for all affected victims of drought and flood in a month. In addition, of greater severity is the water scarcity problem, which is increasing in many areas and is fast becoming a severe issue in many parts of the dry zone of Sri Lanka (Maiththiribala, 2017).

The Northern region of Sri Lanka is located near the vast landmass of the Indian peninsula, which influences the wind pattern of the Northern region of Sri Lanka. In addition to these, the study area contains southwest monsoon and north-east monsoon wind influences. Due to these geographical influences, the study area only influences two types of monsoon winds, short winter and long summer seasons prevailing in the study area. Furthermore, climate change has had its impacts on all parts of the Northern Region of Sri Lanka. Therefore, the economy of Northern Region of Sri Lanka faces considerable challenges from climate change (Balsundarampillai, 2010).

The average rainfall of the Northern region is 1240mm; however, it varies every year and in every station. Four climatic seasons prevail in the study area, viz. the North-East Monsoon Season (NEMS), South West Monsoon Season (SWMS), First Inter Monsoon Season (FIMS), and Second Inter Monsoon Season (SIMS). However, rainfall is not evenly distributed over the four seasons as only the two seasons of the SIMS and NEMS have adequate rainfall. Rainfall is the primary source to determine the entire life system of the Northern region of Sri Lanka because there are no natural rivers or lakes in the region. Rainfall is the only source to fulfill all kinds of water needs in the Northern region of Sri Lanka. More than 67% of the agriculture depends on rainfall, especially during the *Maha* seasonal agriculture activities depend entirely on the rainfall. There are 17 primary and medium irrigation systems functioning in the region, and most of them depend on the rainfall obtained from SIMS and NEMS.

In recent years, the rain-fed agricultural and domestic water supply systems facing difficulties due to the uncertainty of the rainfall and unexpected extreme rainfall events. The absence of rainfall for an extended period creates drought vulnerabilities in the region, and the intense heavy rainfall within the short period also creates flood vulnerabilities in the Northern Region of Sri Lanka. The governing authorities also face difficulties in managing this crisis frequently. Consequently, the water scarcity problem creates communal violence in societies, becoming social unrest among the people in the Northern region, especially in Manthai West and Naanaddan (Piratheeparajah, 2016).

In these contexts, this study aims to evaluate the annual, seasonal, and monthly rainfall trend of the northern part of Sri Lanka from 1970-2019. There are very few studies about the rainfall and temperature in the Northern region of Sri Lanka due to the internal war. Many researchers pointed out this issue in their researches(Balsundarampillai, 2010; Karunathilaka et al., 2017; De Silva, 2014). The study not only fulfills this research gaps on effects of climate change on water resources and its management in the Northern Province of Sri Lanka but is also crucial in supporting the government's reawakening development plans of the Northern region of Sri Lanka after thirty years of internal conflict that will bring the region at par with the rest of the country in terms of sustainable development and achievement of Sustainable Development Goals (SDGs) in the Northern region of Sri Lanka.

2. Literature Review

Many scientists consider climate as the weather system prevailing in the long term, always associated with oceanic surface changes. Mainly, it describes the average weather conditions combined with natural and human-made changes and is the quantitative conclusion of the climate variability in a particular place, region or country, or sphere (Australian Academy of Science, 2015). Usually, climate change is averaged for thirty years in order to be considered significant. These statistical contents include averages, variability, and extremes (Ren & Shrestha, 2017).

Earlier in the 1970s, most scientists believe that climate change is a myth that some people deliberately popularize. However, in recent decades due to occurrences of abnormal and highly unpredictable weather all over the world, most people, including scientists, politicians, and the frequent public, accept that climate change is real, causing many impacts in all parts of the world, and happening now (Singh et al., 2014). Sir David Attenborough, the famous environmentalist, has also warned of the 'crippling problems' the world faces now and in the future because of climate change during the COP-26 summit (Bonjean Stanton et al., 2016). Most climatic scientists now agree that

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climate change is the leading cause of greenhouse gasses (Nachiyunde et al., 2018). Several studies, including various methodologies, models, disparate data, and different analysis models, have concluded that climate change is a real-world problem and a severe issue. Most significantly, 97% of climate scientists agree that climate change is occurring now caused mainly by human-made activities and that humans can do something to reduce its impacts and progression (Rodriquez et al., 2008; Public Health Institute, 2019). Most people facing climate change difficulties can change their lifestyles and behavior to reduce climate change. Weather changes are the day-to-day weather pattern; its time is short, but climate change is long-term.

There is high confidence that precipitation over the mid-latitude land areas of the Northern Hemisphere has increased since 1950. However, area-averaged long-term positive or negative trends have low confidence for other latitudinal zones because of insufficient data quality, incomplete data, or disagreement amongst available estimates (Hartmann et al., 2013). Malmgren et al. (2003) used the moving average Curve and mass curve to study the climate variability in the Northern Region of Sri Lanka. The author has stated the Physical setup of the Northern Region. He has further illustrated the spatial and temporal patterns of the temperature, pressure variations, relative humidity, and rainfall of the Northern Region of Sri Lanka. He has discussed the climate variability of the Northern Region of Sri Lanka, and its economic impacts have been studied. Weerasooriya (2009) conceded that in the disaster history of Sri Lanka, more than 72% of the disasters are related to climatic hazards during the past 100 years.

Changes in rainfall in Sri Lanka have had many impacts on the socio-economic sectors. The annual average rainfall of the southwest monsoon season has increased, impacting the water bodies. Simultaneously, fluctuations in the average temperature induce the water deficit in dry zone areas of Sri Lanka (De Silva, 2014). The direct impact of climate change on groundwater resources depends on the changes in groundwater recharge volume and distribution induced by the received rainfall. Therefore, identifying the climate change impact on groundwater resources requires reliable forecasting of climatic variables and percentage estimation of ground recharge. Kumar (2012) and Manfred (1982) have discussed climate change in climatic parameters such as rainfall, temperature, wind, sunshine, and the mountain area's cloudiness in Sri Lanka.

Manfred (1982) analyzed the rainfall data for 1910-1965 at Mahaillupallama in Sri Lanka and found out about crop failure of the '*Maha*' and '*Yala*' seasons. Also, the author mentioned that the agriculture at Mahaillupallama was mainly affected due to the water crisis, particularly in the Southwest monsoon season. Suppaiah (1996) has used the monthly rainfall data from 1881 to 1980 for 29 stations and the Southern Oscillation Index. He has analyzed the data using the anomalies and standard seviation, and correlation methods. As a result, the author found a significant relationship between Southern Oscillation Index and rainfall in four epochs 1881-1900, 1901-1930, 1931-1960, and 1961-1990.

There is an increasing trend in the seasonal rainfall in the coastal areas of Sri Lanka for the last five decades. The monthly rainfall for May decrease gradually, and the SWMS rainfall also decreasing in the Western and South-Western part of Sri Lanka. However, there is an increasing trend of rainfall in the NEMS. The seasonal changes in the rainfall trend impact the country's water system, agricultural structure, and economic stratifications (Naveendrakumar et al., 2018). Another study revealed an increasing rainfall pattern in Colombo by 3.15 mm/year, and there is a decreasing pattern of rainfall in Kandy and Nuwereliya by 4.87 mm/year and 2.88 mm/year, respectively. Some Sri Lanka stations show a significant decreasing such as Kandy, Diyatalawa, Batticaloa, and Galle (Jayawardene et al., 2005). The rainfall changes in Sri Lanka explained a significant increase in the rainfall in some places, particularly Anurahapuram, Pottuvil, Batticaloa, and Mapakadawewa, showing 19.89 mm/year. Nevertheless, some stations show a downward trend in rainfall, such as Chilaw, Dandeniya, and Iranaimadu, which average is 8.74 mm /year (Karunathilaka et al., 2017).

3. Materials and Methods

The secondary data for this study were collected from the Department of Meteorology in Colombo, Sri Lanka. Rainfall data were collected for 16 stations, including Akkarayankulam, AmbalapperumalKulam, Vavuniya Iranaimadhu, Thirunelveli, Nainathivu Kanukkerni, Pallavarayankaddu, Thannimurippu, Nedunkerny, Mankulam, Karukkaikkulam, Murungan, Muththaiyankaddu,Pavatkulam, and Vavunikkulam from 1970 to 2019 (Figure 1). Data regarding temperature (Monthly maximum, Monthly average and Monthly minimum), rainfall (Annual Total and Monthly total), relative humidity, atmospheric pressure, wind velocity, wind direction, and evaporation were obtained. The National Statistical and Information Department of Sri Lanka was the most vital source for collecting secondary data.

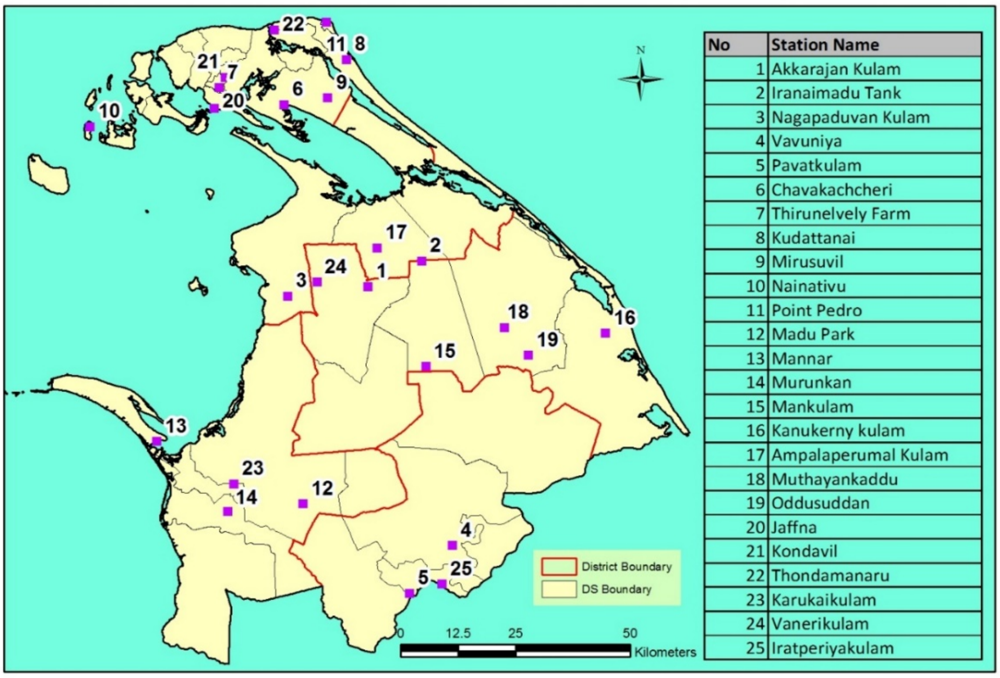


Figure 1: Meteorological/Rain Gauge Stations in the Northern Region

Reports and data of the Irrigation Department of Northern province in each district was the primary source to obtain the rainfall data in the Northern Province of Sri Lanka. Data such as location, catchment area, watercourse, rainfall, capacity, space, full supply depth, length, head of water, maximum discharge, length of the central canal, length of branch canal, length of feeder canal, and irrigation area regarding five primary tanks of Northern Province obtained from this source. In Mullaitivu and Kilinochchi of the study area, this department measures the rainfall over the reservoirs under their maintenance. During floods, this department has the authority and responsibility to monitor and decide on the tank's water levels and the surplus water's evacuation of the surface resources. The irrigation department, rainfall in some stations (Iranimadu, Akkarayankulam, Vavunikkulam, and Muththaiyankaddu), and villages' details were affected during evacuations individual tanks in the districts other than Jaffna collected. This source of data will be used to identify the relationship between climate change and water resources management.

Reports of Economic Development Department *(Tamil Eelam Porunmiya Mempaaddu Niruvanam*) of Liberation Tigers of Tamil Eelam (LTTE). The LTTE was fighting with the Sri Lankan government and ruled the study area for an extended periodsome station data such as Thunukkai, Naddankandal, Puthukkudiyiruppu, Semmalai, and selected years' data of Mullaitivu were obtained from the Economic DevelopmentDevelopment of LTTE.

The Mann- Kendall trend analysis test and Sen's slope analysis method were employed to study the observed rainfall changes in the Northern Region of Sri Lanka. The Mann-Kendall trend analysis method is used by many researchers in various kinds of researches recently. Mann-Kendall trend analysis is one of the essential statistical methods used widely in climate-related studies, especially to analyze the rainfall and temperature-related long-term data (Mazlina Alang Othmana et al., 2016) Authors furtherexplain that this test compares the relative data scales rather than data values themselves. In this test, every data value in the time series is compared with all consequent values. Primarily, the Mann-Kendall statistics (S) are assumed to be zero. If a data value in subsequent periods is higher than in the prior period, S is incremented by 1, and vice-versa. The net result of all such increments and decrements gives the final value of S. The Mann-Kendall statistics (S) is given as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign(x_j - x_k) \quad (1)$$

where, where, x*i* and x*k* are sequential data in the series and

$$\text{Sign } (X_i - X_k) = \begin{cases} +1 \text{ when } (X_i - X_k) & >0 \\ 0 \text{ when } (X_i - X_k) & = 0 \\ -1 \text{ when } (X_i - X_k) & <0 \end{cases} \quad (2)$$

A positive value of 'S' indicates an increasing trend, and a negative value designates a decreasing trend. However, it is necessary to perform a statistical analysis of the meaning of the trend. The test process using the standard approximation test is described by Kendall (1975). This test assumes that there are not many tied values within the dataset. The following equation computes the variance (S)

$$Var\ (S) = \frac{S(n-1)(2n+5) - \sum_{p-1}^{q} +p(t_p - 1)(2_p^t\ +5)}{18} \quad (3)$$

where n is the number of data points, g is the number of tied groups and t_p is the number of data points in the p^{th} group.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}; & if\ S > 0 \\ 0; & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}; & if\ S < 0 \end{cases} \quad (4)$$

The trend decreases if Z is negative, and the computed Z-statistics are higher than the z-value corresponding to the 5% level of significance. The trend is said to increase if the Z is positive, and the computed Z - statistics are more fabulous than the z-value corresponding to the 5% significance level. If the computed Z-statistics is less than the z-value corresponding to the 5% significance level, there is no trend (Chandubhai et al., 2017).

Sen's slope is a nonparametric statistical method to identify the magnitude changes of temperature and rainfall used widely in climatological studies worldwide. Sen identified Sen's slope in 1968 to estimate the magnitude of trends in the data time series. The slope of 'n' pairs of data can be first estimated by using the following equation;

$$\beta_i = \text{Median}\left\{\frac{X_j - X_k}{j-k}\right\} \ \forall \ (k < j) \quad (5)$$

The average of 'n' values of βi is Sen's slope estimator test. A negative βi value denotes a lessening tendency; a positive βi value epitomizes an increasing trend over time. If 'n' is an even number, then the slope of Sen's estimator is calculated using the following equation: In this equation, xj and xk represent values data at the period j and k, respectively, and period j is after time k (k ≤ j).

$$\beta_{med=} \frac{1}{2} \ (\beta[^{n}/_{2}] + \beta\left[^{(n+2)}/_{2}\right] \quad (6)$$

If 'n' is an unknown number, then the estimated slope by using Sen's method can be computed as follows:

$$\beta_{med=\beta}\left[^{(n+1)}/_{2}\right] \quad (7)$$

Lastly, βmed is tested by a two-tailed test at 100 (1−α) % confidence level, and the actual slope of monotonic trend can be projected using a nonparametric test.

4. Results and Discussions

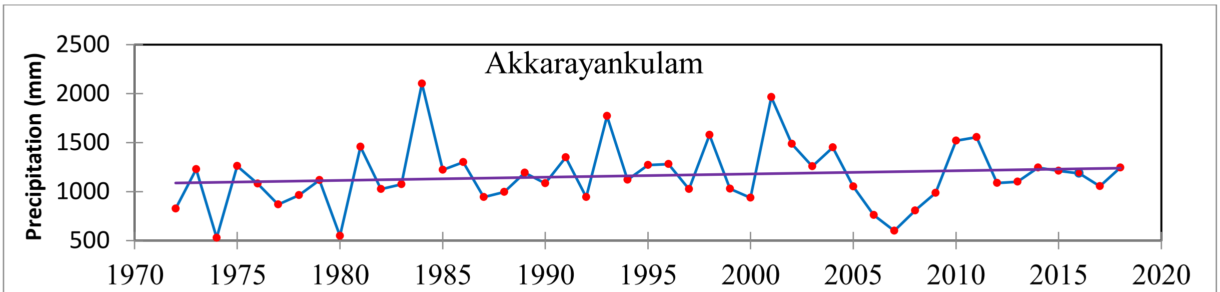
4.1. The Annual Rainfall trend

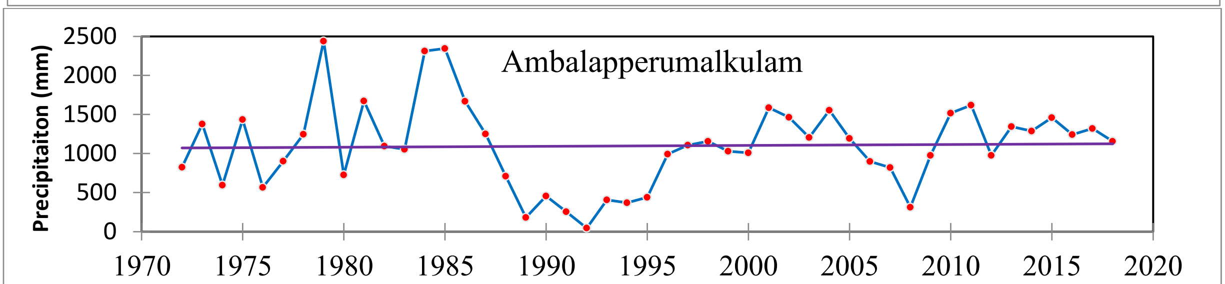
The Mann Kendall (MK) trend analysis shows the mixed results in the rainfall trend of each station of the study area (Table 1). However, most station MK results show that the p values are less than 0.05, and there is the rejection of H_0 of twelve stations. There is an accepting the H_0 only from Kanukkerny, Muththaiyankaddu, Pavatkulam, and Thirunelvely stations only. Rejection of H_0 means there is a trend in the series.

In the study area, there is a trend in the rainfall for 12 stations such as Akkarayankulam, Ambalapperumalkulam, Mankulam, Iranaimadu, Karukkaikulam, Thannimurippu, Murungan, Nainatheevu, Nedunkerny, Pallavarayankaddu, Vavunikkulam, and Vavuniya. If the H_0 is accepted, there is an insignificant trend, which means the significant level is higher than the standard. In this way, there is no trend in the rainfall data series from Kanukkerny, Muththaiyankaddu, Pallavarayankaddu, and Thirunelvely. Figure 2 illustrates the trend pattern of rainfall of all stations of the Northern region of Sri Lanka. So, there is a trend in the study area's rainfall from the observed climate change perspective. In the trend, some stations such as Thirunelvely, Muththaiyankaddu, Kanukkerny, Iranaimadu, and Mankulam stations show the downward trend, and all other stations show the upward trend in the rainfall pattern of the Northern region of Sri Lanka. Significantly, the Iranaimadu, Kanukkerny, and Thirunelvely stations show the significant dawn ward trend, and the Thannimurippu, Naninatheevu, and Nedunkerny stations show a significant upward trend in the rainfall pattern.

Table 1: Mann Kendal trend analysis of rainfall in stations of the The Northern region of Sri Lanka

Series\Test	**Kendall's tau**	**p-value**	**alpha**	**Test interpretation**
Akkarayankulam	0.237	0.040	0.05	Reject H_0
Ambalapperumal	0.273	0.018	0.05	Reject H_0
Mankulam	0.229	0.044	0.05	Reject H_0
Iranaimadu	-0.256	0.024	0.05	Reject H_0
Kanukkerny	**-0.068**	**0.497**	**0.05**	**Accept H_0**
Karukkaikulam	0.264	0.009	0.05	Reject H_0
Thannimurippu	0.236	0.019	0.05	Reject H_0
Murungan	0.245	0.023	0.05	Reject H_0
Muththaiyankaddu	**-0.032**	**0.757**	**0.05**	**Accept H_0**
Nainatheevu	0.415	<0.0001	0.05	Reject H_0
Nedunkerny	0.208	0.045	0.05	Reject H_0
Pallavarayankaddu	0.323	0.021	0.05	Reject H_0
Pavatkulam	**0.136**	**0.182**	**0.05**	**Accept H_0**
Thirunelvely	**-0.003**	**0.985**	**0.05**	**Accept H_0**
Vavunikkulam	0.236	0.042	0.05	Reject H_0
Vavuniya	0.262	0.027	0.05	Reject H_0





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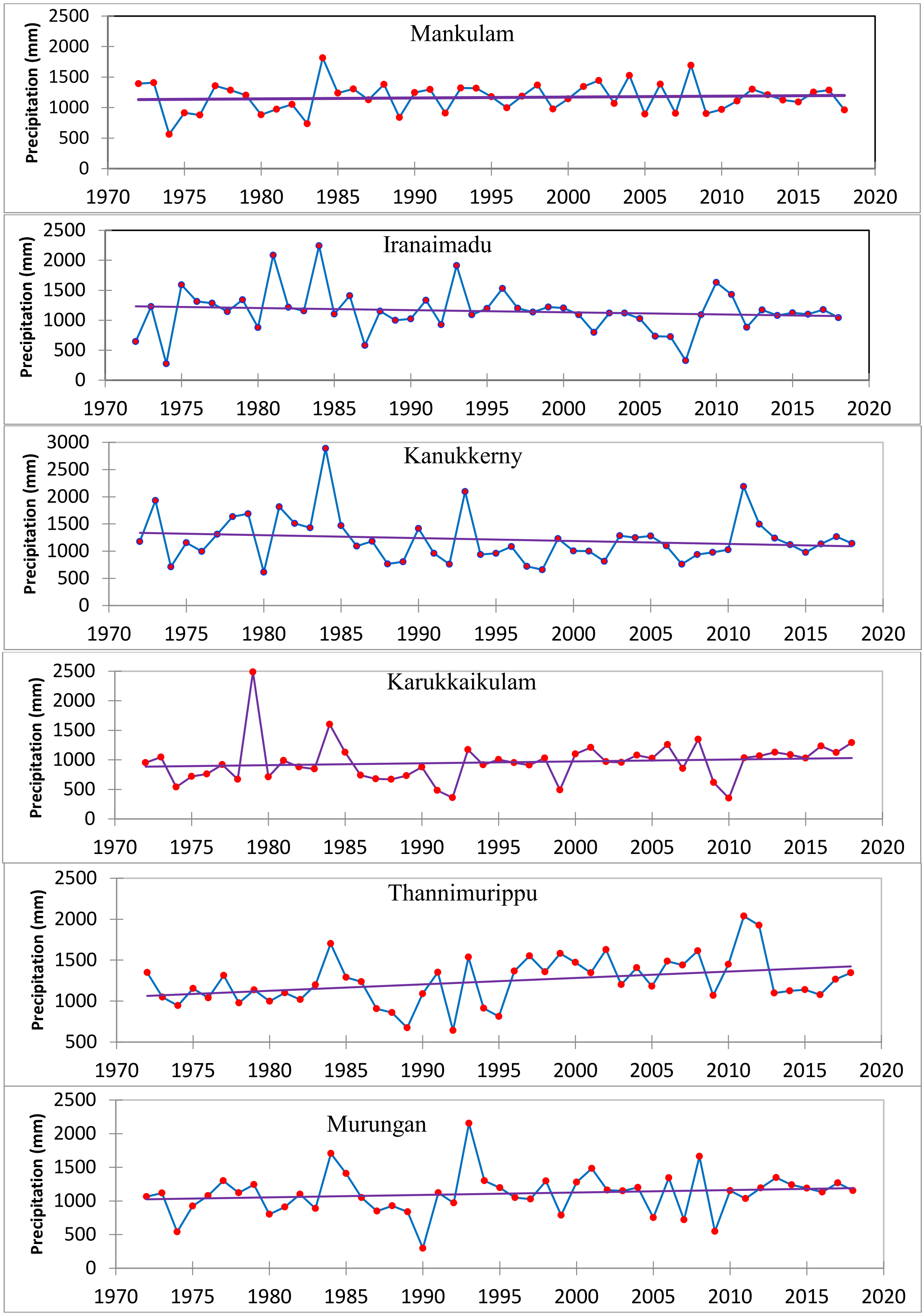

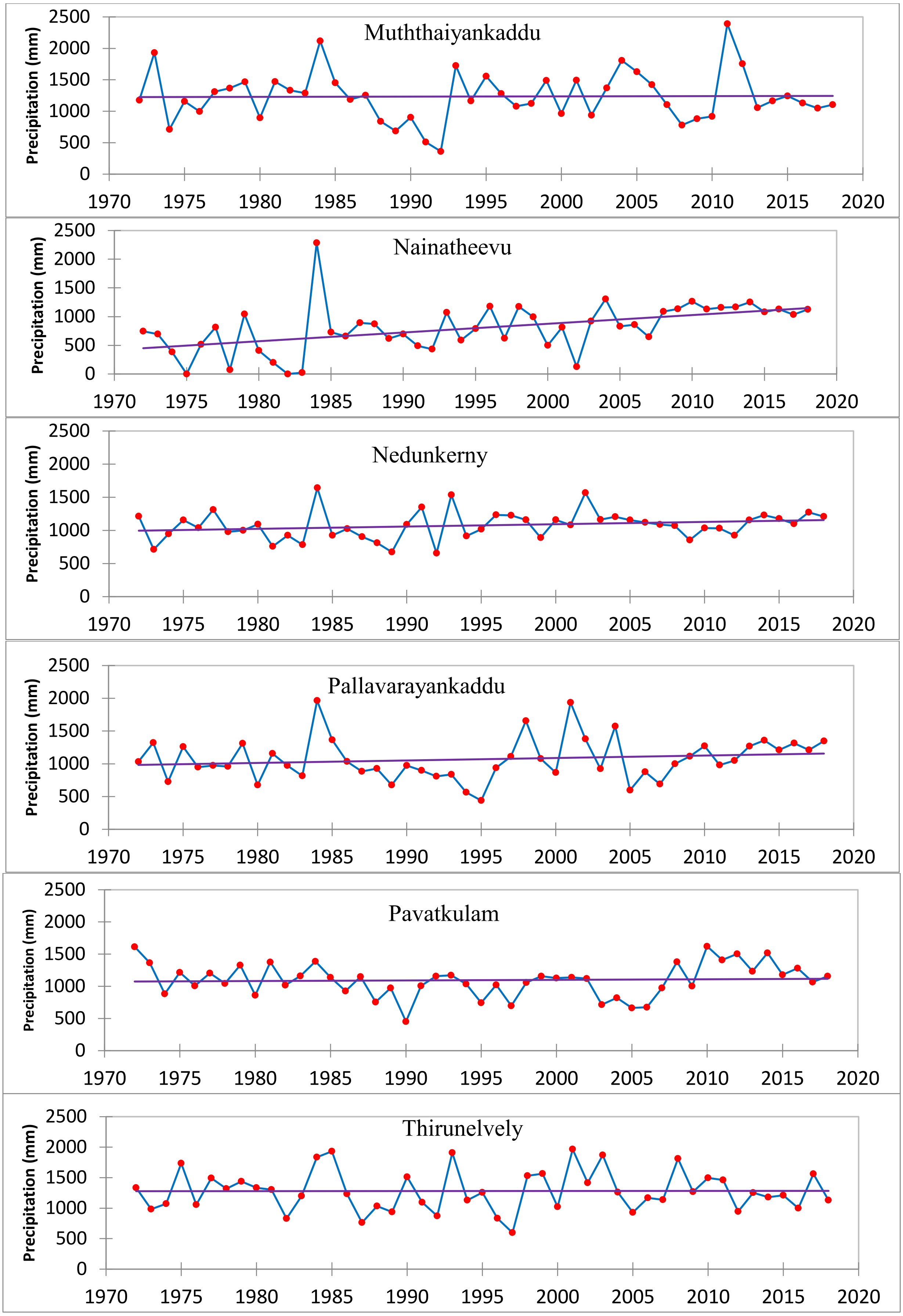
Muththaiyankaddu
Precipitation (mm)
0 500 1000 1500 2000 2500
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Nainatheevu
Precipitation (mm)
0 500 1000 1500 2000 2500
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Nedunkerny
Precipitation (mm)
0 500 1000 1500 2000 2500
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Pallavarayankaddu
Precipitation (mm)
0 500 1000 1500 2000 2500
1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020
Pavatkulam
Precipitation (mm)
0 500 1000 1500 2000 2500
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Thirunelvely
Precipitation (mm)
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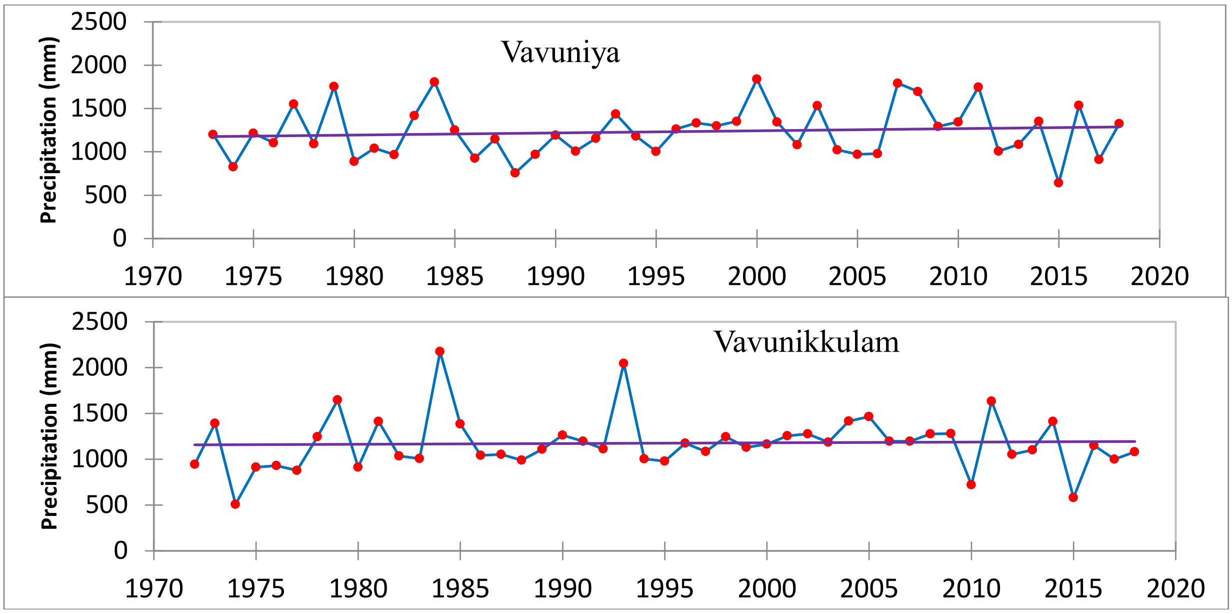
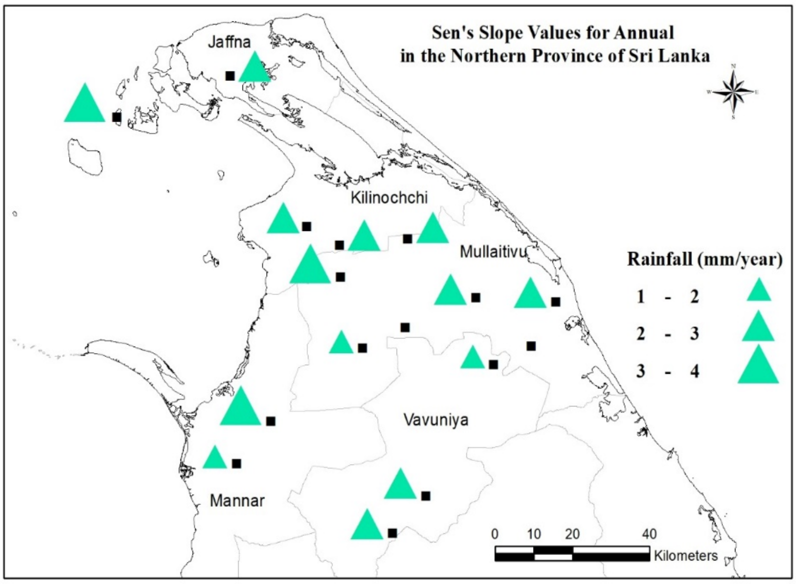


Figure 2: Annual total rainfall trend of different stations of the Northern region of Sri Lanka

The historical annual rainfall of Northern Sri Lanka has increased from 18.76 mm/decade to 37.68 mm/decade from 1970 to 2019. However, the increasing values are varied in every season. For example, as per Sen's slope analysis, the rainfall in the Northeast Monsoon season has been decreasing while at the same time rainfall in the SWMS has been increased in the study area. However, each station's annual values show a rising trend in the study area. Table 2 shows Sen's values of every station on rainfall pattern of the Northern region of Sri Lanka from 1970 to 2019. Sen's slope values for every station and every season show the different values, and Figure 3 shows the details of Sen's slope values of each station of the Northern region of Sri Lanka.



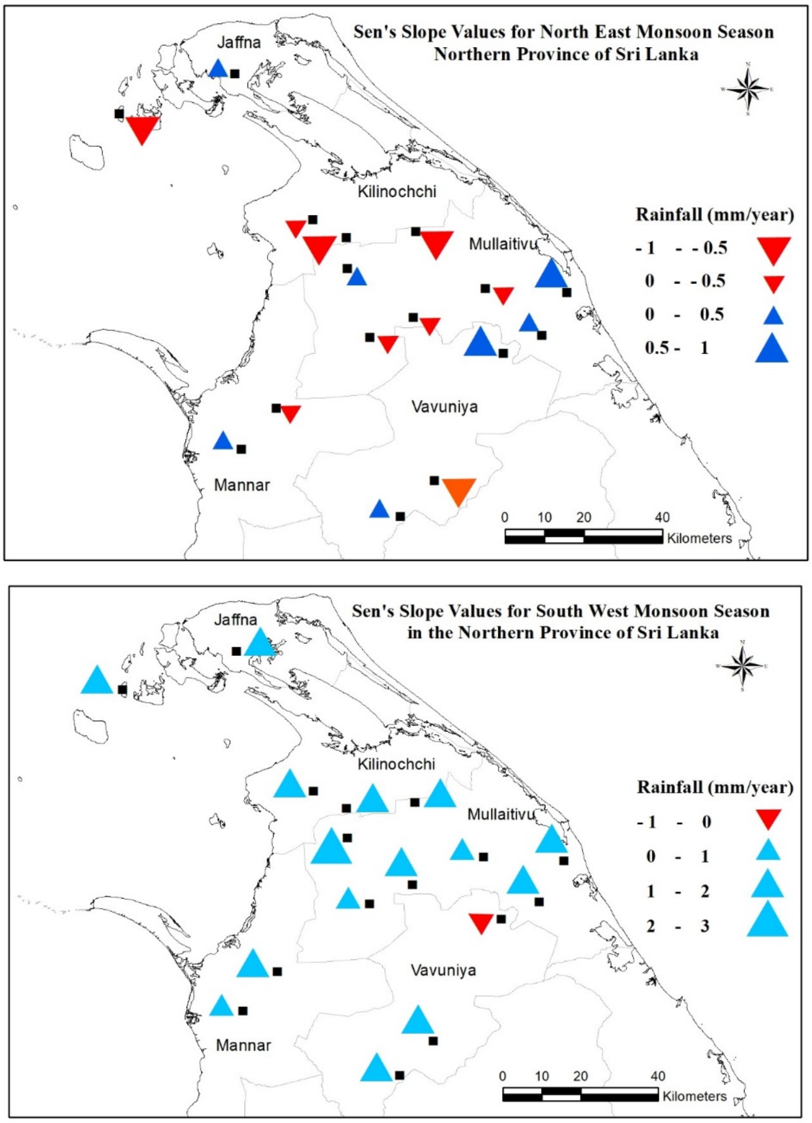


Figure 3: Sen's Slope values of rainfall trend for Annual, NEMS and SWMS in the Northern Region of Sri Lanka

Annual rainfall deviation also varies in every year and every station of the Northern region of Sri Lanka, and Figure 4 illustrating the annual deviation of rainfall of the various stations of the Northern region of Sri Lanka. In 1983, 1984, 1998, and 2012 all the stations of the study area show a deviation in high rainfall than the average. Also in the years 1993, 1999, 2011, and 2016 show the deviation of low in the rainfall in many stations. According to the stations' standard deviation analysis, Pavatkulam, Thirunelvely, Eluvankulam stations have many anomalies in the average rainfall for the last 50 years in the study area.

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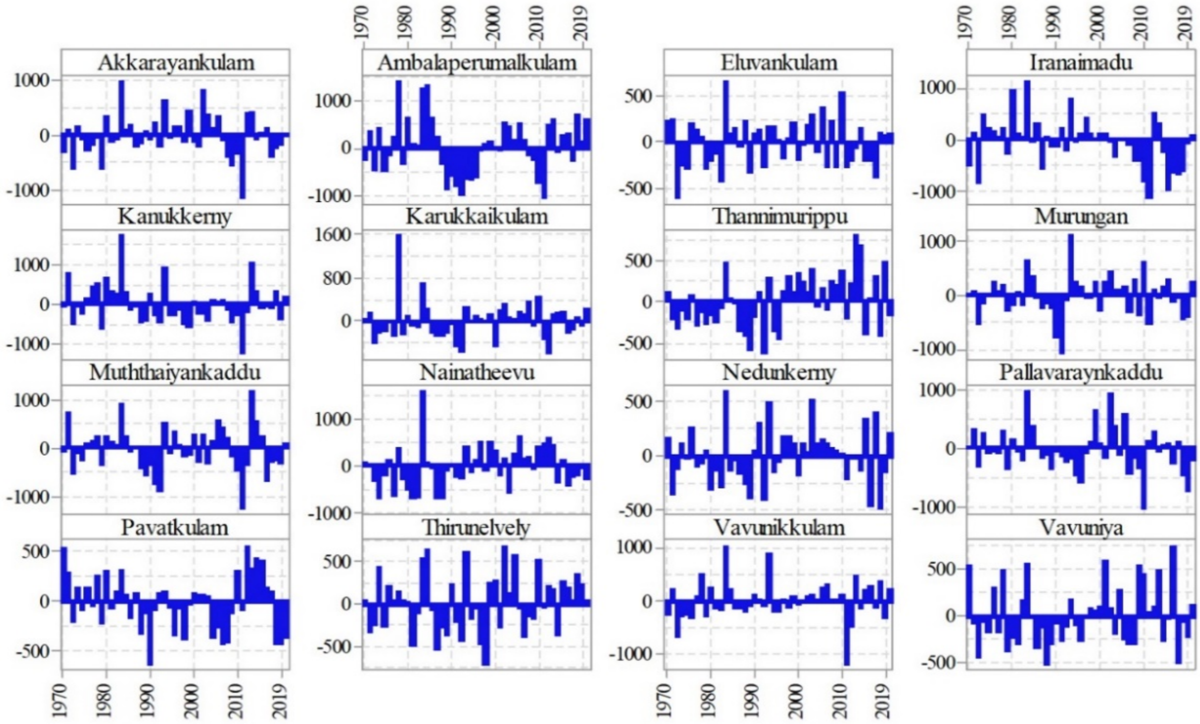

Figure 4: Deviation of annual total rainfall of different stations of the Northern region

4.2. Changes in the Rainfall types

The Northern region of Sri Lanka generally receives its total rainfall from various processes such as monsoon process, cyclonic or frontal process (North-East Monsoon rainfall), convectional process, and expansion Inter-Tropical Convergence Zone (ITCZ). The monsoon process is the leading contributor to the rainfall of the Northern region of Sri Lanka, and it is the response for 65% of the total rainfall. The current climatic period has an 8% rainfall increase compare with the previous climatic period. For example, from 1960 to 1990, convection has 12% of the total rainfall, but it has increased to 29%. However, the conventional process plays a critical role in deciding the amount of rainfall and the rainy-day amount during the summer months in the study area, especially during the past two decades. On the other hand, the convectional process produces unstable and unpredictable weather conditions giving rise to unexpected rainfall. This means that this is one of the crucial things, due to climate change, rainfall shows significant changes in the study area in the present climatic period.

In Northern Sri Lanka, the convectional process generally occurs in the evening and early morning during March, April, May, August, and September. During this period, the sun's position is almost overhead in the study area (At the latitudes near Sri Lanka). As a result, convectional currents have been created during noon, and massive uplift of water vapor into the lower part of the troposphere and cooling by the atmosphere and rainfall occurs between 3.30 p.m. and 6.45 p.m. and 4.30.a.m and 8.00

a.m. This convectional process contributes to rainfall to the study area during the peak water scarcity season and helps recharge the surface and groundwater. The convectional process's average rainfall is more than 330 mm (currently, it is equal to 29% of total rainfall) in the Northern region.

Consequently, this rainfall is vital to the Northern region. Compared with the past climatic period 1930-1960, this decade has seen an increasing influence on the pattern of convectional rainfall by 17%, with some spatial variations in this percentage also identified. Figure 5 illustrates the steadily increasing pattern of convectional rainfall throughout the years; simultaneously, rainfall due to other causes shows the fluctuations. From 1970 to 1980, the average convectional rainfall was 300 mm, but the value increased to 330 mm from 1980-1990. This is further increased to 380 mm during the 1990 to 2015 period. However, it varies from year to year, with are some fluctuations being identified.

Compared to other years, some of the years, such as 1976, 1984,1985, 1989, and 1999 received 40% more rainfall than average convectional rainfall, and 1977, 1988, and 1998 received 40% lower rainfall than the average Northern region. However, Figure 6 shows that 1971, 1984, 1988, and 2001 have more than 175 mm rainfall during the SIMS. Generally, 90% of the total rainfall is experienced during the evenings between 5.30 p.m. to 8.30 p.m. and early mornings between 4.30 a.m. to 7.00 a.m.

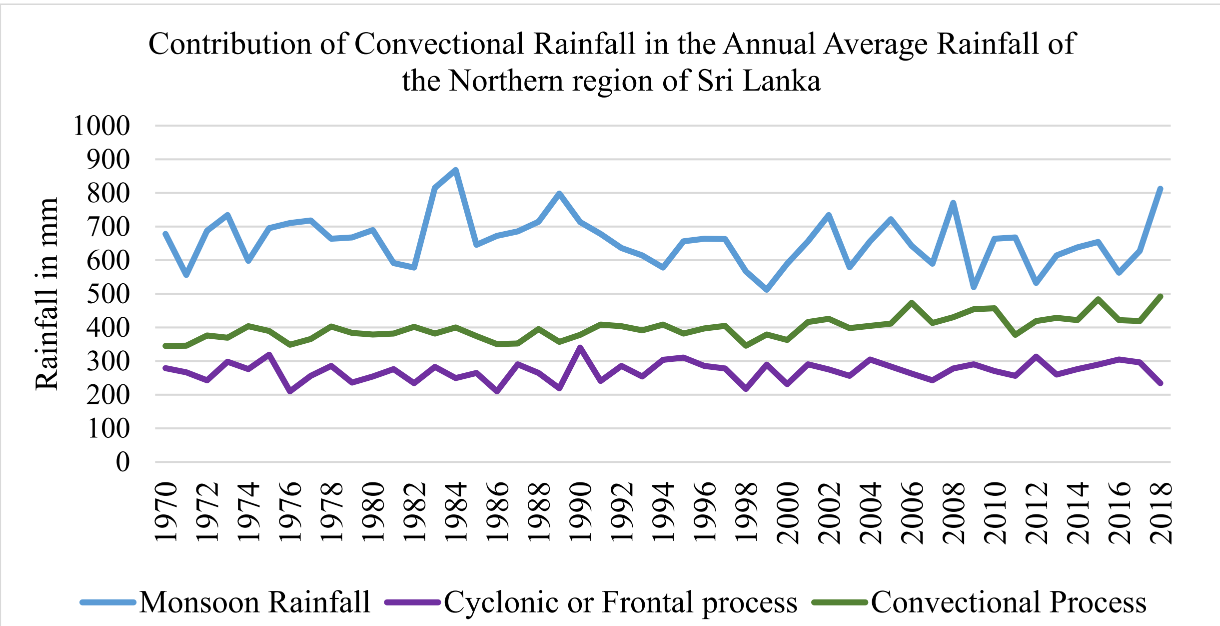

Figure 5: Contribution of Convectional Rainfall in the Annual Average Rainfall of Northern Sri Lanka

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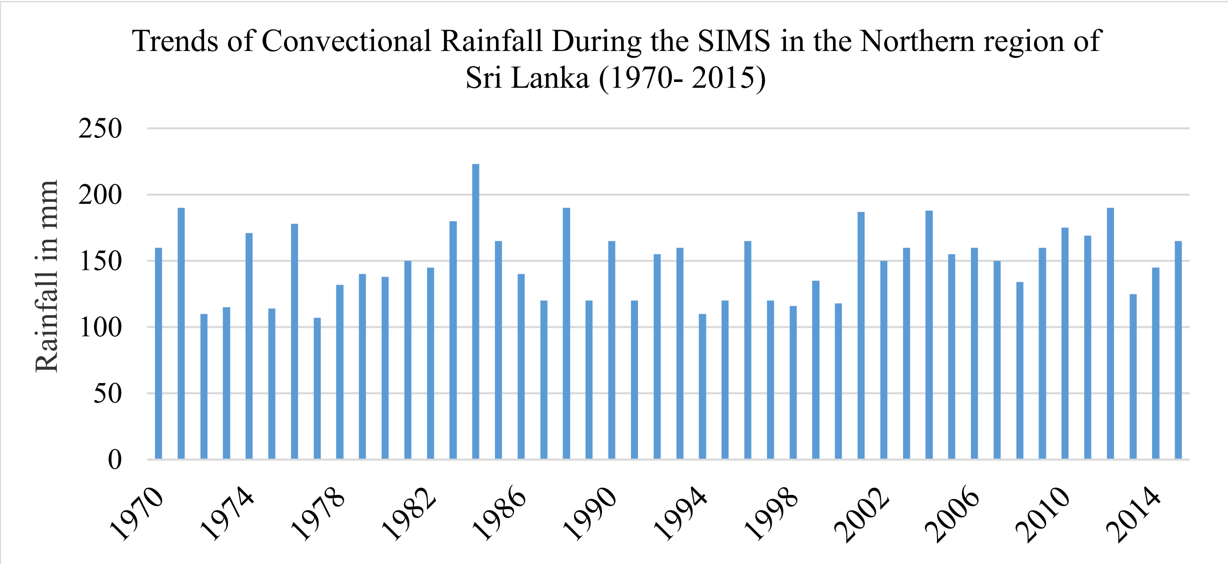

Figure 6: Trends of Convectional Rainfall During the SIMS in Northern Sri Lanka

During the FIMS, the study area receiving a certain amount of rainfall due to the convectional process, especially during the April study area receiving more than 75 mm on average. Figure 7 illustrates the various amount of rainfall experienced in the study area during the FIMS.

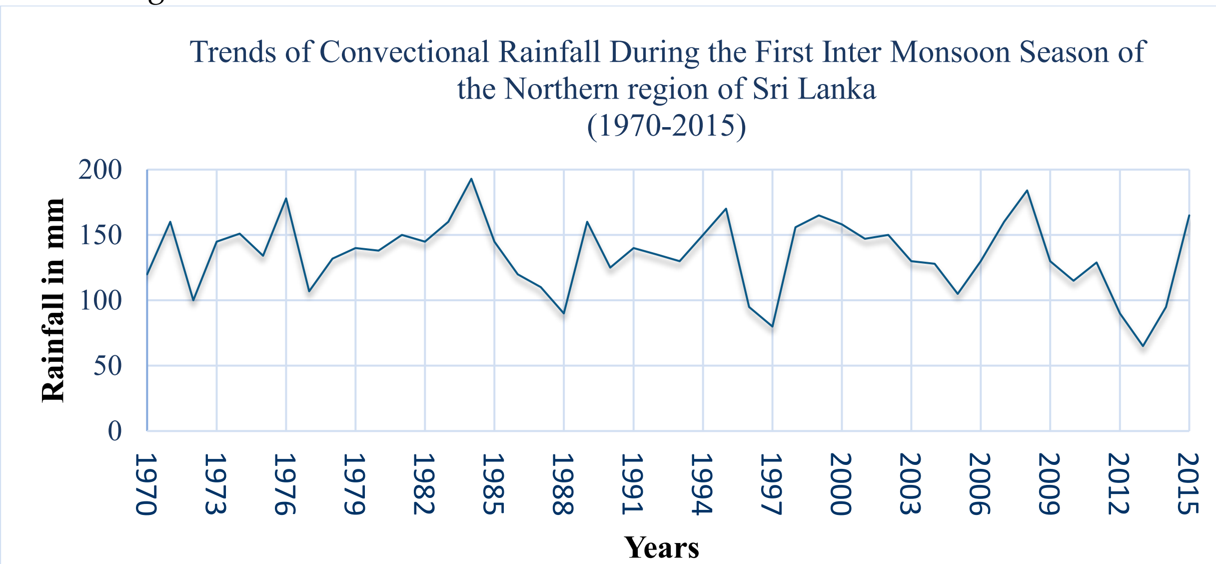

Figure 7: Trends of Convectional Rainfall During the FIMS in the Northern Sri Lanka

Spatially study area receiving the various amount of rainfall. Simultaneously, all places in the study area receiving the highest rainfall during October. The month of October generally receives more than 45% of the total convectional rainfall than all other months. March is receiving more than 25% of its. However, total rainfall due to the convectional process for October is increasing throughout the year. However, an uncertain situation also prevails during the convectional rainfall. Many fluctuations have been identified in this rainfall type. Compared with other periods, the latter part of March and the middle part of April in the FIMS receive higher amounts of rainfall, 50 mm more than other months of June, July, August, September, and October. Convectional rainfall in the FIMS and SIMS is significant because this is the only water source to mitigate the dry period or drought conditions and water scarcity problems. So, this uncertainty will impact the above-said matters. Convectional rainfall is the significant rainfall in the province because it occurs during the two dry seasons of the FIMS and the later part of the SWMS. These two seasons are identified as drought seasons, with most of the province facing severe drought vulnerability. Some regions face extreme drinking water difficulties, especially Manthai West, Madu, Poonakari, Island south, Island North, Karainagar, and Delft divisional secretariat divisions. So, the occurrence of rainfall in these seasons is considered a 'savior' to the people. This convectional rainfall is the primary source for the recharge to the groundwater in the Jaffna district and the mainland of the Northern region.

4.3. Observed Seasonal changes in rainfall

Seasonally there are significant variations identified in the rainfall pattern of the Northern region of Sri Lanka. Seasonal changes in the rainfall were identified as clearly in the study area. The following tables indicate the seasonal variations of the rainfall in the Northern region of Sri Lanka. The SWMS has decreased to 35 mm, and the SIMS rainfall has been increasing by 95 mm. Rainfall for the NEMS has been decreasing by 50 mm, and there are no variations in the rainfall of the FIMS. Generally, SWMS is identified as the driest period in the study area; if the rainfall decreases in the SWMS, the dry period becoming drier and may lead to water scarcity or drought problems in the study area. Agriculture and other economic sectors face a threat due to the Northern region's rainfall pattern changes. 91% of the farmers' concern is that they are not involved in any agricultural activities during this period or doing a minimal extent of agricultural activities due to the water problem. Simultaneously, the respondents explained that they face difficulties getting the water from their wells because of the low water level or the study area's availability during this period of the SIMS has been identified as one of the wettest seasons in the study area. If the average rainfall of this season increases, it will affect the water level of the surface water bodies, and these changes will also affect the study area's cultivation activities. Figure 8 describes the seasonal changes in the Northern region of Sri Lanka's rainfall.

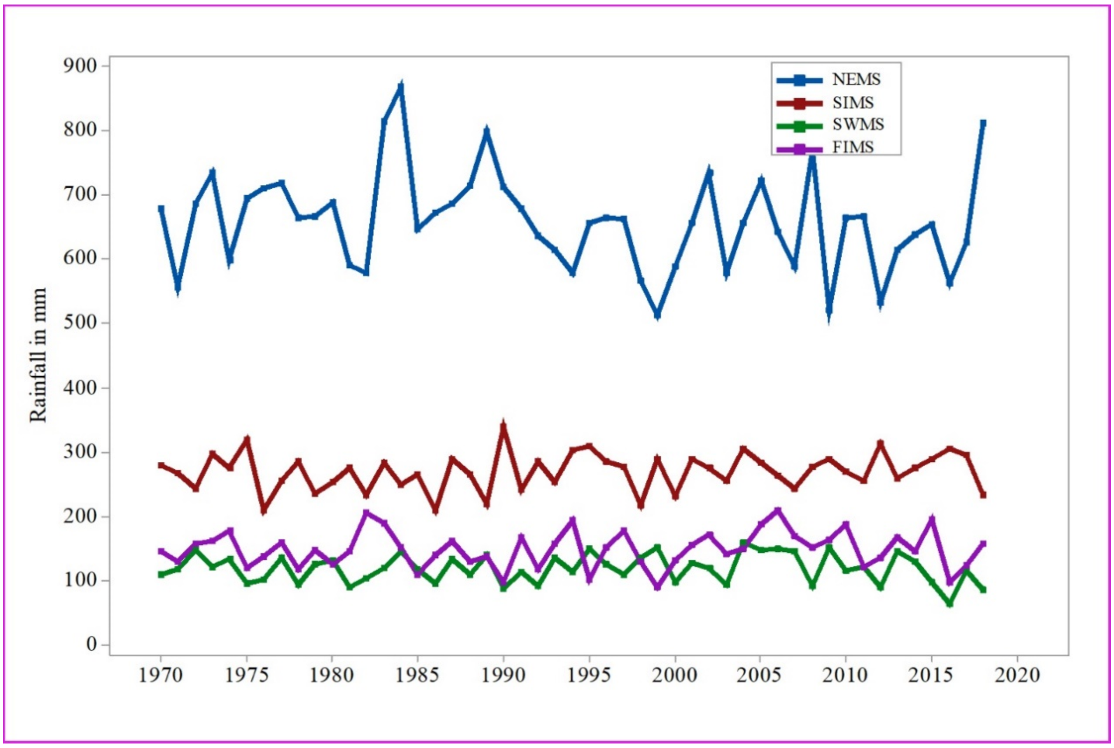

Figure 8: Seasonal rainfall changes of the Northern region of Sri Lanka from 1970 to 2020

There has been a significant trend in the Northern region of Sri Lanka's mean annual rainfall for the last fifty years. However, the trend of increasing rainfall identified by the present study is 18.89 mm/decade. Based on these results, we can conclude that there is a shred of solid evidence for climate change in the Northern region of Sri Lanka. There are many various discussions about the rainfall trend of Sri Lanka based on the climate change perspective. Some researchers have the opinion on decreasing trend of rainfall in Sri Lanka (Chandrapala, 2007; De Costa 2008; Jayatillake et al., 2005). But some other researchers have to oppose these results, and they have elaborated that there is an increasing pattern of trend in the rainfall. Punyawardena et al. (2013) observed that heavy rainfall events have become more frequent in central highlands during the recent period.

Nevertheless, there are variations among the researchers in the increasing amount of rainfall in the Northern region. However, recent researches reveal that a decreasing trend of rainfall from 1961to1990 has decreased by 144 mm (7 %) compared to the period from 1931to 1960 (Chandrapala 1996; Jayatillake et al. 2005). Further researches revealed a downward trend in some stations' rainfall for the period 1949-1980. However, there are temporally and spatially significant variations in the rainfall that has been identified in many places in Sri Lanka. The present study revealed a 13% rainfall decreasing trend in the Northern region from 1970 to 2019 in the NEMS. However, the SIMS and the SWMS show 9% of the increasing rainfall trend during the last half-century in the study area. However, there are variations in the increasing trend amount spatially. Many researchers considering that the changes in the rainfall pattern of a place are clear evidence for the climate change in that particular place (Chandrapala 1996; Basnayake, 2007; Shanthi de Silva, 2009).

The present research revealed that the seasonal rainfall trend is changing pattern. The NEMS is losing its dominance, and SWMS is getting more contribution in the total rainfall of the study area. Most of the climate change studies of Sri Lanka indicate considerable variations in the seasonal rainfall amount. According to the observed climate change of the country, there is an increasing pattern of seasonal rainfall in some parts and a decreasing pattern of rainfall in some parts of Sri Lanka. Especially some studies (Eriyagama & Smakhtin, 2009; Punyawardena et al., 2013; Jayawardene, Sonnadara & Jayewardene, 2005) indicate a decreasing rainfall pattern in SWMS. However, the present study indicating that there is an increasing pattern of rainfall during the SWMS. Various other studies also indicate that spatial distribution of rainfall appears to be changing, although a distinct pattern cannot be recognized yet (De Costa, 2010) (Eriyagama, Smakhtin, Chandrapala, & Fernando, 2010) (S. De Silva, 2006)(De Costa, 2012). However, many researchers seem to agree that the variability of rainfall has increased over time, especially in the Yala season (Chandrapala 2007; Eriyagama et al. 2010; Punyawardena et al., 2013; Eriyagama & Smakhtin, 2009; Shanthi de Silva, 2009; Jayawardene, Sonnadara & Jayewardene, 2005).

Current study analysis on rainfall changes shows only a 16 mm variation of the study area's annual rainfall pattern from 1901 to 2019. However, other climate change studies of Sri Lanka indicate significant variations of rainfall observed in some other parts of Sri Lanka (Basnayake, Fernando & Vithanage, 2002) (Eriyagama & Smakhtin, 2009). The current study reveals very few seasonal and monthly rainfall patterns for an extended period from 1901 to 2019. However, other studies indicating that there are vast variations between the seasons and the months (Shanthi de Silva, 2009) (Suppaiah, 1996) (Jayawardena, 2012) (Naveendrakumar et al., 2018). Based on monthly rainfall studies, there are many variations among climate change and rainfall trend studies. A few studies indicate no changes in the monthly basis rainfall in Sri Lanka; some other studies indicate many changes in the monthly basis rainfall in Sri Lanka. Few authors mentioned the same results of the current studies that minimal changes in the monthly basis rainfall. As per the rainfall, many of the studies indicate the decreasing rainfall pattern, but the current study revealed no significant variations in the rainfall of the study area during the past 100 years.

5. Conclusion

In conclusion, significant changes in the rainfall trend of the Northern region of Sri Lanka have been identified through the Mann Kendall test and Sen's slope estimator methods. The convectional process contributes to the total rainfall of the Northern region of Sri Lanka, becoming a significant rainfall process in the Northern region of Sri Lanka. At the same time, the northeast monsoon wind process is losing its role in contributing to the rainfall in the Northern region of Sri Lanka. The historical annual rainfall of Northern Sri Lanka has increased from 18.76 mm/decade to 37.68 mm/decade from 1970 to 2019. However, their variations in the trend of rainfall temporally and spatially. Particularly Thannimurippu, Nainatheevu, and Nedunkerny stations trend shown in the upward, and at the same time Irnaimdu, Kanukkerny, and Thirunelvely stations show the significant trend on downward in the study area.

Further, the northeast monsoon season is losing its dominance in contributing to the total rainfall pattern. However, the SWMS getting dominance in contributing to the total rainfall in a year. Monthly pattern of the rainfall: November is the crucial month in a year because more than 43% of the total rainfall is receiving in the last two decades. Climate change, especially rainfall changes, has much impact on many socio-economic sectors of the Northern region of Sri Lanka. Even though surface water resources of the study area have much threat to rainfall change. Surface water is the vital natural source for the human existing in the Northern region of Sri Lanka. Therefore, any threat to the surface water in any form should be affected not only to the human being but also to the other living organisms of the Northern region of Sri Lanka. In this context, climate change mitigation measures or climate change adaptation strategies towards protecting the study area's surface water resources is an essential and primary concern of all stakeholders in the sustainability of the Northern region of Sri Lanka.

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