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MICRO-REGIONAL DISPARITIES IN TEMPERATURE AND PRECIPITATION TRENDS ACROSS TOURISM DESTINATIONS IN THE TRINCOMALEE DISTRICT, SRI LANKA (1981–2024)

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Abstract: The Trincomalee District is strategically positioned at the nexus of Sri Lanka's Northern and Eastern Provinces, rendering it a pivotal locale both geographically and economically, particularly as a distinguished hub for tourism. This geographical confluence engenders intricate microclimatic phenomena that exhibit substantial variability across different sectors of the district. A comprehensive understanding of these climatic fluctuations is imperative for fostering sustainable development, especially in the realms of tourism enhancement and resource management. The primary objective of this study is to analyse the micro-regional variations of temperature and precipitation of the Trincomalee District of Sri Lanka. To this end, the study integrates satellite imagery with meticulous meteorological data to rigorously analyze prevailing climate patterns. Employing sophisticated statistical methodologies, such as the Mann-Kendall trend test, enables the detection of significant temporal alterations in temperature and precipitation. Sen's slope estimator further quantifies the velocity of these climatic trends, offering profound insights into the magnitude of environmental shifts. The utilization of ArcGIS software facilitates spatial interpolation, culminating in detailed cartographic representations that vividly depict microclimatic disparities throughout the region. Data on temperature indicates that Serunuwera sustains an average of approximately 27.4°C, whereas Kuchchavali exhibits marginally higher temperatures at 28.3°C, reflecting localized thermal variations. Precipitation metrics reveal pronounced disparities, with urban Trincomalee receiving roughly 959.3 mm annually, contrasted by Mullipothana, which records up to 1955.3 mm—nearly double the amount. Seasonal fluctuations in rainfall are particularly evident in Kinniya and Serunuwera, underscoring the dynamic nature of seasonal climatic patterns. These spatial and temporal heterogeneities complicate the formulation of uniform development policies across the district, necessitating bespoke strategies tailored to diverse microclimates. Ultimately, this research establishes a detailed climatic baseline, equipping policymakers with the essential foundation to craft region-specific strategies. The insights derived from this study are crucial for fostering balanced regional growth that accommodates the district's diverse microclimate conditions.

Keywords: microclimate, temperature, rainfall, Trincomalee District, spatial pattern

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INTRODUCTION

Climate change is one of the most significant phenomena, both natural and anthropogenic, confronting the world today (Jayawardene et al., 2020). Since the dawn of this century, climate change has emerged as a pressing global concern, serving as a foundation for myriad challenges, including shifts in global temperatures and the escalation of greenhouse gas concentrations (Ajani & van der Geest, 2021). Initially perceived as an isolated scientific issue, climate change has evolved into a critical subject that captivates the attention of diverse stakeholders worldwide (Atilgan Türkmen, 2021). It has ascended to a principal concern for governments across nations, necessitating that every individual on the planet contemplate its implications (Sharma et al., 2022). Every region experiences the ramifications of climate change in distinct ways; thus, while it poses a universal challenge, its scale and intensity differ markedly from one locale to another (Munawar et al., 2022). The global industrial revolution and anthropogenic activities, coupled with the rising levels of atmospheric greenhouse gases, are propelling ongoing climatic alterations (IPCC, 2021).

Sri Lanka, situated in the South Asian region, is particularly susceptible to the adverse impacts of climate change (Alahacoon & Edirisinghe, 2021). The Sri Lankan government, alongside various non-governmental organizations, is increasingly prioritizing climate-related concerns (Dasandara et al., 2021). These entities are executing a variety of initiatives, including livelihood projects that engage all sectors capable of contributing to climate resilience, aimed at alleviating the effects of climate change and fostering a sustainable way of life (Samaraweera et al., 2024).

Over 65% of Sri Lanka's population is intricately linked to agricultural activities. Fluctuations in climatic factors, such as temperature and precipitation, significantly disrupt the agricultural sector (Abegunasekara & Kaluthanthri, 2022). Climate constitutes an essential natural phenomenon that underpins all activities vital for human survival in Sri Lanka (Cho, 2020). The implications of climate change will reverberate across numerous sectors, particularly agriculture,

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engendering uncertainties related to weather events that threaten the socio-economic development and advancement of Sri Lanka (Somasundaram et al., 2024). Trincomalee, situated on Sri Lanka's eastern coastline, experiences a tropical wet and dry climate, classified as the Keppan climate classification. Throughout the year, the high temperatures range from 29.3℃ to 34.9℃, while the lows fluctuate between 20℃ and 28℃ (Jayawardena et al., 2018). Trincomalee, a prominent port city located on the northeastern coast of Sri Lanka, holds significant geographical and economic importance both regionally and nationally (Kaleel, 2017). Geographically, it is situated along the strategic Palk Strait, offering a natural deep-water harbor that is one of the finest in the world (Ramkishan et al., 2021). Its natural harbor is well-protected by surrounding land formations, making it an ideal location for maritime activities and naval defense. The city's proximity to key shipping routes connecting the Indian Ocean with the Bay of Bengal enhances its strategic significance (Mehvar et al., 2019).

Economically, Trincomalee is vital due to its deep-water port, which serves as a major hub for maritime trade and transportation (Grabs et al., n.d.). The port facilitates the import and export of goods, including minerals, agricultural products, and manufactured items, contributing substantially to Sri Lanka's economy. Additionally, the surrounding region is rich in natural resources such as minerals, fishery industries, and agricultural products, further bolstering economic activity (Rathakrishnan et al., 2024). The development of industries like shipbuilding, tourism, and energy, particularly the nearby hydroelectric projects and oil tanks, also adds (Ramkishan et al., 2021) to its economic relevance (Mehvar et al., 2019). Furthermore, Trincomalee's strategic position makes it a focal point for international naval and commercial interests, attracting investments and fostering regional cooperation. Overall, its geographical advantages and economic activities make Trincomalee a crucial asset for Sri Lanka's development and security (Ramkishane et al., 2021). Microclimatic variations significantly influence the development and environmental conditions of the Trincomalee district in Sri Lanka. Located along the northeastern coast, Trincomalee experiences diverse microclimates due to its varied topography, proximity to the Indian Ocean, and local landscape features (Mehvar et al., 2019). Coastal areas tend to have higher humidity, moderate temperatures, and strong sea breezes, which impact agriculture, settlement patterns, and infrastructure development.

With their hills and forests, inland regions often exhibit cooler temperatures and different wind patterns, creating localized climates that favor certain crops or hinder others. These microclimatic differences affect the distribution of vegetation, the prevalence of pests and diseases, and the availability of water resources, all of which are crucial for economic activities such as fishing, agriculture, and tourism. For example, areas with favorable microclimates support the cultivation of coconuts and paddy, forming the backbone of local livelihoods, while regions with less favorable conditions may face challenges in agricultural productivity. Additionally, microclimatic factors influence urban planning and disaster management, especially in mitigating the impacts of climate variability and extreme weather events (Zita et al., 2025). Overall, understanding these microclimatic variations is essential for sustainable development and resource management in the Trincomalee district.

Sri Lanka is currently experiencing heightened vulnerability to the impacts of climate change, primarily due to significant and extreme fluctuations in rainfall and temperature patterns. These climatic variations pose serious challenges to the country's environmental stability, socio-economic development, and overall resilience. Within this context, the Trincomalee district emerges as a critical area of concern. As a prominent tourism hub renowned for its natural attractions—such as pristine beaches, historical sites, and diverse marine ecosystems—it draws a considerable number of both international and local visitors. The district's tourism industry is highly dependent on stable climatic conditions; any abrupt or sustained changes in rainfall and temperature can adversely affect the natural landscapes, marine activities, and overall visitor experience. If the climate-induced alterations in rainfall and temperature directly impact these natural and cultural assets, it could lead to a decline in tourist arrivals, thereby affecting local livelihoods and economic development. Furthermore, such changes could disrupt other development activities within the district, including agriculture, fisheries, and infrastructure projects, which are also sensitive to climatic conditions. In light of these concerns, this study aims to analyze the regional variations of rainfall and temperature within the Trincomalee district. By examining spatial and temporal patterns of climatic changes, the research seeks to identify specific areas and periods most vulnerable to climate fluctuations. The findings will provide valuable insights for policymakers and stakeholders to develop targeted adaptation strategies, ensuring the sustainable growth of tourism and other development initiatives in the face of ongoing climate change.

LITERATURE REVIEW

Understanding the spatial and temporal variability of rainfall and temperature is crucial for managing water resources, agriculture, disaster mitigation, and environmental planning (Cehan et al., 2024). Recent research has employed diverse methodologies—including dynamical modeling, machine learning, statistical analysis, and remote sensing—to investigate these variations across different regions globally. The study by An improved method for dynamical extended-range forecasting of persistent severe rainfall (Zhang et al., 2025) emphasizes the integration of the Model for Prediction Across Scales - Atmosphere (MPAS-A) with regional models to enhance forecasts of persistent rainfall events. This approach highlights the importance of high-resolution dynamical models in capturing regional rainfall patterns, especially in areas prone to severe weather. Similarly, Spatio-Temporal Characteristics of Climate Extremes in Sub-Saharan Africa (Zita et al., 2025) underscores the influence of large-scale oceanic teleconnections, such as the El Niño–Southern Oscillation (ENSO), on regional climate extremes, indicating that atmospheric circulation patterns significantly modulate local variability.

Several studies leverage machine learning to analyze rainfall and temperature variability. For instance, Ensemble learning of catchment-wise optimized LSTMs (Hosseini et al., 2025) demonstrates how ensemble learning enhances regional rainfall-runoff modeling in the Basque Country, revealing fine-scale heterogeneity. Similarly, Understanding Climate Change Impacts on Streamflow (Ande et al., 2025) applies machine learning techniques to predict future streamflow changes in the Godavari Basin, reflecting the capacity of data-driven methods to capture complex regional climate responses. These studies collectively underscore the effectiveness of machine learning in deciphering regional climate variability and improving predictive accuracy. Research on hydro-climatic variability, such as Hydro-Climatic Variability and Peak Discharge Response (Mohammadi et al., 2025), investigates how climate fluctuations influence river basins like Zarrinehrud in Iran. The findings reveal that interannual variability and climate extremes significantly impact peak discharges, with implications for flood management. Similarly, Spatio-Temporal Variations of Indonesian Rainfall (Ariska et al., 2024) explores how Indo-Pacific oceanic modes, including ENSO and Indian Ocean Dipole (IOD), drive regional rainfall shifts, emphasizing the complex interplay between oceanic patterns and regional climate. Regional climate variability's influence on agriculture is exemplified by Analyzing Wheat Production in Jordan (Farhan et al., 2025). It emphasizes how changes in temperature and rainfall, combined with population dynamics, affect crop productivity, highlighting the need for climate-informed agricultural planning (Chau, 2024). The study illustrates that regional climate variability can have profound socio-economic consequences (Zuluaga et al., 2011). Several studies examine the relationship between large-scale climatic indices and regional rainfall. The Relation Between Major Climatic Indices and Subseasonal Precipitation (Arruda et al., 2025) demonstrates correlations between indices like ENSO, the South American Monsoon, and regional precipitation in Brazil. Similarly, Variability in Summer Rainfall and Rain Days over the Southern Kalahari (Kekana et al., 2025) investigates ENSO and the Botswana High's influence, revealing how teleconnections modulate regional rainfall and temperature patterns.

Research focusing on extremes, such as Spatial and Temporal Variations' Characteristics of Extreme Precipitation and Temperature in Jialing River Basin (Liao et al., 2024), highlights the influence of atmospheric circulation patterns on local extremes. Moreover, Variability in Summer Rainfall and Rain Days illustrates how climate oscillations impact the frequency and intensity of rainfall events, which are vital for disaster preparedness and environmental management (Yuan et al., 2025). Future projections based on climate scenarios are discussed in The Spatiotemporal Evolution, Driving Mechanisms, and Future Climate Scenario-Based Projection of Soil Erosion (Huang et al., 2025). The study underscores how climate change may exacerbate regional variability in rainfall and temperature, leading to increased soil erosion and environmental degradation. Regional studies such as Analysis of Rainfall Distribution in Pakistan (Haseeb et al., 2025) and Impact of Seasonal Variations on Wastewater Treatment in Lake Como (Lawrence et al., 2024) demonstrate localized assessments of rainfall and temperature variability. These works offer insights into how regional climate patterns influence infrastructure, water quality, and environmental protection efforts (Bai et al., 2024). Finally, the application of GIS and remote sensing, as seen in Analyzing Wheat Production in Jordan (Farhan et al., 2025), highlights the importance of spatial analysis in understanding regional climate variability. Such tools facilitate detailed mapping and modeling of rainfall and temperature patterns across diverse landscapes. The collective body of research underscores that regional variations in rainfall and temperature are driven by a combination of atmospheric circulation patterns, oceanic teleconnections, and local geographic factors. Advances in dynamical modeling, machine learning, and remote sensing have significantly improved our understanding of these spatial and temporal patterns. Recognizing these variations is vital for effective resource management, disaster mitigation, and adapting to ongoing climate change impacts across different regions globally.

DATA AND METHODOLOGY

Study Area

The Trincomalee District has been designated as the focal area for this study. Serving as the administrative headquarters of the Eastern Province (Figure 1-A), Trincomalee District stands as a pivotal urban center, largely due to its expansive natural harbor(Kaleel, 2017). It is situated approximately 113 miles south of Jaffna and 69 miles from the city of Batticaloa, at coordinates 8° 34' 0" N and 81° 14' 0" E, encompassing an area of 2,727 square kilometers (Figure 1-B).

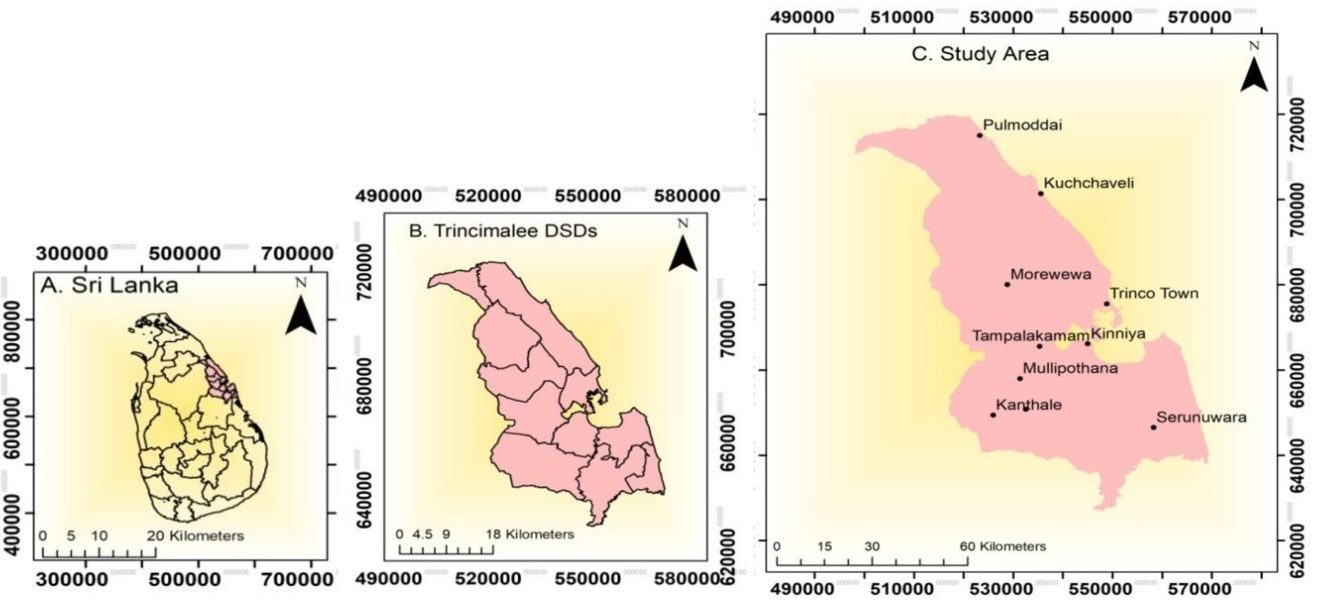


Figure 1. The location of the Trincomalee district of Sri Lanka (A). The study area is located on the Eastern coast of Sri Lanka, which is very famous for tourist activities in Sri Lanka (B &C). (Source: National Atlas of Sri Lanka, 2025)

The district is bordered to the north by Mullaitivu District, to the west by Anuradhapura and Polonnaruwa Districts, to the south by Batticaloa District, and to the east by the Indian Ocean. The Trincomalee District boasts a population of 443,807, comprising three principal ethnic groups: the Tamils, the Sinhalese, and the Muslims. It is administratively divided into 230 Grama Niladari divisions and 11 Divisional Secretariat divisions (Figure1-C). The district experiences its highest precipitation, 309.77 mm, during November and December. The average temperature in Trincomalee District is a comfortable 27.6°C (81°F), with an average annual rainfall of 1,318 mm (Meteorology, 2015). The northern region of Trincomalee is characterized by the Vanni Range, while the southern part features the High Mountain Range.

Trincomalee is a prominent tourist destination in Sri Lanka, attracting approximately 80,000 visitors annually. The district is renowned for its stunning natural attractions, including pristine beaches, scenic landscapes, and opportunities for relaxation, making it a favored spot for leisure and sightseeing. A significant majority of visitors, around 68.7%, visit primarily to explore the numerous tourist attractions, while 18.33% seek pleasure-seeking tours focused on relaxation and enjoyment. Other reasons for visiting include beauty and treatment experiences (9.09%), festivals and performances (3.03%), and business-related activities (3.03%). In terms of spending habits, some tourists spend between USD 80-150 per day, whereas more affluent travelers, such as flashpackers, diaspora tourists, and divers tend to spend between USD 150-250 daily. The key attractions that draw visitors include the district's beautiful beaches, natural scenery, and opportunities for rejuvenation, with about 66.67% of tourists specifically coming for these attractions. Overall, Trincomalee's combination of natural beauty, cultural experiences, and leisure options continues to make it a popular destination in Sri Lanka.

Data

Data collection constitutes the fundamental component of any scholarly investigation. In this context, both primary and secondary data have been employed to examine the microclimatic disparities within the Trincomalee district. Rainfall and temperature data spanning from 1981 to 2022 for the Trincomalee district were acquired from analyzed satellite imagery and the Department of Meteorology of Sri Lanka. To delve into the microclimatic differences in the Trincomalee district, monthly and annual rainfall records over 41 years were gathered from various selected tourist locales, including Kinniya, Trincomalee City, Morawewa, Thambalagamam, Jayanthipuram, Serunuwera, Pulmoddai, Kuchchaveli, Mullipothanai, and Kanthale. Moreover, fifty-seven samples were incorporated into the study, utilizing a primary data collection method grounded in interviews to ascertain the impacts of microclimatic variations. Additionally, supplementary statistical data pertinent to the research were sourced from an array of journals, articles, and research reports. The areas chosen for the study within the Trincomalee district are delineated in Table 1.

Table 1. Geographical distribution of the rain gauge stations in the Trincomalee district (Source: National Atlas of Sri Lanka, 2025)

Stations	Elevation (m)	Longitudes (East)	Latitudes (North)
Morewewa	24	8.6280556	81.0333333
Kinniya	8	8.502565	81.1802778
Trinco town	8	8.5872222	81.2154682
Kanthale	33	8.3511111	81.0069444
Thampalakamam	3	8.4972222	81.0919444
Mullipothana	32	8.4286111	81.0561111
Kuchchaveli	1	8.8213889	81.0947222
Pulmoddai	18	8.9447222	80.9830556
Serunuwera	8	8.3247222	81.3005556
Jeyanthipuram	24	8.3688889	81.0669444

Methods of analysis

The methodology of data analysis is paramount for the effective execution of a study. All data acquired for this research have been meticulously examined employing a systematic and appropriate technique. In this endeavor, the Mann-Kendall seasonal variation detection method, alongside Sen's slope estimation, has been utilized to ascertain the microclimatic differences within the Trincomalee district. The analytical procedures were conducted utilizing the software known as Minitab 17, which subsequently facilitated a thorough descriptive analysis. The purpose of the Mann-Kendall seasonal variation detection method (Mann, 1945; Kendall, 1975;Gilbert, 1987) is to statistically evaluate whether a consistent upward or downward trend exists for a variable over time. This method is one of the fundamental statistical techniques widely employed in climate-related studies, particularly for the long-term analysis of rainfall and temperature (Ogou, 2021). The estimation of temperature and rainfall from 1981 to 2024 in the Trincomalee district of Sri Lanka was meticulously examined utilizing Sen's slope estimation and the Mann-Kendall seasonal difference detection method (Saini et al., 2020). This method serves to evaluate whether the climatic trends of temperature and rainfall over 41 years have been increasing or decreasing and whether such changes are statistically significant (Praveen et al., 2020).

The results of Sen's slope estimation revealed both positive and negative values, indicating trends of increase and decrease, respectively. A total of 41 years of climatic data were employed for this analysis. The Mann-Kendall seasonal difference detection method and Sen's slope estimation were instrumental in studying the alterations in temperature and rainfall within the Trincomalee district of Sri Lanka. The Mann-Kendall method is adept at detecting trends within time series data, such as precipitation, temperature, and river discharge. Its utility extends to all forms of measurement. Each data point in the time series is compared with its subsequent values. Statistically, these parameters are initially regarded as zero via the Mann-Kendall temporal difference detection method (Okafor et al., 2017). Should the data value in the following period exceed that of the preceding period, it is incremented by one, and conversely. This culminates in a net result reflecting all such increments and decrements. The Mann-Kendall temporal statistic (λ) is represented as follows.

$$s = \sum_{i=1}^{n_{-1}} \quad \sum_{j=i+1}^{n} \quad \operatorname{sgn}\left(\varkappa_j - \varkappa_i\right) \qquad (01)$$

Here, \(x_j \) represents the sequential data points, \(n \) denotes the length of the time series, and the function \(\operatorname{sign}(x_i - x_j)\) assumes the value -1 when \(x_i - x_j < 0 \), 0 when \(x_i - x_j = 0 \), and 1 when \(x_i - x_j > 0 \). The expected value \(E[S] \) and variance \(V[S] \) of the statistic \(S \) are provided as follows:.

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{bmatrix} +1, & > & \left(x_j - x_i\right), \\ 0, & = & (xj - xi), \\ -1 & < & \left(x_j - xi\right) \end{bmatrix} \qquad (02)$$

A positive value of λ indicates an increasing trend, and a negative value indicates a decreasing trend.

$$var(s) = \frac{n(n-1)(2n=5) - \sum_{i=1}^{m} -i(i)(i-1)}{18} \qquad (03)$$

where, n = the total quantity of data points; m = the number of groups exhibiting tied values, and ti denotes the quantity of ties corresponding to the extent i. A tied group constitutes a collection of sample data points sharing an identical value.

$$Zc = \begin{bmatrix} \frac{S-1}{\sqrt{var}}(s) \;\; 0, s = 0, & s > 0, \\ \frac{S=1}{\sqrt{var(s)}}, & s < 0 \end{bmatrix} \qquad (04)$$

Positive ZS values signified an escalating trend, whereas negative ZS values reflected a declining trajectory.

If the value of n is positive, the trend is characterized as increasing. Conversely, if n is negative, the trend is classified as decreasing. Additionally, the computed n-statistic exceeds the n-value corresponding to the 5% significance level. If the calculated n-statistic falls below the n-value associated with the 5% significance level, no trend is observed (Yang, 2022). The variable nU maintains a constant normal scale; a positive nU value signifies an increasing trend, whereas a negative value denotes a decreasing trend for that interval. If both nU and nU2 are present, the null hypothesis is dismissed.

Sen's slope is a nonparametric statistical technique extensively employed in global climate research to ascertain the magnitude of variations in temperature and precipitation. Introduced by Sen in 1968, this method evaluates the strength of trends within time series data (Senatilleke et al., 2022). In this context, temporal changes and the true slope are estimated utilizing the approach formulated by Sen (1968). The estimation of Sen's slope is a widely embraced method for assessing the magnitude of precipitation and temperature trends over time, with its value derivable via Equation (05).

$$\text{Ti} = Ti = \frac{\text{xj}-\text{xk}}{j-k} \;\; f \text{ or i} = 1,2,3, \ldots \ldots \ldots \ldots \ldots \ldots \text{n, j. k}, \qquad (05)$$

where Xj and Xk = the data values at times j and k (j > k), respectively. If there is only one datum in each period, then N = n(n−1) 2, where number of periods. If there are multiple observations in one or more periods, then N < n(n−1) 2, where the total number of observations. The N values of Qi are ranked from the least to the highest, and the median slope or Sen's slope estimator was calculated as. The slope of the curve is the average of the n values of the data points at the same time point. The slope estimate of the curve is calculated using equation (6).

$$Qi = \begin{cases} 1^T\left(n + {}^1\!/_2\right), & n \;\; is \;\; odd \\ {}^1\!/_2 \left(T\left(\frac{n}{2}\right) + \right. & {}_{T(n+2}/2, n \;\; is \; even \end{cases} \qquad (06)$$

Te Qmed sign reflects the data trend, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different from zero, the computation of the confidence interval of Qmed at a specific probability is done. The procedure for detecting spatial variations in mean temperature and precipitation can be encapsulated in the five-point method. This approach is employed to discern the spatial distribution of temperature and precipitation, and it is frequently utilized by geologists. This technique represents a linear amalgamation of data, serving as a precise interpolation method. The five-point method was implemented using ArcGIS 10.4. Utilizing secondary data collected for this study, which includes rainfall and temperature statistics as well as demographic characteristics of the selected regions within the Trincomalee district, we aimed to identify the variability in temperature and precipitation, specifically the spatial trends associated with these variables. The geographical coordinates of the study areas were mapped onto an Excel spreadsheet, incorporating latitude and longitude, along with the corresponding temperature and rainfall measurements from the observation stations, which were subsequently converted into DBF format. Following this, the locations of the observation stations were charted using the ArcGIS method, and the spatial trends of temperature and rainfall were depicted through the five-point interpolation method, subjecting the results to descriptive analysis.

RESULTS AND DISCUSSION

Spatial Trend of Temperature in Trincomalee

Upon examining the spatial variation of temperature in the Trincomalee district from 1981 to 2022, as illustrated in Figure 2, it becomes evident that temperature fluctuates significantly across different regions. Analyzing the 41-year average temperature trend within the same period reveals that the most pronounced increases in temperature have occurred in the Pulmoddai and Kuchchavali areas, while a more moderate trend is evident in Thambalagamam, Kinniya, Mullipothana, Kanthale, and Morawewa. A modest temperature rise has also been noted in the Serunwera and urban areas of Trincomalee. The peak annual average temperature recorded stands at 28.31 degrees Celsius, contrasted by a minimum of 27.43 degrees

Celsius. Notably, the highest temperature in the Pulmoddai area soared to 31.38 degrees Celsius in 1996. The spatial temperature variation throughout the Trincomalee district is distinctly observable, as depicted in Figure 2.

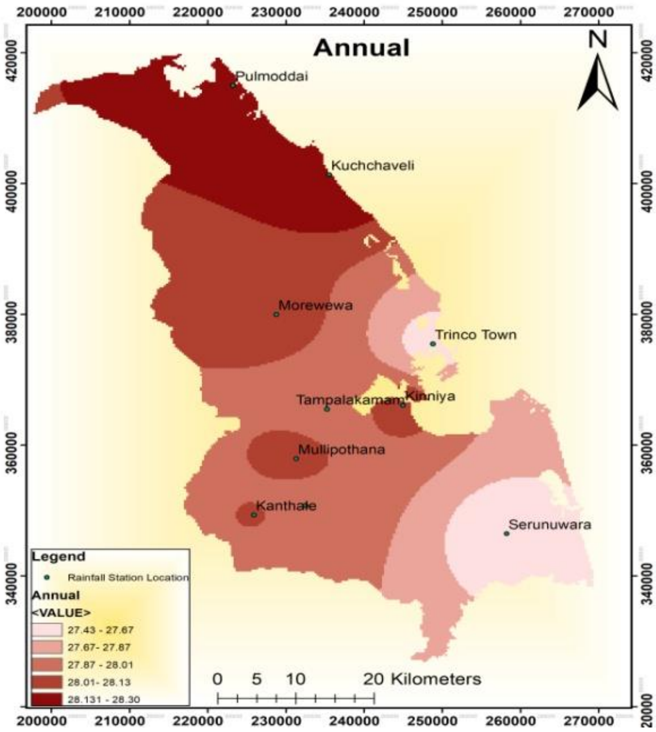
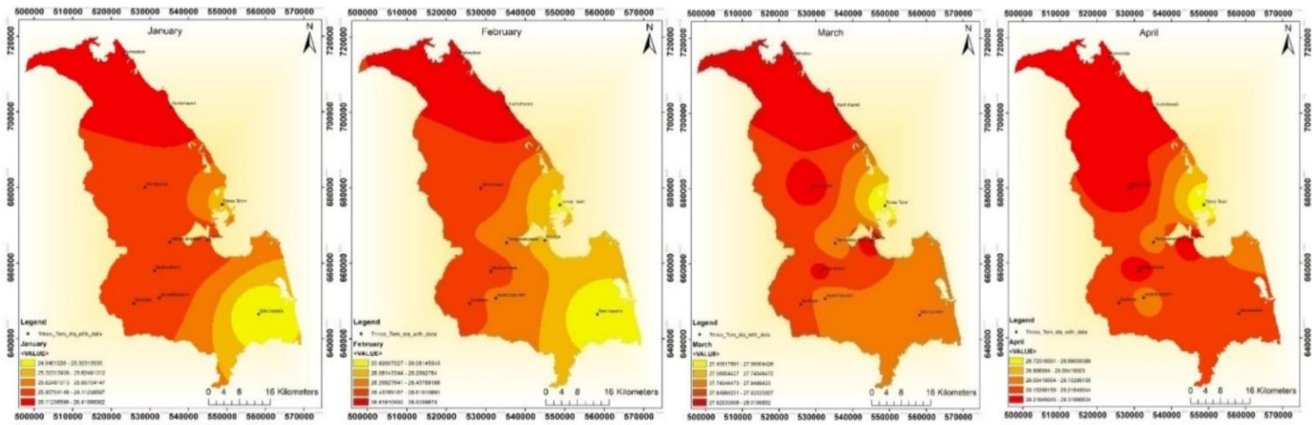


Figure 2. Spatial pattern of annual temperature increase in the Trincomalee district of Sri Lanka for forty years from 19 82 to 2024. The Northern part of the study area receives more rainfall than the other areas

Upon examining the spatial fluctuations of the monthly temperature trends within the Trincomalee district, it is noted that the apex temperature recorded in January was 26.42℃, whereas the nadir temperature registered at 24.94℃. The highest temperatures were documented in Pulmoddai, Morawewa, Kanthale, Kuchchavali, Mullipothana, and Kinniya during January, whereas the lowest temperatures were observed in the urban vicinity of Trincomalee and Serunwera. In February, the zenith temperature achieved was 26.83℃, with the minimum temperatures once again noted in the same locales of Pulmoddai, Morawewa, Kanthale, Kuchchavali, and Mullipothana. The temperature trend continued to reflect lower readings in the urban areas of Trincomalee and Serunwera. March and April saw the highest temperatures recorded in Pulmoddai, Morawewa, Kuchchavali, Kinniya, Serunuwera, and Mullipothana, whereas the coolest readings were registered in Thambalagamam and Kanthale, particularly in the urban sectors of Trincomalee. During May and June, the peak temperatures of 29.8℃ and 29.39℃ were recorded in Kuchchavali and Pulmoddai, with significant warmth also noted in Morawewa, Thambalagamam, Kanthale, Jayanthipuram, Mullipothana, and Kinniya during the preceding months.

Conversely, the lowest temperature trend was documented in the Trincomalee urban area, and Serunuwera was noted at 28.95℃ and 28.52℃. For July, August, September, and October, the highest temperatures of 29.1℃ were reached in both Kuchchavali and Pulmoddai, while the minima were seen in Morawewa, Thambalagamam, Kanthale, Jayanthipuram, Mullipothanai, and Kinniya. The trend of lowest temperatures persisted in both the urban areas of Trincomalee and Serunwera. In November and December, the peak temperatures recorded were 27.59℃ and 26.95℃, respectively, in Kuchchavali and Pulmoddai, with the lowest averages once again marked in Morawewa, Thambalagamam, Kanthale, Jayanthipuram, Mullipothanai, as well as in Trincomalee urban area and Kinniya. This phenomenon is illustrated in Figure 3.



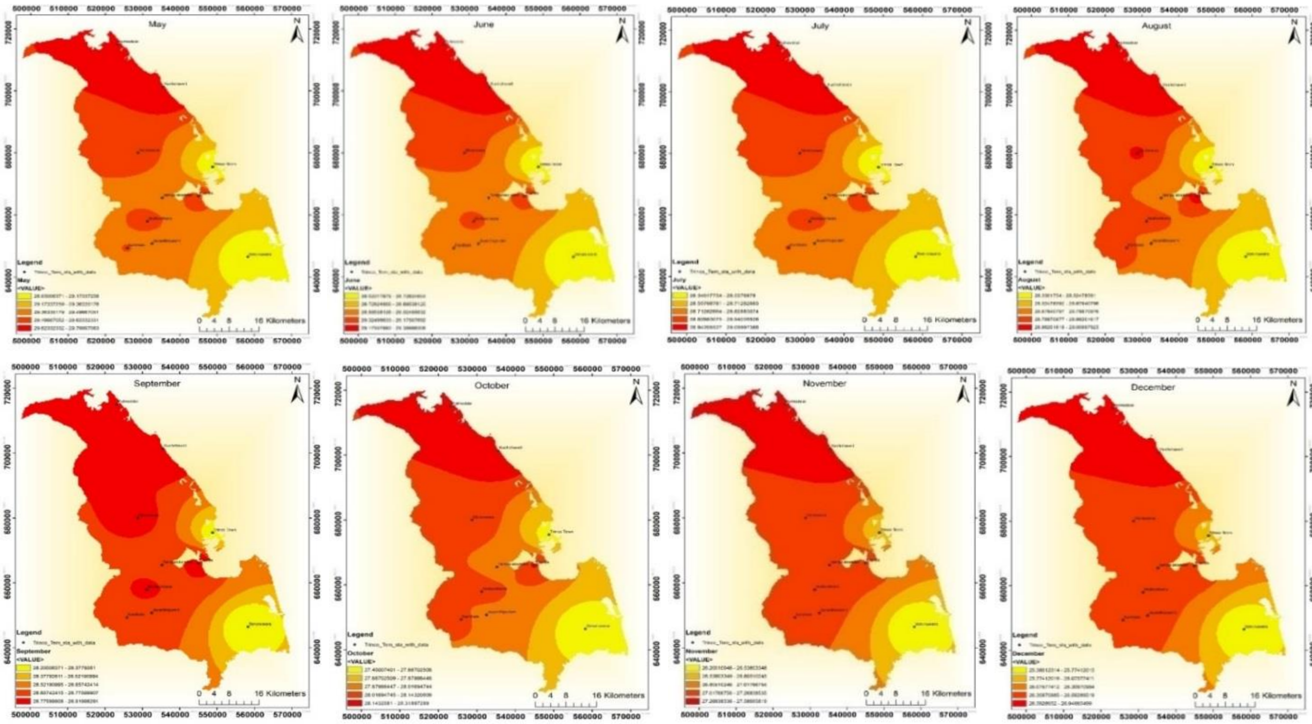


Figure 3. Spatial pattern of monthly temperature increase in the Trincomalee district of Sri Lanka

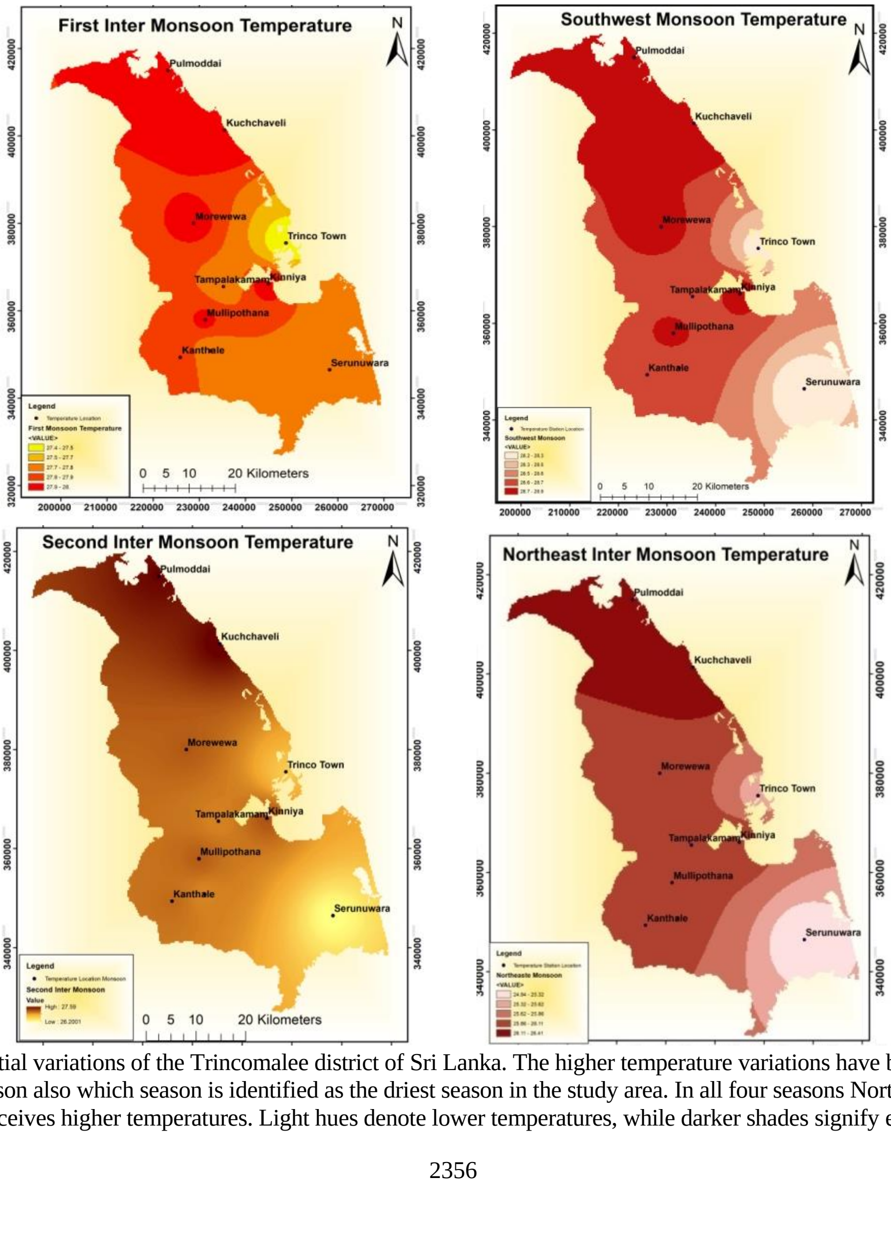


Figure 4. Seasonal spatial variations of the Trincomalee district of Sri Lanka. The higher temperature variations have been found in the First Intermonsoon Season also which season is identified as the driest season in the study area. In all four seasons Northern region of the Trincomalee district receives higher temperatures. Light hues denote lower temperatures, while darker shades signify elevated thermal levels

Analyzing the spatial temperature trends of the Trincomalee district reveals a pattern of fluctuations throughout the months. The apex temperature, recorded in April, reached 29.32°C, while the nadir was noted in January at 24.94°C. The lowest temperatures were observed in the Trincomalee district during March and April, whereas the highest temperatures were prevalent in other locales. From May to October, maximum temperatures were documented in regions such as Pulmoddai, Kuchchavali, Morawewa, and Kanthale, while minimum temperatures were experienced in the urban areas of Trincomalee and Serunuwera. The seasonal temperature patterns exhibit distinct spatial variations. This phenomenon is illustrated in Figure 4.

During the northwest monsoon, temperatures are elevated in Pulmoddai and Kuchchavali, with the Cherunuwera area registering the lowest temperatures during this season. Furthermore, in the second inter-monsoon period, elevated temperatures persist in Pulmoddai and Kuchchavali, while regions such as Morawewa, Kanthale, Mullapothana, Thambalagamam, and Kinniya display relatively uniform temperatures. Notably, rainfall increases during this second inter-monsoon period, coinciding with a consistent temperature trend.

Throughout the southwest monsoon, temperatures soar in areas such as Pulmoddai, Kuchchavali, Thambalagamam, and Morawewa, while the urban area of Trincomalee, along with Mullapothana and Serunuwera, experiences notably cooler temperatures. During the first inter-monsoon period, temperatures remain low in the Trincomalee urban area, contrasting with the higher temperatures prevalent in Pulmoddai, Kuchchavali, Thambalagamam, and Morawewa during this time.

Temporal Trends of Temperature in Trincomalee District

The annual average temperature trend observed in the selected regions of the Trincomalee district is on a discernible rise. Notably, the Kuchchavali area has recorded the highest annual average temperature at 28.05 degrees Celsius. Moreover, there has been a subtle increase of 0.007 degrees Celsius over the past 41 years. Conversely, the Trincomalee urban area has documented the lowest annual average temperature, measuring 27.36 degrees Celsius. The Kuchchavali area is experiencing a heightened annual average temperature trend, rising by 0.012 degrees Celsius. The annual average temperature in Kinniya stands at 27.95 degrees Celsius, while the Thampalagamam area registers an annual average of 27.76 degrees Celsius. Lastly, the Kanthalai area records an annual average temperature of 27.86 degrees Celsius (Figure 5).

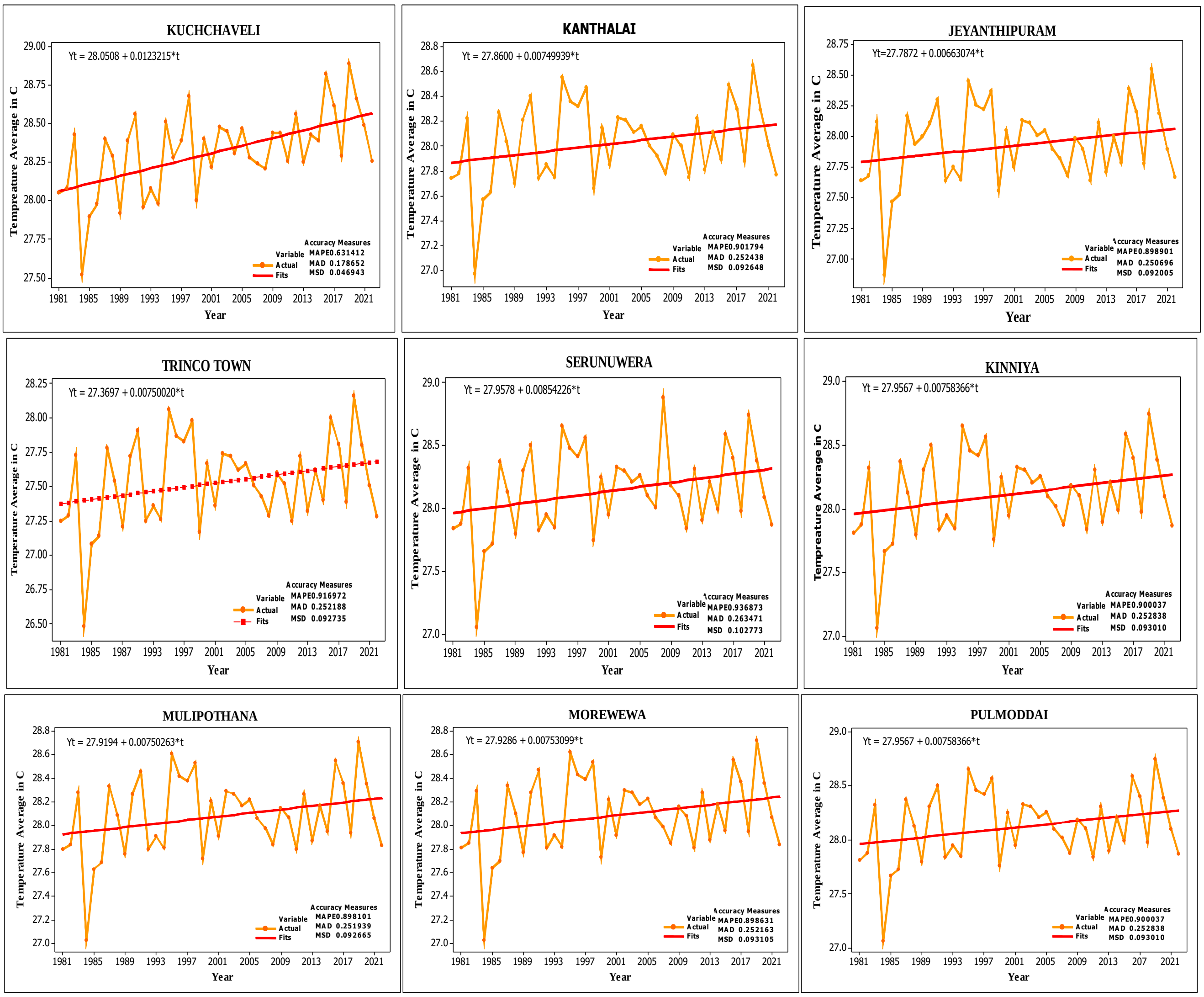


Figure 5. The annual pattern of temperature increase in the Trincomalee district of Sri Lanka. Figures representing the stations. All stations of the study area show the increasing pattern of temperature, but there are variations of this pattern between the stations

Upon examining the seasonal temperature trends within the designated regions of the Trincomalee district, it is evident that the Mullipothana area experiences the most significant temperature rise, with an increase of 0.48 degrees Celsius. In contrast, the urban areas of Trincomalee, alongside Jayanthipuram, Kuchchavali, and Kanthale, exhibit a more uniform increase of 0.39 degrees Celsius. Conversely, the Morawewa area records the least increase, with a rise of 0.38 degrees Celsius. This information is illustrated in Table 2.

Table 2. Sen's Slope estimation values for the different areas of the Trincomalee district (Source: Data Analysis)

Station	Sen's Slope value/Decade (Temperature)	Temperature Trend
Morewewa	0.38	Rising
Kinniya	0.44	Rising
Kanthale	0.39	Rising
Tampalakamam	0.44	Rising
Mullipothana	0.48	Rising
Kuchchaveli	0.39	Rising
Pulmoddai	0.41	Rising
Serunuwara	0.45	Rising
Jayanthipuram	0.39	Rising
Trinco town	0.39	Rising

Spatial trend of Rainfall in the Trincomalee district

In the Trincomalee district, it has been noted that rainfall exhibits significant variability across different regions. Consequently, the spatial discrepancies in precipitation throughout the Trincomalee district from 1981 to 2022 are depicted in Figure 6. Notably, the highest levels of rainfall were documented in the areas of Mullipothana, Thambalagamam, Kanthale, and Morawewa, whereas the urban expanse of Trincomalee, along with Pulmottai and Serunwera, experienced the lowest precipitation. The Jayanthipuram area, conversely, recorded a moderate quantity of rainfall.

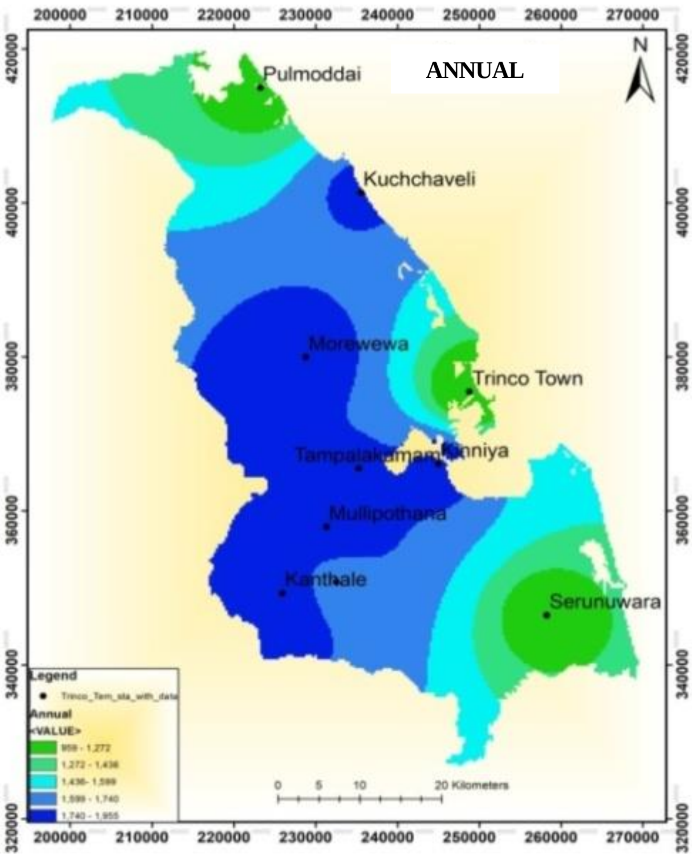


Figure 6. Spatial annual total rainfall changes in the Trincomalee district of Sri Lanka. The Central part of the study area shows higher annual total rainfall than the other areas. But significantly, the Northern and Southern regions of the study area show a lesser annular rainfall pattern

Upon examining the spatial variations of monthly precipitation in the Trincomalee district, it was observed that the zenith of rainfall occurred in November, registering at 329.40 mm, while the nadir was noted in June, with an anomalous measurement of -0.789239 mm. The second inter-monsoonal winds significantly contribute to the peak rainfall experienced in November. Furthermore, the volume of precipitation brought by the southwest monsoon winds in the Trincomalee district is on a downward trajectory (Figure 7).

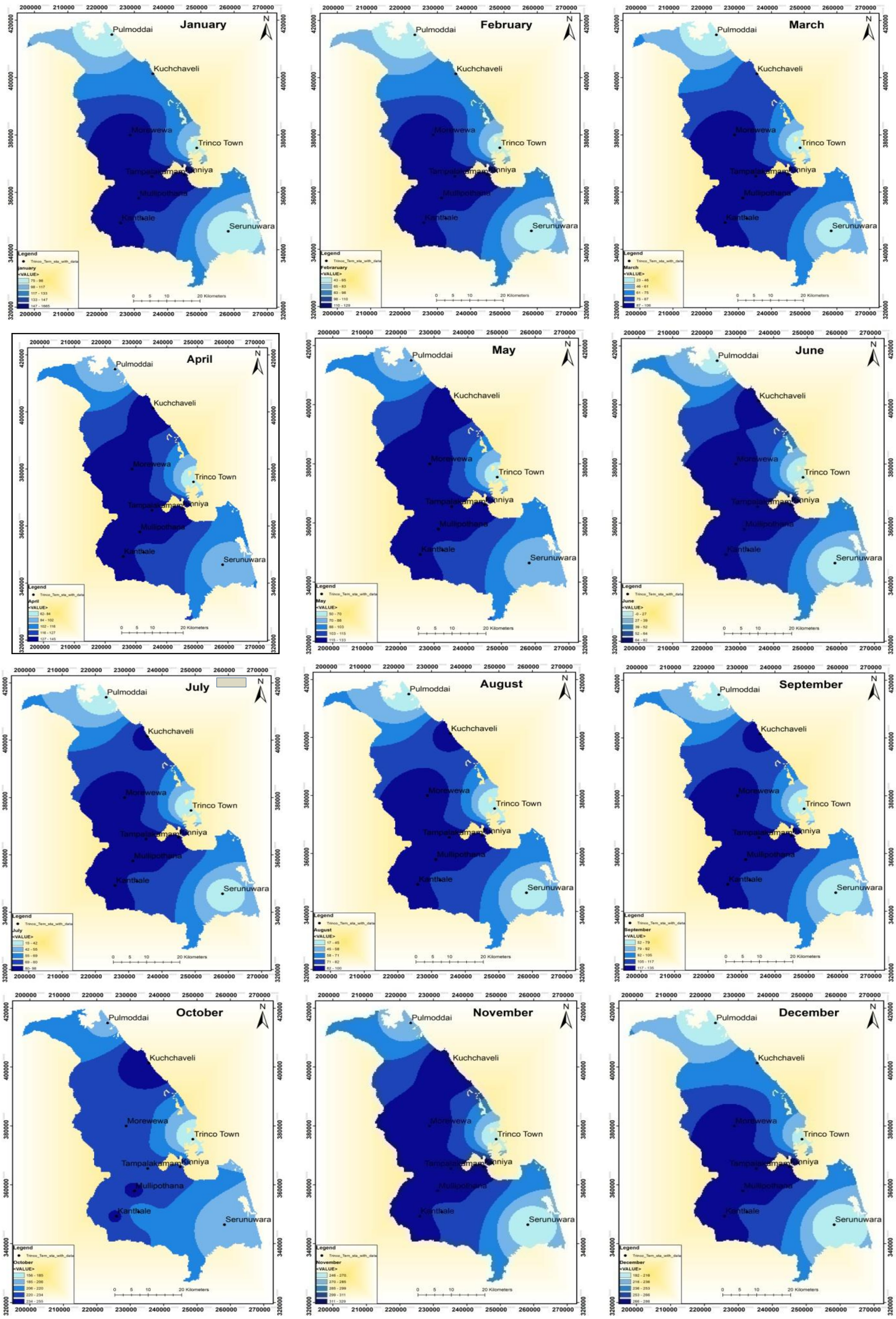


Figure 7. Spatial pattern of monthly rainfall increasing in the Trincomalee district of Sri Lanka
The significant variations of the spatial pattern of rainfall have een identified in the month of December

Temporal trends of Rainfall in Trincomalee district

Upon examining the temporal patterns of precipitation in the Trincomalee district, it becomes evident that the rainfall trends at the selected stations evolve, exhibiting an increase in richness and volume (Figure 8).

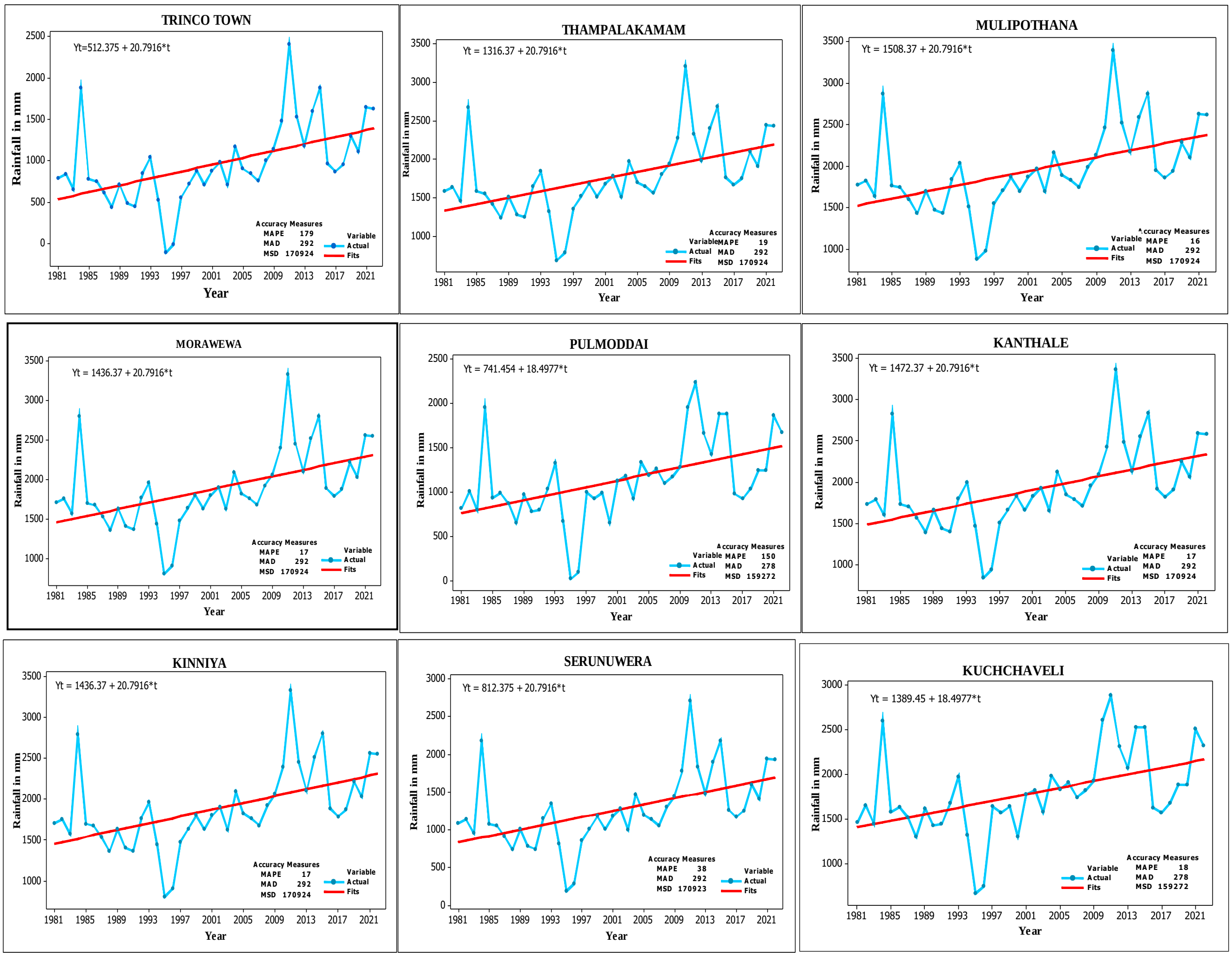


Figure 8. The annual pattern of Rainfall is increasing in the Trincomalee district of Sri Lanka. The trending pattern of the annual rainfall of all stations of the Trincomalee District shows an increasing trend. Compared to other locations, Pulmoddai has a significant increase in Rainfall

Based on the annual precipitation data from selected locations within the Trincomalee district, it is observed that the annual rainfall trends exhibit fluctuations, both increasing and decreasing. In the Kuchchavali area, these trends reflect a mixed pattern, with a maximum annual rainfall recorded at 2879.41 mm in 2011, while a minimum of 669.84 mm was noted in 1995. The average annual rainfall trend in this region has shown an increase of 18.49 mm, culminating in a total rise of 758.09 mm for 41 years. Similarly, the Morawewa area has demonstrated a variable rainfall trend, peaking at 3329.28 mm in 2011 and dipping to 808.56 mm in 1995. The average annual rainfall has increased by 20.79 mm, resulting in a cumulative rise of 852.39 mm over the same 41-year period. In the Thambalagamam area, the annual rainfall pattern also reflects both increases and decreases, with a maximum recorded at 3209.28 mm in 2011 and a minimum of 688.56 mm in 1995. The average annual rainfall trend here has similarly risen by 20.79 mm, totaling an increase of 852.39 mm across 41 years. The Serunuwera area displays analogous trends, with its peak annual rainfall reaching 2705.27 mm in 2011, while the lowest recorded figure was 284.77 mm in 1996. The average annual trend has increased by 20.79 mm, translating to a total rise of 852.39 mm over four decades. In the Pulmoddai area, fluctuations are similarly noted, with a maximum of 2231.41 mm in 2011 and a recorded minimum of just 21.84 mm in 1995. The average annual rainfall trend has seen an increase of 18.49 mm, leading to a total elevation of 758.09 mm over 41 years.

The Kanthalai region experiences an annual trend of increases and decreases, with its maximum annual rainfall at 3365.28 mm in 2011, and a minimum of 844.56 mm documented in 1995. The average annual rainfall trend has escalated by 20.79 mm, producing an overall increase of 852.39 mm for 41 years. Likewise, the Kinniya region presents an annual rainfall trend that fluctuates, reaching a maximum of 3329.28 mm in 2011, while the minimum remains at 808.56 mm from 1995. The average annual trend has increased by 20.79 mm, reflecting a cumulative rise of 852.39 mm over four decades. In the urban area of Trincomalee, the annual rainfall trend is also marked by fluctuations, with its maximum recorded at 2405.28 mm in 2011, and an unusual minimum of -15.25 mm in 1996. The average annual trend has risen by 20.79 mm, leading to an increase of 852.39 mm over 41 years. The Jayanthipuram region parallels the observed patterns, experiencing a maximum annual rainfall of 3065.28 mm in 2011 and a minimum of 544.56 mm in 1996. The annual average rainfall trend is increasing by 20.79 mm, culminating in a total rise of 852.39 mm over 41 years.

The Mullipothana region also experiences fluctuations in annual rainfall, with a peak of 3401.28 mm recorded in 2011 and a minimum of 880.56 mm in 1995. The annual average rainfall trend has increased by 20.79 mm, yielding an overall rise of 852.39 mm across 41 years. When considering the annual rainfall trends across the selected areas of the Trincomalee district as a whole, it is noteworthy that the Mullipothana area records the highest rainfall at 1508 mm, while the Trincomalee urban area registers the lowest at 20.79 mm. The Sen's slope values within the study area, alongside variations across each selected region, as well as the Sen's slope estimates for rainfall across different climatic seasons, elucidate the alterations in rainfall patterns. Table 3 delineates the Sen values for each region concerning rainfall patterns from 1981 to 2022, revealing a discernible upward trend in the Sen values across the Trincomalee district.

Table 3. Sen's Slope estimation values for the different seasons of different stations of the Trincomalee district

Station	Season	Sen's Slope Value/Decade	Rainfall Trend
Morewewa	NEM	2.68	Rising
	SWM	2.71	Rising
	FI M	2.11	Rising
	SIM	2.52	Rising
	ANNUAL	10.02	Rising
Kinniya	NEM	2.59	Rising
	SWM	2.12	Rising
	FI M	2.04	Rising
	SIM	2.91	Rising
	ANNUAL	9.66	Rising
Kanthale	NEM	2.85	Rising
	SWM	1.89	Rising
	FI M	2.12	Rising
	SIM	2.18	Rising
	ANNUAL	9.04	Rising
Tampalakamam	NEM	1.89	Rising
	SWM	1.68	Rising
	FIM	1.95	Rising
	SIM	1.92	Rising
	ANNUAL	7.44	Rising
Mullipothana	NEM	2.28	Rising
	SWM	2.57	Rising
	FI M	2.19	Rising
	SIM	2.67	Rising
	ANNUAL	9.71	Rising
Kuchchaveli	NEM	2.31	Rising
	SWM	2.46	Rising
	FI M	2.12	Rising
	SIM	2.35	Rising
	ANNUAL	9.24	Rising
Pulmoddai	NEM	1.98	Rising
	SWM	2.19	Rising
	FI M	1.85	Rising
	SIM	2.28	Rising
	ANNUAL	8.3	Rising
Serunuwara	NEM	2.31	Rising
	SWM	1.75	Rising
	FI M	1.69	Rising
	SIM	1.2	Rising
	ANNUAL	6.95	Rising
Jayanthipuram	NEM	1.35	Rising
	SWM	1.39	Rising
	FI M	1.17	Rising
	SIM	1.63	Rising
	ANNUAL	5.54	Rising
Trinco town	NEM	2.48	Rising
	SWM	2.64	Rising
	FI M	2.15	Rising
	SIM	2.86	Rising
	Annual	10.13	Rising

The results of the Mann-Kendall seasonal variation analysis show that rainfall trends are consistent across each region in the study area. This can be observed in Table 4.

Table 4. Mann-Kendall trend analysis result of the Trincomalee district

Series	P-value	Alba	Kendall's tau	Test interpretation
Morewewa	0.0231	0.05	0.277	Reject H0
Kinniya	0.0312	0.05	0.291	Reject H0
Trinco Town	0.1724	0.05	0.201	Reject H0
Kanthale	0.0751	0.05	0.284	Reject H0
Tampalakamam	0.1512	0.05	0.251	Reject H0
Mullipothana	0.3053	0.05	0.228	Reject H0
Kuchchaveli	0.1652	0.05	0.267	Reject H0
Pulmoddai	0.2916	0.05	0.255	Reject H0
Serunuwara	0.0272	0.05	0.248	Reject H0
Jayanthipuram	0.3124	0.05	0.281	Reject H0

The seasonal rainfall pattern reveals notable variations in precipitation across selected regions of the Trincomalee district. During the second inter-monsoon season, the rainfall in this area experiences an increase, while the influence of the first inter-monsoon season wanes. Specifically, in the Kinniya region, rainfall during the second inter-monsoon peaks at 2.91 mm. Furthermore, the seasonal rainfall patterns in Trincomalee are observed to exhibit considerable spatial variability.

Notably, the highest levels of rainfall occur in October, November, and December, whereas the least precipitation is noted in June, July, and August. The Trincomalee district benefits from substantial rainfall due to the effects of the second inter-monsoon winds and the northwest monsoon, while the impact of the southwest monsoon diminishes.

This phenomenon is illustrated in Figure 9. The second inter-monsoon winds contributed to a maximum recorded rainfall of 255.153 mm, predominantly in the areas of Mullipothana, Thambalagamam, Morawewa, and Kinniya. Conversely, the southwest monsoon has resulted in minimal rainfall, registering at a low of -0.078 mm in the urban areas of Trincomalee, Serunwera, and Pulmoddai. The least rainfall in Pulmoddai was documented at 14.55 mm in August.

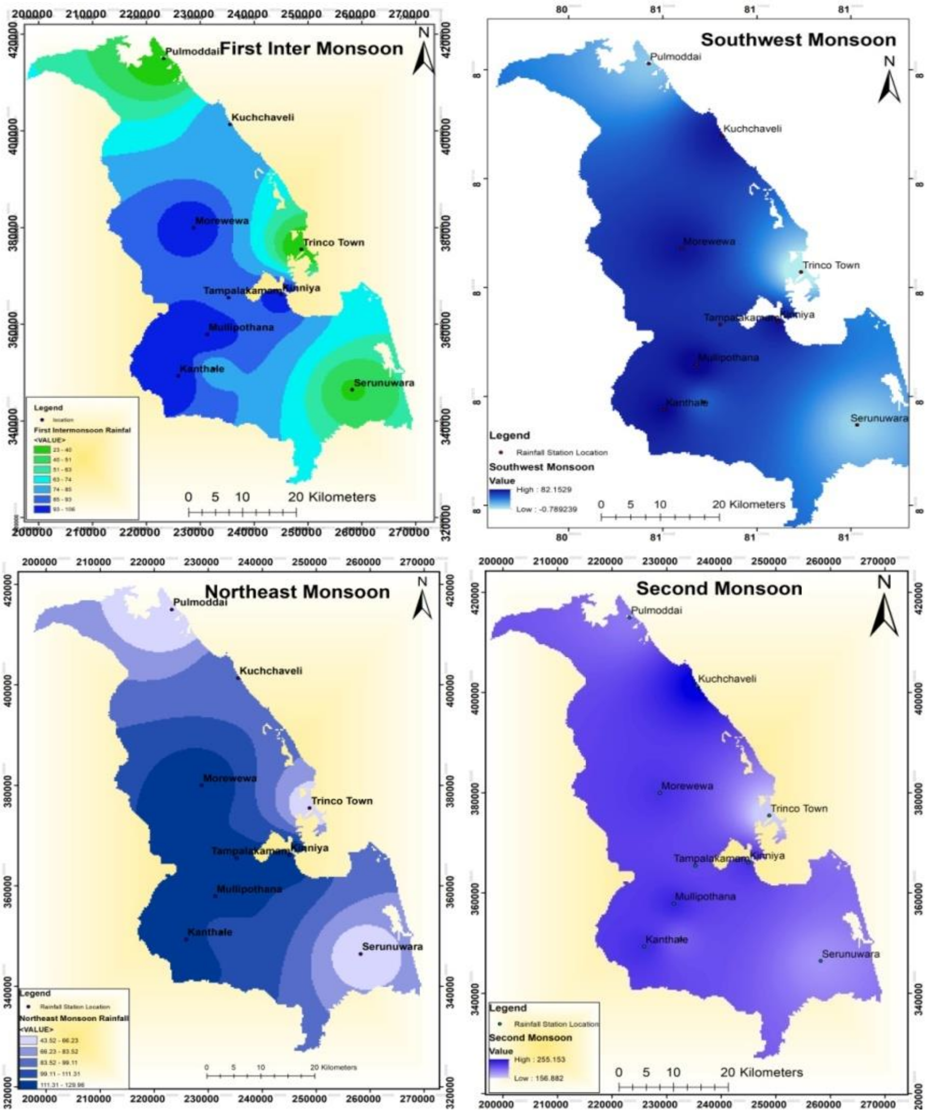


Figure 9. Seasonal spatial variations of the Trincomalee district of Sri Lanka. During the Northeast Monsoon Season, the central part of the study area receives higher rainfall than the other areas. Further, during the southwest monsoon season, many parts of the study area receive low rainfall

DISCUSSION

While the rainfall patterns in the Trincomalee district exhibit a consistent trend, the regional spatial analysis for 41 years reveals that the Mullipothana area experiences the highest precipitation, whereas the Pulmotte and Kuchacheli areas record the least. In exploring the temporal dynamics of rainfall, it becomes evident that fluctuations occur based on specific monthly data from various locales throughout the year. Notably, the overall rainfall trend in the Trincomalee district shows an increase of 20.79 millimeters. Analysis of the selected regions indicates that the Trincomalee district receives more rainfall during the second inter-monsoon phase than during the southwest monsoon period (Sanjeewani & Manawadu, 2016). A striking rise in rainfall is observed in May when analyzing the monthly average rainfall trend for the district. Conversely, the temperature trend exhibits the least increase in June relative to the other months.

According to Sen's slope estimation for various rainfall seasons within the Trincomalee district, an upward trend in precipitation is noted across all seasons. In comparison to other areas, the north monsoon rainfall trend in the Kanthale region rises by 2.85 mm, while the minimum rainfall trend in the Jayanthipuram area shows an increase of 1.35 mm. Furthermore, the south monsoon's maximum rainfall trend rises by 2.85 mm in Kanthale, while the minimum rainfall trend in Jayanthipuram increases by 1.39 mm. The influence of the southwest monsoon results in a recorded decline of -078 mm in rainfall in urban Trincomalee, Serunweera, and Pulmoddai. The Pulmoddai area specifically noted its lowest rainfall in August, measuring 14.55 mm. The second inter-seasonal rainfall trend in the Kinniya region is on the rise by 2.91 mm compared to other areas, whereas the lowest increase in rainfall is observed in Serunweera by 1.2 mm. The first inter-seasonal rainfall trend in Jayanthipuram shows an increase of 1.17 mm, while in Mullipothana, it surges relative to other areas. Based on the seasonal annual average rainfall trend, the annual average precipitation in Trincomalee City climbs to 10.13 millimeters, with the Thambalagama region recording the lowest annual average at 7.44 millimeters. Seasonal fluctuations in rainfall patterns manifest notable disparities across the Trincomalee district.

Examining spatial variations in temperature in the Trincomalee district over the 41 years from 1981 to 2022 reveals distinct regional disparities. The most significant increase in temperature has occurred in the Kuchchavali area, whereas the Trincomalee urban area exhibits the least increase. The temporal assessment indicates a declining trend in the monthly average temperature, with slight rises noted in November, December, and January, along with increases in May and June.

The highest recorded annual average temperature in the Trincomalee district is 28.05 degrees Celsius in Kuchavali, with a trend increasing by 0.012 degrees Celsius annually. In contrast, the temperature trend in the Jayanthipuram area reveals a decline relative to other regions. Utilizing Sen's slope estimation across different temperature seasons in Trincomalee shows that temperatures rise in each season. The most significant increase is observed in Mullipothana at 0.48 degrees Celsius, while a consistent rise of 0.39 degrees Celsius is noted in the urban areas of Trincomalee, Jayanthipuram, Kuchchavali, and Kanthale. The last increase of 0.38 degrees Celsius occurred in Morawewa.

This study illuminates the variations in both annual and monthly temperature trends in the Trincomalee district, alongside the disparities in annual, monthly, and seasonal rainfall trends, underscoring the spatial discrepancies in rainfall and temperature across the selected areas. Such variations unveil the region's microclimate. Research conducted by Nagamuthu (2022) indicates that the microclimate of the Northern Province is marked by spatial and temporal disparities in temperature and rainfall, aligning with the findings of this study. Additionally, the study's results regarding the microclimate in Trincomalee corroborate the findings of Jayawardene et al.(2005)

Senatilleke et al. (2022) revealed that shifts in annual, monthly, and seasonal rainfall levels in northern Sri Lanka significantly affect the physical and economic environment. This aligns with the study conducted. Furthermore, Sivakumar & Stefanski (2011)ssessed the impacts of climate factors on agriculture, which is consistent with this research. Similarly, findings from Gunasinghe et al. (2023) indicate that both temperature and rainfall exhibit monthly and seasonal trends.

CONCLUSION

Within the microclimatic landscape of the Trincomalee district, discernible spatial and temporal fluctuations in temperature and precipitation manifest. Although the overall precipitation pattern across the district exhibits a consistent trend, a detailed analysis over forty-one years reveals that the Mullipothanai region experiences the most substantial rainfall, whereas Pulmoddai and Kuchchaveli record the lowest. The rainfall trajectory indicates an upward trend, increasing by approximately 20.79 millimeters. Notably, the district receives greater rainfall during the second inter-monsoon period than during the southwest monsoon. An examination of monthly averages reveals a pronounced surge in rainfall during May, while temperature trends demonstrate the least increment in June relative to other months.

The second inter-seasonal rainfall exhibits a notable rise of 2.91 mm in the Kinniya area, contrasting with the minimal increase of 1.2 mm observed in Serunwera. The first interseasonal rainfall in Mullipothana displays a more pronounced upward trend than in other regions. On an annual scale, the average rainfall across Trincomalee City is increasing at an estimated rate of 10.13 mm, with the Thampalagamam area experiencing the smallest increase of 7.44 mm. The spatial variation in temperature over the forty-one-year period reveals distinct differences among localities.

Kuchchaveli has experienced the most significant temperature escalation, whereas Trincomalee City exhibits the least. Slight increases are observed during November, December, and January, with notable rises also occurring in May and June. The highest recorded annual average temperature in the district is 28.05°C, measured in Kuchchaveli, with an annual temperature increment of approximately 0.0123°C per year.The differences observed between the annual and monthly temperature trends, along with the variations in seasonal rainfall patterns, highlight the presence of diverse and localized climate conditions—known as microclimates—within the Trincomalee district. This microclimatic heterogeneity indicates that different areas within the district experience distinct climate behaviors over short spatial scales.

For example, some regions may show significant temperature fluctuations throughout the year or different rainfall timings and intensities compared to neighboring areas. These variations are influenced by factors such as topography, proximity to water bodies, vegetation cover, and land use patterns. Recognizing this heterogeneity is crucial for effective local planning, tourism activities, agriculture, and resource management, as it underscores the need for tailored strategies that account for these localized climate differences rather than relying solely on district-wide averages.

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