Exploring Monsoonal Rainfall Patterns in Trincomalee District, Sri Lanka Using Thiessen Polygon Method

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Abstract

Climate change poses a severe threat, significantly impacting South Asia's vital agriculture, including in Sri Lanka. The lack of detailed analysis of rainfall patterns is a critical issue in Sri Lanka. This study addresses the impact of climate change on rainfall dynamics at a regional level. It employs a mono strategy to evaluate rainfall patterns in the Trincomalee district using computational techniques and the Thiessen polygons method. Additionally, it examines the spatial distribution of these patterns in monsoonal rainfall within Divisional Secretariat Divisions (DSDs) over four decades, from 1983 to 2022. The examination of Thiessen polygon patterns revealed remarkable spatial parallels between the Northeast monsoon (NEM) and Second-inter monsoon (SIM), with rainfall ranging from 646 to 747.7 mm/ decade. Most Thiessen polygons indicated reduced rainfall distribution in coastal DSDs compared to inland areas, with values ranging from 79.5 to 500.1 mm/ decade and during the potential seasons of the NEM and SIM, with rainfall amounts of 500.1 and 438 mm/ decade, respectively. Out of the 40 years of data, approximately 38 years recorded their maximum daily rainfall during either the SIM or NEM. This further validated the synchronization of SIM and NEM. Notably, peak rainfall events were higher during the SIM compared to the NEM. The study recommends that rain-fed paddy farmers prepare their land by the end of the second or third week of September to synchronize with the rainfall during the SIM and promote rainwater harvesting for irrigation. In regions with lower monsoon rainfall, such as Verugal and Muthur, diversifying crops to those with lower water needs is suggested. For other regions without the apparent tendency of patterns, maintaining existing crop strategies is advised. This comprehensive study aims to assist policymakers in effectively responding to the impact of climate change on rainfall in the Trincomalee District, Sri Lanka.

Keywords: *Divisional Secretariat Division, Monsoon, Pattern, Thiessen polygon*

Introduction

Crop production is highly responsive to alterations in climate, both in the short term and over extended periods (Thadshayini *et al.,* 2020). Severe weather conditions, such as prolonged droughts and unanticipated flooding, can devastate crop cultivation and lead to a direct decrease in yields (Bouman, 2001).

Agriculture in the Eastern province significantly contributes to the national agricultural output through crop and livestock production. Monsoonal precipitation is paramount in Trincomalee District, Sri Lanka, where it significantly influences agriculture and the management of water resources. The dry zone primarily relies on rainfall from the Northeast monsoon. Trincomalee's rainfall pattern aligns with that of the dry zone. Periodically, the dry zone faces droughts and extended dry spells. In 2016, Sri Lanka experienced a notable decrease in rainfall, evident in the Trincomalee district, which resulted in significant damage to paddy fields due to insufficient rainfall (Thadshayini *et al.*, 2020). Lack of spatial based studies rainfall trend and pattern analysis for Trincomalee District is noted as a critical issue that needs to be addressed at the regional level since Trincomalee has unique climatic characteristics. Proper analysis is necessary to understand how rainfall dynamics have evolved in the Trincomalee District at DSD level. The primary objective of the study is to map the rainfall distribution within the Trincomalee region of Sri Lanka for the period of 40 years from 1983 to 2022. The primary objective was attained via:

- Evaluating the rainfall patterns in the Trincomalee district, employing spatial based Thiessen polygons method.
- Assessing the patterns manifest within the context of Divisional Secretariat Divisions (DSDs) using GIS techniques.

Literature Review

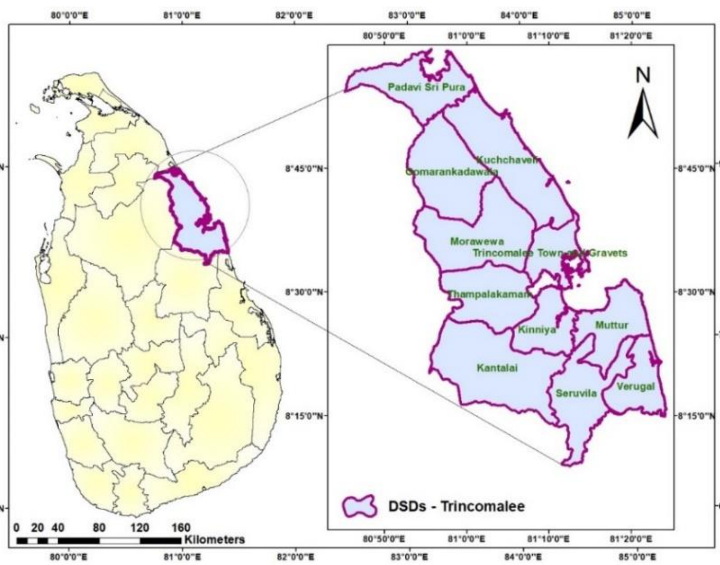
Wickramaarachchi *et al*. (2020) emphasize that climate change in rainfall patterns varies depending on the location. Therefore, conducting a location-specific analysis is crucial for evaluating its effects and implementing effective mitigation strategies. They corroborate the statement by the study where they procured a notable increase in the annual total rainfall at Kantale, Batticaloa, Pottuvil, and Mylambaveli in the Eastern province. However, the Allai tank in the Eastern region experienced a significant decrease in this season. The Northeast monsoon exhibited a significant increase in seasonal total rainfall at four stations in the Eastern province.

The Thiessen polygon method is employed in geographical analysis and hydrology to partition an area into polygons, determined by their proximity to specific points or stations. These polygons are structured to ensure that any spot within a particular polygon is closer to its designated point than to any other neighboring points. Widely applied in meteorology, hydrology, and environmental studies, this technique serves as an interpolation method for estimating data between measurement points (Wu *et al*., 2019).

Methodology

a. Study Area

This study was conducted based on 11 Divisional Secretariat Divisions (DSDs) of Trincomalee District in Sri Lanka (Figure 1). Trincomalee District is situated between 8° 56' 28.125" N and 8° 8' 56.905" N latitudes and 80° 46' 16.355" E and 81° 12' 35.200" E longitudes encompassing altitudes ranging from 1 to 177.3 m above mean sea level in the Eastern Province, located on the eastern coastal side. During the Northeast monsoon, Trincomalee tends to receive its primary rainfall, and the Southwest monsoon is generally less significant in Trincomalee compared to other parts of Sri Lanka. The northeast monsoon prevails from December to February, while the southwest monsoon occurs from May to September. There are two inter- monsoon periods: The First Inter-Monsoon from March to April and the Secon- Inter Monsoon from October to November. The district is divided into 11 DSDs such as Gomarankadawala, Kantalae, Kinniya, Kuchchaveli, Morawewa, Muttur, Padavi Sri Pura, Seruvila, Thampalakamam, Trincomalee Town and Gravets and Verugal.



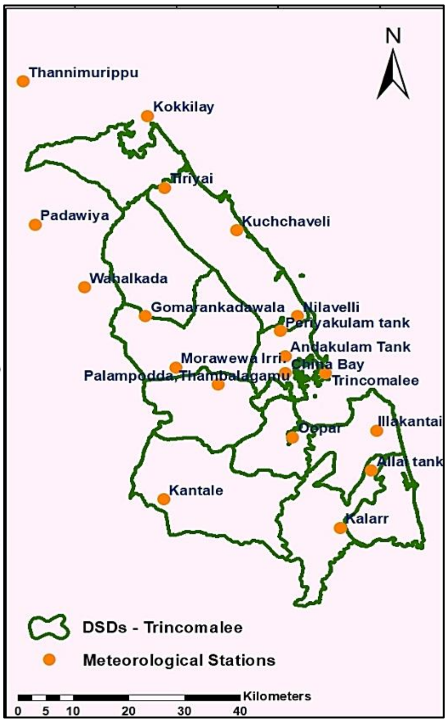


Figure 1: Study Area & Locations of selected meteorological stations

b. Data Collection

Meteorological stations

The focus was primarily on showcasing rainfall dynamics within the 11 Divisional Secretariat Divisions of the Trincomalee district. Approximately 19 meteorological stations were selected based on the influence of Thiessen polygons. As the polygons were drawn, some meteorological stations outside the Trincomalee district were also included. Thus, these outstations were also incorporated into the study. In this study, 19 meteorological stations were selected (Figure 1), with 15 stations located in the Trincomalee district and an additional two stations each from the Anuradhapura (Padawiya & Wahalkada) and Mullaitivu districts (Thannimurippu & Kokilai).

Rainfall data

Initially, rainfall data from chosen meteorological stations was acquired from the Department of Meteorology Sri Lanka. The Normal Ratio Method was used to identify and fill in some missing data. However, certain stations needed more records. CHIRPS data with a spatial resolution of 2.5 minutes (~21 km² at the equator) was employed from the WorldClim platform to address this issue. The data was consolidated based on Sri Lanka's monsoonal patterns, including the Northeast Monsoon, First Inter-Monsoon, Southwest Monsoon, and Second-inter Monsoon. This study utilized 40 years of rainfall data from 1983 to 2022, and the dataset was divided into four decades for analysis. The average rainfall for each decade was calculated by considering 10 years, and this information was integrated into the pattern analysis.

c. Thiessen Polygon method analysis

Initially, data from 15 meteorological stations within the Trincomalee district were utilized to create Thiessen polygons using ArcGIS 10.8, and it was exploited to create bisected areas for each station based on the data collected when constructing the Thiessen polygons relative to other stations.

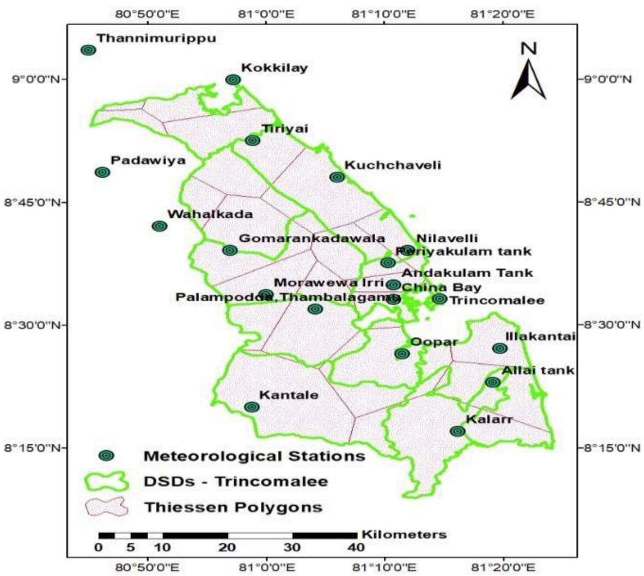


Figure 2: Thiessen polygons' contribution

Eventually, it resulted in the generation of 15 polygons. However, it was observed that these polygons did not cover the entire district boundary. Thus, 4 extra points from outside the

Trincomalee district were integrated. These 4 meteorological stations were considered part of the outstation influence area in the Thiessen polygon. As mentioned earlier, two stations were considered from Anuradhapura and Mullaitivu. Eventually, 19 polygons were created. Henceforth, 11 DSDs and 19 Thiessen polygons were weighed to attribute pattern generation. Accordingly, 46 sub-polygons were segregated and harnessed to generate the patterns based on DSDs (Figure 2).

Figure 3 shows the flow diagram of Thiessen polygon method used to analyze the rainfall pattern for Trincomalee District.

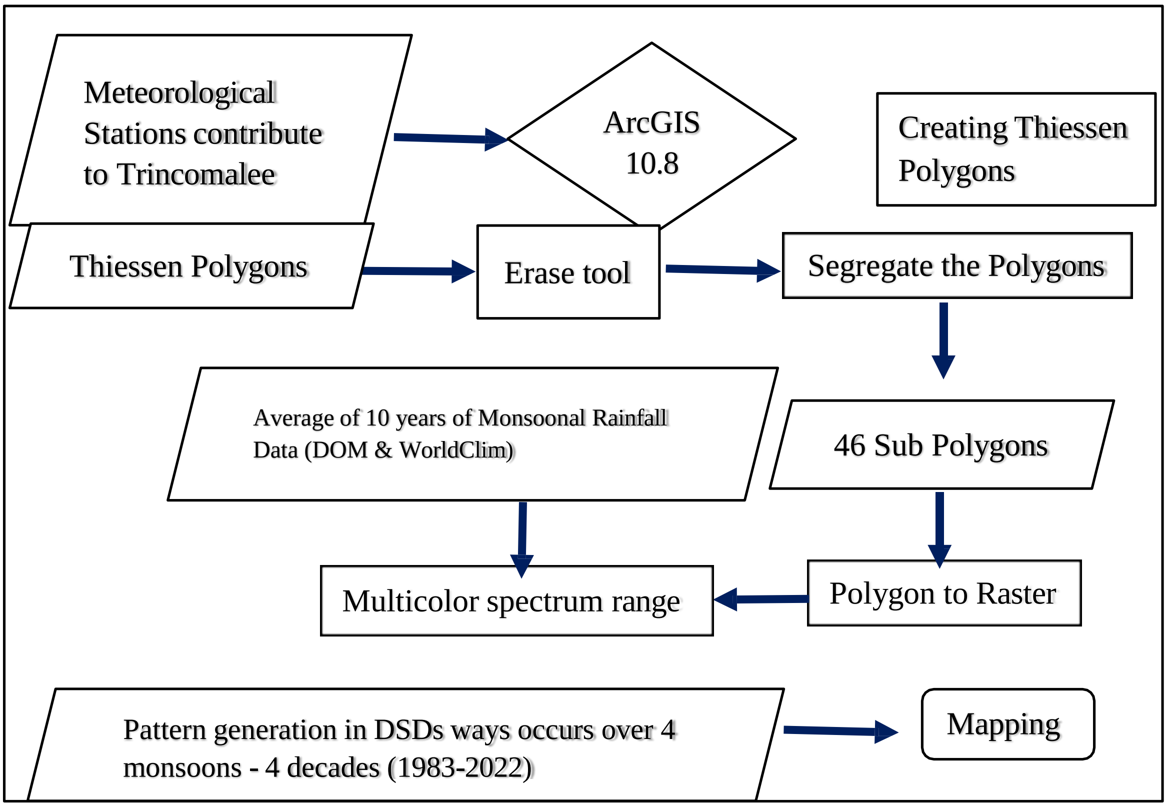


Figure 3: The schematic flow chart of the Thiessen polygon patterns

Forty years of rainfall data were divided into four decades: 1983-1999, 1993-2002, 2003-2012, and 2013-2022. Each decade was further divided into 4 monsoonal seasons. Average rainfall for a season of each decade was calculated. The average monsoonal rainfall was represented in rainfall contributing polygons to DSDs. Thiessen Polygons assumed that the rainfall distribution was uniform across all rain stations, assuming the rainfall coverage was consistent. This assumption stood as the most plausible when dealing with extensive and uniform rainfall patterns, especially over flat terrain areas (Al-Ozeer *et al.*, 2020).

The output results were obtained using ArcGIS 10.8 software in calculating and preparing the Thiessen polygons across Trincomalee District. The CHIRPS data was downloaded in TIFF format. A Python code was generated using Spyder from the Anaconda package to achieve the extraction of the image. Rasterio, Numpy, Os, and Pandas were used to extract TIFF files from WorldClim. The coordinates of the meteorological stations' locations were integrated into Python codes to extract the rainfall values. Ultimately, the collected rainfall data was acquired in a ".csv" format, encompassing information from 19 meteorological stations and their respective rainfall records within the specified period. Subsequently, this data underwent further processing to segregate it based on the duration of the monsoon.

Results and Discussion

a. Thiessen polygon analysis for Rainfall pattern

Due to the existence of 19 Thiessen polygons and 46 sub-polygons, the impacts and allocations of the polygonal area towards the DSDs became evident. The results were categorized and were set to be discussed based on the monsoonal changes over decades, showcasing the Thiessen polygon patterns across four decades in alignment with the monsoon seasons.

Figure 3 expresses that Trincomalee typically receives significant rainfall during Northeast monsoon. However, in the generation of Thiessen polygon patterns, it became evident that the rainfall in the Trincomalee district had decreased over the last decade compared to the third decade. Moreover, a noticeable difference in rainfall distribution across Trincomalee was observed concerning the average monsoonal precipitation. Between 1983 and 1992, Seruvilla and Verugal DSDs experienced the highest (653.25 mm/decade) recorded rainfall within a specific boundary area. However, to a certain extent, Thampalakamam, Morewewa, and Kantale DSDs experienced lower rainfall than Seruvilla and Verugal. However, Muthur, Kinniya, Trincomalee Town & Gravets, and Gomarangadawala encountered a mixed range of rainfall comprising higher, moderate, and lower values. Especially, Padavi Sripura and Kuchchaveli underwent lower rainfall in maximum areal coverage.

From 1993 to 2002, Thampalakamam, Morewewa, and Kantale showed spatial patterns similar to those of the first decade. However, Kinniya witnessed a slight increase and the upper portion of Muthur experienced a higher rainfall distribution. Meanwhile, the lower portion of Muthur experienced a lower rainfall distribution than the previous decade. A drastic drop was observed in Kantale, Seruvilla, and Verugal DSDs, which were the lowest (515.82 mm/decade) in the rainfall distribution.

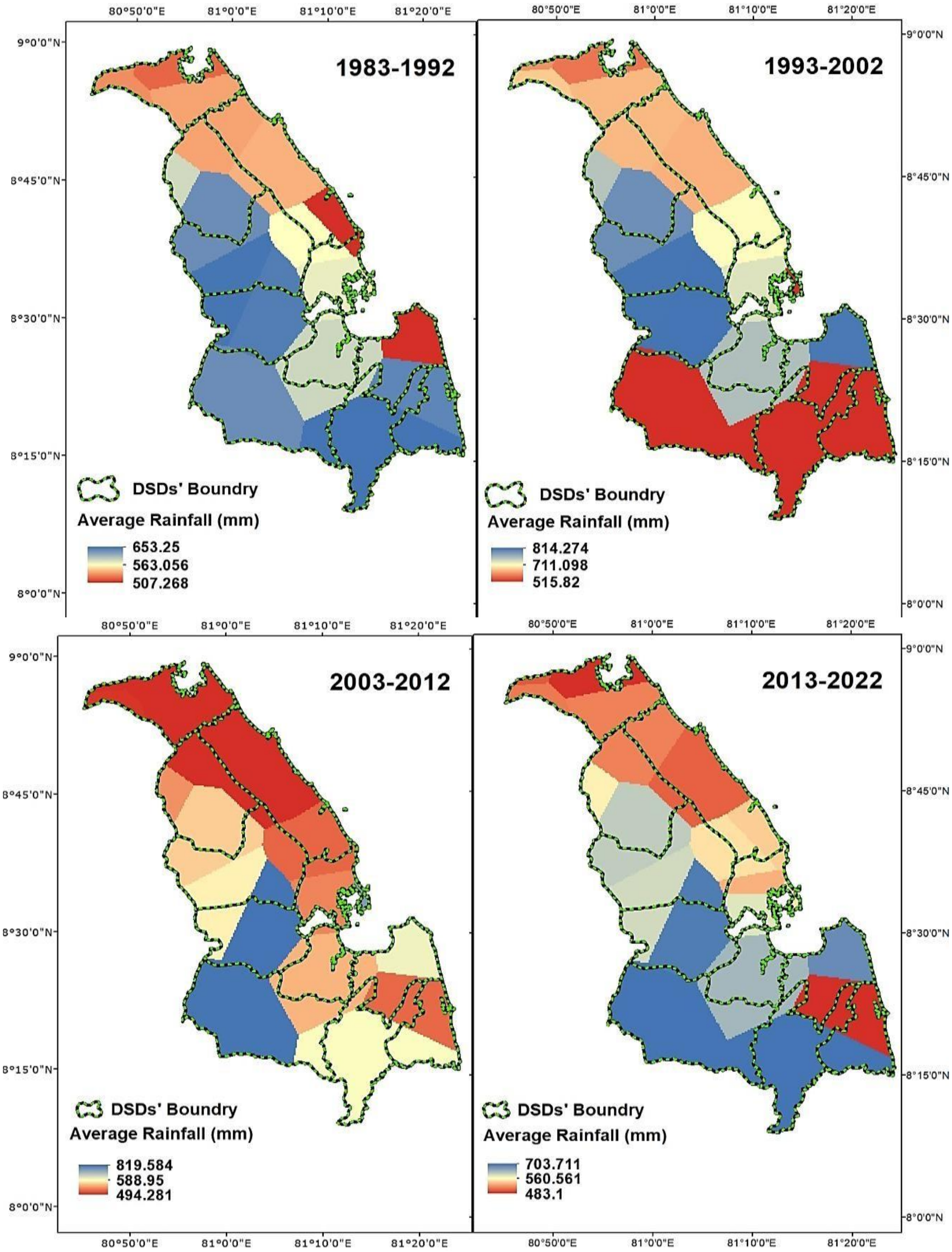


Figure 4: Northeast monsoon’s Thiessen polygon patterns from 1983 to 2022

From 2003 to 2012, Padavi Sripura and Kuchchaveli endured almost the lowest (494.28 mm/decade) rainfall distribution. On the other hand, the other 9 DSDs encountered a mixed range of rainfall comprised of higher, moderate, and lower values. Eventually, from 2013 to 2022, Kantale and Seruvilla’s rainfall distribution was more similar to that in the first decade. Meanwhile, Kinniya experienced the same level of rainfall distribution as in the second decade. Padavi Sripura and Kuchchaveli went through lower rainfall, but not as extreme, in the third decade, but a more obvious decrease than in the first and second decades. The remaining 6 DSDs experienced a varied spectrum of rainfall, encompassing higher, moderate, and lower values.

Based on the statements above, Padavi Sripura and Kuchchaveli exhibited a notably higher prevalence of lower rainfall distribution than other DSDs during the study period. From 1993 to

2022, rainfall distribution consistently declined in the upper Verugal and lower Muthur regions. Thampalakamam received appreciable rainfall distribution from 1983 to 2002; however, this pattern was partially reduced in the following years from 2003 to 2022. Looking at the broader picture, the third decade comprised much lower rainfall distributed areas than other decades. Especially, Padavi Sripura, Kuchchaveli, Gomarangadawala, Morawewa, Trincomalee Town & Gravets, Maximum area of Morewewa, Kinniya, Seruvilla, Verugal, and Muthur witnessed lower rainfall distribution for that decade's precipitation records.

Figure 5 conveys that typically, the First-inter monsoon consistently received the least amount of rainfall among the four monsoons observed in Trincomalee. Among those, over the past decade, rainfall has decreased within the Trincomalee district compared to the third decade.

Between 1983 and 1992, Seruvilla and Verugal DSDs witnessed moderate rainfall in a specific area. However, Thampalakamam, Morewewa, Gomarangadawala, and Kantale DSDs experienced comparatively higher rainfall than Seruvilla and Verugal. Meanwhile, Muthur, Kinniya and Trincomalee Town & Gravets encountered a varied range of rainfall, encompassing moderate and lower values. Specifically, Padavi Sripura and Kuchchaveli predominantly experienced lower rainfall across a significant area.

From 1993 to 2002, Thampalakamam and Kantale displayed lower spatial rainfall distribution than the first decade. Nevertheless, Kinniya, Morewewa, Padavi Sripura, Kuchchaveli, and Gomarangadawala experienced a slight rise in rainfall distribution.

In 2003 and 2012, Thampalakamam and the maximum area of Kantale experienced nearly the highest rainfall distribution. Morewewa and Gomarangadawala witnessed relatively lower rainfall distribution than Thampalakamam and Kantale. Conversely, the remaining 7 DSDs witnessed varied rainfall, encompassing the lower and lowest values. During this decade, no moderate rainfall distribution was observed, as all instances fell within the patterns of highest (254.56 mm/decade), lower, and lowest (108.15 mm/decade) values.

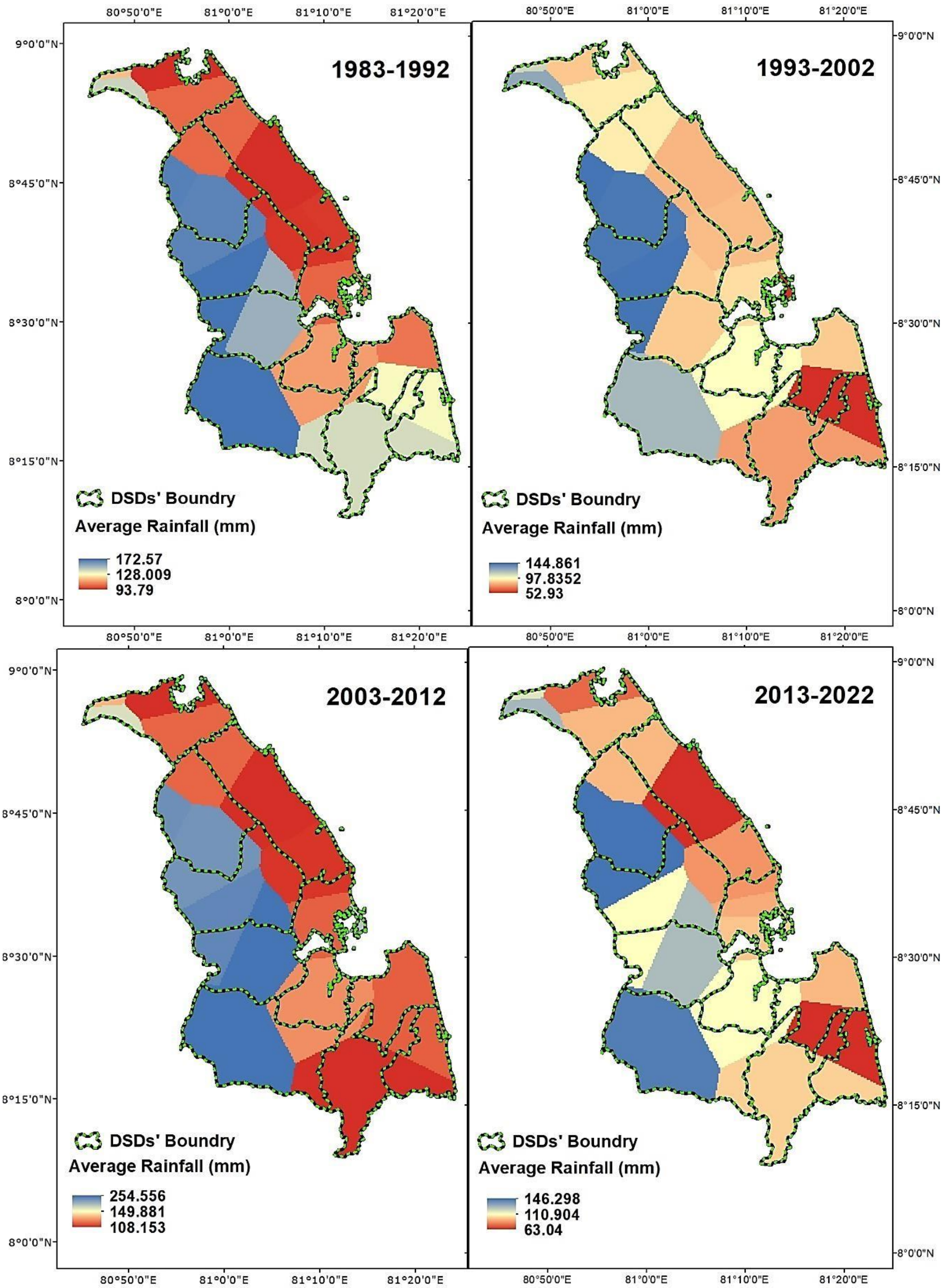


Figure 5: First-inter monsoon's Thiessen polygon patterns from 1983 to 2022

From 2013 to 2022, all 11 DSDs encountered a mixed-range rainfall distribution comprising highest (146.3 mm/decade), moderate (110.9 mm/decade), lower, and lowest (63.04 mm/decade) values. Still, the overall amount of rainfall received in this decade was lower than in the third decade.

According to the above statements, during the study period, Padavi Sripura and Kuchchaveli consistently showed a significantly higher occurrence of lower rainfall than other DSDs, mirroring this pattern during the Northeast monsoon. Over the last four decades, Morewewa, Gomarangadawala, Thampalakamam, and Kantale emerged as the areas receiving the highest rainfall within the Trincomalee district. Apart from these DSDs, the remaining areas did not exhibit consistent or recurring patterns; instead, they displayed unique compiled patterns specific to each DSD.

Figure 6 articulates that the Southwest monsoon did not exert an elevated influence.

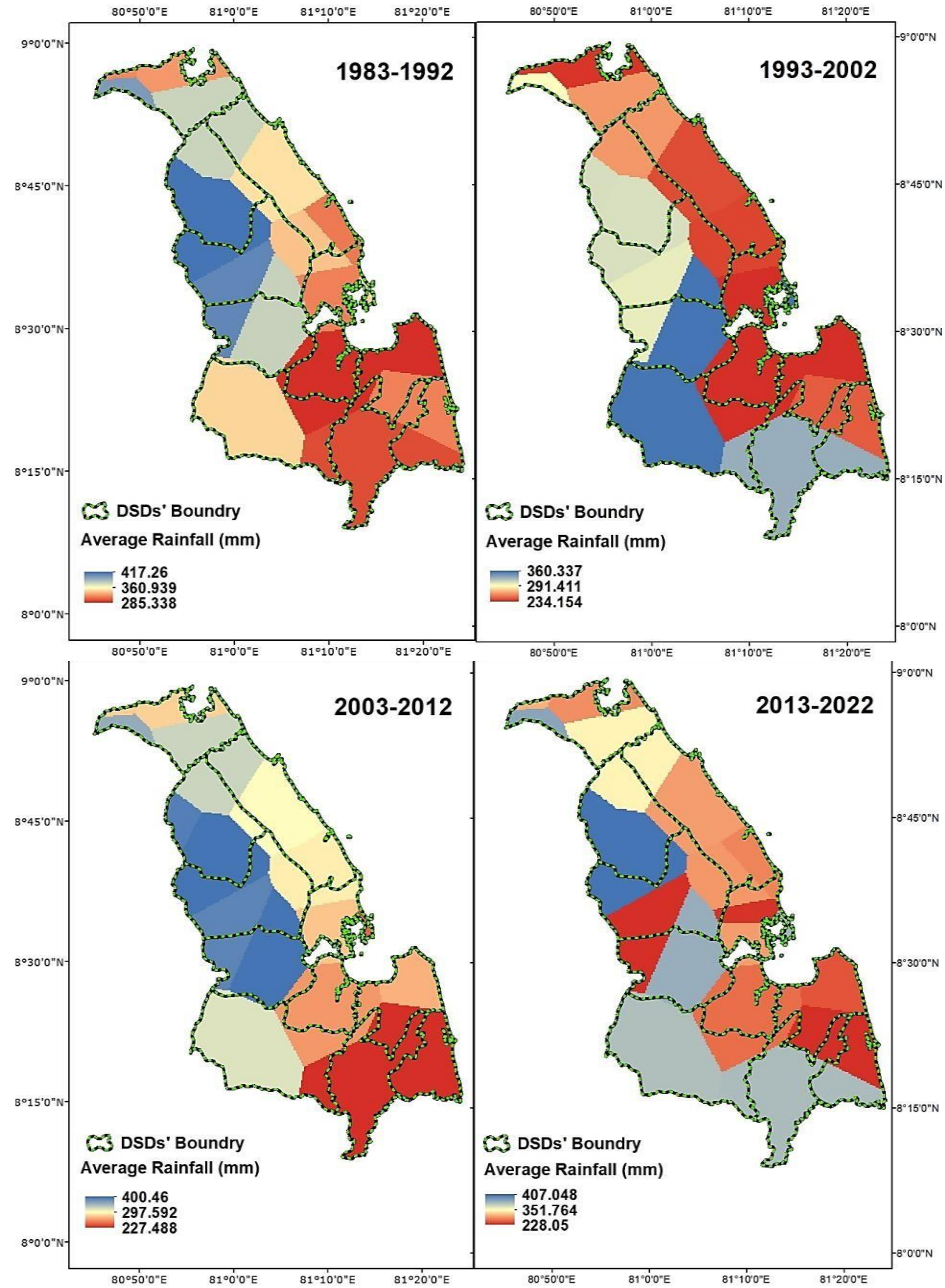


Figure 6: Southwest monsoon's Thiessen polygon patterns from 1983 to 2022

Trincomalee since the southwestern and central regions of Sri Lanka received abundant rainfall, and the northern and eastern parts of Sri Lanka experienced relatively less precipitation during this season. From 1983 to 1992, the Muthur, Kinniya, Seruvilla, and Verugal DSDs encountered almost inferior rainfall distribution. Meanwhile, the Thampalakamam, Morewewa, and Gomarangadawala DSDs experienced notably higher rainfall than others. During the same period Padavi Sripura, Kuchchaveli, and Trincomalee Town & Gravets witnessed a varied spectrum of rainfall, including moderate and lower values. Meanwhile, Kantale witnessed a divergent spectrum of rainfall, including the lowest and lowest values.

Between 1993 and 2002, Muthur, Kinniya, Padavi Sripura, Kuchchaveli, and Trincomalee Town & Gravets exhibited the least spread of rainfall across their areas. However, Verugal and Seruvila encountered slightly higher rainfall than in the first decade. However, Thampalakamam, Morewewa, Kinniya, and Gomarangadawala noticed a wide range of precipitation, incorporating the maximum (360.34 mm/decade), elevated (291.41 mm/decade), minimum, and reduced (234.15 mm/decade) values.

From 2003 to 2012, Seruvilla and Verugal DSDs had the lowest (227.49 mm) rainfall distribution. However, the total rainfall received during this decade was less than that of the third decade. Kinniya, Trincomalee Town & Gravets encountered slightly higher rainfall than Verugal and Seruvilla. Muthur and Kantale perceived varied ranges of rainfall incorporating the elevated (297.59 mm/decade), minimum, and reduced (227.49 mm/decade) values. Padavi Sripura and Kuchchaveli received relatively higher rainfall distribution than the second decade. Thampalakamam, Morewewa, and Gomarangadawala DSDs experienced notably higher rainfall than others.

In 2013 and 2022, Muthur, Kuchchaveli, Kinniya, and Trincomalee Towns and Gravets encountered the lower and lowest (228.05 mm/decade) rainfall distribution. Interestingly, other DSDs noticed varying precipitation ranges, encompassing maximum (407.05 mm/decade), elevated (351.76 mm/decade), minimum, and reduced values. Even DSDs that traditionally received higher rainfall, such as Morewewa, Gomarangadawala, and Thampalakamam, encountered a mixed range of precipitation.

Figure 7 displays that before the Northeast monsoon arrived, the Second-inter monsoon approached. Consequently, the Northeast monsoon influence and display rainfall patterns similar to the Second inter - monsoon.

From 1983 to 1992, the Muthur, Seruvilla, and Kantale DSDs encountered a diverse rainfall range from the lower to the lowest (285.34 mm/decade). Additionally, Verugal experienced notably the lowest rainfall distribution. However, Kinniya experienced comparatively greater rainfall than the previously mentioned DSDs. Padavi Sripura, the primary area of Kuchchaveli, and Gomarangadawela experienced higher wetness levels than other DSDs. The remaining DSDs had relatively lower wetness levels than Padavi Sripura, the primary area of Kuchchaveli, and Gomarangadawela.

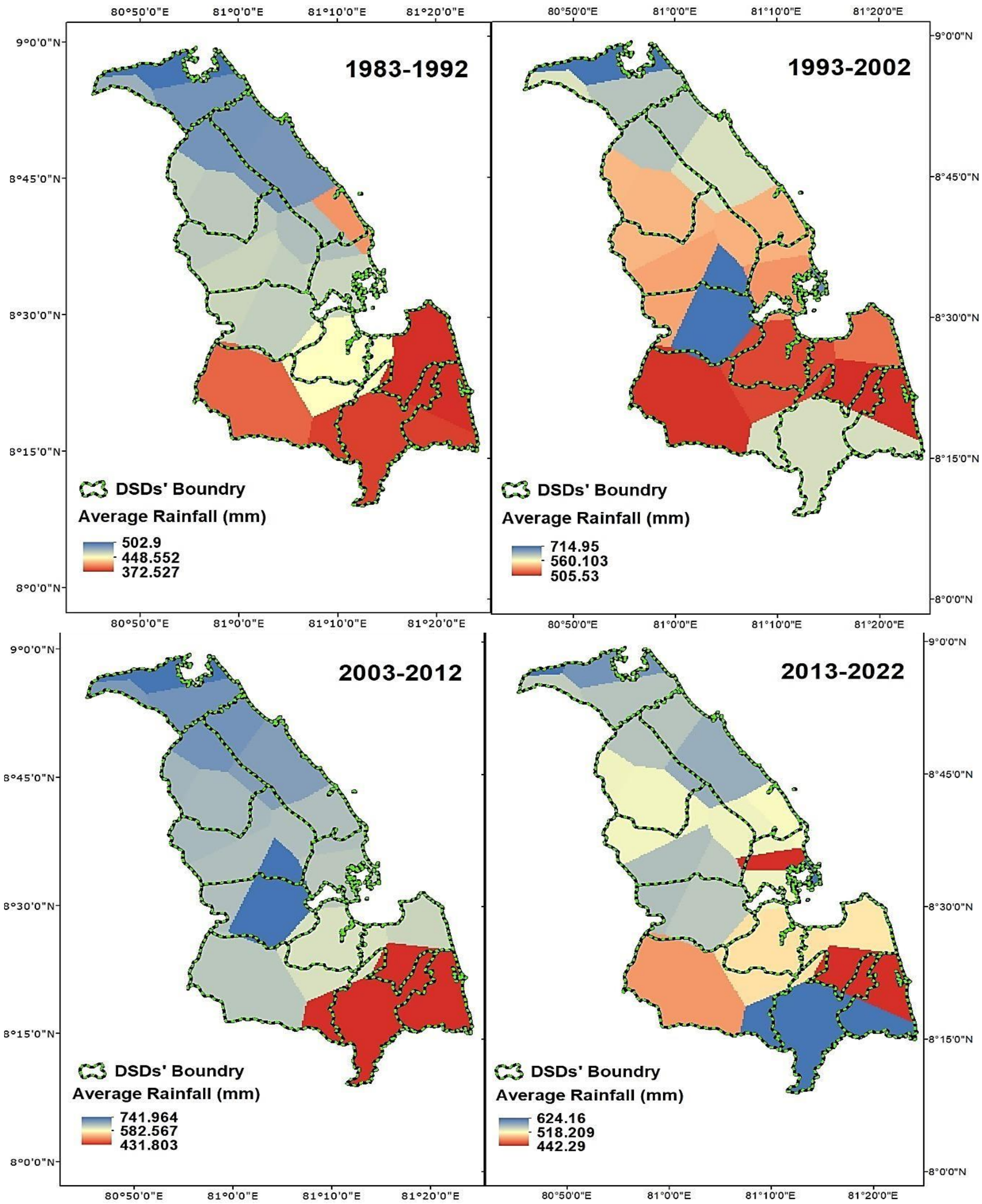


Figure 7: Second-inter monsoon’s Thiessen polygon patterns from 1983 to 2022

In 1993 and 2002, Padavi Sripura, the maximum area of Kuchchaveli and the maximum area of Seruvilla, encountered higher rainfall distributions in their regions. Conversely, the other 8 DSDs experienced a broad precipitation spectrum, encompassing maximum (714.95 mm/decade), elevated (560.1 mm/decade), minimum, and reduced (505.53 mm/decade) values. Between 2003 and 2012, Seruvilla, Verugal, and the southern part of Muthur received the least rainfall distribution. In contrast, all 8 DSDs experienced a broader range of wetness across their entire regions.

From 2013 to 2022, all 11 DSDs encountered a mixed range rainfall distribution, comprising highest (624.16 mm/decade), moderate (518.21 mm/decade), lower, and lowest (442.29 mm/decade) values among Thampalakamam, Padavi Sripura, and Seruvilla, which witnessed higher rainfall.

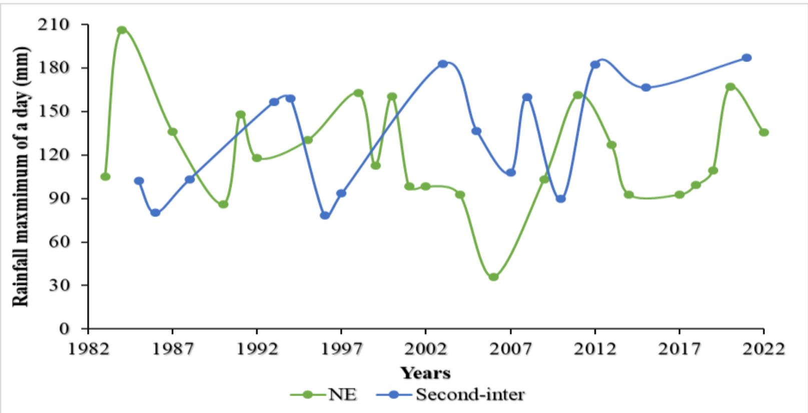
Table 1: Average Monsoonal rainfall tiers over decades

Decade	**Monsoons**	**High Values (mm/decade)**	**Mid Values (mm/decade)**	**Low Values (mm/decade)**
1983-1992	North East	653.25	563.06	507.27
	First-inter	172.57	128.01	93.79
	South West	417.26	360.94	285.34
	Second-inter	502.90	448.55	372.53
1993-2002	North East	814.27	711.10	515.82
	First-inter	144.86	97.84	52.93
	South West	360.34	291.41	234.15
	Second-inter	714.95	560.10	505.53
2003-2012	North East	819.58	588.95	494.28
	First-inter	254.56	149.88	108.15
	South West	400.46	297.59	227.49
	Second-inter	741.96	582.57	431.80
2013-2022	North East	703.71	560.56	483.10
	First-inter	146.30	110.90	63.04
	South West	407.05	351.76	228.05
	Second-inter	624.16	518.21	442.29

Table 1 reveals that the Northeast monsoon contributed significantly to rainfall, closely followed by the Second-inter monsoon. Over the last 40 years, high rainfall values peaked in the Northeast, First-inter, and Second-inter monsoons in the third decade. Conversely, the different in high rainfall values was observed in the Northeast and Second-inter monsoons in the first decade, while the Southwest and First-inter monsoons were recorded in the second decade. This pattern highlighted the influence of the Northeast and Second-inter monsoons, indirectly indicating similarities. A simultaneous peak was evident during the second decade for the Northeast and Second-inter monsoons. It is well-recognized that valley points within the low values alternated across each decade for all monsoons, lacking specific decade indicators. In the second decade, nearly equal low rainfall values were observed for both the Northeast and Second-inter monsoons. Subsequently, the low rainfall values were similar between the Northeast and Second-inter monsoons post the first decade.

The Thiessen polygon pattern analysis showed that the Northeast and Second-inter monsoons exhibited remarkable similarities, prominently observed in both spatial and temporal analyses. Furthermore, most Thiessen polygon configurations showed that rainfall distribution was lower in DSDs near the ocean or coastal areas than in the interior regions. According to the research carried out on the Development of Pakistan's New Area Weighted Rainfall Using the Thiessen Polygon Method, it was discovered that this method, known for its simplicity, speed, and practicality, resulted in a newly improved time series. This updated series encompasses rainfall data from both hilly areas and plains, effectively meeting the current needs more comprehensively compared to previous versions (Faisal & Gaffar, 2012). Findings from the study of Effects of rain gauge distribution on estimation accuracy of areal rainfall revealed that alterations in rain gauge distribution within a watershed result in the Thiessen polygon method adjusting solely the weights of nearby rain gauges while keeping the weights of other gauges unaltered, thereby limiting its capacity to accurately depict the spatial pattern of rainfall (Cheng *et al.*, 2011).

Figure 8 illustrates that notably maximum number of higher peaks were observed during the Second-inter monsoon compared to the Northeast monsoon.



NE – Northeast monsoon Second-inter - Second-inter monsoon

Source – Department of Meteorology, Sri Lanka

Figure 8: Yearly peaks: Maximum daily rainfall of Trincomalee District

The upward trends of rainfall during the Second-inter monsoons is the occurrence of floods. This is notably observed in Seruvila, Kinniya, and the extensive regions of Padavi Sripura and Kuchaveli, displaying a significant increase. These areas are particularly susceptible to frequent flooding (Suthakaran & Rajendram, 2021). Similarly, Wickramaarachchi *et al.* (2020) found that analyzing seasonal trends unveiled fluctuating rainfall patterns along Sri Lanka's Northwestern and Eastern coastlines, showcasing both rising and falling tendencies from 1986 to 2016.

Conclusion & Recommendation

The study resulted in the examination of Thiessen polygon patterns revealed striking similarities between the Northeast and Second-inter monsoons, evident in spatial and temporal analyses. Further, the study exhibits that the DSDs closer to the coastal region consistently experienced the least rainfall patterns. Verugal and Muthur, compared to other DSDs, exhibited the lowest rainfall (438.04 mm/ decade & 500.12 mm/ decade) in both the Second-inter and Northeast monsoons, where Muthur is a significant contributor to paddy cultivation in Trincomalee district. This suggests that a single day's data could reflect a season's broader monthly rainfall distribution.

Out of 11, six DSDs within Trincomalee District play a significant role in crop production, particularly in cultivating paddy. These are Padavi Sripura, Kantale, Thampalakamam, Gomarangadawela, Muthur, and Kinniya. Among these, Kinniya and the extensive regions of Padavi Sripura and Kuchaveli witnessed a positive pattern of rainfall in Theissian polygon analysis which aligns with the Maha season, commencing in September and concluding by March. Therefore, rain-fed paddy farmers in this region are recommended to ready their land by the end of the second or third week of September to synchronize with the rainfall during the Second-inter monsoon. Moreover, these DSDs were encouraged to engage in rainwater harvesting as part of an integrated water management policy. This practice would support irrigated cultivation within these areas and could serve as an additional supply for neighboring DSDs facing water shortages.

Farmers cultivating paddy in DSDs, especially those experiencing low rainfall in the Northeast and Second-inter monsoons, namely Verugal and Muthur, are advised against extensive paddy cultivation. Instead, it is recommended to consider growing Other Field Crops (OFC) or vegetables, as paddy necessitates ample water, particularly during its initial growth phase.

Kinniya, Kuchchaveli, and Padavi Sripura as regions with higher susceptibility to flood risks. Residents in these areas should remain vigilant and aware of potential disasters.

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