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# Spatio Temporal Analysis of Rainfall Variation, Precipitation Ratio, and Rainfall Anomaly Index (RAI) in and around Neyveli Lignite Mine Area, Tamil Nadu

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## Abstract

The Meteorological Parameters like Rainfall in and around the Neyveli lignite mine area are Subject to wide variability in time and space.This variability has assumed a more Pronunced dimension due to climate changes. The Rainfall Variation is Characteristics changes critical for agriculture, the environment, and Water Resources. The present study aims to understand the spatial distribution of rainfall and its influences in the Rainfall Variation and Precipitation Ratioon time scale of 12 months at eleven stations andthe Rainfall Anomaly Index (RAI). For evaluation,the rainfall data of 11 rain gauge stations from 2000-2019 were collected fromNeyveli Lignite Corporation India Limited (NLCIL).Map of spatial variations of Annual and Seasonal Rainfall Mean Rainfall, Precipitation Ratio,Rainfall Variability,Rainfall Anomaly Index(RAI) in the interpolation of datasets was performed by the inverse distance weighted IDW,Thiessen polygon function inbuilt within from produced ARCGIS10.1 software.

**Keywords:** Rainfall variation, Precipitation Ratio, Rainfall Anomaly index(RAI), Spatial map, ArcGIS.

## 1. Introduction

The primary source of freshwater is rainfall, which plays a significant role in the planning of water resource projects, agriculture, and other related domains. Its climate varies from dry sub-humid to semi-arid, McKee et al.,(1993) developed the Standardized Precipitation Index (SPI) to quantify precipitation deficits on multiple timescales (3, 6, 12, 24, and 48months), and it appears to be the most influential index. It is based only on the precipitation field and can be computed on different timescales (Bordi and Sutera, 2007; Bordi et al., 2009). As the index is standardized, wetter thannormal conditions can also be monitored (Seiler et al., 2002). The Rainfall Anomaly Index (RAI), developed by (Rooy et al., 1965), is used to classify Rainfall Anomalies' positive and negative severities. It is considered as an index of remarkable procedural simplicity because it requires only precipitation (Freitas 2005; Fernandes et al. 2009).The continent's susceptibility to climatic impacts is increasing due to continual change and unpredictability, a lack of institutional capacity, limited adaptive capability, and an overreliance on climate-sensitive economic sectors like agriculture(Gebrechorkos et al., 2019; Mbigi et al., 2021). Geospatial Technology is helpful in capturing, storing, updating, retrieve and analyzing a large amount of geographic and attribute data.Consideringits efficiency, the present study involved the Spatiotemporal variation in rainfall pattern, its ratio, and anomaly.

## 2. Methodology

### 2.1 Study Area

The study area restricted between the co-ordinates of 11°20'00" N to 11°45'00" N latitudes and 79°24'00" E to 79°40'00" E longitudes with a total geographical area of 1007 Sq.km. (*Figure.1*). The Neyveli Township marks the Northern limit, while the Vellar River marks the southern boundary of the study area. Chennai – Thanjavur highway via Panruti – Vadalur marks the Eastern limit,and Virdachalam-Ulundurpettai-highway marks the western limit of the Study area. The base map of the study area has been prepared from the Survey of India toposheet (58M/5 58M/6, 58M/7, 58M/9, 58M/10&14, and 58M/11) on a 1:50,000 scale.

### 2.2 Data and Methods

Monthly rainfall data for 20 years (2000-2019) from11 rain gauge stations Ulundurpet, Sethiyathopu, Virudhachalam, Srimushnam, Panruti, Pelanthurai, Mine- I, Mine- IA, Mine- II, Card, and Block-16- Neyveli in the study area have been used. Long-term seasonal and annual rainfall patterns within the study area were analyzed. The average seasonal rainfall has arrived from daily rainfall data. The yearly and monthly variation of rainfall and precipitation ratio data were

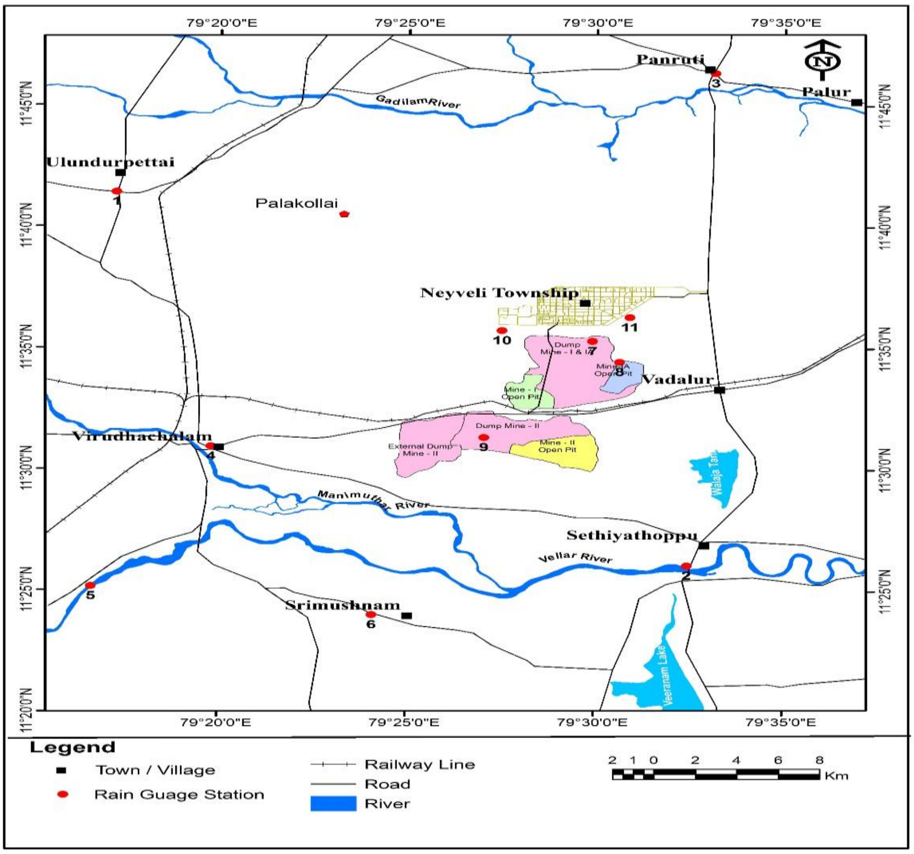



*Figure1*.**Rain Gauge Location in the Study Area**

used to compute the SPI and RAI for all stations in the study area. The spatial distribution map has been drawn with the help of ArcGIS 10.1 software and, it has been analyzed and interpolated by inverse distance weighted (IDW).

### 2.2.1 Mean Areal Raınfall

*A) Arithmetic Mean Method:*

The arithmetic average method used only those gauging stations within the topographic basin and was calculated using:

$$P=((P1+P2+P3+\cdots.Pn))/n$$

$$P=\Sigma\,(Pi/n)$$

Where,

P = average precipitation depth (mm)

Pi = precipitation depth at gauge (i) within the topographic basin (mm)

n = total number of gauging stations within the topographic basin

*B)Thiessen Polygon Method:*

This concept was implemented by drawing perpendicular bisector to straight lines connecting each two rain gauges. The procedure involves connecting each precipitation station with consecutive lines, constructing perpendicular bisectors, and forming polygons with these bisectors. The area of the polygon is determined. The ratio of the province of each polygon to the total area is taken as the weight. The average or weighted rainfall is a sum of the product of the precipitation of each gauge.

$$\frac{A1p1 + A2p2 + A3p3 + \ldots + Anpn}{A1 + A2 + A3 + \cdots + An} P = \sum_{i=1}^{n} \frac{Aipi}{A}$$

$$Precipitation = \frac{\sum Polygon\ area\ for\ the\ each\ station\ X\ precipitation}{\sum Total\ Polygon\ Area}$$

P1 to Pn is the rainfall at gauges 1 to n, and A1 to An are the areas of the respective polygons. The Thiessen polygon map of the study area with rain gauge stations is shown in Figure.3.

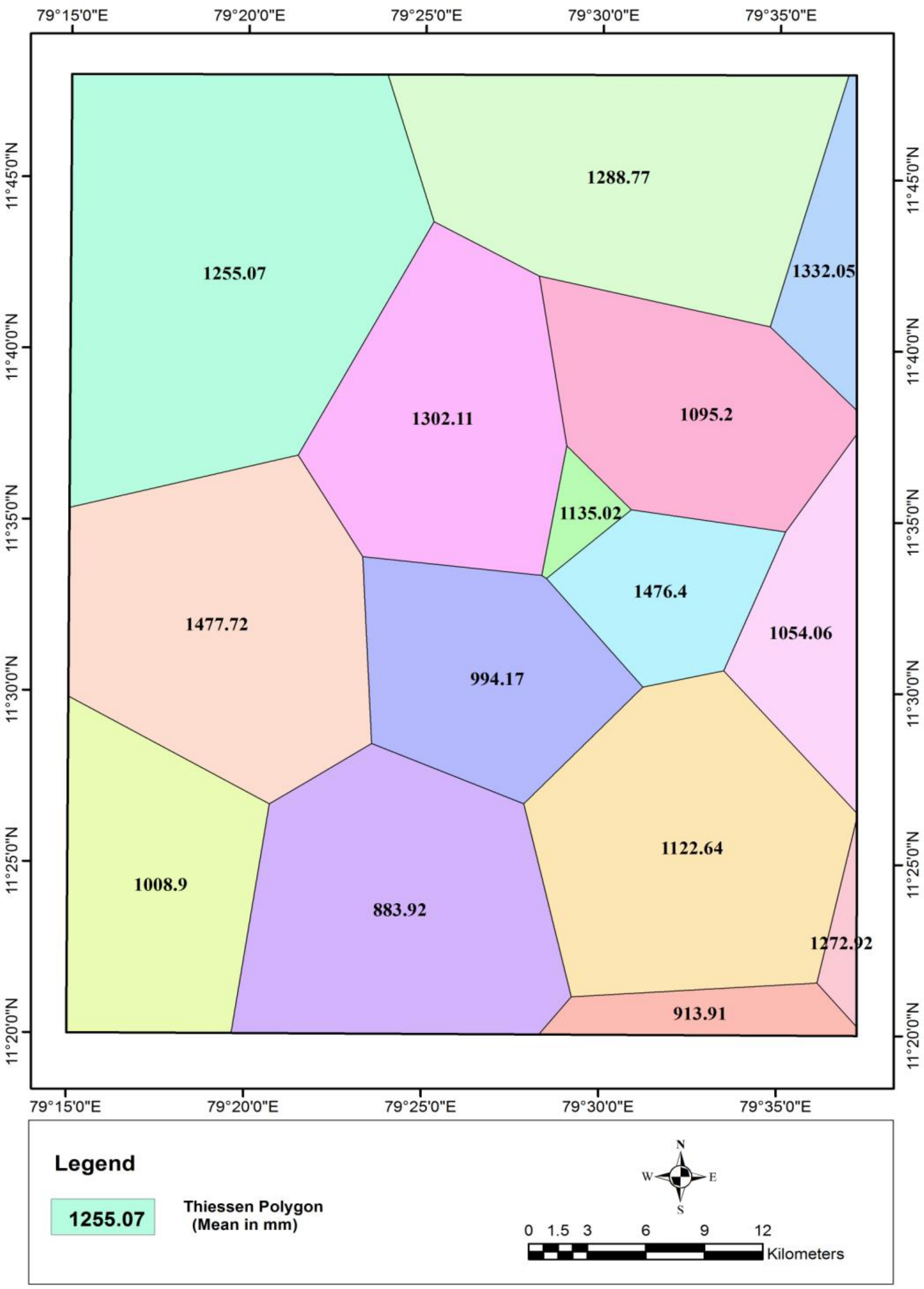



*Figure 3.***Thiessen polygon map of the Study Area with Mean Rain fall**

### 2.2.2 Precipitation Ratio

A simple precipitation ratio may bring the abnormalities of rainfall at any location. The higher the ratio, the higher will be the abnormality in the rain and vice versa

$$\text{Precipitation ratio} = (Px-Pn)/Pm*100$$

Where,

Px= Maximum Rainfall over the series of the year

Pn=Minimum rainfall over the series of the year

Pm=Mean annual rainfall

### 2.2.3 Rainfall Variability

Variability of Rainfall refers to variations in rainfall from the average amount. The variability of rainfall is computed with the help of the following formula:

C.V. = (Std / Mean) x 100

Where,

C.V = Coefficient of variability

Std = Standard deviation

M = Mean

The spatial and temporal variability of rainfall is analyzed based on daily rainfall records from 1st January to 31st December each year from 2000 to 2019. "Variability" is defined as the ratio of the standard deviation to the mean value of rainfall. Lower the variability, higher the rainfall, and higher the variability lowers the rainfall. The rainfall variability is calculated for the 11 rain gauge stations located within the study area is given in *Table* 1.

### 2.2.4 Rainfall Anomaly Index (Rai)

The Annual Rainfall Anomaly Index (RAI) was calculated from the precipitation data to analyze the frequency and intensity of the dry and rainy years in the studied area. RAI, developed and firstly used by Rooy (1965) and adapted by Freitas (2005), constitutes the following equations:

$$\boldsymbol{RAI = 3\ \left[\frac{N - \bar{N}}{\bar{M} - N}\right]}\ \text{For positive anomalies}$$

$$\boldsymbol{RAI = -3\ \left[\frac{N - \bar{N}}{\bar{X} - \bar{N}}\right]}\ \text{For negative anomalies}$$

Where:

N = current monthly/yearly rainfall, in other words, of the month/year when RAI will be generated(mm);

$\overline{N}$ = monthly/yearly average rainfall of the historical series (mm);

$\overline{M}$ = average of the ten highest monthly/yearly precipitations of the historical series (mm);

$\overline{X}$ = average of the ten lowest monthly/ yearly precipitations of the historical series (mm);

## 3. Result And Discussion

### 3.1 Annual and Seasonal Mean Rainfall Data

As precipitation is the primary source of recharge directly or indirectly to the groundwater reservoir, a detailed study on its intensity was carried out. The Neyveli area gets rainfall from both the southwest and the northeast monsoons. GIS was employed to determine the spatial distribution of the rainfall variation in the study area. The rainfall location and the corresponding calculated values of its attributes were given as an input to generate interpolation raster maps

*Annual Mean Rainfall Mean Rainfall*

The study area has a tropical climate characterized by long and severe summer, moderate monsoon, and mild winter. March, April, and May are summer months, while the southwest monsoon gets rain from June to August. However, the real monsoon months are September, October, November, and December, when the area is influenced by the northeast monsoon, followed by winter in January and February. The area gets its maximum rainfall due to the northeast monsoon, i.e., 56% of the average annual rainfall is brought by the northeast monsoon. The spatial distribution of the mean annual precipitation is shown in *Figure*. 4A. The location of the study area itself is a significant factor in the distribution of rainfall. The Bay of Bengal in the east plays a vital role in the spatial distribution of rainfall.

The daily rainfall data for twenty years (2000 - 2019) from 11 meteorological stations within the study area presume that the average annual rainfall is 1224.05mm. Therefore, the derived yearly mean rain during winter, summer, southwest, and northeast monsoon seasons are 49.94, 143.45, 346.13, and 687.28 mm, respectively (*Fig. 2*).

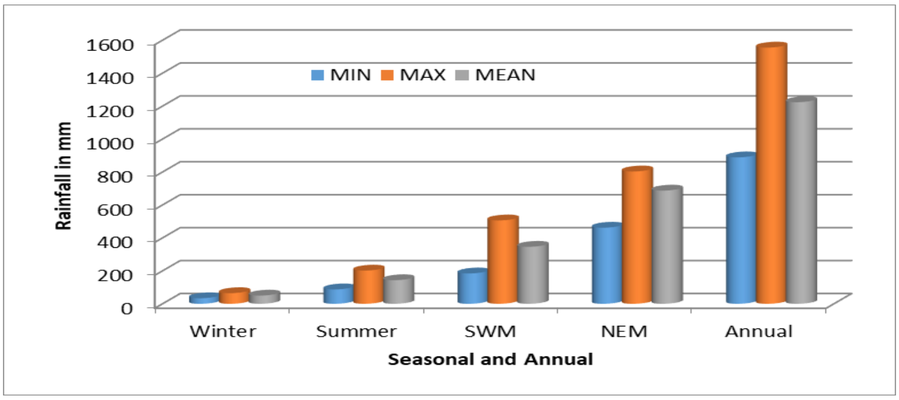



***Figure 2*.Average Seasonal and Annual Rainfall in mm (2000 -**

In the Thiessen Polygon method, weights are assigned to each rain gauge depending on its relative location. This method involves constructing polygons around each gauge, resulting from perpendicular bisectors joining two adjacent rain gauges. Polygon formed from the boundary of the effective area is assumed to be controlled by a gauge. The derived average annual rainfall is 1170.66mm based on the Thiessen polygon method. The average yearly mean rainfall varies from 883.92mm as a minimum in Ulundurpet to 1477.73mm as a maximum in Mine-II (Fig. 4).

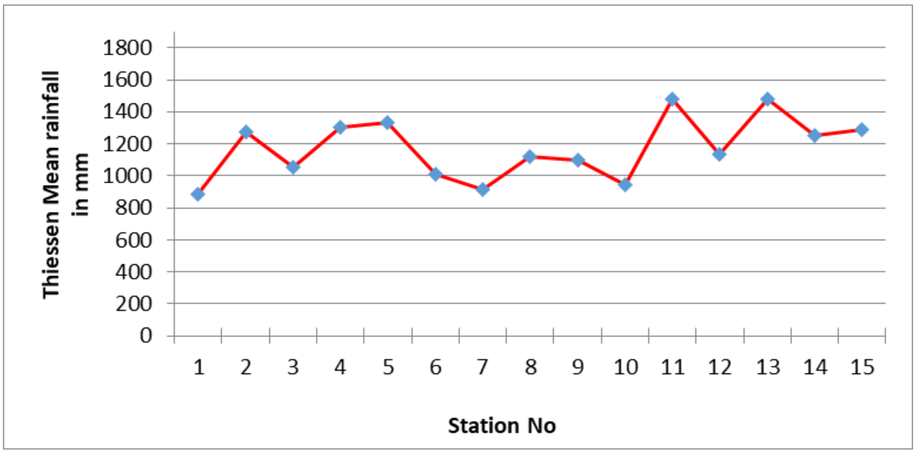



***Figure 4.* Thiessen Mean Annual Rainfall in mm (2000 – 2019)**

*North East Monsoon Mean Rainfall*

Northeast Monsoon is called retreating monsoon, which prevails from October to December itis an essential rainy season in the study area which receives 56% of the mean annual rainfall. Sethiathope experiences a maximum rainfall of 803.51mm, and Ulundurpet gets a minimum of 461.98mm (*Figure*. 4B). Except for Ulundurpet, Vridhachalam, Pelandurai, and Srimushnamalmost all the rain gauge stations receive >670mm rainfall in this season, and most of the agricultural activities in the study area depend upon rainfall from this season.

*South West Monsoon Mean Rainfall*

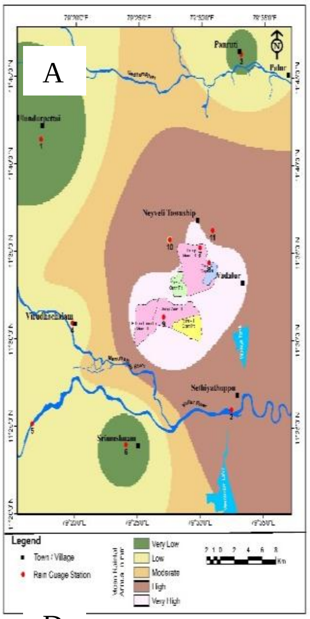
Southwest monsoon prevails in the period from July to September. The moisture-laden wind from the Indian Ocean causes the southwest monsoon. The average rainfall of this season is 346.13mm, and it forms 28% of the mean annual precipitation. The highest rainfall was recorded in Mine-II Neyveli (506.22mm) and the lowest in Panruti (184.45mm). The spatial distributional pattern of the rain exhibits that the rainfall with <315mm is observed in Srimushnam, Panruti, Sethiyathope, and Ulundurpet (*Fig*. 4C), 315 to 380mm of Rainfall in Vridhachalam and Pelandurai, and more than 445mm of Rainfall in Mine-I, Mine IA, Mine-II, CARD, and Block-16 Neyveli.

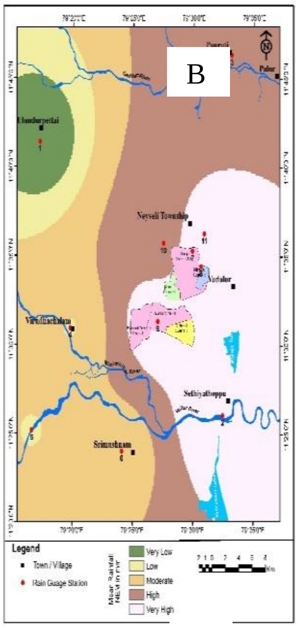
*Summer Season Mean Rainfall*

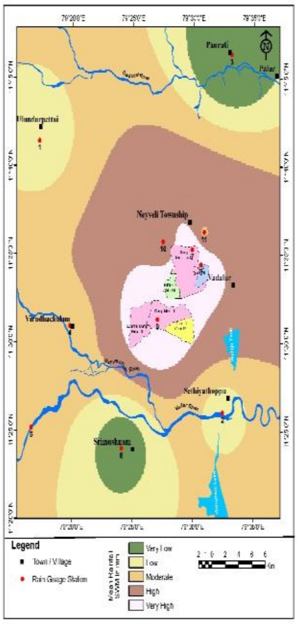
The average rainfall of the summer season is mainly due to the convection effect, and this season contributes about 12% of mean annual rain in the study area. However, the region experiences low rainfall during the summer season, and it is the second driest among all seasons. This season, rainfall varies from 87.51 (Panruti) to 201.66mm (Mine – II), averaging 143.45mm. The spatial distributional pattern of the rain in the summer season is shown in *Figure*. 4D. It is observed that the highest rainfall in Mine-II (>185mm), higher rainfall category (160 and 185mm) at Mine – I, the lowest rainfall in Srimushnam, and Panruti (<110mm), and an intermediate class of rainfall range from 110 to 160mm in the rest of the area were observed.

*Winter Season Mean Rainfall*

During the winter season, the region heavily experiences deficient rainfall, and it is the driest season among all seasons. This season, rainfall varies from 33.86 (Panruti) to 64.78mm (Sethiathope), with an average rainfall of 49.94mm. This season contributes 4% of the mean annual rainfall to the study area. The spatial distributional pattern exhibits lesser rainfall with <40mm in Ullundurpet and Panruti, higher rainfall with 52 to 58mm in Mine-I, Mine IA, Mine II, CARD, and Block – 16. The highest rainfall with >52mm at Sethiathope (*Fig. 4E*) and the moderate rainfall ranges from 40 to 652mm are occupied in the region between the lowest and higher rainfall categories.

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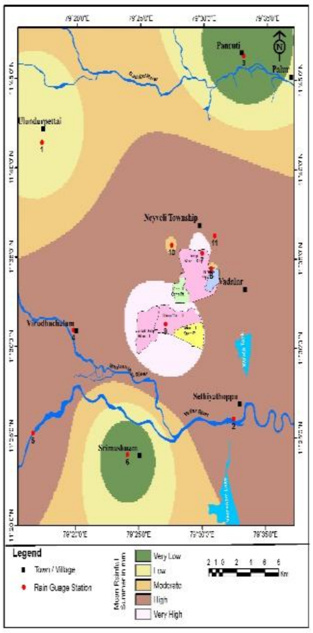


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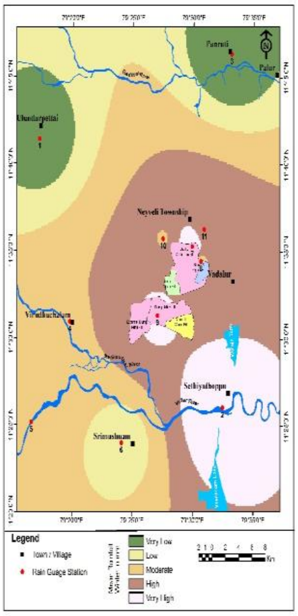



***Figure4.*Spatial Map for Annual and Seasonal Mean Rainfall Data- A)Annual B)North East Monsoon C)South west Monsoon**

### 3.2 Annual and Seasonal Precipitation Ratio

*Annual Precipitation Ratio*

The annual precipitation ratio varies between 73.11 in Mine-II and 199.84 in Srimushnam, with a mean of 127.38. The spatial distributional pattern of precipitation ratio is shown in *Figure*. 5A. The higher abnormalities (>175) are observed in Panruti and Srimushnam. Moderate levels of abnormality in rainfall with a precipitation ratio of 125 to 175 were observed in the Sethiathope, Pelandurai, and Ulundurpet. Almost equal precipitation ratio values are observed in other regions expressing lesser abnormalities (*Figure. 5A*)

*North-East Monsoon Precipitation Ratio*

The precipitation ratio of the Northeast monsoon season varies from 7143.10 (Sethiathope) to 255.18 (Panruti), with a mean of 188.49. The spatial variation of precipitation ratio of Northeast monsoon is shown in *Figure*. 5B. The spatial illustration of the precipitation ratio of NEM indicates that the western and northern part of the study area representing the Pelandurai, Vridhachalam, Ullundurpet, and Panruti, is experiencing the moderate to a higher abnormality in Rainfall (>210). On the other hand, the southeastern part of the study area represents the stations at Sethiathope, Mine II, and Mine IA, experiencing low rainfall abnormalities.

*Southwest Monsoon Precipitation Ratio*

The precipitation ratio of southwest monsoon varies between 90.53 at Block-16, Neyveli as a minimum, and 381.14 at Srimushnam as maximum. The spatial pattern of southwest monsoon precipitation ratio (*Fig. 5C*) expresses higher abnormality (>320) in the southern part represented by Srimushnam and lesser abnormality (<150) in the eastern and

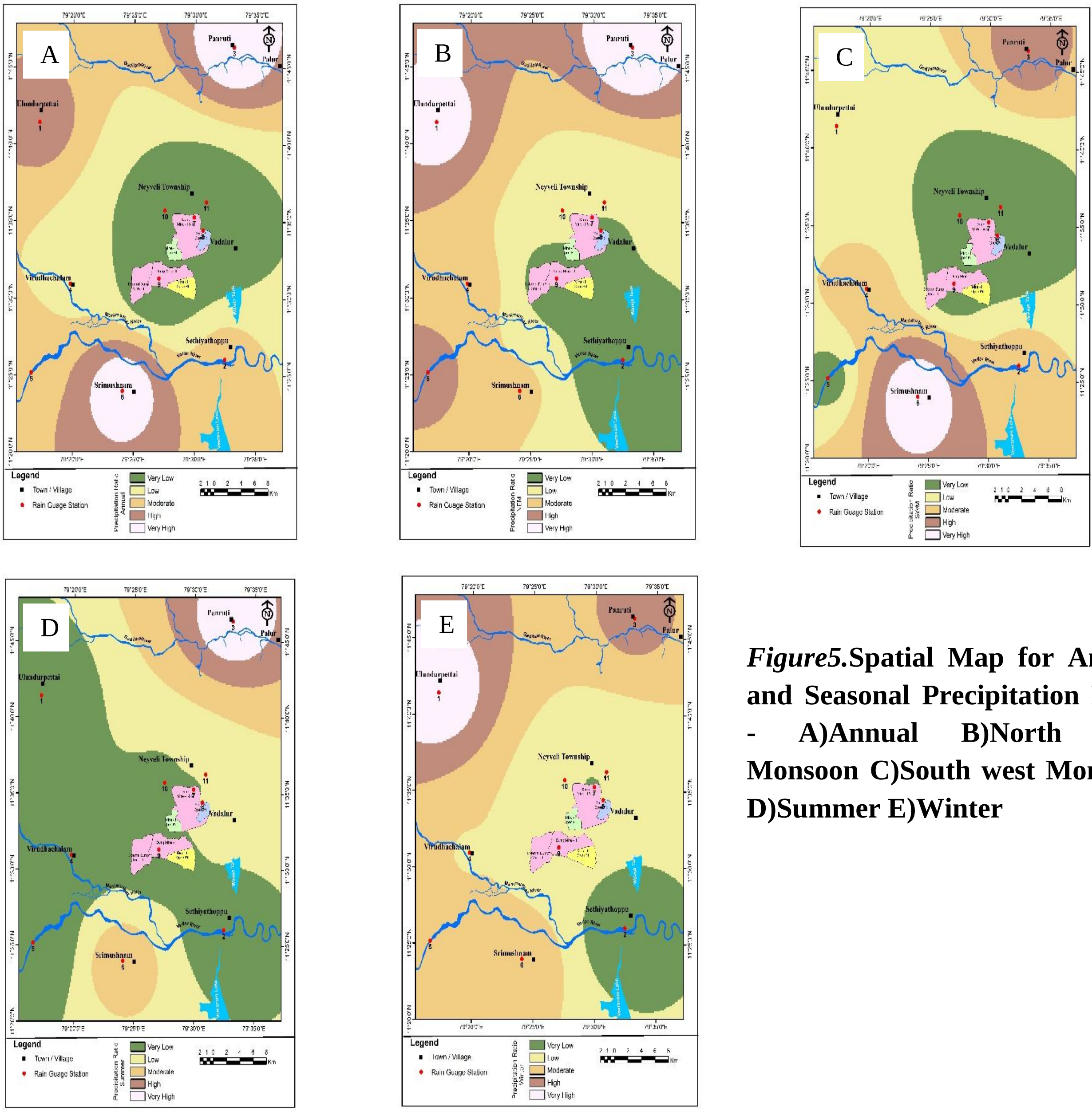



***Figure5.*****Spatial Map for Annual and Seasonal Precipitation Ratio - A)Annual B)North East Monsoon C)South west Monsoon D)Summer E)Winter**

southwestern part of the study area designated by Mine-I, Mine-IA, Mine-II, CARD, Block-16, and Pelandurai.

*Summer Precipitation Ratio*

The precipitation ratio of the summer season ranges between 253.44 at Pelandurai as minimum and 516.74 at Panruti as maximum indicates that the region representing Pelandurai experiences significantly lesser abnormality in rainfall pattern, and the Panruti represents the highest level of irregularity in rainfall pattern. The precipitation ratio with >350 has expressed the spatial distribution of higher levels of abnormality in the rainfall pattern were observed in the Panruti and Srimushnam (*Fig.*5D). The lesser irregularity in rainfall pattern with the precipitation ratio of <300 was represented by Ullundurpet, Vridhachalam, Pelandurai, Mine-I, Mine-II, CARD, and Sethiathope.

*Winter Precipitation Ratio*

The precipitation ratio of the winter season varies from 481.67 (Sethiathope) to 923.97 (Ulundurpet), and its spatial variation is shown in *Figure*. 5E. The spatial diagram of the precipitation ratio indicates the southeastern region of the study area (Sethiathope, Vridhachalam, Mine-I, Mine-IA, Mine-II, CARD, and Block-16) experiencing the common abnormality in rainfall (<660) and the northwestern part (Ullundurpet) experiencing the higher irregularity in rainfall pattern (>84).

**3.3 Annual and SeasonalRainfall Variability**

*Annual Variability of Rainfall*

The coefficient of variability was calculated from the long-term mean annual rainfall and standard deviation of each rainfall station. A simple calculation of rainfall variation may bring rainfall intensity to any location. Higher the variability, lesser will be the rainfall and vice versa. The calculated mean annual variability for the 11 rain gauge stations located in the study area varies from 22.76 in Mine-IA as a minimum to 57.35 in Panruti as a maximum. The spatial distributional pattern of the rainfall variability in the study area is shown in *Figure*. *6A*Lesser rainfall variability with <35 representing the higher rainfall is observed in Mine-I, Mine-IA, Mine-II, CARD, and Block-16. Moderate to higher rainfall variability (>40), representing lesser rainfall occurrences, are observed in Panruti, Srimushnam, and Ulundurpet.

*Northeast Monsoon Variability of Rainfall*

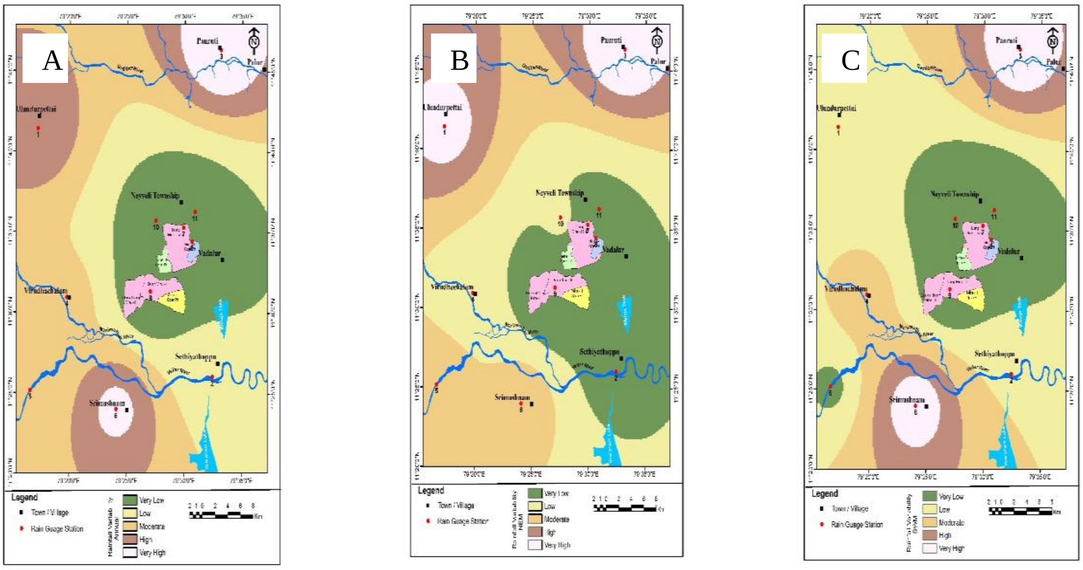
The mean Northeast monsoonal variability of the study area is 47.48 and stretches between 37.43 at Mine-II as minimum and 65.54 at Panruti as maximum. The lesser rainfall variability nature indicates that the northeast monsoon influences the rainfall in the study area. The spatial pattern of Northeast monsoon rainfall variability (*Fig.6B*) expresses lesser variability (<45) occurrence in the eastern part represented by Sethiathope, Vridhachalam, Mine-I, Mine-IA, Mine-II, and Block-16. This region receives a higher amount of rainfall when compared to the western areas of the study area with higher variability (>50). The maximum variability index (>60) is observed in Panruti and Ulundurpet. The annual variability and precipitation ratio are high for winter and summer and low for Northeast monsoon, indicating that the Northeast monsoon influences the catchment.

*Southwest monsoon Rainfall Variability*

This season contributes 28% of the total annual rainfall, and the average rainfall variability of this season is 42.37. It varies between 25.49 at Block-16 as minimum and 82.54 at Panruti as maximum. The lesser rainfall variability has represented the spatial distributional pattern of the higher level of rainfall pattern with <40 was observed in the Ullundurpet, Pelandurai, Mine-I, Mine-IA, Mine-II, CARD, and Block-16 (*Fig*.6C). In the study area, moderate to a lesser variability (40 - 70) suggests a considerable amount ofrainfall contribution from this season. On the other hand, the higher rainfall variability represented scanty occurrences with >70 at Panruti and Srimushnam.

*Summer Season Rainfall Variability*

The average summer seasons rainfall variability of the study area is 76.83, and it varies between 62.96 at Mine-II as minimum and 115.94 at Panruti as maximum. The drastic downgrading of rainfall variability concerning NEM and SWM and upgrading rainfall variability concerning winter during the summer season indicates that the rainfall during the summer season is higher than that of winter and less than that of monsoons. The spatial variation of rainfall variability of the summer season is shown in *Figure. 6D.*



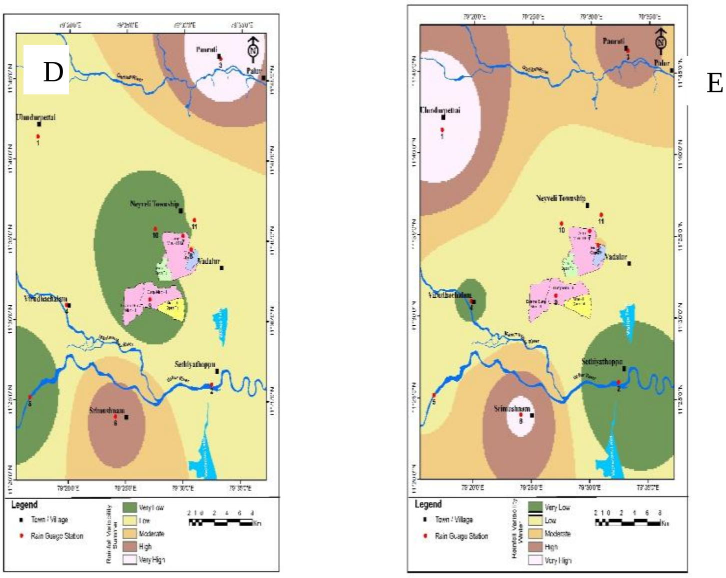




***Figure 6.*****Spatial Map for Annual and Seasonal Rainfall Variation - A)Annual B)North East Monsoon C)South west Monsoon D)Summer E)Winter**

The spatial diagram of the rainfall variability of the summer season indicates that the higher variability (>105) with lesser Rainfall at Panruti and lesser variability (<75) with higher Rainfall at Ullundurpet, Vridhachalam, Pelandurai, Mine-I, Mine-IA, Mine-II, CARD, and Block-16.

*Winter Season Rainfall Variability*

The rainfall variability inthe winter season varies between 130.88 (minimum) in Sethiathope and 209.01 (maximum) in Ulundurpet, with an average of 164.60. The higher variability in the winter season, amongst all seasons, informs the occurrence of low rainfall during winter. The spatial variation of precipitation pattern in the form of rainfall variability of the winter season is shown in *Figure*. *6E*. The spatial depiction of the rainfall variability of the winter season indicates that the western part of the study area represents the Ullundurpet, and Srimushnamare experiencing the scanty rainfall expressed with the variability of >109. On the other hand, the southeastern region of the study area represents the stations at Sethiathope, Vridhachalam, Mine-I, Mine-IA, Mine-II, CARD, and Block-16experiencing the higher rainfall with the lesser rainfall variability <160.

### 3.4 Rainfall Anomaly Index (RAI)

From the precipitation data, the Annual Rainfall Anomaly Index (RAI) was calculated to analyze the frequency and intensity of the dry and rainy years in the study area and is shown in *Table*1. In addition, the drought and rainy years have been visualized using RAI from 2000 to 2019 (Fig. 7), enabling us to identify periods where these events were more intense and lasting.

The positive values observed in Figure 7 represent rainy or wet years, and there are no negative values that represent the absence of dry years in the study area. Therefore, the occurrence of 20 years with a positive RAI indicates varying from very humid to humid nature in the study area. In other words, there were no more years of drought than rainy ones.

The 2005 lowest positive value, with an RAI of 0.32, represents low humidity. The most excellent positive value was 2019, with an average RAI of 2.91, classified as very humid. Concerning the occurrence of drought and rainy years, a consecutive rainy year favors the water supply in the study area, as is the case from 2000 to 2019. Panruti is the region that remained very humid, and Mine-IA experiences a less humid climate.

**Table 1**

***Seasonal and Annual Rainfall Variability in the Study Area (2000 - 2019)***

| S.No | Rain Gauge Station | RAI |
|---|---|---|
| 1 | Ullundurpet | 1.39 |
| 2 | Sethiathope | 0.92 |
| 3 | Panruti | 1.88 |
| 4 | Vridhachalam | 1.09 |
| 5 | Pelandurai | 1.08 |
| 6 | Srimushnam | 1.44 |
| 7 | Mine-I | 0.68 |
| 8 | Mine-IA | 0.51 |
| 9 | Mine-II | 0.67 |
| 10 | CARD | 0.72 |
| 11 | Block-16 | 0.73 |

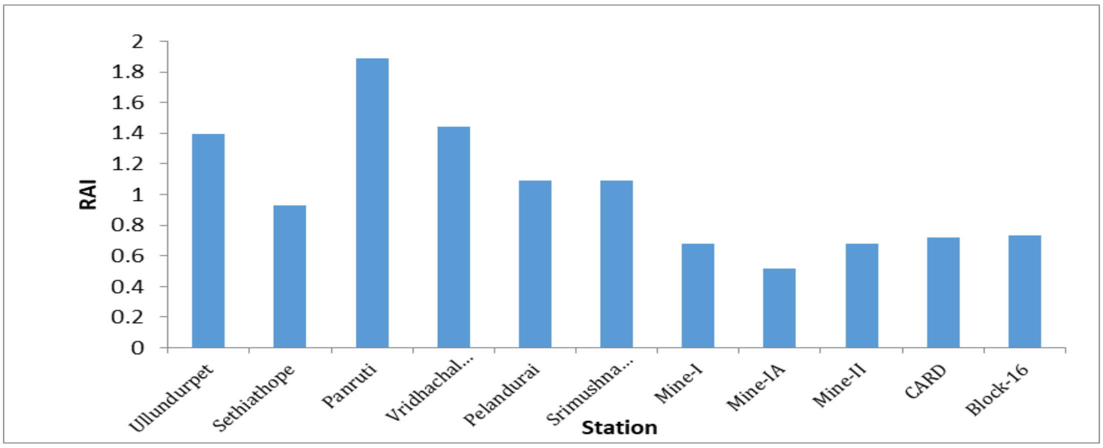



***Figure 8*. Rainfall Anomaly Index (RAI) of the Study Area**

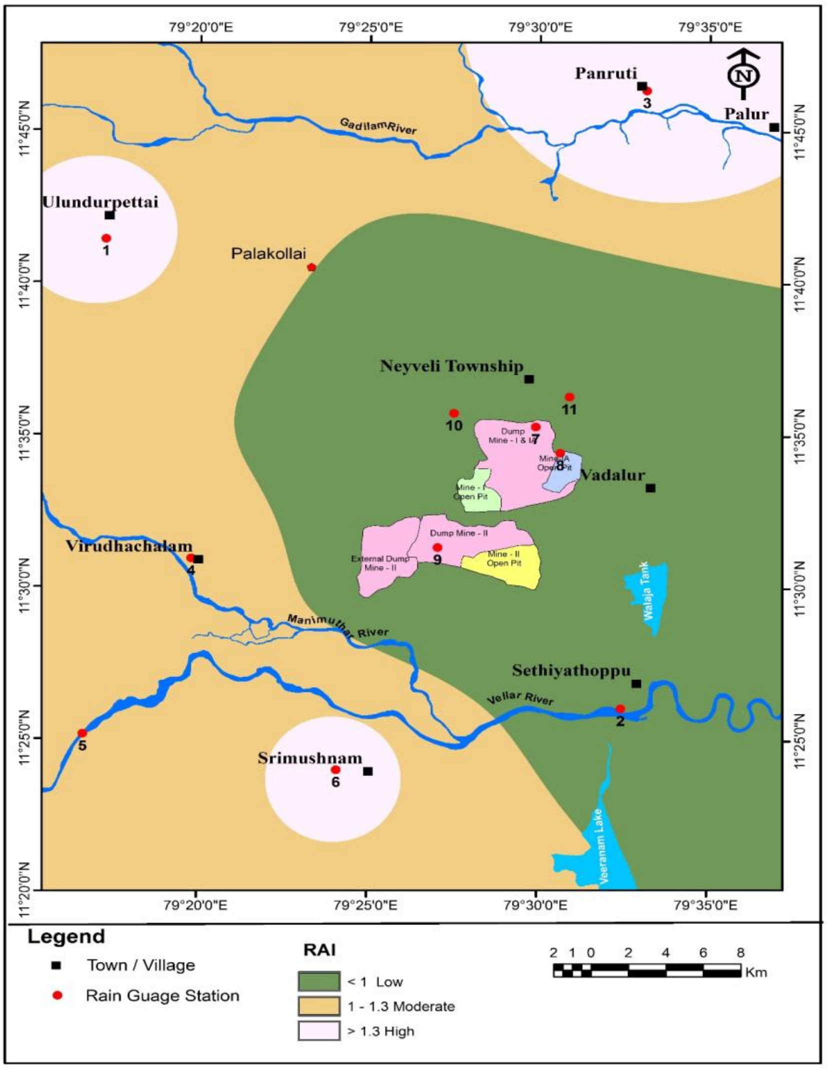



***Figure 7*. Spatial distributions of the Rainfall Anomaly**

*Figure.* 7shows the spatial distribution of the mean RAI across the study area. It is also possible to observe that the average RAI was positive for the entire region. The mean rainfall anomaly index of the study area varies from 0.515 in Mine-IA as a minimum to 1.888 in Panruti as a maximum and falls within the humid class. Humidity is the presence of water vapor in the atmosphere. The more water evaporates in a given area,the more water vapor rises into the air. Therefore, the higher the humidity of that area is hot places tend to be more humid than cool places because heat causes water to evaporate faster.

The RAI variation within the study area was also observed, with a clear division in the spatial distribution of precipitation. The southeast portion presented a lower RAI than in the west and northeast. The spatial depiction of RAI shows Panruti corresponds to high humidity. Ullundurpet, Vridhachalam, Pelandurai, and Srimushnam are experiencing moderate moisture, and Sethiathope, Mine-I, Mine-IA, Mine-II, CARD, and Block – 16 are experiencing low humidity.

## 4. Conclusion

The present study deals with the distribution of Rainfall, Variability,Precipitation Ratio,and rainfall Anomaly Index at 11 stations chosen from in and around Neyveli for observation. It shows the annual rainfall pattern. The spatial distribution of rainfall is vital for planning water resource projects and other agricultural activities. In general, the study area comprises 4 Stationsconcerning altitudes. The region having low height receives high rainfall, the middle Station obtains moderate rain, and the high-altitude Station experiences low rainfall. The analysis results depict the inverse relationship between Rainfall and Rainfall Variability. Low variability indicates the Average Rainfall at the given location as reliable, whereas the high variability denotes the wide fluctuation. The RAI shows the northern part of the study area with high humidity, the western part with moderate, and the southern region shows low humidity.The lesser humidity corresponds to the region under the dense vegetation. This condition provides greater evapotranspiration consequently expresses orographic rainfall.

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