Investigating Rainfall Patterns in South Singhbhum: A Non-Parametric Approach Utilizing Mann-Kendall Tests and Sen's Slope Estimator

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ABSTRACT

Aims: The investigation carried out in this study focuses on the analysis of rainfall patterns within the South Singhbhum region by utilizing non-parametric statistical methodologies with the objective of identifying any discernible trends and variations that have occurred over time.

Place and Duration of Study: South Singhbhum region of Odisha is extended between latitude $20^o\,58'58.238''N$ to $22^o\,34'\,1.051'\,N$ and longitude $84^o\,43'30.304''E$ to $86^o\,42'35.307''\,E$. The area spread over $19,609\ km^2$ on 45 blocks of Eight district in Odisha, India. The duration of time extended from 2008 to 2022.

Methodology: The Mann-Kendall (MK) test is utilized to effectively detect the presence of monotonic trends within both the annual and seasonal rainfall datasets. Furthermore, the sequential Mann-Kendall (S-MK) test is employed to provide a comprehensive understanding of the temporal progression of these identified trends. The Sen's slope estimator is applied to accurately quantify the magnitude of the observed changes in rainfall patterns.

Results: The annual study shows a steady declining trend from 2008 to 2021, with a Sen's Slope of 2.0376 and a Z value of 1.0949. However, March is the only month with a positive trend, as seen by its Sen's Slope of 3.0328 and Z value of 1.9708. There are significant variances in Sen's Slope values, which show disparities in the amount of changes, even if negative trends are common. The steepest negative slope is in July (-3.554), and the highest slope is in August (8.981). The S-MK Test was used to determine the start time of the South Singhbhum Region's annual rainfall time series, which revealed statistically declining patterns. It has been observed that the area's rainfall tendency varies frequently. In 2009, 2011, 2017, and 2019, the lines in the u(t) and u'(t) graphs intersect. The rainfall series experienced a reduction from 2008 to 2009, a rise from 2009 to 2011, a decrease from 2011 to 2017, another increase from 2017 to 2019, and a decline starting in 2019.

Conclusion: The findings demonstrate that the South Singhbhum Region's rainfall patterns are trending negatively, which makes it clear that quick implementation of comprehensive water resource management methods is necessary to support sustainable development initiatives in the near future.

Keywords: Rainfall patterns, South Singhbhum, Mann-Kendall (MK) test, Sequential Mann-Kendall (S-MK) test, Sen’s slope estimator

1. INTRODUCTION

Analyzing rainfall trends and slopes is crucial for effective water resource management, as highlighted in various studies. Examining rainfall patterns and gradients is essential for efficient water resource administration, as emphasized in several research investigations. A study conducted in Uganda highlighted the importance of comprehending the fluctuations in rainfall by utilizing statistical measures such as the Mann-Kendall test and Sen's slope estimator. These metrics revealed the presence of both significant and inconsequential trends in various places (Okirya & Du Plessis, 2024). Furthermore, research conducted in the state of Chhattisgarh, India, revealed the existence of variations in rainfall patterns across different areas. This highlights the need of implementing policies that effectively manage water resources by analyzing these trends (Sahu et al., 2024). Moreover, a study conducted in Osun State, Nigeria, discovered alterations in the rainfall patterns, with certain months showing a decline. This highlights the significance of using water conservation measures in agriculture to address the issues posed by climate change (Rabba, 2022). Kunchala et al., (2023) employed the Mann Kendall and Sen's slope trend analysis to forecast irregular rainfall patterns that affect water resource management in the North-Eastern Visakhapatnam District, India. An analysis has shown that there are fluctuating patterns in the amount of rainfall each year in the Periyar River Basin, which has an influence on the availability of water. The temperature exhibits notable increases, particularly during the winter season (Khan et al., 2024). An investigation has identified a rise in both yearly and seasonal rainfall. Additionally, the use of Sen's approach in slope analysis has helped to measure the extent of this trend, which is useful for making sustainable plans (Maddamsetty & TV, 2023). Understanding long-term patterns and their impact on streamflow in the Nilwala River Basin, Sri Lanka can be aided by rainfall trend analysis using the Mann-Kendall test and slope analysis (Panditharathne et al., 2022). Jayanta et al., (2020) observed both upward and downward trends in annual and monsoon rainfall in the semi-arid Ajmer area, with varying slopes. Mandal et al., (2021) conducted an analysis of long-term rainfall patterns across India using ITA and MK tests. They found declining trends in the majority of subdivisions. This study assists in the management of water resources and the planning of agricultural activities. Mohan Kumar et al., (2022) employed statistical methods such as Mann-Kendall, Sen's slope test, and innovative trend analysis to detect upward trends in annual rainfall. These findings can be valuable for better water resource management and agricultural planning in the Thamirabharani river basin. Prabhakar et al., (2019) performed a comprehensive study of long-term rainfall variability in Odisha State, India, utilizing data spanning from 1901 to 2013. The researchers utilized nonparametric statistical tests, namely the Mann-Kendall, modified Mann-Kendall, and Theil-Sen's slope tests, to analyze the rainfall patterns. The results revealed an average yearly rainfall of around 1438 mm, with a notable concentration during the monsoon season. Their investigation highlighted variations in rainfall distribution among areas, detected a significant alteration in 1945, and emphasized patterns that are valuable for agricultural and water resources management. Gouda et al., (2017) analyzed the variation in monsoon rainfall in Odisha, India, by utilizing the daily gridded rainfall data provided by the India Meteorological Department (IMD). The researchers conducted a comparison of monsoon patterns at national, regional (specifically in Odisha), and sub-regional levels. They discovered a lack of coordination in the seasonal monsoon classifications across these different scales. In addition, they examined the effects of El Niño, La Niña, and the Indian Ocean Dipole (IOD) on rainfall. They found that these factors had a substantial impact on India's total rainfall, but not on Odisha's. They observed a positive association between Odisha's rainfall and the IOD. Panda & Sahu, (2019) conducted an analysis of the variations in monsoonal rainfall and temperature in the KBK districts of Odisha from 1980 to 2017, considering both long-term and short-term variability. By employing the Mann-Kendall test and Sen's slope estimator, it was determined that there has been an upward trend in yearly maximum and minimum temperatures, but monsoon temperatures have experienced a decline. The data revealed a notable upward trend in rainfall, which was statistically significant at a 99% confidence level. However, the analysis of temperature changes yielded conflicting findings in terms of statistical significance. Mohapatra et al., (2021) examined the regional and temporal distribution of long-term rainfall in Odisha from 1951 to 2019 using comprehensive gridded data. The researchers utilized the regional Kendall test to identify patterns in yearly rainfall and employed relative thresholds to examine instances of intense and exceptional rainfall. Their research indicates a growing pattern of higher average annual rainfall, accompanied by a notable increase in intense rainfall events, namely between 2000 and 2019. This suggests that there will be fewer days with moderate rainfall and more days with heavy storms in the future. Nageswararao et al., (2019) performed a thorough assessment of the rainfall patterns at the district level in Odisha, India. The study included four seasons (winter, pre-monsoon, monsoon, and post-monsoon) and utilized high-resolution gridded rainfall data from 1901 to 2013. The researchers conducted an analysis of the influence of the El Nino Southern Oscillation (ENSO) on seasonal rainfall. They discovered notable patterns, including a rise in intense rainfall episodes and changes in the distribution of rainfall throughout the area. Their research emphasizes the diverse and varied rainfall patterns in Odisha and underscores the crucial significance of this study for agriculture policy and climate risk management in the context of global warming. Sharma & Singh, (2019) conducted an analysis of rainfall seasonality in Jharkhand State, India spanning a period of 102 years. They determined the rainfall seasonality index and individual seasonality index values. Trend analysis was conducted on the annual data using the Mann-Kendall test, sequential Mann-Kendall test, and Sen's slope technique. Their research revealed that rainfall exhibits a pronounced seasonal pattern, characterized by a lengthy period of drought. Additionally, they detected a noteworthy albeit inconsequential decline in the individual seasonality index in some regions, which might potentially affect agricultural practices. Sahoo & Padhi, (2022) examined alterations in rainfall patterns and trends in thirty districts of Odisha, India, across a 30-year span (1990–2019) by utilizing daily rainfall data. The researchers analyzed the changes in annual and monsoon rainfall over a period of ten years, seeing variances in different districts. Some districts showed an increase in average rainfall, while others saw a drop. In addition, the researchers computed the seasonality index (SI) and employed the Mann-Kendall test to evaluate trends, specifically identifying substantial alterations in districts such as Koraput and Gajapati. Mohanty et al., (2024) performed a thorough examination of groundwater patterns in Odisha, India, spanning a 30-year timeframe (1990-2020). They utilized spatio-temporal water level data from 746 different sites. The researchers identified key areas where future groundwater levels may vary and established the factors that affect variations in water levels. The study revealed that water level trends exhibit seasonal and regional variations, which are driven by factors such as the intensity of rainfall, population increase, industrial activity, and land use. Additionally, several districts have been identified as high-risk areas for future groundwater availability.

The rationale for doing this study arises from the growing apprehensions over climate uncertainty and its influence on local weather patterns, particularly in regions such as South Singhbhum, where agriculture and water supplies rely significantly on rainfall. Gaining insight into the extended patterns of rainfall is essential for adjusting to any shifts in the climate, which might have substantial consequences for the security of food, the availability of water, and the general socio-economic stability in the area. Due to the crucial significance of rainfall for the well-being of local communities, it is imperative to evaluate if there have been substantial changes in rainfall patterns. This will allow policymakers and stakeholders to create efficient measures to minimize and adjust to these changes.

This study has two main aims. The primary objective is to examine the annual rainfall data for South Singhbhum by employing non-parametric methods like the Mann-Kendall (MK) and sequential Mann-Kendall (S-MK) tests to detect any noteworthy patterns or changes over time. Furthermore, the study aims to measure the extent of these changes by utilizing Sen's slope estimator, which will offer a precise depiction of the alterations in rainfall patterns. The project aims to provide useful insights into the climatic dynamics of the region and help to informed decision-making in areas such as water resource management, agricultural planning, and sustainable development.

The subsequent segment of the manuscript delineated in Section 2 encompasses the sources of materials utilized for analytical purposes, centering on the methodologies employed for data analysis and the specifics of the statistical techniques implemented, such as the Mann–Kendall (MK) test, the Modified Mann–Kendall (MMK) test, the Sequential Mann–Kendall (S-MK) test, and Sen's slope estimator, to examine the rainfall trends within the South Singhbhum region. Section 3 elaborates comprehensively on the study area, its significance, topographical features, and the sources of rainfall data. Section 4 presents the outcomes derived from the aforementioned methodological framework and discusses the implications of rainfall patterns in the South Singhbhum region for the sustainable management of water resources. In conclusion, Section 5 encapsulates the results, constraints, and potential directions for forthcoming research emanating from this study.

2. MATERIAL AND METHODS

2.1. Study Area

South Singhbhum Craton region of Odisha is extended between latitude $20^{o}58'58.238''N$ to $22^{o}34'1.051''N$ and longitude $84^{o}43'30.304''E$ to $86^{o}42'35.307''E$. The area is spread over $19{,}609 km^2$ on 45 blocks of Six District in Odisha. The region is full of natural resources and famous for its mineral resources, such as iron ore, manganese, bauxite, chromite, etc., and the area is formed from hilly, plateau, and residual hills. The following comparative table provides detailed information about the research that has been conducted previously in this area. The area is spread over 19,609 square km. on 45 blocks of 8 districts in Odisha as shown in Figure 1.

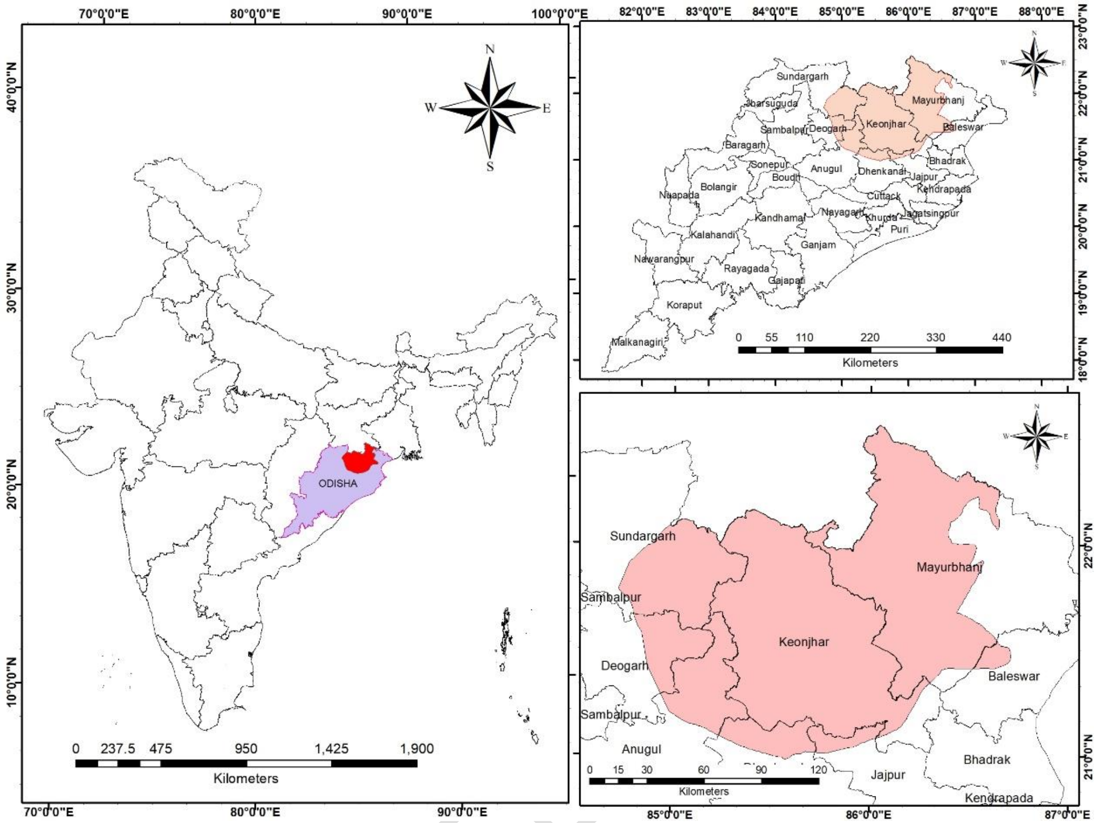


Figure 1: Location of the study area

The South Singhbhum Craton region is a landlocked region, and it is surrounded by Jharkhand state in its North direction. The various blocks of the same district and the nearby ones encircle the area. These blocks are Gurundia, Gurundia, Baneigarh of Sundargarh district, Barkot, Teleibani, Remali from Bargarh district, Akaniha block of Anugul, Kankadahad of Dhenkanal dangabadi, Sukinda block from Jajpur, Hatadihi, Ghasipura of Keonjhar, Kaptipada, Udala, Bangiriposi, Saraskana, Shamakhunta, Kuliana, and Bisoi blocks from Mayurbhanj district and it is encircled by the block Oupada, Nilagiri, and Bhadrakh of Balasswar district. It is a part of South Singbhum Craton, which lies in parts of Odisha. It consists of four river basins, namely Subarnarekha, Bhudhabalunga, Baitarani and Brahmani River basins.

2.2. Data Collection

The primary dataset employed for the research consists of rainfall data that includes both the durations and intensities of rainfall within the South Singhbhum area of Odisha, India. A comprehensive collection of twenty-two (22) years of monthly rainfall data, spanning from the year 2000 to 2021, has been procured from the Indian Meteorological Department (IMD) located in Bhubaneswar.

2.3. Data Processing

Microsoft Excel software was used to manage and process long-term rainfall data. The MATLAB programming language is used to estimate slopes and do trend analysis. The data was then organized chronologically, allowing for a methodical assessment of annual rainfall patterns across time. To delineate the area of interest that is the South Singhbhum Region ArcGIS software has been used.

2.4. Methodology

For the purpose of examining the spatial and temporal variations in rainfall throughout the entire annual cycle. The rainfall series varied spatially and temporally. Factors like instruments, observing practices, station environment situation and location of the station may impact the uniformity of rainfall data time series (Huang et al., 2015).

2.4.1. Mann–Kendall (MK) test

The MK statistical test requires sample data which should be serially independent (Yue & Wang, 2004). The MK statistic, S, is defined as:

$$S = \sum_{j=1}^{m-1} \sum_{k=j+1}^{m} sgn\left(x_k - x_j \right) \tag{1}$$

where x_j and x_k are the j^{th} and k^{th} term in the sequential data of sample size m and for $x_k - x_j = \theta$.

$$sgn\,(\theta) = \begin{cases} 1, & if\ \theta > 0 \\ 0, & if\ \theta = 0 \\ -1, & if\ \theta < 0 \end{cases} \tag{2}$$

Assuming independent data with identically scattered, the variance and mean of the S statistic in equation (3) and equation (4) may be calculated as given by Dinpashoh et al., (2011); Kendall, (1975); Mann, (1945)

$$E[S] = 0, \tag{3}$$

$$Var(S) = \frac{m(m-1)(2m+5)}{18}. \tag{4}$$

The standard normal deviate (Z statistics) is then computed

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var\,(S)}}, & if\ S > 0, \\ 0, & if\ S = 0 \\ \dfrac{S+1}{\sqrt{Var\,(S)}}, & if\ S < 0 \end{cases} \tag{5}$$

Where the values of Z exceeding ± 1.96 denote a 5% threshold of statistically significant positive or negative trends within the time series, respectively.

2.4.2. Modified Mann–Kendall (MMK) test

The modified variance of S is used in MMK statistical test for minimizing the influence of significant autocorrelation coefficients from the time series as reported by the authors (Hamed & Rao, 1998). The modified spatial and temporal variance of S, labelled as $Var(S)*$, is expressed as follows:

$$Var\,(S)^* = Var\,(S)\frac{m}{m^*} \tag{6}$$

where m^* = adequate sample size. Based on the work reported by Hamed & Rao, (1998), the $\frac{m}{m^*}$ ratio may be defined as

$$\frac{m}{m^*} = 1 + \frac{2}{m\,(m-1)(m-2)} \sum_{i=1}^{m} (m-1)(m-i-1)(m-i-2)ri \tag{7}$$

where m = actual number of sample data and $ri = lag - i$ represents the significant autocorrelation coefficient of rank I of time series. The computed values of $Var(S) * (Eq.4.6)$ are used for the $Var(S)$ in equation (4). The results are compared with threshold levels at 5%, and the values above ± 1.96 are significant level.

2.4.3. Sequential Mann–Kendall (S-MK) test

The S-MK Test is used to find out whether the series increases or decreases over time. While the test presents the results graphically, it can also determine the starting point of the trend (Zeybeko\uglu, 2023). The t value, which is the test statistic, is calculated by summing the n_i values obtained by counting the smaller ones from the previous ranks for each rank. The mean value of t's is calculated by equation (8); variance $Var(t)$ is calculated by equation (9) and Test statistic $u(t)$ is calculated by equation (10). The backward test statistic $u'(t)$ is calculated similarly to $u(t)$ (Chatterjee et al., 2013). The point where $u(t) - u'(t)$ intersects shows where the trend starts.

$$t = \sum_{i=1}^{n} n_i \tag{8}$$

$$E(t) = \frac{n(n-1)}{4} \tag{9}$$

$$u(t) = \frac{(t - E(t))}{\sqrt{Var\ (t)}} \tag{10}$$

When estimating the forward sequential statistic, $u(t_i)$, we use the original time series $(x_1, x_2, \dots, x_n)$. On the other hand, the values of the backward sequential statistic, $u'(t_i)$, are estimated in the same way, but we start from the end of the series. When estimating $u'(t_i)$, the time series is rearranged so that the last value of the original time series is placed first $(x_1, x_2, \dots, x_n)$.

The sequential variant of the Mann-Kendall test statistic enables the identification of an approximate starting point of an emerging trend. The estimated prospective trend turning point can be located by plotting the curves of $u(t_i)$ and $u'(t_i)$ and identifying their junction. If the point of intersection between $u(t_i)$ and $u'(t_i)$ falls inside the range of the standardized statistic at a 5% significance level, it may be concluded that there is a noticeable change at that specific point in the time series. Furthermore, if there is at least one value of the reduced variable that exceeds a selected threshold of significance for a Gaussian distribution, the null hypothesis (H_0: The sample being studied does not exhibit the start of a new trend) is rejected.

2.5. Sen's slope estimator

Sen, (1968) gave nonparametric procedure for a linear trend in time series in terms of slopes. The slope estimates (Q_i) of m pairs of data are calculated using the following expression as:

$$Q_i = \frac{x_j - x_k}{j - k}; \text{for } i = 1, 2, 3, \dots, m. \tag{11}$$

The median of Q_i is derived from:

$$\beta = \begin{cases} \dfrac{Q(m+1)}{2}; & m\ is\ odd \\ \dfrac{1}{2}\left(\dfrac{Qm}{2} + \dfrac{Q(m+2)}{2}\right); & m\ is\ even \end{cases} \tag{12}$$

The results are compared with threshold levels at 5%, and the β values above ± 1.96 are significant (increasing/decreasing) trends.

3. RESULTS AND DISCUSSION

3.1. Basin Wise Rainfall characteristics during the years 2008–2021

Figure 2 represents the comparisons between the normal and actual rainfall in Baitarani and Brahmani River basin since last two decades. The trend line showing that average of actual rainfall between consecutive years. The actual rainfall was highest in the year 2011 and lowest actual rainfall was recorded in 2010. The years which recorded more than average actual rainfall are 2001, 2003, 2005, 2007, 2008, 2009, 2011, 2013, 2014, 2016, 2018, 2020 and the years that receives lower than the actual average annual rainfall are 2000, 2002, 2004, 2006, 2010, 2012, 2015, 2017, 2019. The annual average rainfall trend line increased in the year 2007 & 2008 and declined between the year 2009 and 2010.

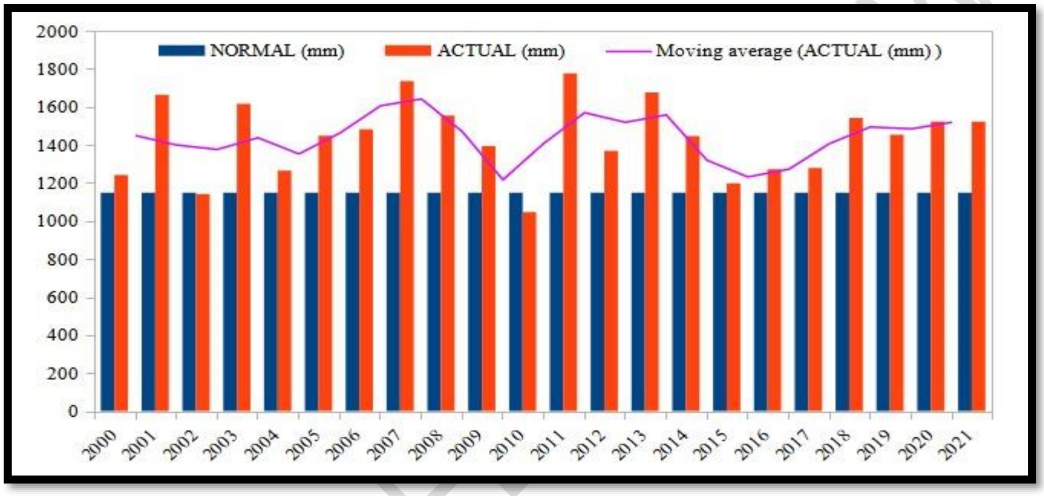


Figure 2: Comparison between the Normal and actual Rainfall in Baitarani and Brahmani River Basin

Figure 3. represents the comparison between the normal and actual rainfall in the Subarnarekha River basin for the last twenty years. The trend line represents the annual average rainfall of two consecutive years. It was observed that the trend line was highest between 2006 and 2007, with a sharp decline from 2007 up to 2009, which is the lowest moving average rainfall. The years which recorded more than the moving average rainfall are 2001, 2003, 2007, 2008, 2009, 2011, 2013, 2017, and 2019; and that recorded less than the moving average are 2000, 2002, 2004, 2005, 2006, 2010, 2012, 2014, 2015, 2016, 2018, 2020.

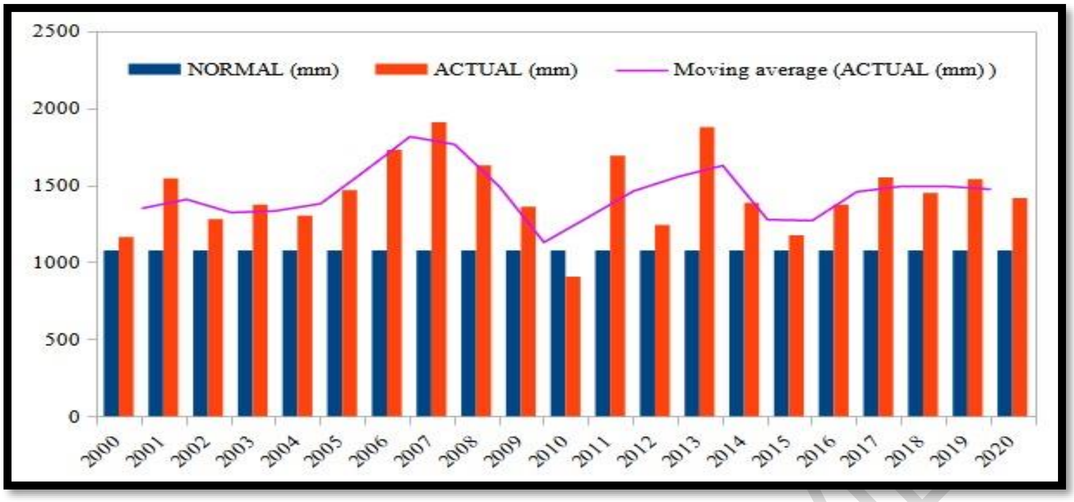


Figure 3.: Comparison between the Normal and Actual Rainfall in Subarnarekha River Basin

3.2. Block-wise Rainfall characteristics during the years 2008–2021

In Figure 4, The examination of the 2008 rainfall data from several blocks indicates substantial fluctuations in monthly rainfall patterns. The monsoon months, which span from June to September, are of utmost importance as they contribute significantly to the overall annual rainfall. For example, Bahalda experienced the greatest average annual rainfall of 183.58 mm, with a significant amount of rainfall in July (1063 mm). Ghatgaon experienced an average annual rainfall of 198.25 mm, with the highest amounts being in July (697 mm) and August (576 mm). On the other hand, blocks such as Danagadi and Koira experienced considerably lower yearly averages of rainfall, measuring 77.75 mm and 76.90 mm respectively. The majority of rainfall in these areas occurred within a limited number of monsoon months. For example, Danagadi received 301 mm of rainfall in August and 632 mm in September. The average monthly rainfall varied from 1.46 mm in March to 65.23 mm in May before the monsoon, and from 16.56 mm in October to 0.95 mm in November after the monsoon.

Due to this fluctuation, it is necessary to implement customized water management methods in order to ensure the sustainable utilization of water throughout the year. Regions characterized by abundant rainfall, such as Bahalda and Ghatgaon, should prioritize the optimization of rainwater collection techniques and the enhancement of storage infrastructure to effectively handle surplus water, hence potentially reducing the likelihood of flooding. In contrast, regions such as Danagadi and Koira, which receive less rainfall, require strong irrigation systems and conservation methods to maximize the utilization of scarce water resources. Effective water management, guided by these rainfall patterns, is essential for agriculture, residential water supply, and general regional progress, aiding in the reduction of the negative effects of both droughts and heavy rains.

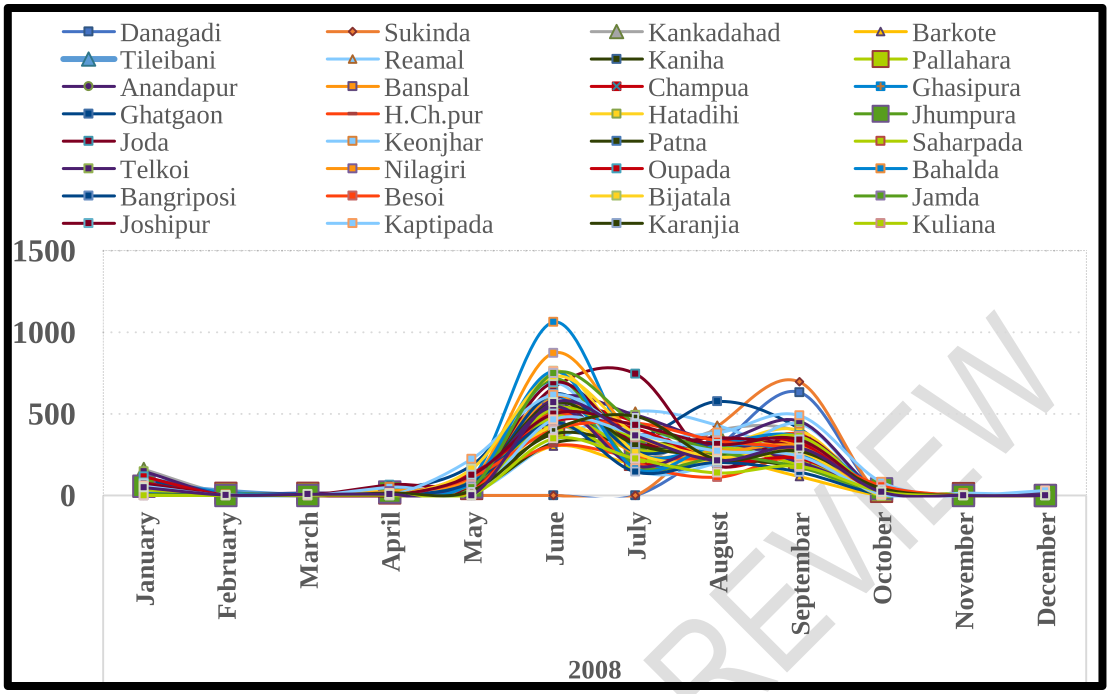


Figure 4: Block wise monthly average rainfall of South Singhbhum Region in 2008

Figure 4 represents comparison of the monthly average rainfall of south Singhbhum region in 2009. In the Manson time i.e., from June to September, the rainfall in the south singhbum region is expectedly high as compare to other months. Kusumi block traced highest monthly average rainfall in month July and Kaptipada block traced highest monthly average rainfall in August.

In Figure 4, The examination of the 2009 rainfall data for several regions in Odisha reveals notable regional and seasonal disparities. The months of June, July, August, and September, which are part of the monsoon season, experienced the greatest amount of rainfall. Among these months, July regularly had the highest recorded rainfall values in most areas. As an example, Kankadahad experienced an exceptional 895 mm of rainfall in July, which significantly contributed to its yearly normal of 167 mm. Similarly, Ghatgaon experienced rainfall of 602 mm in July and 508 mm in August, resulting in a significant yearly average of 163.41 mm. On the other hand, blocks like Danagadi and Sukinda did not get any rainfall over the entire year, which could suggest specific weather conditions in those areas or problems with data reporting. The regional distribution of rainfall highlights the necessity of implementing customized water management measures to tackle situations of both excessive and insufficient rainfall.

The consequences of this distribution of rainfall have significant ramifications for the management of water resources and the planning of agricultural activities. Regions with high levels of rainfall, such as Kankadahad and Ghatgaon, have difficulties such as excessive flooding, water accumulation, and soil erosion. Consequently, the construction of dams and reservoirs, together with the implementation of efficient water management techniques, becomes necessary. As an illustration, Oupada received a significant amount of rainfall, measuring 577 mm in August and 476 mm in September, leading to an average annual rainfall of 178.08 mm. On the other hand, areas with very little rainfall, like Danagadi and Sukinda, should prioritize water conservation, effective irrigation, and the use of drought-resistant agricultural methods. Through comprehending these patterns, local authorities can enact strategies to alleviate the detrimental impacts of severe weather, guaranteeing sustainable agricultural output and water resource management throughout the region.

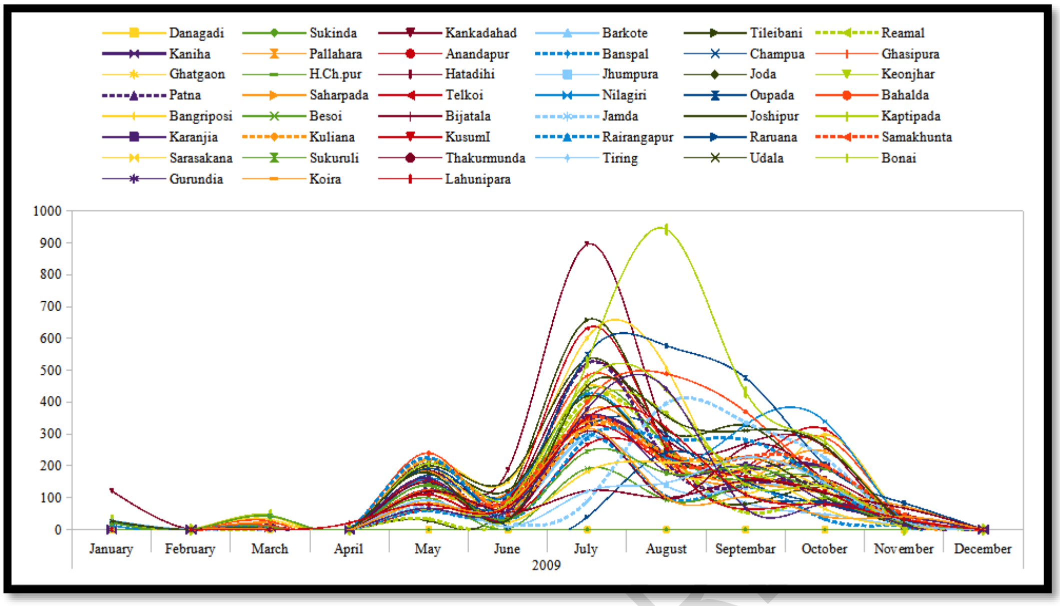


Figure 5: Block wise monthly average rainfall of South Singhbhum Region in 2009

The rainfall data for the Singhbhum region in 2010, as shown in Figure 6, demonstrates notable differences in both space and time across several blocks and months. In terms of average monthly rainfall, August experienced the largest amount (209.49 mm), with July closely following (229.50 mm), which suggests the height of the monsoon season. In contrast, the months of January, February, and November had very little rainfall, with an average of only 2.74 mm, 0.22 mm, and 7.04 mm correspondingly, which is normal for the dry season. Danagadi and Anandapur experienced significantly high annual average rainfall, with measurements of 161.08 mm and 173.75 mm respectively. In contrast, Tiring and Barkote blocks had substantially lower average rainfall, with measurements of 43.73 mm and 45.73 mm respectively. The patterns emphasize the region's reliance on monsoon rains and the significant periods of drought that occur outside of the rainy season, highlighting the difficulties of managing water resources and planning agriculture in the Singhbhum region.

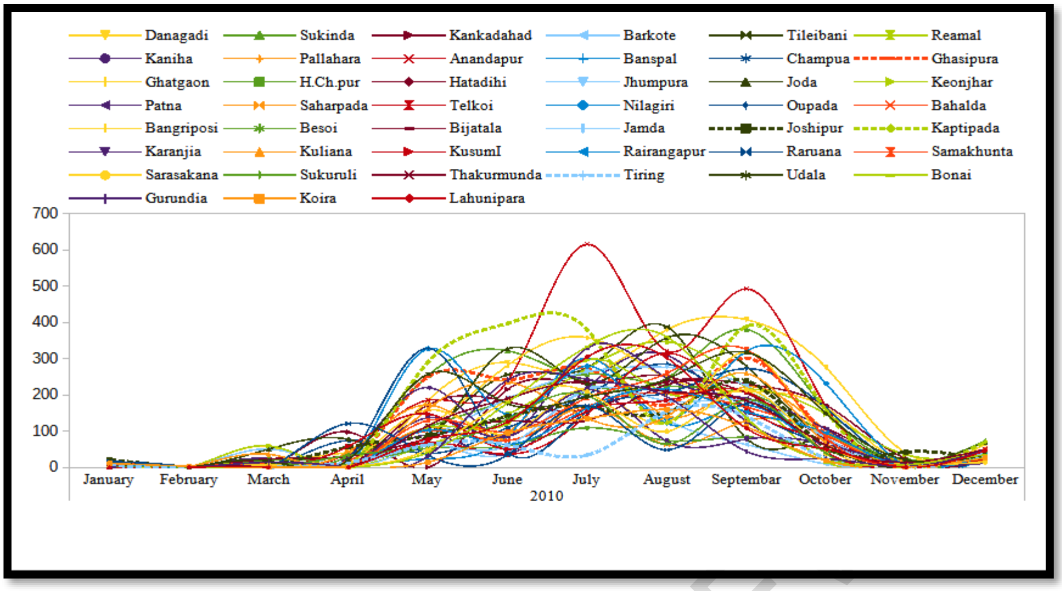


Figure 6: Block wise monthly average rainfall of South Singhbhum Region in 2010

The rainfall data for the South Singhbhum region in 2011, as presented in Figure 7, exhibits substantial diversity among various blocks and months. The monsoon months, specifically from June to September, experience the most significant amount of rainfall. In August, certain areas, such as Danagadi (664 mm), Sukinda (732 mm), and Joda (573 mm), reach their maximum levels of rainfall. The majority of the yearly rainfall in this region is concentrated in these months, indicating a strong reliance on the monsoon. January and December typically have minimal rainfall, which is characteristic of the arid season. The blocks of Anandapur and Joda see the highest annual average rainfall, with 304.85 mm and 234.88 mm respectively, mainly due to very high monsoon rainfall. On the other hand, blocks like Barkote and Besoi exhibit the lowest annual averages of 78.77 mm and 104.63 mm respectively, indicating less fluctuation and lower levels of rainfall throughout the monsoon season. This data highlights the crucial significance of the monsoon in determining the amount of water available in the region, as well as the significant variations in rainfall distribution throughout different areas.

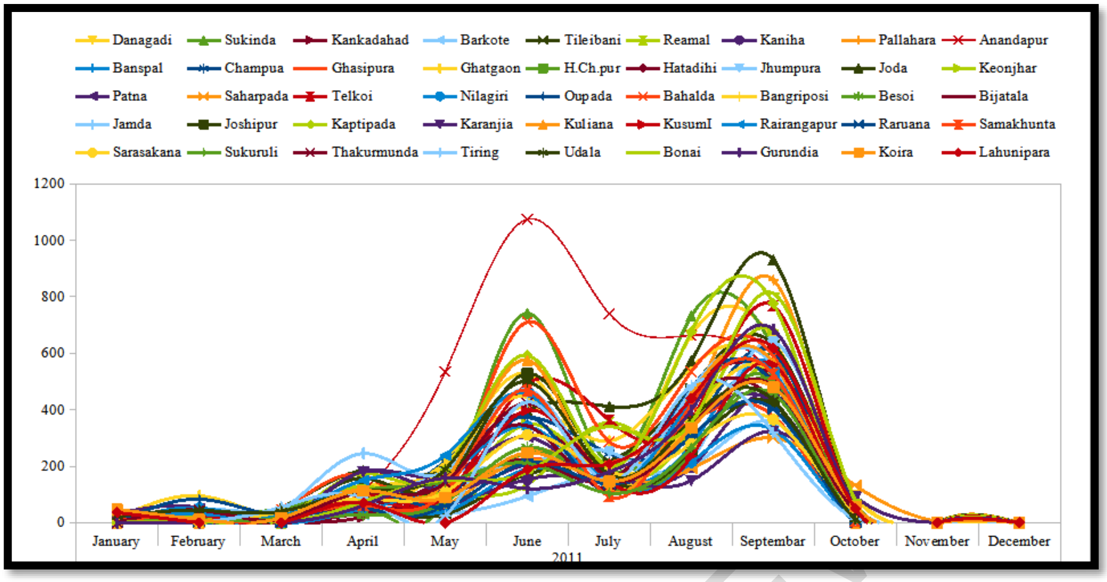


Figure 7: Block wise monthly average rainfall of South Singhbhum Region in 2011

In Figure 8, the rainfall data for the South Singhbhum region in 2012 shows notable fluctuations in rainfall levels throughout various blocks and months. The monsoon months, specifically June to September, experienced the most significant amount of rainfall. July and August were the months with the most rainfall, averaging 264.09 mm and 370.13 mm of rainfall, respectively. Pallahara and Ghatgaon saw exceptionally heavy rainfall during this period, with Pallahara receiving 643 mm of rainfall in August and Ghatgaon receiving 580.9 mm. In contrast, the months of January, February, March, and December, which are characterized by dry weather, experienced very little rainfall. In fact, some areas reported no rainfall whatsoever during these months. For example, Danagadi and Sukinda experienced a complete absence of rainfall throughout these months. Kaptipada had the highest average annual rainfall at 175.42 mm, while Hatadihi had the lowest average at 66.23 mm. The data emphasizes the notable differences in rainfall patterns, both in terms of location and time, in the South Singhbhum region. This information is crucial for making informed decisions on agricultural planning and managing water resources.

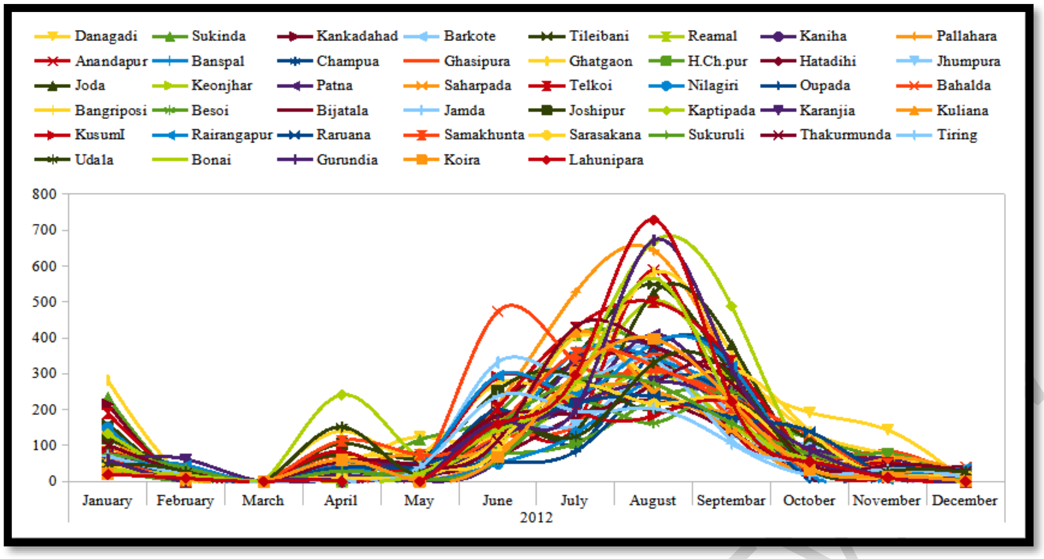


Figure 8: Block wise monthly average rainfall of South Singhbhum Region in 2012

The rainfall data for the South Singhbhum Region in 2013, as shown in Figure 9, demonstrates notable fluctuations among various blocks and months. The month of October had the highest average monthly rainfall, with a recorded amount of 433.79 mm. It was followed by July, which had an average rainfall of 425.58 mm, and August, with an average of 328.53 mm. These figures indicate a significant monsoon season. Danagadi and Bahalda blocks encountered torrential rains, with average annual rainfall of 223.75 mm and 263.25 mm, respectively, indicating significant variations in rainfall distribution throughout different regions. In contrast, the least humid periods occurred in November and December, with minimal or no rainfall recorded in all areas. The data demonstrates a distinct seasonal trend, wherein the months preceding the monsoon season (January to May) experience notably lower levels of rainfall in comparison to the months during the monsoon season (June to October). The seasonal pattern highlights the significance of the monsoon in determining the amount of water available in the region. Moreover, several regions like Nilagiri and Bahalda had exceptionally heavy rainfall during particular months, namely October and May, respectively, which had a substantial impact on their overall yearly averages. The data offers vital information about the spatial and temporal patterns of rainfall in the South Singhbhum Region, which is significant for agricultural planning and water resource management.

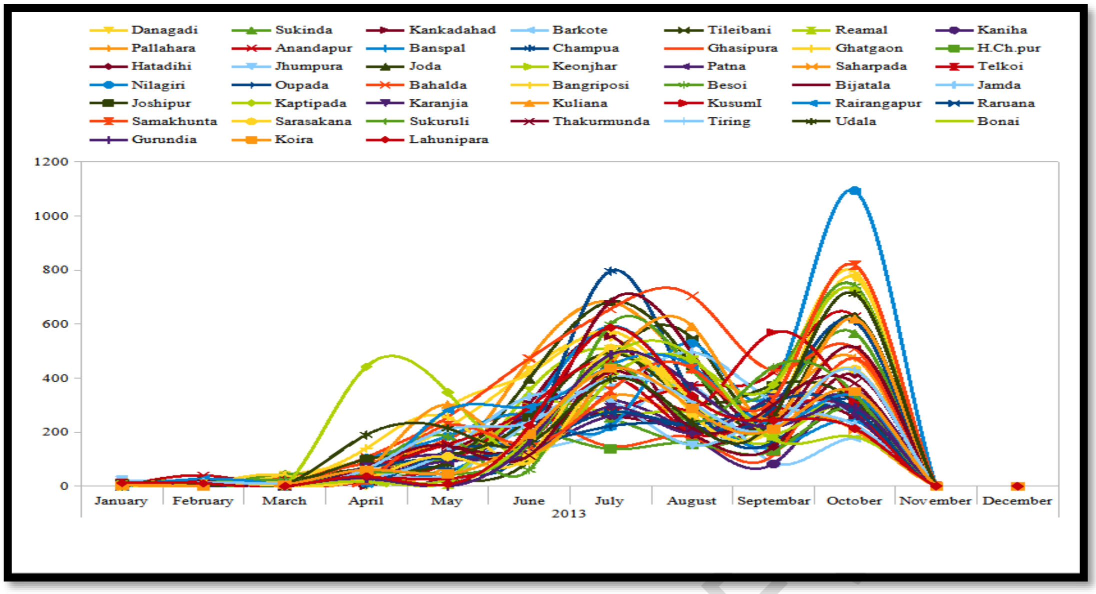


Figure 9: Block wise monthly average rainfall of South Singhbhum Region in 2013

Figure 10 provides the monthly mean rainfall statistics for different blocks in the South Singhbhum region throughout the year 2014. The data reveals substantial fluctuations in rainfall patterns across various months and sectors. Significantly, the region encounters minimal or nonexistent rainfall in January, November, and December. Rainfall commences in May and reaches its peak during the monsoon season in June, July, and August, with July being the most rainfall-intensive month in most areas. Pallahara and Kaptipada experienced unusually heavy rainfall in July, with rainfall levels reaching 753 mm and 594 mm, respectively. In contrast, areas like Danagadi and Sukinda experienced significant rainfall during the months of June and July, but received very little rainfall outside of the monsoon season. The region experienced a range of monthly rainfall, with the lowest amount being 6.66 mm in January and the highest amount being 472.75 mm in July. The average annual rainfall across all areas demonstrates a clear seasonal trend, highlighting the significant influence of the monsoon season on the region's overall water supply.

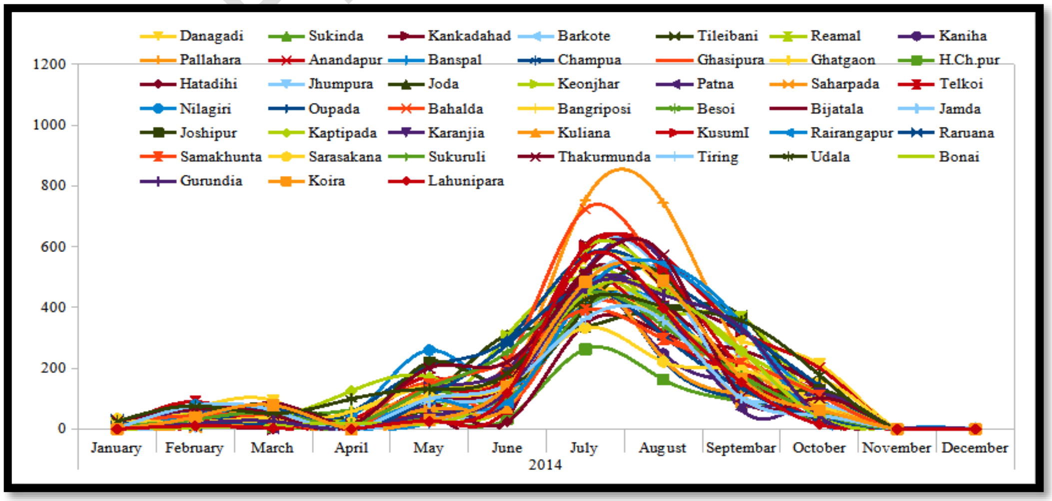


Figure 10: Block wise monthly average rainfall of South Singhbhum Region in 2014

The Figure 11 provides a comprehensive overview of the average monthly rainfall in the South Singhbhum Region in 2015, including statistics for various blocks. The data demonstrates substantial fluctuations in rainfall, both in terms of time and location. The monsoon months from June to September exhibit the highest levels of rainfall, with July recording the highest averages, such as 641 mm in Danagadi and 827 mm in Bahalda. Conversely, the months with low rainfall, specifically from November to February, experience very little or no rainfall. Specifically, blocks such as Ghatgaon and Bahalda demonstrate significant monthly fluctuations, indicating the unequal dispersion of rainfall throughout the region. The blocks in the region have significant variations in yearly rainfall levels, with H.Ch.pur receiving an average rainfall of approximately 45.8 mm and Bahalda receiving an average rainfall of 151.4 mm. The data highlights the urgent requirement for effective water resource management and strategic planning to tackle the challenges of both floods and droughts in the South Singhbhum Region.

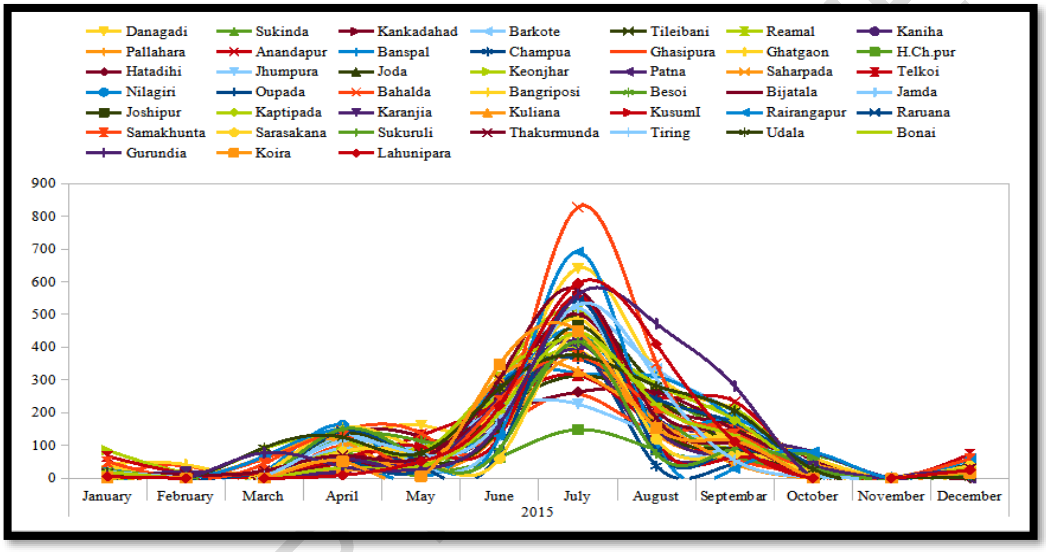


Figure 11: Block wise monthly average rainfall of South Singhbhum Region in 2015

Figure.12 presents the mean monthly rainfall in 2016 for several blocks in the South Singhbhum Region. The rainfall patterns exhibit substantial fluctuation both within months and between blocks. June, July, August, and September are the months with the most amount of rainfall, with August having the highest average rainfall of 351.86 mm. Nilagiri and Udala blocks recorded the greatest annual averages of rainfall during the monsoon season, with 162.82 mm and 158.68 mm respectively, indicating significant regional rainfall. In contrast, January, November, and December were the months with the least amount of rainfall, and most areas experienced very little rainfall during these months. The patterns highlight the seasonal variation in rainfall in South Singhbhum, where a significant monsoon season accounts for the majority of the yearly rainfall. The results also indicate significant disparities among blocks, which might be attributed to localized geographical and meteorological variances within the region. The region experienced an annual average rainfall of 125.25 mm, with a notable concentration of rainfall throughout the middle months of the year.

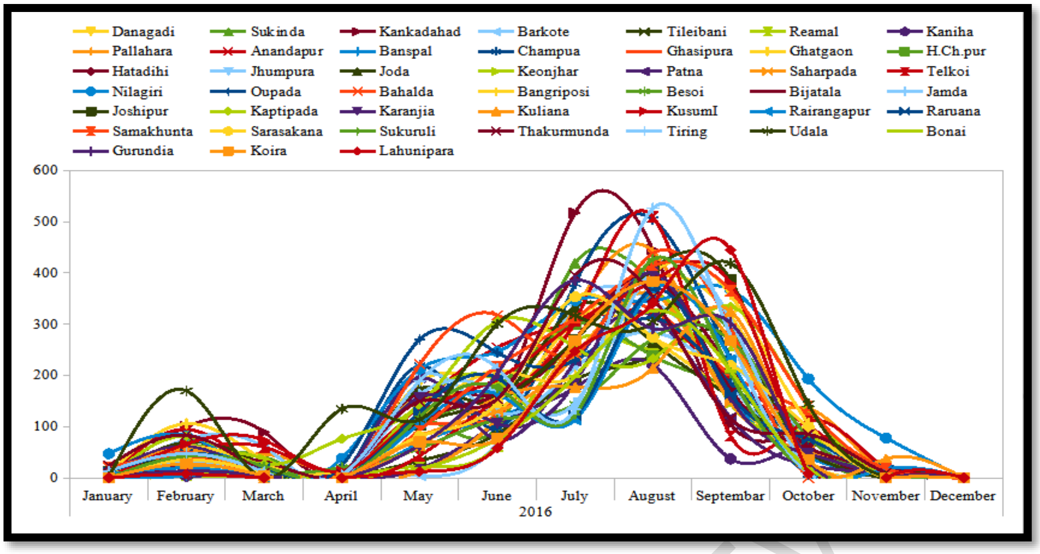


Figure 1: Block wise monthly average rainfall of South Singhbhum Region in 2016

Figure.13 presents a comprehensive summary of the monthly mean rainfall in different blocks of the South Singhbhum Region for the year 2017. The data demonstrates substantial fluctuations in rainfall patterns throughout the year. In the months of July and August, the majority of areas had significant rainfall during the monsoon season, with certain areas receiving more than 300 mm on average. During these months, areas such as Pallahara, Ghatgaon, and Bonai had rainfall over 400 mm. Conversely, the winter months spanning from December to February experienced significantly reduced levels of rainfall, with certain areas getting insignificant quantities. On the whole, the region had an average yearly rainfall of around 277.68 mm, with significant fluctuation across different areas, indicating the diverse climatic conditions within the territory. This data is essential for comprehending local hydrological trends and for making well-informed decisions concerning agriculture, water management, and infrastructure development in the region.

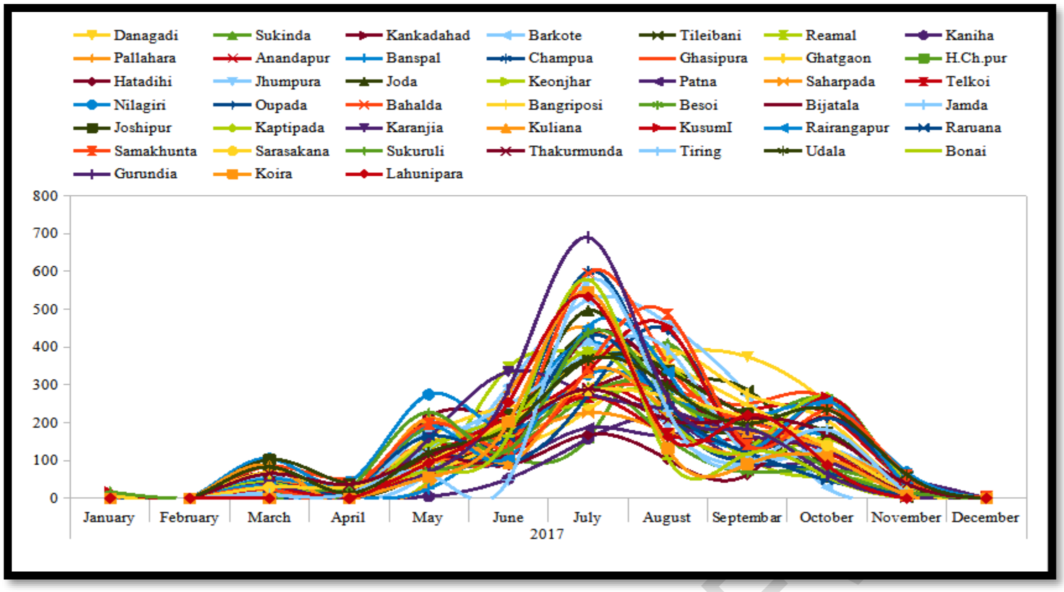


Figure 13: Block wise monthly average rainfall of South Singhbhum Region in 2017

Figure 14 provides the average monthly rainfall information for different blocks in the South Singhbhum Region throughout the year 2018. There is considerable variety in rainfall patterns among different areas, with certain blocks having significantly higher average rainfall than others. Ghatgaon, Telkoi, and Thakurmunda had the most significant rainfall, with an average monthly rainfall of around 170 to 190 mm during the monsoon period. In contrast, areas such as Danagadi and Sukinda experienced comparatively lower levels of rainfall, with an average of approximately 100 mm each month. In 2018, the South Singhbhum Region experienced an average monthly rainfall of around 41 mm. The data illustrates the spatial diversity of rainfall in the area, which is affected by geographical factors such as altitude and closeness to the coastline. Gaining a comprehensive understanding of these changes is essential for the successful management of water resources and the planning of agricultural activities in the region.

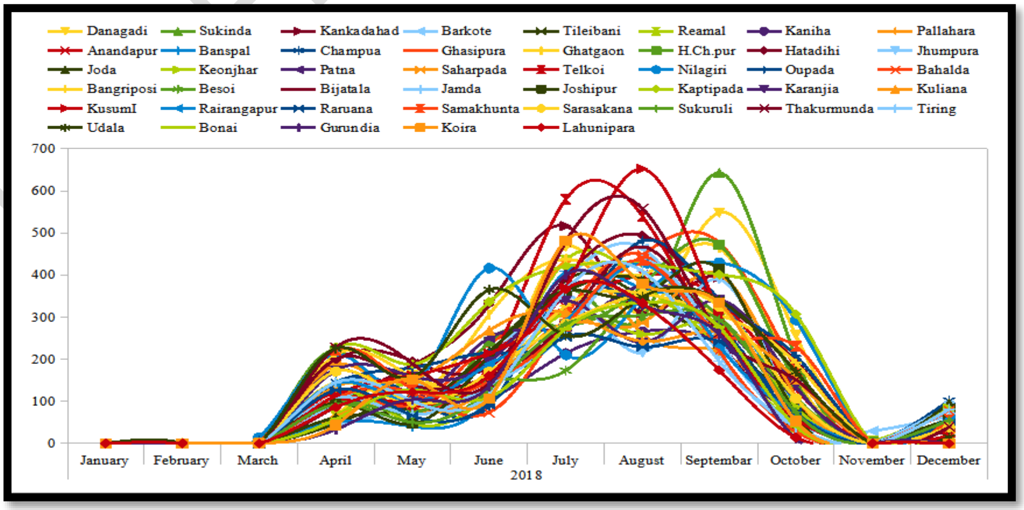


Figure 2: Block wise monthly average rainfall of South Singhbhum Region in 2018

Figure 15 provides the monthly mean rainfall statistics for different blocks in the South Singhbhum Region in 2019. The region displays great variations in rainfall patterns, with certain areas such as Ghasipura and Bahalda receiving considerably higher rainfall than other locations throughout the year. As an illustration, Ghasipura experienced a maximum rainfall of 796.5 mm in September, whilst Bahalda reported a peak of 525.4 mm in August. Conversely, many areas such as Danagadi experienced less rainfall during the most of the months. The region experienced an average rainfall of 300.8 mm, with significant fluctuations from month to month. The period from June to September typically experienced the greatest rainfall in most areas, whereas November and December were significantly drier. These differences emphasize the significance of localized data in comprehending regional weather patterns and their consequences for agriculture, water resource management, and disaster preparedness in the South Singhbhum Region.

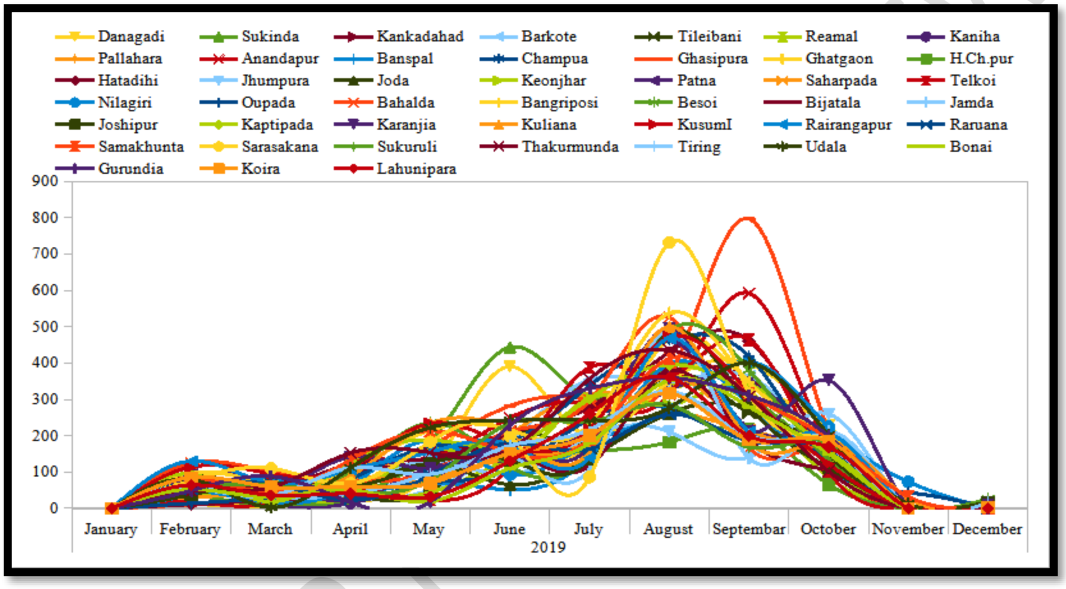


Figure 3: Block wise monthly average rainfall of South Singhbhum Region in 2019

Figure 16 provides a thorough summary of the average monthly rainfall in the South Singhbhum Region for the year 2020, categorized by several blocks within the region. There is clear and notable disparity in rainfall patterns, both in terms of timing and geographical distribution. For example, in January, the amount of rainfall varies from a minimum of 2 mm in Kusumi to a maximum of 99.5 mm in Ghasipura. The region has a consistent variety of rainfall patterns throughout the year, highlighting the intricate nature of this diversity. Furthermore, there is a significant rise in the average rainfall across the blocks from January to August, with August having the highest average rainfall. Nevertheless, there is a significant decrease in rainfall in September, which is then followed by very little rainfall in October, November, and December. The variability in rainfall can have significant consequences for sectors such as agriculture, water resource management, and infrastructure planning. This highlights the need for reliable data collection and analysis to make informed decisions and develop effective methods for adaptation.

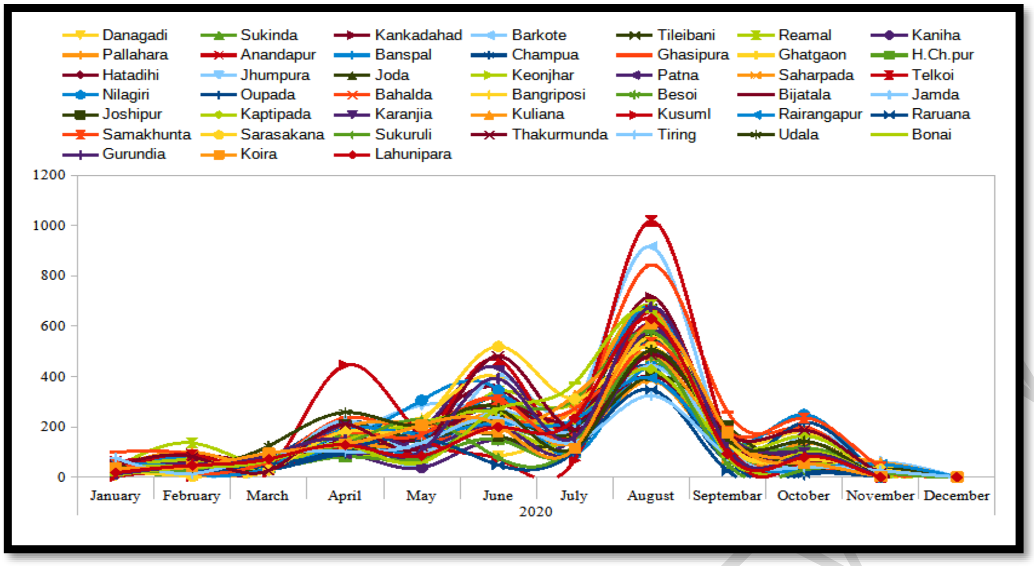


Figure 4: Block wise monthly average rainfall of South Singhbhum Region in 2020

Figure 17 presents a thorough summary of the monthly mean rainfall in the South Singhbhum Region for the year 2021, categorized by several blocks. Every block displays distinct rainfall patterns, leading to a wide range of average rainfall statistics. As an example, the Danagadi and Sukinda blocks receive considerably more rainfall in May compared to other months, with Danagadi recording an impressive 343mm and Sukinda receiving 308.5mm. In contrast, the Kaniha block experiences comparatively lower levels of rainfall throughout the year, with zero rainfall occurring in some months. The region experiences significant variance in average rainfall, with May being the month with the highest rainfall, followed by June and July. This difference is expected to have an impact on agricultural practices, water resource management, and the overall dynamics of the ecosystem in the region. Gaining insight into these patterns can assist in developing more effective planning and adaptation strategies for communities that depend on these resources.

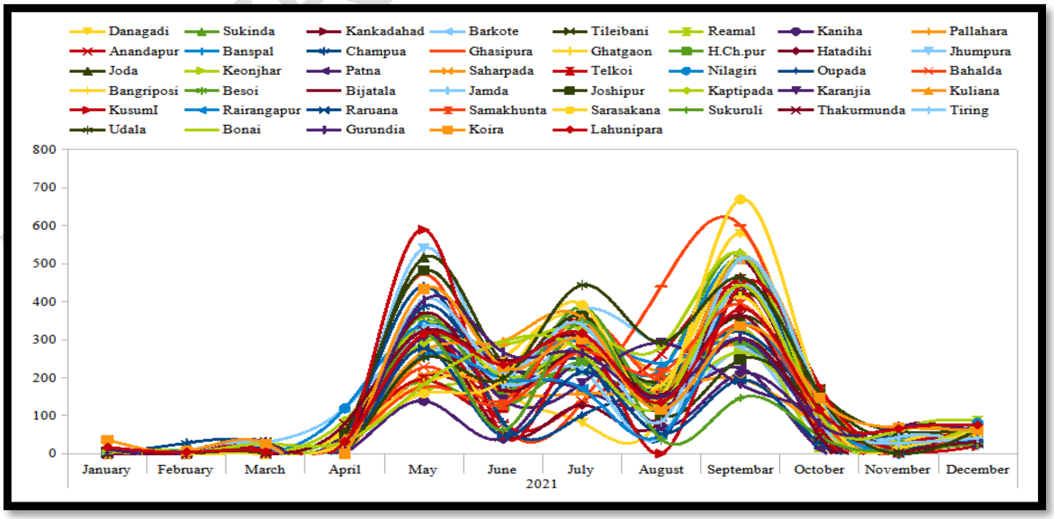


Figure 5: Block wise monthly average rainfall of South Singhbhum Region in 2021

3.3. Rainfall trend analysis with annual time steps

The analysis of average monthly rainfall data in the South Singhbhum region from 2008 to 2021 highlights notable fluctuations in both seasons and years, as depicted in Figure 18. During the monsoon months (June to September), there is a significant amount of rainfall, with July and August experiencing particularly heavy rainfall. For instance, in July 2014, there was a recorded rainfall of 472.75 mm, while in August 2020, it reached 557.99 mm. On the other hand, the dry months (November to February) usually experience very little rainfall, with some periods even seeing almost no rainfall, like in February 2009 and November 2013. In 2009, there was a significant decrease in the average annual rainfall, with only 99.48 mm recorded. However, in 2020, there was a substantial increase, with the highest average annual rainfall reaching 141.31 mm. These fluctuations highlight the importance of flexible agricultural practices and strong infrastructure to effectively handle droughts and floods. Similar to a quantitative analyst, one can infer from the observed anomalies and extremes in rainfall patterns that there may be broader climate change impacts. This highlights the significance of ongoing monitoring and thorough analysis in order to develop effective planning and resilience strategies in the region.

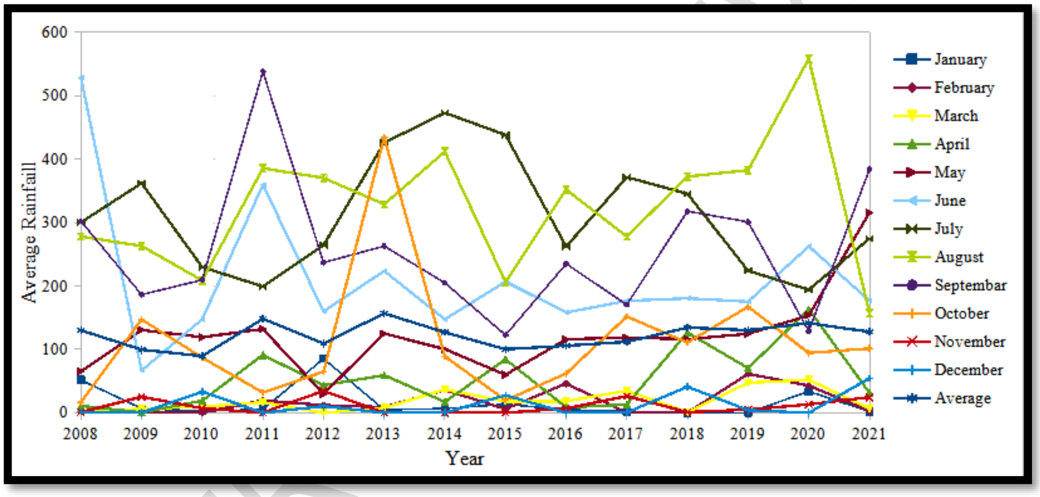


Figure 18: Monthly Average rainfall pattern in South Singhbhum region

Table 1: The value of Mann – Kendall Test and the Sen's Slope Estimator

Period	Mann – Kendall Test		Sen's Slope Estimator	
	Z_{cr}	**Z**	**Trend**	β
January	1.96	-1.6423	Negative trend	-0.6367
February	1.96	1.0402	Negative trend	0.9919
March	1.96	1.9708	Positive trend	3.0328
April	1.96	1.5329	Negative trend	4.6433
May	1.96	1.3139	Negative trend	4.8434
June	1.96	0.3285	Negative trend	1.8474
July	1.96	-0.5474	Negative trend	-3.554
August	1.96	0.6569	Negative trend	8.981
September	1.96	0	Negative trend	-0.1048
October	1.96	1.3139	Negative trend	5.4563

November	1.96	0.5474	Negative trend	0.1942
December	1.96	0.8759	Negative trend	0.0859
Annually	1.96	1.0949	Negative trend	2.0376

Table.1 displays the most important monthly and annual trends in the South Singhbhum region from 2008 to 2021, as determined by the Mann-Kendall test and Sen's Slope Estimator and the outcomes of the studies carried out at 95% confidence levels. Throughout this time frame, the majority of months show a downward trend, with Z values that do not surpass the critical value of 1.96. This implies that there are no statistically significant trends present. In January, there is a negative trend with a Z value of -1.6423 and a Sen's Slope of -0.6367. Similarly, in July, there is a significant negative trend with a Z value of -0.5474 and a slope of -3.554. On the other hand, March stands out as the sole month with a positive trend, supported by a Z value of 1.9708 and a Sen's Slope of 3.0328. Despite the prevalence of negative trends, there are notable variations in Sen's Slope values that indicate differences in the magnitude of changes. In August, the slope is the highest at 8.981, while in July, it is the steepest negative slope at -3.554. Figure.19 illustrates a comparison of the results obtained from Sen's Slope for both the monthly and yearly rainfall in the south Singhbhum region.

Over the 2008-2021 period, the annual analysis reveals a consistent downward trend, characterized by a Z value of 1.0949 and a Sen's Slope of 2.0376. While the annual Z value does not reach statistical significance, it does indicate a prevailing negative trend. These negative trends persisting throughout most months suggest possible long-term shifts in the region's environmental conditions. Understanding the temporal dynamics of environmental variables in the South Singhbhum region is crucial for informing policy-making and strategic planning to mitigate adverse impacts and promote sustainable development.

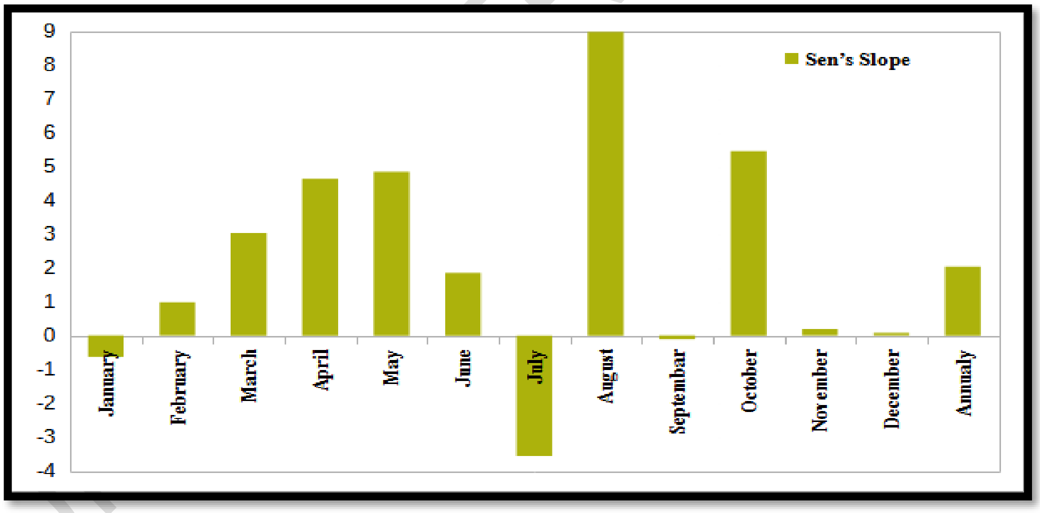
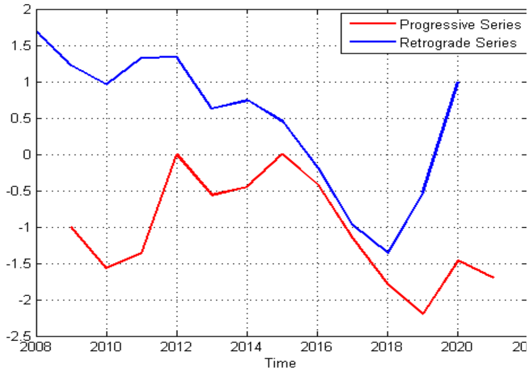


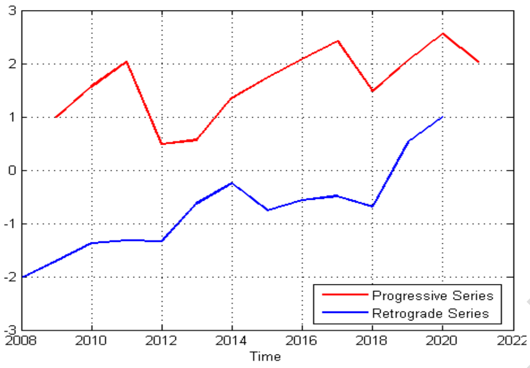
Figure 6: Sen's Slop estimator for the monthly and annual rainfall in the south Singhbhum region

Figure 20 presents the results of the sequential MK test for the monthly average rainfall in the South Singhbhum region, showing the progressive and retrograde trends of the monthly rainfall. Figure 20 (a) shows that negative trend remains same throughout the time period in the month of January. In the month of February, as depicted in Figure 20 (b), the trend changed four times. It began as a positive trend in 2009 and continued to decline from 2010 to 2018, then increased from 2018 to 2020 before declining once more from 2020.

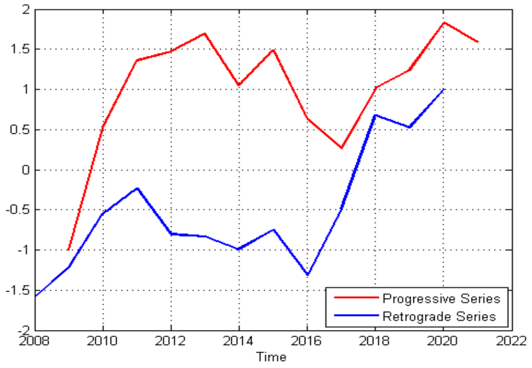


(a) January

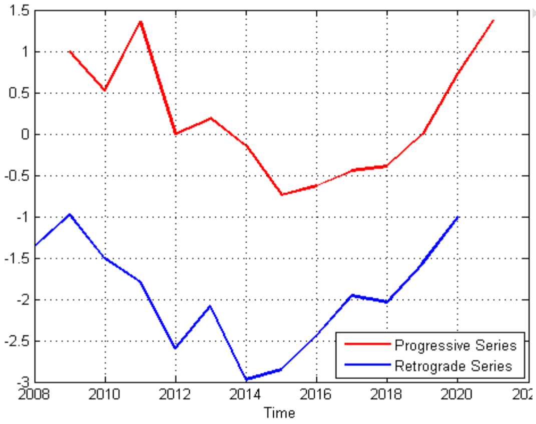
(b) February



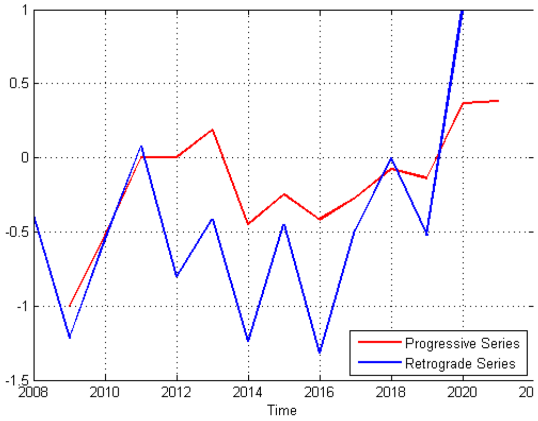
(c) March



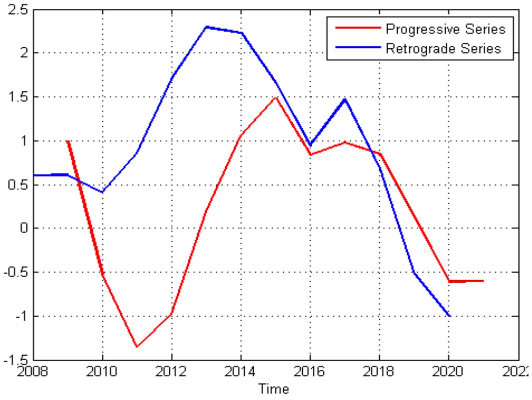
(d) April



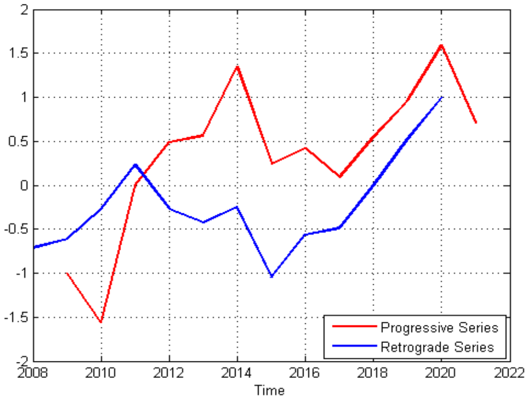
(e) May



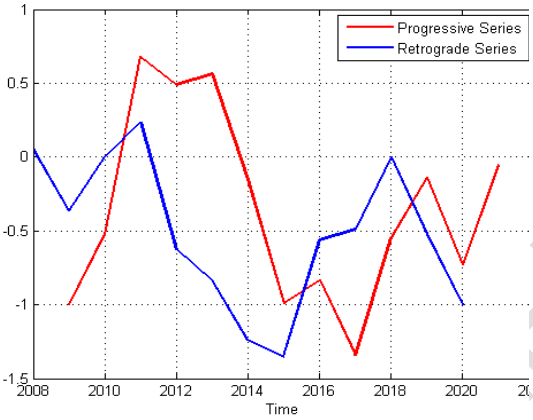
(f) June



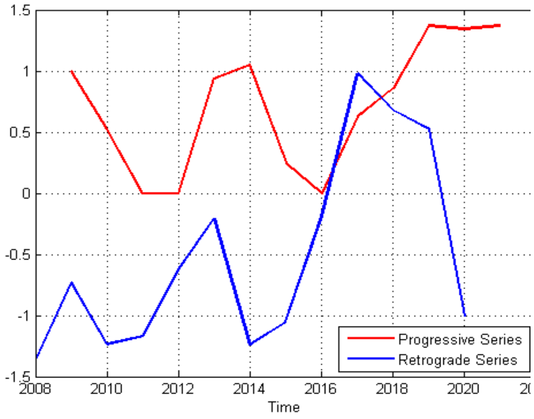
(g) July



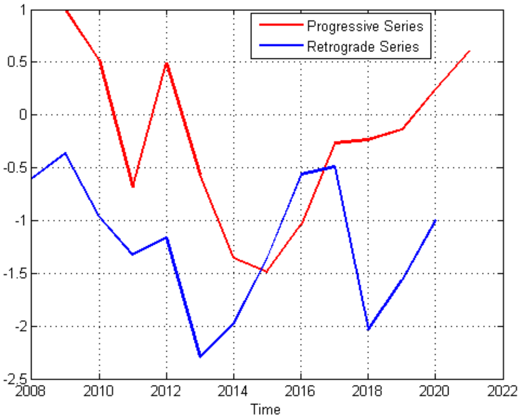
(h) August



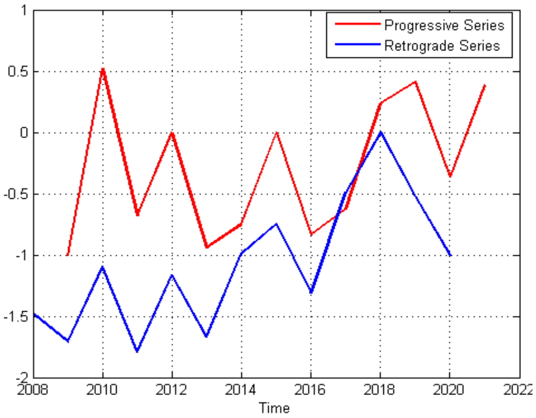
(i) September



(j) October



(k) November



(l) December

Figure 7: Sequential Mann-Kendall test for monthly average rainfall in south Singhbhum region

The trend has remained unchanged over the specified time period in the month of March, April and May as shown in Figure.21 (c), (d), (e). In the month of June as depicted in Figure.21 (f), the trend changed four times. It began as a positive trend in 2010 and continued to decline from 2010 to 2011, then increased from 2018 to 2019 before declining once more from 2019. In July, as shown in Figure.21 (g), the trend altered twice. It began as a negative trend in 2009, turned positive from 2009 to 2018, and then decreased after 2018. Figure 21(h) shows that the trend changed once in August. It started as a negative trend in 2011 and then became positive. Figure.21 (i) shows that the trend changed three times in September. It started out as a negative trend in 2011, then became positive from 2011 to 2015, then negative from 2015 to 2019, and finally positive. Figure 21 (j) shows that the trend changed twice in October. It began as a negative trend in 2016, went positive from 2016 to 2018, and then turned negative in 2018. The trend changed twice in November, as Figure.21 (k) illustrates. It started off as a downward trend in 2015, went up from 2015 to 2017, and then went down again in 2017. The trend changed twice in 2017 in December, as seen in Figure 21(l), indicating that the trend line is unaffected.

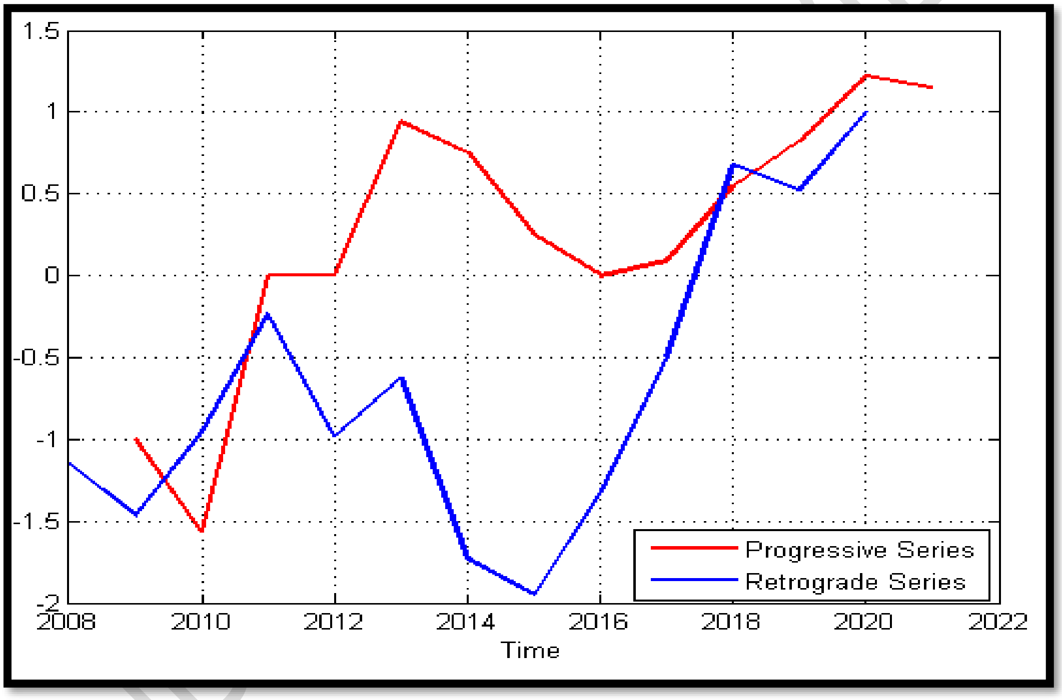


Figure 21: Sequential Mann Kendall Test for annually average rainfall in the south Singhbhum region

Figure 21 presents the results of the sequential MK test for the annual average rainfall in the South Singhbhum region, showing the progressive and retrograde trends of the annual rainfall. The annual rainfall time series from the South Singhbhum Region, which showed statistically downward trends, were subjected to the S-MK Test in order to establish the beginning time of the tendency. The rainfall trend in the area has been seen to fluctuate often. The lines in the $u(t)$ and $u'(t)$ graph intersect in 2009, 2011, 2017, and 2019. From 2008 to 2009, the rainfall series began to decline; from 2009 to 2011, it increased; from 2011 to 2017, it decreased; from 2017 to 2019, it increased once more; and from 2019, it began to decline.

4. CONCLUSION

This work provides a comprehensive and extensive analysis of the complex rainfall patterns in the South Singhbhum area. It utilizes advanced non-parametric statistical methods that are currently being used in cutting-edge research. The utilization of the Mann-Kendall and sequential Mann-Kendall tests has revealed noteworthy monotonic trends present in both annual rainfall distributions. Additionally, Sen's slope estimator has been employed to accurately quantify the magnitude of these observed changes over time. The analysis reveals significant changes in the climate patterns of the region, which have important consequences for managing water resources and planning agricultural operations in the area. This research strongly emphasizes the urgent need to create and put into action flexible solutions that can effectively deal with the problems presented by changing climatic circumstances. The documented and observed negative trend in rainfall patterns in the South Singhbhum Region makes it abundantly evident that comprehensive water resource management strategies must be implemented immediately in order to support sustainable development initiatives in the near future. This will ensure that the area can successfully negotiate the intricacies of climate change. In conclusion, the results greatly add to the discussion on sustainable development in the South Singhbhum region. These findings offer unique insights that can be used to shape policies and practices. Hence, it is crucial for stakeholders to acknowledge the significance of these results and adopt proactive efforts to incorporate them into future planning and resource management frameworks.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author hereby declaresthat NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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