

ANALYSIS OF VARIATION OF RAINFALL TRENDS AND PATTERNS OVER THE INDIAN SUBCONTINENT

Abstract

Rainfall plays a pivotal role in any region's agricultural productivity, water resources management, and overall socio-economic development. Hence an understanding of the changing patterns and trends of rainfall is crucial for effective planning, resource allocation, and climate change adaptation strategies. To conduct this study, long-term monthly rainfall for a period of 121 years (1901-2021) from India meteorological department across the Indian subcontinent were collected and analyzed. A detailed analysis of monthly, annual, seasonal and non-seasonal rainfall was carried out. The findings reveal significant changes in rainfall trends and patterns over the Indian subcontinent. Both inter-annual and intra-seasonal variability were observed, highlighting the complex nature of rainfall dynamics in the country. The study also examined the impact of climate phenomena such as El Niño (dry) and La Niña (wet) on the rainfall patterns, emphasizing their influence on the interannual variability using the SPI as an indicator. The yearly SPI analysis revealed that 61 years were wet where the rainfall was more than the normal rainfall out of which 17 years were very wet leading to flood like situations. A more detailed analysis of dry and wet months in the monsoon season was done in order to have an idea regarding the availability of rainfall during the monsoon months for crop planning and irrigation scheduling. All the monsoon months witnessed water scarcity conditions in 50%-60% of the total 121 years' time period. The results of this research contribute to a better understanding of rainfall dynamics in the Indian subcontinent, aiding scientists, water resource managers, and climate scientists in making informed decisions. Moreover, the findings highlight the need for further research and the development of potent climate models to accurately predict future rainfall trends in the face of climate change.

Keywords: Rainfall trends, Rainfall patterns, Indian subcontinent, Climate variability, Water scarcity, SPI

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I. INTRODUCTION

Rainfall is one of the most crucial natural resources that is essential for the survival of life on earth. In India, monsoon season plays a major role in any country's economy and livelihood of the people. India receives its rainfall from both the South-West Monsoon and the North-East Monsoon. The South-West Monsoon ranging between June to September, is responsible for 75% of the country's total rainfall. In Contrast, the North-East Monsoon which occurs from October to December, brings rainfall to the parts of South India. The Study of Rainfall Data Analysis in India is essential because it provides insights into the distribution, variability, and trends of rainfall patterns in the country. The analysis of rainfall data can help Scientists, Meteorologists, Weather and Farmers to make informed decisions related to Water Management, Crop Planning and Disaster Management. Furthermore, it can help Researchers to study the impact of climate change on rainfall patterns and its consequences on the country's environment and economy state. In this research paper we explored rainfall data of India for the last 121 years and its variation throughout the decades. Using statistical technique, the trends and patterns over the years were analyzed and studied. Several studies have been conducted on Rainfall data Analysis in India using various statistical techniques like Trend Analysis, Seasonal Analysis and Frequency Analysis. These studies have provided valuable insights into the variability and trends of rainfall patterns in different regions of the country. However, there is still a need for further research to improve our understanding of the complex relationship between climate and rainfall in India. In this study, we focused on this complexity of rainfall variation in the country as a whole. The rainfall variation in India is much complex that it cannot be predicted exactly as we proclaim. Even though studies have been made on the depending factors, these patterns and trends varies even with the slightest influence of an external factor. The study focusing on the analysis of the rainfall data, will examine the impact of climatic change on the country's rainfall patterns. The findings of this research can contribute to the development of strategies for multipurpose of the rainfall dependent strategies and sectors such as water management and disaster management, and other related domains in the country. Assessing the overall distribution of rainfall, locate areas with high and low rainfall rates, and look into seasonal fluctuations and looking into long-term rainfall trends spanning over ten number of decades to analyze the trend of rainfall, whether it is increasing or decreasing, and going through significant changes. Rainfall is the chief source of water source in the Indian subcontinent. It is aiding a number of main as well as minor sectors in the country. One of the main importance of Rainfall Analysis is the role it plays for agriculture. It determines crop yields, affect food security and influences rural livelihoods. In Water Resource Management, rainfall patterns influence water availability for drinking, irrigation and hydroelectric power generation. Another aspect is climate change assessment; Studying the long-term rainfall trends helps in understanding climate variability in order to identify potential climate change impacts, and to develop adaptation strategies. Annual and Seasonal Rainfall Trend study includes the analysis of annual Rainfall patterns over the past century including inter-annual variations and long-term Trends. This includes studying seasonal rainfall patterns, particularly the impact of South-West Monsoon and the North-East Monsoon. This can help in the identification of Drought and Flood prone regions based on historical rainfall data. Extreme Rainfall Events are also studied which includes analysis of extreme rainfall events, including heavy precipitation, cyclonic disturbances, their frequency and intensity over the century that can help in the evaluation of the socio-economic and environmental impacts of

extreme rainfall such as floods, landslides and infrastructure damage. Analyzing rainfall data from the last 121 years provides crucial insight into India's historical precipitation patterns, regional variations, extreme events and potential climatic change impacts. This comprehensive analysis is vital for Scientists, researchers and stakeholders to develop effective strategies for sustainable water management, agricultural planning, disaster preparedness

II. LITERATURE REVIEW

The rainfall trends and patterns over the Indian subcontinent are diverse and influenced by various factors, including the monsoon system, regional geography, and climate variability. Conducting detailed research in this field is essential for ensuring the long-term well-being and prosperity of India's population and its upcoming days. Several studies have been done on trend and pattern analysis of rainfall in different climatic regions of India and some of them are summarized below.

The researchers in [1] examined the short-term and long-term fluctuations in seasonal rainfall and also variation of temperature in 3 districts of Odisha namely Kalahandi, Bolangir and Koraput. In this study, statistical analysis was done on the rainfall and temperature values for the years 1980 to 2017. Sen's slope estimator and the Mann-Kendall test were used to analyze the trend and variations of rainfall. The annual highest and lowest temperatures have been seen to trend upward during the past 37 years of monitoring, whereas the maximum and minimum temperatures during the rainy season have been seen to trend downward. For the time period under observation, more statistically significant trends in rainfall have been found (99% confidence interval). For the monsoon period, the trend analysis reveals an upward trend with a Sen's slope of 4.034. While the minimum temperature shown a cooling tendency (Sen's slope value, 0.006), the maximum temperature had a moderate warming or increasing trend (Sen's slope value, 0.29). The trend analysis of the minimum temperature is not statistically significant, even though the highest temperature is at 95% confidence level. Another investigation [2] separated India into four sub-divisions (northwest, northeast, west-central, central northeast, and peninsular India) and examined rainfall data by correlating rainfall and the Southern Oscillation Index (SOI) for three different time periods: 1949 to 1965, 1966 to 1990, and 1991 to 2016. This study included regime shift analysis and statistical analysis of rainfall data. The investigation for the years 1949–2016 revealed a very large downward trend from July to October. For the time periods 1949–1965 and 1966–1990, the monsoon months, from June to September, had a high positive link with SOI, which slowly decreased from 1991–2016. Similar substantial positive correlations between the SOI and rainfall during the months of October and December were seen between 1949 and 1965. The authors stressed the value of these analyses and findings for hydrologists, decision-makers, planners, agriculturists, and other specialists in order to regulate water resources as effectively as possible.

In order to calculate the normal rainfall, rainfall deficiency, rainfall surplus, and seasonal rainfall, the authors in [3] examined the daily rainfall data of a few chosen circle headquarters for a period of 30 years. In order to examine the variability of rainfall, the monthly and yearly rainfall data were used to produce statistical variables such as mean, standard deviation, and coefficient of variation. The outcome demonstrated that the research period's rainfall pattern was unpredictable. The probability distribution with the best match

was chosen based on the smallest difference between the actual and predicted values. These studies support other aspects of farm management, such as planning irrigation and preparing the ground for planting and agriculture. Planners of water resources, farmers, and urban engineers can utilize this information to evaluate the availability of water and implement water-saving measures. Another research [4] evaluated the accuracy of several rainfall disaggregation algorithms using hourly rainfall depths. The modeling of watershed, stream, and water quality systems is aided by the hourly rainfall. Due to the low density of stations collecting hourly precipitation data, this study relied on the disaggregation of daily rainfall values or the transfer of data from adjacent stations. In this study, four distinct approaches for estimating the depths of hourly precipitation were examined for accuracy. The biases and accuracy of methods for converting observed daily depths into hourly amounts or transferring rainfall data for neighboring gauges were assessed using the hourly rainfall records from 74 gauges situated within or close to the Chesapeake Bay watershed. The study found that none of the four techniques could reliably forecast hourly rainfall, and that transferring hourly rainfall readings from neighboring gauges or breaking down daily total rainfall made it impossible to obtain correct estimates of hourly rainfall intensities.

The researchers in [5] analyzed the rainfall pattern in the Rangareddy district. Various climatic parameters such as monsoon rainfall, maximum and minimum temperature, forest cover, wind speed and relative humidity were considered for this study. Multiple regression models were used for rainfall analysis. It was observed that the rainfall was increasing with time and attaining the district normal rainfall after the year 2005. The rainfall was estimated as 804 mm in the year 2005 and 926 mm in the year 2010. A trend analysis of yearly maximum, minimum and average temperature were studied with respect to the variation of rainfall amounts. It was observed that, the rainfall showed a decreasing trend with the increase in annual average temperature. The analysis of relative humidity for a period of 18 years showed increasing trend of rainfall with the increase in annual humidity. Similarly, an analysis of annual wind velocity with rainfall was studied for period of 18 years and it was observed that the rainfall was increasing with increase in wind velocity.

In a different research by [7], the atmospheric downscaling approach and artificial neural networks were used to forecast rainfall. The goal of the study was to use large-scale measurements of wind speed and precipitable water to estimate the average 12-hour rainfall in the Chikugo River basin, Kyushu Island, Southern Japan. The investigation revealed that pairing two neural networks in series might significantly enhance intermittency reproduction. Additionally, a long data series was needed to induce variability, and categorizing intensity may enhance probabilistic forecasting. According to the survey, the region performed better overall in the winter and spring than it did in the summer and fall. [10] used the Mann-Kendall test, trend-free pre-whitening Mann-Kendall, modified Mann-Kendall (MMK), and innovative trend analysis (ITA) to examine the seasonal as well as yearly rainfall variability and trends in the seven states of North East India from 1901 to 2020. The data showed that the annual and seasonal rainfall varied across all seven of these states. Even though the results were generally consistent, considerable variations were found in the rainfall patterns in Assam and Meghalaya following the monsoon, in Arunachal Pradesh before the monsoon, in Mizoram before the monsoon, in Tripura during the winter, and in Tripura during the monsoon. In comparison to the other three approaches, the MMK test was shown to be able to predict changes in rainfall distribution over seasons to a considerable extent at varied significance levels.

The rainfall data for a period of 29 years (1967-1995) of Agro-meteorological Observatory, Jabalpur, was analyzed by [11] at weekly, monthly, seasonal and annual basis to cater to the rainfall-based cropping system with a minimum risk to efficiently utilize the available rainfall for increased production. The average annual rainfall was estimated as 1369 mm. The *Kharif*, *Rabi* and summer seasons received 1229.32 mm, 110.86 mm and 28.8-mm rainfall, respectively. The highest rainfall was recorded in the August month (495.08 mm) while April received the lowest amount of rainfall (3.68 mm). It was observed that about 89 per cent of total annual rainfall was received between 23rd and 39th standard meteorological weeks. The normal distribution was used for predicting the weekly rainfall probabilities of receiving at least 10, 20, 30 and 40 mm of rainfall. In a similar study, [14], the rainfall trends and patterns at monthly, seasonal and annual timescale were analyzed in India using monthly rainfall data for a period of 135 years (1871–2005) for 30 sub-divisions. As per the study, about 50% of the sub-divisions showed an increasing trend in annual rainfall, but a more statistically significant trend was observed only in Haryana, Punjab and Coastal Karnataka. Similarly, only one sub-division (Chhattisgarh) indicated a significant decreasing trend out of the 15 sub-divisions. The study also indicated that during June and July, the number of sub-divisions with increasing rainfall was almost equal to those showing decreasing rainfall. The study also showed that in the entire country, no significant trend was detected in the annual, seasonal, or monthly rainfall.

The authors in [15] tried to establish a relationship between the dates of onset of monsoon rainfall and the earliest sowing week at Chandigarh. In this study, an attempt was also made to correlate the amount of monsoon rainfall i.e., rainfall in July, August and September months. It was concluded from the analysis that date of onset of monsoon rainfall highly influenced the July rainfall and the total seasonal rainfall only. It was also observed that the monthly rainfall of August and September were independent of the incidence of onset of monsoon rainfall at Chandigarh.

Many researchers also analyzed rainfall data to characterize the drought events and water scarcity conditions in various parts of India. The authors in [6] analyzed the rainfall data in order to give an early warning system for the drought on real-time multi reservoir operations. An early warning system was developed by the researchers and proposed for drought management during the real-time reservoir operation. The system was composed of 3 main elements viz. drought vigilance, water consumption measures, and policy making. A new drought index was used in this study for characterization of drought severity. The drought warning procedures were effectively applied to two parallel reservoir regions in northern Taiwan for demonstration. In another study, the spatio-temporal variation of drought episodes was carried in Portugal by [8] using the Standardized Precipitation Index at multiple time scales (1, 6 and 12 consecutive months and 6 months from April to September and 12 months from October to September) using the principal component analysis and cluster analysis. In this way, 3 different and spatially well-defined regions were identified with different temporal variation of droughts namely north, central and south regions of Portugal.

To evaluate the severity of a drought in a region, several researchers combined multiscale rainfall data and satellite remote sensing methods. Based on the Standardized Precipitation Index (SPI) and vegetative condition index (VCI), the authors of [13] examined the spatiotemporal variation of drought episodes in the northern highlands of Ethiopia. According to the results analysis, the research area's eastern and southern zones have

experienced periodic cycles of drought over the past few decades. Additionally, a delay in time between the peak VCI value and the precipitation values acquired from the meteorological stations located across the research region was noted. The VCI values and the precipitation for the previous two months and the current month showed a strong correlation. In different research, [9] computed the SPI and four other Palmer's indices, the PDSI, WPLM, PHDI, and Palmer moisture anomaly Z-index, and compared them to a drought index generated from water balance for the purpose of assessing hydrological droughts in 14 sub-watersheds of the Pinios river basin. The findings demonstrated that the water balance-derived drought index, which can measure drought severity and duration in all sub-watersheds, is a good indicator of hydrological drought. In risk and decision analysis at the study region, SPI at 3- and 6-month timeframes, the WPLM, and the drought index generated from the water balance may all be employed. In a related work, the researchers in [12] used the Standardized Precipitation Index (SPI) and GIS-based interpolation approaches to evaluate variations in temporal and spatial drought trends in the Tel River basin of India.

The above study interprets that while the monsoon season accounts for the majority of India's yearly rainfall, a more thorough investigation of the seasonal distribution of precipitation and intra-seasonal variability is required. Understanding the distribution of rainfall during the monsoon season as well as the occurrence of dry spells or wet spells would aid in managing water resources and agricultural planning.

III. STUDY AREA AND METHODOLOGY

1. Study Area: India is the seventh-largest country in the world, with a total area of 3,287,263 square kilometers. India is located between 8°4' north and 37°6' north latitude and 68°7' east to 97°25' east longitude, north of the equator. Rainfall in India exhibits drastic variation both spatially and temporally. The country's diverse topography, influenced by factors such as monsoons, oceanic currents, and regional climate systems, contributes to this variability. Understanding the patterns and trends of rainfall is crucial for so many sectors especially agricultural planning, water resource management, and disaster preparing. India experiences two major monsoon seasons: the Southwest Monsoon (June-September) and the Northeast Monsoon (October-December). The Southwest Monsoon, also known as the summer monsoon, is the primary source of rainfall for most parts of the country. It accounts for around 75-90% of the annual rainfall and it is critical for agricultural activities. The monsoon's onset, withdrawal, and spatial distribution significantly impact crop yields and water availability.

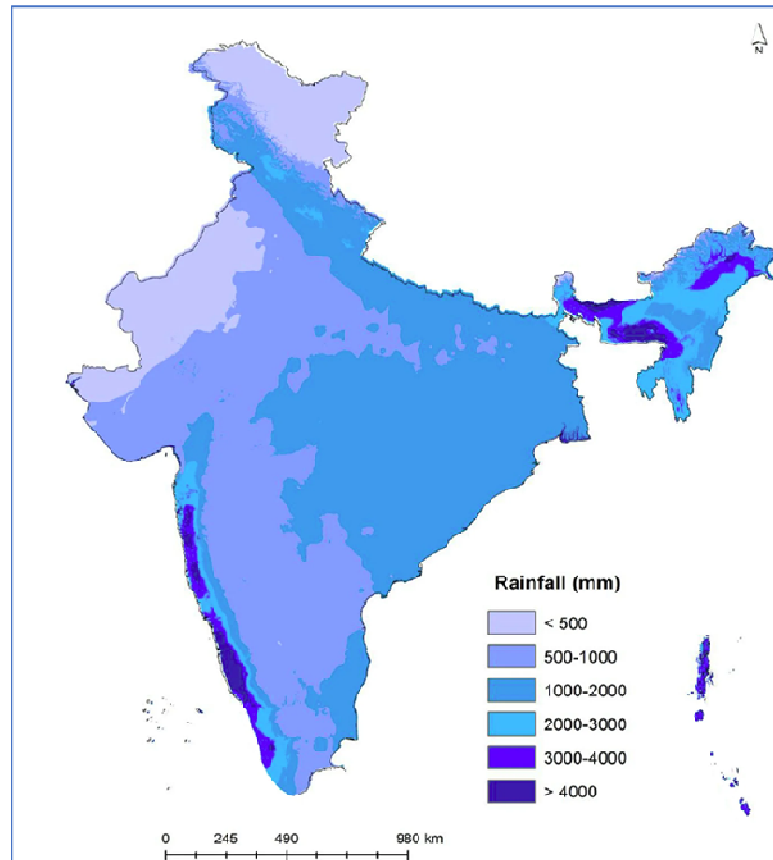


Figure 1: Annual Rainfall Distribution in India(Source: https://th.bing.com/th/id/OIP.p_ReK-K_SbqdpuXVrGLnrAHaIo?pid=ImgDet&rs=1)

Spatially, Rainfall patterns vary across different regions of India. The Western Ghats and northeastern states receive heavy rainfall due to orographic effects and proximity to moisture-laden winds. The coastal areas, including the Western Coast and the Bay of Bengal region, also experience substantial rainfall. In contrast, arid and semi-arid regions such as Rajasthan and parts of Gujarat receive minimal precipitation. At several scales, temporal variation in rainfall is seen. The term "inter-annual variability" describes changes in rainfall totals from one year to the next. The El Nio and La Nia, which are two climate events, have an impact on this variability. Over India, these two occurrences are typically accompanied by decreased rainfall and increased precipitation, respectively. These climatic patterns influence the frequency of droughts and floods in various regions of the nation.

- 2. Methodology:** The monthly rainfall data for a period of 121 years (1901-2021) was collected from the India Meteorological Department in this study. The collected rainfall data was preprocessed to take care of missing data, outliers, and irregularities. Further, a basic statistical analysis was carried out as it gives insights into the average rainfall, variability, trends, and statistical properties of rainfall patterns. These parameters form the foundation for analyzing and understanding the behavior of rainfall, enabling informed decision-making and planning in various sectors impacted by precipitation. The wet and dry years were calculated using the Standardized Precipitation Index (SPI) for the yearly

and monthly rainfall data. The SPI was calculated using the equation 1 and the dry and wet years were categorized using table 1.

$$SPI = (X - \bar{X}) / \sigma \dots\dots\dots(1)$$

Where,

X is the observed precipitation value for the month

\bar{X} is the long-term average (mean) of the precipitation data for that month

σ is the standard deviation of the precipitation data for that month

Table 1: Drought categories using SPI

SPI values	Drought Category
0 to – 0.99	Mild drought
-1.00 to - 1.49	Moderate drought
-1.50 to - 1.99	Severe drought
-2.0 or more	Extreme drought

Figure 2 shows the detailed methodology adopted in this study.

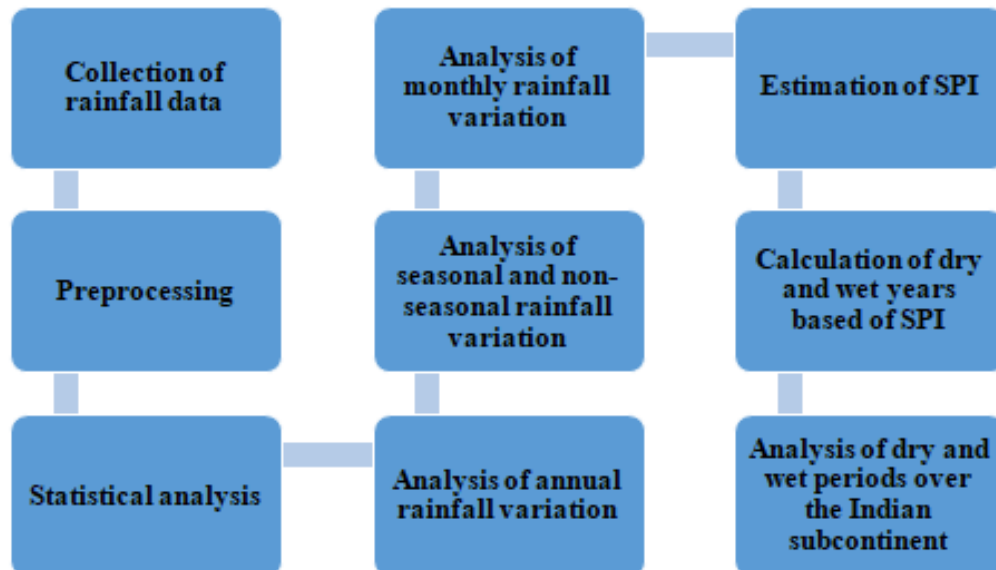


Figure 2: Methodology Flow Chart

IV. RESULTS AND DISCUSSION

1. Annual and Seasonal Rainfall Analysis: The monthly data for a period of 121 years was analyzed and it was observed that the highest rainfall was occurred in the year 1917 i.e. 1344.5 cm and the lowest rainfall was observed in the year 1918 i.e. 856.5 cm as mentioned in figure 3. A huge temporal variation was observed in the rainfall in every decade. As India is an agriculture dependent country and depends on rainfed agriculture, hence a more detailed analysis of seasonal and non-seasonal rainfall was carried out to have a clear idea about the contribution of monsoon rainfall (figure 4). In the histogram, the black bars represent monsoon rainfall and the red bars represent non-monsoon rainfall. It was observed that around 70-80% of rainfall is received during June-September leading to water scarcity and drought conditions during non-monsoon season and waterlogging or flood conditions during monsoon season. By plotting monsoon seasons separately, it becomes possible to assess the strength and timing of the monsoon. Analyzing the onset, duration, and withdrawal of the monsoon season provides insights into the temporal distribution and overall performance of the monsoon rainfall. This information is crucial for agriculture, water resource planning, and climate change studies.

The distribution of rainfall within the monsoon season is not uniform and there are variations in the timing, intensity, and duration of rainfall between different months. By examining the rainfall variation during monsoon months i.e., June, July, August, and September separately, it becomes possible to identify any shifts, anomalies, or trends in the seasonal distribution of rainfall. Each month within the monsoon season has specific implications for different crops. Say, June is crucial for the sowing of major kharif crops, while August and September are important for crop maturation and harvesting. Analyzing the monsoon rainfall variation of these months helps assess the adequacy of rainfall for each critical agricultural period. Researchers gain insights into the temporal and spatial dynamics of the monsoon season in India. It helps in understanding the seasonality, regional differences, agricultural implications, water resource management, and climate change impacts associated with the monsoon rainfall. The study depicted a wide variation in rainfall in the monsoon months over the period under observation, figure 5.

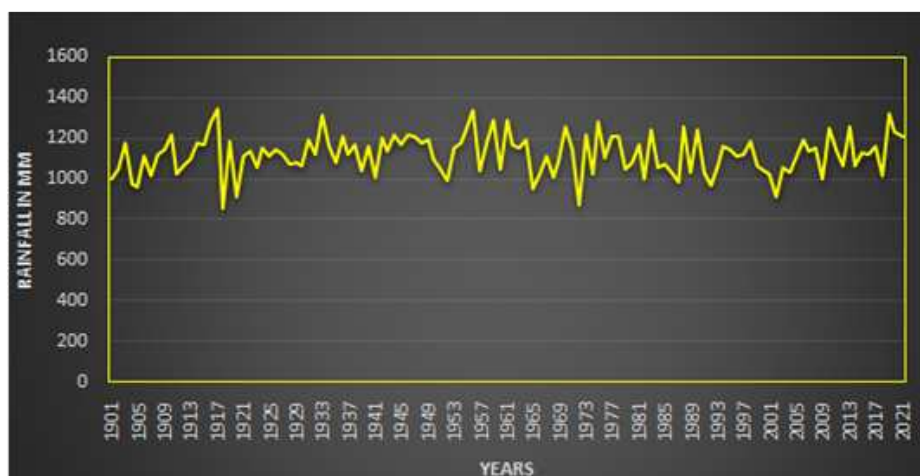


Figure 3: Annual variation of rainfall in India (1901-2021)

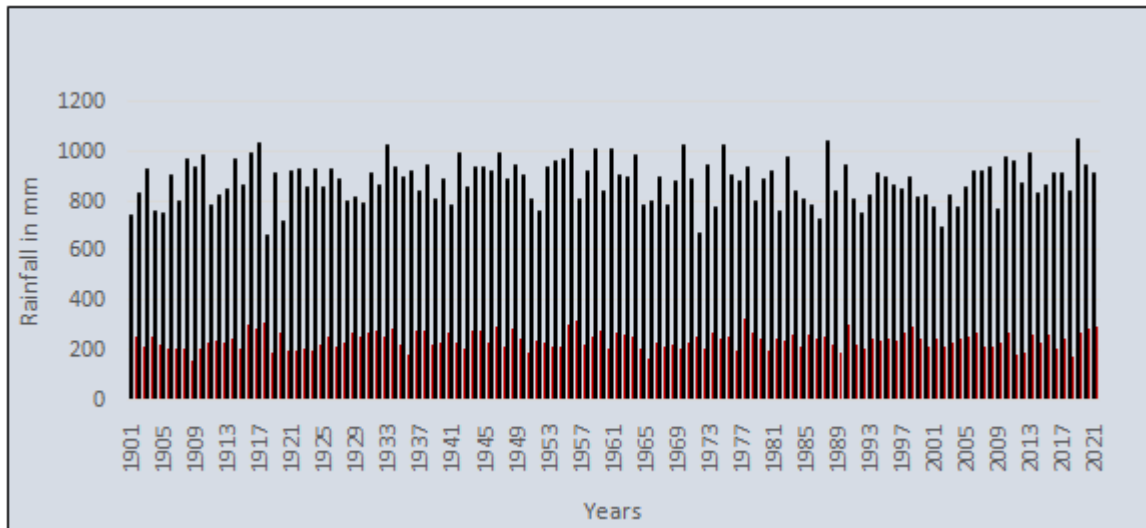


Figure 4: Seasonal and Non-Seasonal variation of rainfall in India (1901-2021)

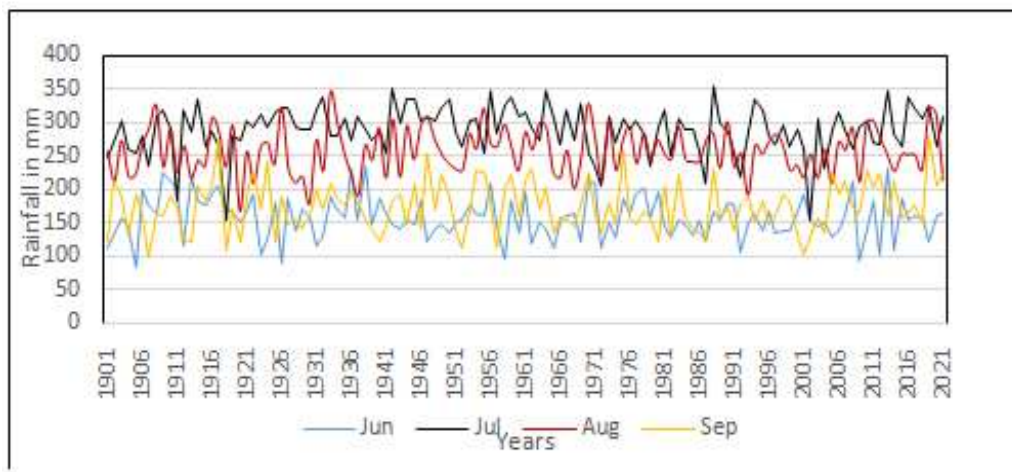


Figure 5: Variation of rainfall in monsoon months in India (1901-2021)

2. Analysis of Dry and Wet Years: As mentioned in the methodology section, the SPI was estimated to categorize the dry and wet years. The yearly SPI analysis revealed that 61 years were wet where the rainfall was more than the normal rainfall out of which 17 years were very wet leading to flood like situations. Similarly, mild drought conditions were observed for almost 41 years and severe to extreme drought conditions were observed for 7 years for the period under observation as mentioned in table 2. This information is vital for planning and allocation of water for various purposes such as agriculture, drinking water supply, industry, and ecosystems.

Table 2: Annual variation of SPI values

SPI Category	No. of years
0 to -0.99	41
-1to-1.45	11
-1.5 to -1.99	3
above -2	4
0 to 1	44
1 to 2	17

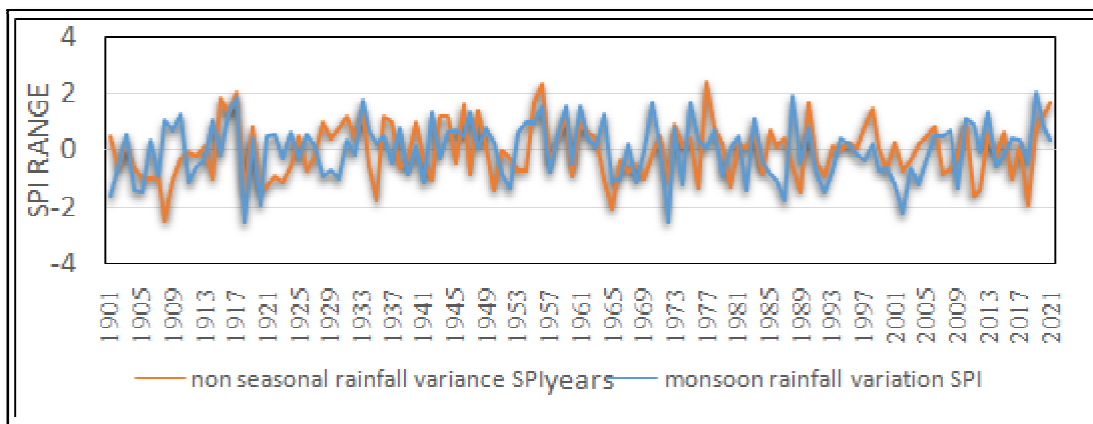


Figure 6: Variation of SPI values in monsoon season and non-monsoon season.

A more detailed analysis of dry and wet months in the monsoon season was done in order to have an idea regarding the availability of rainfall during the monsoon months for crop planning and irrigation scheduling. The variation of SPI in monsoon and non-monsoon season is shown in figure 6. More extreme droughts were experienced by the country during the non-monsoon season. It was observed that around 54% of the 121 June months were dry months while rest months were wet showing the availability of water for crops as mentioned in Table 3. Similarly, around 42% of the July months were found dry, (table 4) with different intensity of water scarcity which is not at all good for crop planning as plants need more water during the early growth stages than the late growth stages. The analysis of SPI in August months indicated that around 42 years were dry with mild water scarcity and 51% of the total August months had shown water scarcity, whereas around 49% of the years showed wet conditions as per table 5. No extreme drought was observed in any September month for the entire period under observation. However, mild to severe drought was observed in September for 55% of the years under the observation period as shown in table 6. The monthly SPI analysis enables the vulnerable regions to develop early warning systems, emergency response plans, and infrastructure designs that account for potential flooding, landslides, or water scarcity.

Table 3: Variation of SPI values in June month (1901-2021)

SPI Value Category	No. of years
0 to -0.99	46
-1to-1.45	11
-1.5 to -1.99	6
above -2	2
0 to 1	34
1 to 2	21

Table 4: Variation of SPI values in July month (1901-2021)

SPI Value Category	No. of years
0 to -0.99	40
-1to-1.45	4
-1.5 to -1.99	3
above -2	5
0 to 1	52
1 to 2	16

Table 5: Variation of SPI values in August month (1901-2021)

SPI Value Category	No. of years
0 to -0.99	42
-1to-1.45	15
-1.5 to -1.99	3
above -2	2
0 to 1	38
1 to 2	20

Table 6: Variation of SPI values in September month (1901-2021)

SPI Value Category	No. of years
0 to -0.99	45
-1to-1.45	16
-1.5 to -1.99	5
above -2	0
0 to 1	34
1 to 2	20

V. CONCLUSION

This study was aimed at analyzing the rainfall patterns and trends all over the Indian sub-continent and the study revealed significant insights into the complex dynamics of

precipitation across the country. The annual rainfall of 121 years was analyzed and it was observed that the maximum amount of rainfall was occurred in the year 1917 and the least rainfall was observed in the year 1918 for the entire period under observation. It was also observed that around 70 to 80% of rainfall is received during monsoon season (June-September) leading to water scarcity and drought conditions during non-monsoon season and waterlogging or flood conditions during monsoon season. By examining the rainfall variation during monsoon months i.e., June, July, August, and September separately, it was observed that there are variations in the timing, intensity, and duration of rainfall between different months. The yearly SPI analysis revealed that 61 years were wet where the rainfall was more than the normal rainfall out of which 17 years were very wet leading to flood like situations. A more detailed analysis of dry and wet months in the monsoon season was done in order to have an idea regarding the availability of rainfall during the monsoon months for crop planning and irrigation scheduling. All the monsoon months witnessed water scarcity conditions in 50%-60% of the total 121 years' time period. Analysis of station wise daily rainfall data would improve the accuracy of the study and will be benefited for the farmers.

REFERENCES

- [1] A. Panda, N. Sahu, "Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir and Koraput districts of Odisha, India," *Atmos Sci Lett.*;20:e932. <https://doi.org/10.1002/asl.93210> of 10PANDAANDSAHU, 2019.
- [2] G. Akhoury, K. Avishek, "Statistical analysis of Indian rainfall and its relationship with the Southern Oscillation Index," *Arab J Geosci*, vol. 12, 255, 2019. <https://doi.org/10.1007/s12517-019-4415-z>.
- [3] G Arvind, P Ashok Kumar, S Girish Karthi and C R Suribabu, "Statistical Analysis of 30 Years Rainfall Data: A Case Study," *IOP Conf. Series: Earth and Environmental Science* 80 (2017) 012067 doi :10.1088/1755-1315/80/1/012067.
- [4] methods," *Journal of Hydrologic Engineering*, vol. 9, (2), pp. 71-78, 2004.
- [5] G. K. Viswanadh, M. Vidyadhar, M. V. S. S. Giridhar, "Rainfall analysis in Rangareddy district," *Proceedings of International Conference on Advanced Modelling Technique for Sustainable Management of Water Resources*, pp 35-40, Jan 2004.
- [6] H., Wen-Cheng, Y. Lun-Chin, "A drought early warning system on real-time multi reservoir operations," *Water Resources Research*, vol. 40, 1, pp. 1-13, 2004.
- [7] J. Olsson, C. B. Uvo, K. Jinno, A. Kawamura, K. Nishiyama, N. Koreeda, T. Nakashima, O. Morita, "Neural network for rainfall forecasting by atmospheric downscaling," *Journal of Hydrologic Engineering*, vol. 9, (1), pp. 1-12, 2004.
- [8] J. F. Santos, I. P. Calvo, M. M. Portela, "Spatial and temporal variability of droughts in Portugal," *Water Resources Research*, vol. 46, W03503, 13, 2010, doi:10.1029/2009WR008071
- [9] L. Vasiliades, A. Loukas, N. Liberis, "A Water Balance Derived Drought Index for Pinios River Basin, Greece," *Water Resour. Manage*, vol. 25, pp. 1087-1101, 2011.
- [10] S. L. Bora, K. Bhuyan, Pa. Jyoti Hazarika, J. Gogoi, K. Goswami, 2022, "Analysis of rainfall trend using non-parametric methods and innovative trend analysis during 1901-2020 in seven states of North East India," *Current Science*, vol. 122, no. 7, April 2022.
- [11] S. K. Srivastava, A.P. Upadhyay, A.K. Sahu, A.K. Dubey, "Rainfall characteristics and rainfall-based cropping strategy for Jabalpur region," *Journal of Soil Conservation*, vol. 28, (3), pp. 204-211, 2000.
- [12] Mishra, and R. Nagarajan, "Spatio-temporal drought assessment in Tel river basin using Standardized Precipitation Index (SPI) and GIS," *Geomatics, Natural Hazards and Risk*, vol. 2(1), pp.79 - 93. 2011.
- [13] T. Gebrehiwot, A. V. Veen, B. Maathuis, "Spatial and Temporal assessment of drought in Northern highlands of Ethiopia," *International [1] journal of applied earth observation and geoinformatics*, vol.13, pp. 209-221. 2011.
- [14] V. Kumar, S. K. Jain, Y. Singh, "Analysis of long-term rainfall trends in India," *Hydrol. Sci.* vol. 55(4), pp. 484-496, 2010.
- [15] Y. Agnihotri, and R. Murti, "Relationship between onset of monsoon with sowing weeks and monthly seasonal rainfall at Chandigarh," *Journal of Indian Water Resources Society*, vol.21, (2), pp. 60-64, 2001.