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Precipitation Trend Analysis of Highland, India

Anila Arelt, Shivakumar J Nyamathi

Abstract: ***Highland regions often rely heavily on agriculture for livelihoods. Rainfall (including snowfall) trends can directly impact crop yields and agricultural productivity. Monitoring rainfall trends aid in assessing the impacts of climate change on biodiversity, habitat suitability, and ecosystem services. Highland regions are particularly vulnerable to climate change impacts. Analyzing long-term rainfall trends provides valuable insights into climate change patterns and helps in formulating adaptation strategies to cope with changing environmental conditions. This study is based on the long-term rainfall analysis using a novel method called the 5-year lag method. The analysis has been carried out annually and the four seasons- January and February (winter/cold weather season), March, April, and May (Pre-monsoon/summer/hot weather/thunderstorm season), June, July, August and September (South-west monsoon/summer monsoon season), October, November and December (Post-monsoon/north-east monsoon/retreating south-west monsoon season).***

Keywords: ***5-Year Lag Method, Annual Rainfall Analysis, Seasonal Rainfall Analysis.***

I. INTRODUCTION

India is an agricultural country and farmers depend on timely rainfall for the cultivation of crops. But recent years have witnessed certain extreme rainfall events which have created havoc in the country claiming the life and property of the people of India. The trend of extreme rainfall events was not common about one and half a decade ago. In the year 2005, Maharashtra witnessed heavy rainfall, in 2013 Uttarakhand, in 2015 Gujarat and Tamil Nadu, 2016 Assam, 2017 Nepal and adjoining states - the northern portion of the country, including Assam, West Bengal, Bihar, Rajasthan and Uttar Pradesh, 2018 Kerala and 2019 – Kerala, Madhya Pradesh, Karnataka, Maharashtra, and Gujarat were the most severely affected. Consolidation of analysis of trends of rainfall has indicated that rainfall shows a decreasing trend in the annual rainfall, but the frequency of extreme rainfall has been increasing in the past few decades, in most of the studies [1-21][25][26][27][28][29], with few exceptions where there is an increase in average annual rainfall [22]. Few studies also show that there is no trend in the annual rainfall [23-24].

The term "Highlands of India" typically refers to the mountainous regions of the country, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, and Arunachal Pradesh. This mountain range is home to some of the world's highest peaks, including Mount Everest and Kanchenjunga. The highlands of India play a crucial role in the country's rainfall patterns, influencing the climate and ecosystems across different regions. The heavy rainfall received in these highland regions supports diverse flora and fauna, contributes to the water resources, and shapes the agricultural practices in surrounding areas. Hence, in this study, an attempt has been made to study the rainfall trend in the historical data by the 5-year lag method for annual and seasonal rainfall.

II. MATERIALS AND METHODOLOGY

A. Study Area and Data used

The Indian Himalayan region covers a vast area from the western part of the country to the eastern border with Nepal and Bhutan. It extends from the state of Jammu and Kashmir in the west to the state of Arunachal Pradesh in the east. The climate in the Himalayan region varies with altitude, ranging from subtropical to alpine and tundra climates. The region experiences heavy rainfall during the monsoon season, which contributes to its lush forests and diverse ecosystems. The location map of the study area is shown in Fig. 1.

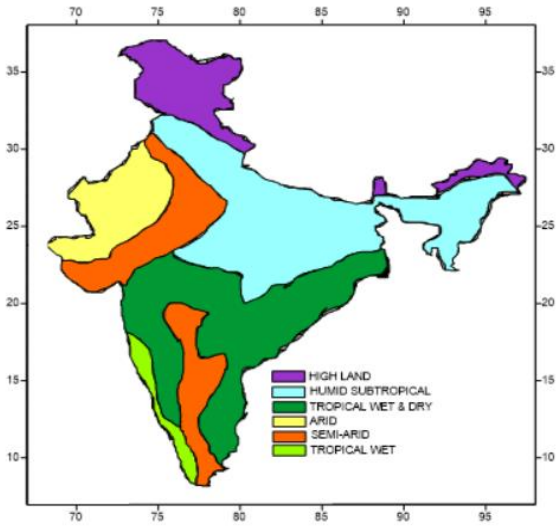

Fig. 1. Location of High Land in India (Koppen Classification)

The post-processed daily rainfall data for the years 1951 to 2017 (1-degree x 1-degree grid – approximately 111km x 111km) was collected from the India Metrological Department (IMD) for India (excludes Andaman and Nicobar Islands and Lakshadweep). The highland covers approximately 37 grids, which is about 455877 sq. km.

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B. Methodology

The post-processed daily rainfall data for the years 1951 to 2017 (67 years) of rainfall are classified into 8 groups with half a decade lag. The analysis of rainfall trends has been carried out both annually and seasonally.

For the annual rainfall analysis, the 67 years of rainfall data were made in 8 groups of about 35 years with a lag of 5 years. For each of these groups, the rainfall analysis was carried out. The groups are – 1951-1985, 1956-1990, 1961-1995, 1966-2000, 1971-2005, 1976-2005, 1981-2010, 1986-2015 and 1991-2017 (32 years). From the daily rainfall data, the maximum value of rainfall was extracted for each year for each location. Then from the maximum values of rainfall extracted for the years 1951 to 2017, maximum and minimum values of rainfall were sorted and analysed statistically. The methodology is shown in Fig. 2.

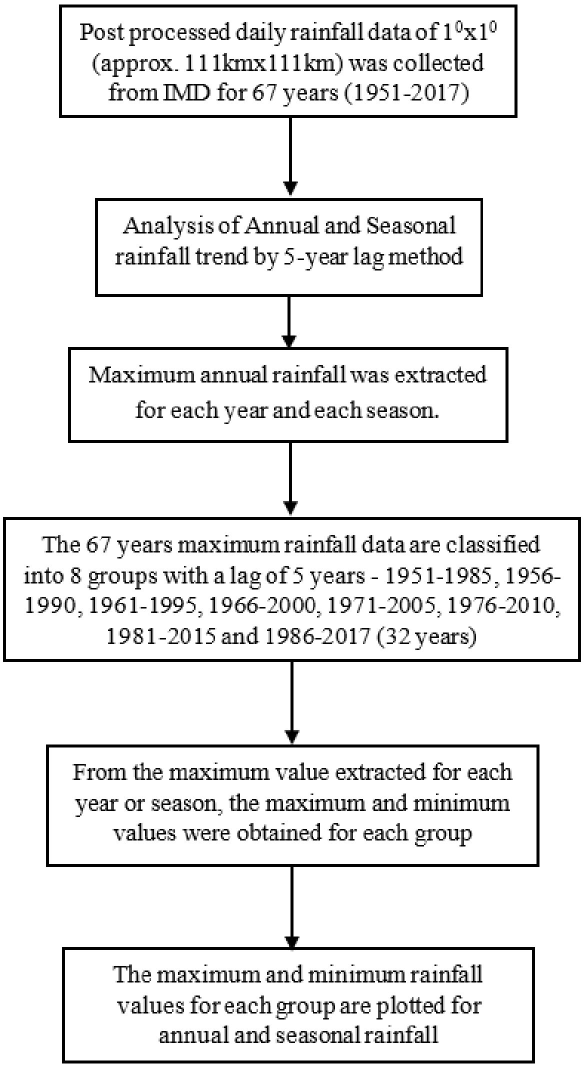

Fig. 2. Annual Rainfall Variability for Highland

For the seasonal rainfall analysis, the daily rainfall data are segregated into four seasons. As per IMD, the four seasons are classified as – January and February (winter/cold weather season), March, April, and May (Pre-monsoon/summer/hot weather/thunderstorm season), June, July, August, and September (South-west monsoon/summer monsoon season), October, November and December (Post-monsoon/north-east monsoon /retreating south-west monsoon season). Then for each of these seasons, the maximum rainfall was extracted for each year. The 67-year maximum seasonal rainfall data were made in 8 groups of about 35 years with a lag of 5 years. For each of these groups, the rainfall analysis was carried out. The groups are – 1951-1985, 1956-1990, 1961-1995, 1966-2000, 1971-2005, 1976-2005, 1981-2010, 1986-2015 and 1991-2017 (32 years). Then from the maximum seasonal values of rainfall extracted for the years 1951 to 2017, maximum and minimum rainfall values were further extracted and analysed statistically.

III. RESULTS

Rainfall analysis is a critical component for understanding and managing the hydrological cycles that influence ecosystems, agriculture, and water resource availability. By examining key statistical measures such as maximum, minimum, average, and standard deviation values, we gain valuable insights into the variability and distribution of precipitation over a specific period. These statistical parameters offer a comprehensive view of rainfall patterns, aiding in the assessment of climate trends, the identification of extreme weather events, and the development of effective water resource management strategies.

A. Annual Rainfall Analysis

The annual rainfall studies provide valuable insights into climate change trends and patterns. By analyzing historical rainfall data over decades or centuries, scientists can identify long-term climate trends, such as changes in precipitation patterns, shifts in rainfall seasons, and variations in extreme weather events. The rainfall trend in annual rainfall is as shown in Fig. 3 and further, the percentage variations of the maximum rainfall and standard deviations from the mean is also projected in Fig. 4.

The following outputs have been extracted from the graphs.

- Temporal Trends: The maximum rainfall values remain constant at 403.5 mm across all the years. The minimum rainfall values show slight variability but generally hover around 117.1 mm.
- Standard Deviation of Maximum Rainfall: There is a gradual decrease in the standard deviation of maximum rainfall from 84.6 mm in 1951-1985 to 106.1 mm in 1986-2017. This suggests a potential reduction in the variability of maximum rainfall over the years, indicating more consistent patterns.
- Mean of Maximum Rainfall: The mean of maximum rainfall shows some fluctuations, with values ranging from 209.03 mm in 1966-2000 to 231.82 mm in 1981-2015. There is an overall increasing trend in the mean of maximum rainfall, suggesting a potential long-term shift in average precipitation.
- Comparison between Years: The years 1976-2010 and 1981-2015 stand out with higher maximum rainfall values, higher means, and higher standard deviations compared to earlier periods.

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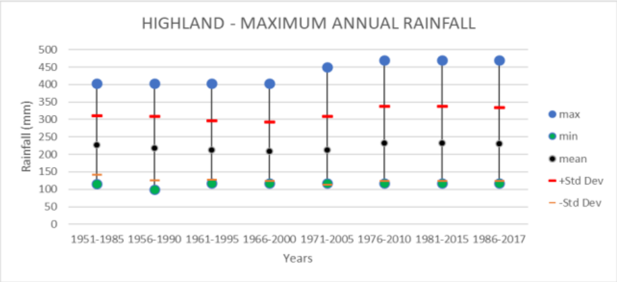

Fig. 3. Annual Rainfall variability for Highland

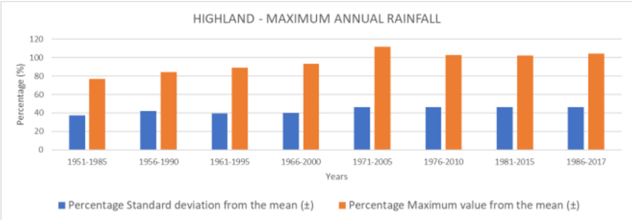

Fig. 4. Percentage Rainfall Variability of Maximum Rainfall and Standard Deviation from Mean Rainfall

B. Seasonal Rainfall Analysis

The seasonal rainfall studies help in agricultural forecasting and planning, flood risk assessment, water supply management, tourism, and recreation.

January and February (Winter/Cold Weather Season)

Rainfall patterns in the Highland region during winter vary depending on the specific location and elevation The rainfall trend in the cold weather season rainfall is shown in Fig. 5 and further, the percentage variations of the maximum rainfall and standard deviations from the mean are projected in Fig. 6.

- Temporal Trends: The maximum rainfall values show a consistent pattern, staying around 253.2 mm until 1961-1995. Afterward, there is a noticeable decrease to 155.6 mm, and this lower level is maintained in subsequent years. The minimum rainfall values show a consistent pattern, staying around 13.4 mm throughout the entire period.
- Standard Deviation of Maximum Rainfall: The standard deviation of maximum rainfall shows some fluctuations, ranging from approximately 30.74 mm to 45.82 mm. There is no clear trend in the standard deviation over the different periods.
- Mean of Maximum Rainfall: The mean of maximum rainfall shows a decreasing trend, from around 97.17 mm in 1951-1985 to approximately 92.88 mm in 1986-2017. This indicates a potential long-term shift towards lower average maximum rainfall.
- Comparison between Years: The years 1961-1995 and 1986-2017 stand out with lower maximum rainfall values and mean values compared to earlier periods.

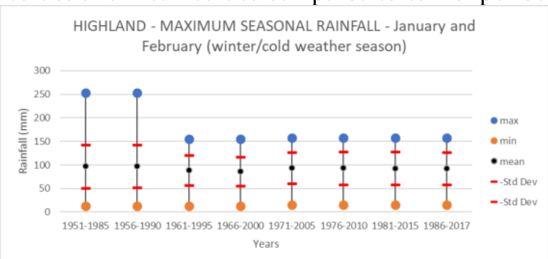

Fig. 5. Rainfall Variability in Cold Weather Season

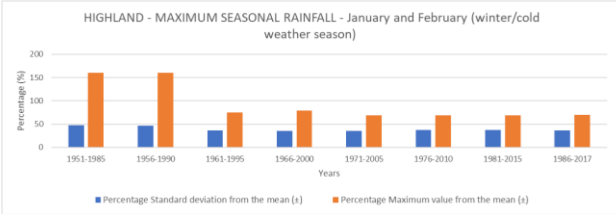

Fig. 6. Percentage Rainfall Variability of Maximum Rainfall and Standard Deviation from Mean Rainfall in Cold Weather Season

March, April, and May (Pre-monsoon/summer/Hot Weather/Thunderstorm Season)

In the Highland region, March, April, and May mark the transition from winter to spring and eventually into the pre-monsoon season with increasing temperatures and rainfall as the region moves from winter towards the summer monsoon season. The rainfall trend in the pre-monsoon, season rainfall is as shown in Fig. 7, and the percentage variations of the maximum rainfall and standard deviations from the mean are projected in Fig. 8.

- Temporal Trends: The maximum rainfall values show consistency until 1966-2000 when there is a significant increase to 284.6 mm, and this higher level is maintained in subsequent years. The minimum rainfall values show consistency, staying around 14.4 mm.
- Standard Deviation of Maximum Rainfall: The standard deviation of maximum rainfall shows fluctuations, ranging from approximately 39.10 mm to 47.24 mm. There is no clear trend in the standard deviation over the different time periods.
- Mean of Maximum Rainfall: The mean of maximum rainfall shows an increasing trend, from around 106.68 mm in 1951-1985 to approximately 115.13 mm in 1986-2017. This indicates a potential long-term shift towards higher average maximum rainfall.
- Comparison between Years: The years 1966-2000 and 1981-2015 stand out with higher maximum rainfall values compared to earlier periods.

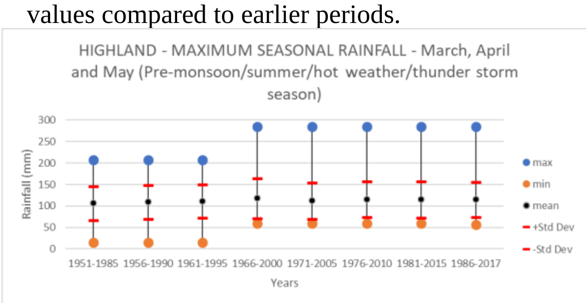

Fig. 7. Rainfall Variability in Pre-Monsoon Season

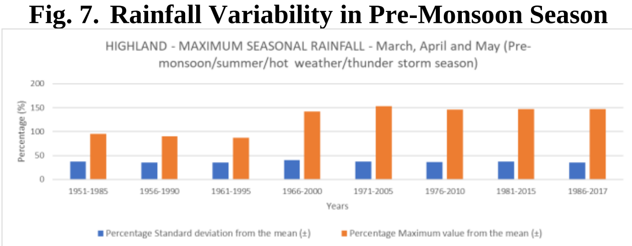

Fig. 8. Percentage Rainfall Variability of Maximum Rainfall and Standard Deviation from Mean Rainfall in Pre-Monsoon Season

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June, July, August, and September (South-West Monsoon/Summer Monsoon Season)

In the Highland region, June marks the onset of the monsoon season. July and August continue to see significant rainfall in the Himalayan region, although the intensity may gradually begin to taper off towards the end of the month and September marks the transition from the monsoon season to the summer-monsoon period. The rainfall trend in the summer-monsoon, season rainfall is as shown in Fig. 9, and the percentage variations of the maximum rainfall and standard deviations from the mean are projected in Fig. 10.

- Temporal Trends: The maximum rainfall values show consistency from 1951-1985 to 1961-1995, with a slight increase in later periods. The minimum rainfall values show some variation but generally remain above 75 mm.
- Standard Deviation of Maximum Rainfall: The standard deviation of maximum rainfall shows fluctuations, ranging from approximately 82.05 mm to 108.23 mm. There is some variability in the standard deviation over the different time periods.
- Mean of Maximum Rainfall: The mean of maximum rainfall shows a fluctuating pattern, ranging from around 198.24 mm in 1956-1990 to approximately 229.57 mm in 1976-2010. This indicates some variability but doesn't exhibit a clear increasing or decreasing trend over the different time periods.

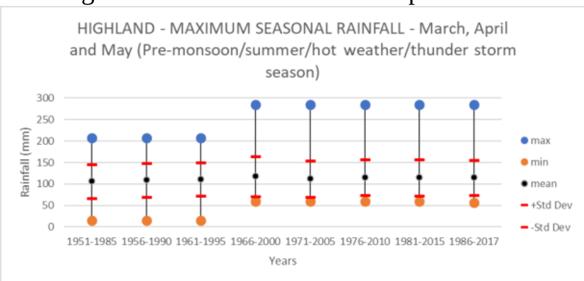

Fig. 9. Rainfall Variability in Pre-Monsoon Season

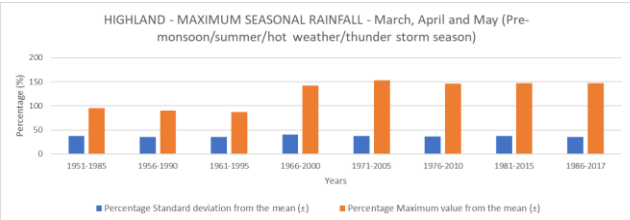

Fig. 10. Percentage Rainfall Variability of Maximum Rainfall and Standard Deviation from Mean Rainfall in Pre-Monsoon Season

- Comparison between Years: The years 1976-2010 stand out with higher maximum rainfall values compared to other periods. The standard deviation is particularly high in 1976-2010, indicating greater variability.

October, November, and December (Post-monsoon/ north-east monsoon/retreating south-west monsoon season)

In the Highland region, October, November, and December mark the transition from the pre-monsoon season to the post-monsoon season. The rainfall trend in the summer-monsoon, season rainfall is as shown in Fig. 11, and the percentage variations of the maximum rainfall and standard deviations from the mean are projected in Fig. 12.

- Temporal Trends: The maximum rainfall values show some variability over the years, with a peak in 1951-1985. The minimum rainfall values show a general decreasing trend over the years.
- Standard Deviation of Maximum Rainfall: The standard deviation of maximum rainfall displays fluctuations, with a peak in 1956-1990 and a relatively lower value in 1986-2017. There is some variability in the standard deviation over different time periods.
- Mean of Maximum Rainfall: The mean of maximum rainfall shows a decreasing trend over the years, with the lowest value in 1986-2017. This indicates a decline in the average maximum rainfall over these periods.
- Comparison between Years: The years 1951-1985 and 1956-1990 stand out with higher maximum rainfall values, while 1986-2017 has the lowest mean maximum rainfall.

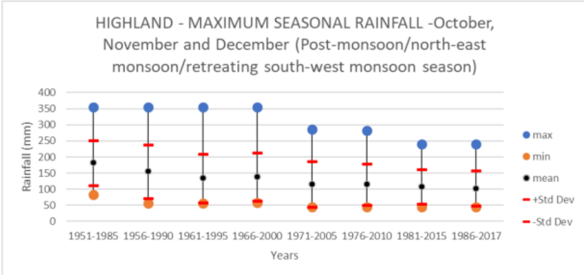

Fig. 11. Rainfall Variability in Post-Monsoon Season.

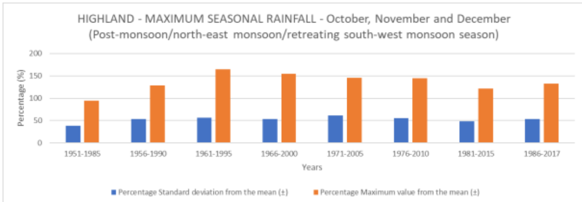

Fig. 12. Percentage Rainfall Variability of Maximum Rainfall and Standard Deviation from Mean Rainfall in Pre-Monsoon Season

IV. DISCUSSIONS

The Annual rainfall analysis of temporal trends in rainfall data reveals several significant findings. Firstly, the maximum rainfall values remain constant at 403.5 mm across all the years examined, indicating a consistent upper limit in precipitation. Conversely, while the minimum rainfall values exhibit slight variability, they generally hover around 117.1 mm, suggesting relative stability in lower precipitation thresholds. Furthermore, there is a noticeable decrease in the standard deviation of maximum rainfall from 84.6 mm in 1951-1985 to 106.1 mm in 1986-2017, implying a reduction in the variability of maximum rainfall over time and suggesting more consistent precipitation patterns. However, despite these trends, the mean of maximum rainfall displays fluctuations, ranging from 209.03 mm in 1966-2000 to 231.82 mm in 1981-2015, indicating a potential long-term shift towards higher average precipitation levels.

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Notably, the years 1976-2010 and 1981-2015 stand out with higher maximum rainfall values, means, and standard deviations compared to earlier periods, suggesting periods of increased rainfall variability and potentially higher precipitation levels during these timeframes.

The analysis of temporal trends in Cold weather season rainfall data reveals several noteworthy patterns. Firstly, the maximum rainfall values demonstrate consistency, hovering around 253.2 mm until 1961-1995, after which a noticeable decrease to 155.6 mm occurs and persists in subsequent years. Conversely, the minimum rainfall values exhibit stability, remaining around 13.4 mm throughout the entire period. The standard deviation of maximum rainfall displays fluctuations, ranging from approximately 30.74 mm to 45.82 mm, with no clear trend observed over different time periods. However, the mean of maximum rainfall shows a decreasing trend, declining from around 97.17 mm in 1951-1985 to approximately 92.88 mm in 1986-2017, suggesting a potential long-term shift towards lower average maximum rainfall levels. Notably, the years 1961-1995 and 1986-2017 stand out with lower maximum rainfall values and mean values compared to earlier periods, indicating periods of reduced precipitation intensity.

The analysis of temporal trends in Pre-monsoon rainfall data reveals several notable patterns. Initially, maximum rainfall values exhibit consistency until 1966-2000, after which a significant increase to 284.6 mm occurs and is sustained in subsequent years. Conversely, minimum rainfall values remain consistent, hovering around 14.4 mm throughout the entire period. The standard deviation of maximum rainfall displays fluctuations, ranging from approximately 39.10 mm to 47.24 mm, with no discernible trend observed across different time periods. However, the mean of maximum rainfall demonstrates an increasing trend, rising from around 106.68 mm in 1951-1985 to approximately 115.13 mm in 1986-2017, suggesting a potential long-term shift towards higher average maximum rainfall levels. Notably, the years 1966-2000 and 1981-2015 stand out with higher maximum rainfall values compared to earlier periods, indicating periods of elevated precipitation intensity. The analysis of temporal trends in summer monsoon rainfall data reveals several key findings. Initially, maximum rainfall values exhibit consistency from 1951-1985 to 1961-1995, with a slight increase observed in later periods. Conversely, minimum rainfall values display some variation but generally remain above 75 mm throughout the entire period. The standard deviation of maximum rainfall shows fluctuations, ranging from approximately 82.05 mm to 108.23 mm, indicating some variability in precipitation intensity over different time periods. However, the mean of maximum rainfall demonstrates a fluctuating pattern, ranging from around 198.24 mm in 1956-1990 to approximately 229.57 mm in 1976-2010, suggesting variability in average maximum rainfall levels without a clear increasing or decreasing trend. Notably, the years 1976-2010 stand out with higher maximum rainfall values compared to other periods, with a particularly high standard deviation indicating greater variability in precipitation patterns during this timeframe.

The analysis of temporal trends in post-monsoon rainfall data reveals several notable patterns. The maximum rainfall values exhibit some variability over the years, with a peak observed in 1951-1985, indicating fluctuations in precipitation intensity. Conversely, the minimum rainfall values display a general decreasing trend over the years, suggesting a potential decline in lower precipitation thresholds.

The standard deviation of maximum rainfall shows fluctuations, with a peak in 1956-1990 and a relatively lower value in 1986-2017, indicating variability in precipitation patterns over different time periods. However, the mean of maximum rainfall demonstrates a decreasing trend over the years, reaching its lowest value in 1986-2017, indicating a decline in average maximum rainfall levels over these periods. Notably, the years 1951-1985 and 1956-1990 stand out with higher maximum rainfall values, while 1986-2017 has the lowest mean maximum rainfall, suggesting varying precipitation patterns and intensities across different timeframes

V. CONCLUSION

The yearly fluctuations in maximum rainfall in the Highland can be influenced by various factors like Monsoon dynamics, atmospheric circulation patterns, topography and orographic effects, climate oscillations, land use changes, extreme weather events, and long-term climate trends. The Indian Summer Monsoon plays a crucial role in bringing rainfall to the Highland. Changes in atmospheric circulation patterns, such as the position and strength of the jet stream and the presence of atmospheric disturbances, can influence rainfall patterns in the Highland. The complex topography of the Highland can enhance rainfall through orographic lifting, where moist air is forced to rise over mountain ranges, leading to increased precipitation on windward slopes. Climate Oscillations: Large-scale climate oscillations, such as the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), can modulate weather patterns and influence rainfall variability in the Highland. Human activities, such as deforestation, urbanization, and changes in land use, can alter local microclimates and precipitation patterns. Urban heat island effects, changes in surface albedo, and modifications to natural drainage systems can influence the distribution and intensity of rainfall in urban and peri-urban areas, potentially affecting maximum rainfall values. Extreme weather events such as heavy rainfall, thunderstorms, and cyclones can cause spikes in maximum rainfall values in certain years. These events may be influenced by natural climate variability, such as ENSO events, as well as anthropogenic factors like climate change. Over longer timescales, changes in global climate conditions, including anthropogenic climate change, can influence rainfall patterns in the Highland. While single-year variability may be primarily driven by natural factors, long-term trends in maximum rainfall can reflect shifts in climate regimes due to factors like global warming. In conclusion, while there are overall trends towards more consistent precipitation patterns and potential shifts in average precipitation levels over time, there are also periods of increased variability and intensity in rainfall, indicating the complex and dynamic nature of regional climate patterns. Further research and monitoring are necessary to fully understand and adapt to these changing precipitation trends.

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Funding	No, I did not receive.
Conflicts of Interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Yes, It is relavant. Data is collected from the India Meteorological Department. The data collected is used for academic research work only. The data collected is under the condition that this data will not be published anywhere.
Authors Contributions	All authors have equal contributions in this article.

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