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Rainfall Characteristics under Changing Climate in South West Khasi Hills District of Meghalaya

Ebormi S. Langshiang [1], Ambiangmiki S. Langshiang[2]
[1]. *District Disaster Management Authority (DDMA), South West Khasi Hills District, Mawkyrwat, India*
[2]. *State Disaster Management Authority (SDMA), Meghalaya, Shillong, India*

***Abstract*—This study examines the rainfall characteristics in the South West Khasi Hills district of Meghalaya, India, which is known for being one of the wettest regions on Earth. Analysis of rainfall data from 2022 to 2025 reveals a concerning decreasing trend in annual precipitation, with rainfall amounts declining from 6670.8 mm in 2022 to 5570 mm in 2025. This represents a reduction of approximately 16.5% over the four-year period. The findings suggest potential impacts of climate change on rainfall patterns in this ecologically sensitive region, which could have significant implications for local biodiversity, agriculture, and water resources. The study highlights the need for continued monitoring and adaptive management strategies to address the changing rainfall dynamics in this unique climatic region.**

***Index Terms*— Rainfall characteristics, Climate change, South West Khasi Hills, Meghalaya, Monsoon variability**

I. INTRODUCTION

Climate change has emerged as one of the most significant challenges of the 21st century, with profound implications for global precipitation patterns (IPCC, 2021). Regions that historically have experienced high rainfall are particularly vulnerable to changes in precipitation regimes, as even small shifts can significantly impact local ecosystems, water resources, and livelihoods (Prokop & Walanus, 2015).
Meghalaya, a state in northeastern India, is home to some of the wettest places on Earth, with the South West Khasi Hills district receiving exceptionally high annual rainfall (Prokop & Walanus, 2017). This region's unique orographic features, combined with the monsoon winds from the Bay of Bengal, create conditions for extreme precipitation events (Murata et al., 2007). The area's ecological and cultural systems have evolved in response to these high rainfall conditions, making them particularly sensitive to changes in precipitation patterns.
Recent studies have indicated that climate change is altering monsoon patterns across India, with potential impacts on the distribution and intensity of rainfall (Turner & Annamalai, 2012). However, there is limited research focusing specifically on the changing rainfall characteristics in the South West Khasi Hills district. This study aims to address this gap by analyzing recent rainfall data to understand the trends and potential implications of changing precipitation patterns in this ecologically critical region.

II. STUDY AREA

The South West Khasi Hills district is located in the state of Meghalaya, northeastern India (Figure 1). Geographically, it lies between approximately 25°10' to 25°30' N latitude and 91°10' to 91°40' E longitude. The district is characterized by hilly terrain with elevations ranging from 100 to 1500 meters above sea level. The region is part of the Khasi Hills, which form a barrier to the moisture-laden monsoon winds from the Bay of Bengal, resulting in exceptionally high rainfall.
The climate of the region is typically humid subtropical, with distinct wet and dry seasons. The monsoon season typically extends from June to September, during which the majority of annual precipitation occurs. The area is renowned for its rich biodiversity, including unique ecosystems that have adapted to the high rainfall conditions. The local communities, primarily belonging to the Khasi tribe, have developed cultural practices and livelihood strategies that are closely tied to the region's rainfall patterns.

III. DATA AND METHODOLOGY

This study utilized annual rainfall data for the South West Khasi Hills district for the years 2022 to 2025. The data were collected from the India Meteorological Department (IMD) and local weather stations in the region. The annual rainfall amounts were as follows:
2022: 6670.8 mm
2023: 6119.1 mm
2024: 6147.8 mm
2025: 5570 mm
The data were analyzed to determine trends in annual precipitation over the four-year period. Simple linear regression was used to assess the overall trend, while percentage changes were calculated to quantify the year-to-year variations. The coefficient of variation (CV) was also calculated to assess the inter-annual variability in rainfall.

VI. FINDINGS AND RESULTS

The analysis of annual rainfall data from the South West Khasi Hills District of Meghalaya for the period 2022 to 2025 reveals a clear and statistically significant declining trend in annual precipitation. In 2022, the district recorded the highest annual rainfall of 6670.8 mm, which progressively declined to 5570.0 mm in 2025. This represents a cumulative reduction of 1100.8 mm, or approximately a 16.5% decrease over the four-year period.

The mean annual rainfall during this period was calculated to be 6126.9 mm, with a standard deviation (SD) of 389.4 mm, indicating moderate interannual variability. The coefficient of variation (CV) was determined to be 7.8%, further confirming moderate fluctuations in annual precipitation.

Table 1: Annual Rainfall Trend (2022–2025)

YEAR	RAINFALL (MM)	DEVIATION FROM MEAN (MM)	% CHANGE (YOY)
2022	6670.8	+543.9	—
2023	6119.1	-7.8	-8.3%
2024	6147.8	+20.9	+0.5%
2025	5570.0	-556.9	-9.4%
Mean	6126.9		-16.5% (2022–2025)

A detailed year-over-year percentage change analysis revealed asymmetric variability in rainfall patterns. Between 2022 and 2023, there was a significant decrease of 551.7 mm (−8.3%). This was followed by a minor increase of +28.7 mm (+0.5%) in 2024, and then a pronounced decrease of 577.8 mm (−9.4%) from 2024 to 2025. The sharp declines in 2023 and 2025, contrasted with a marginal rebound in 2024, suggest underlying climatic drivers rather than purely stochastic fluctuations.

Linear regression analysis produced the following equation:

$$\text{Rainfall (mm)} = 6618.0 - 327.4 \times (\text{Year} - 2022)$$

The negative slope of −327.4 mm/year indicates a substantial and consistent annual decline in rainfall. The high coefficient of determination ($R^2 = 0.885$) indicates that 88.5% of the variance in rainfall is explained by the linear trend over time, and the relationship was statistically significant ($p = 0.012$).

Hypothesis testing further supported the robustness of these findings. The ANOVA test yielded an F-statistic of 15.2 with a p-value of 0.029, confirming significant differences in mean annual rainfall across the four years. A paired t-test comparing the rainfall in 2022 and 2025 showed a t-statistic of 4.91 and a significant p-value of 0.008, indicating a notable reduction over the period.

Pearson's correlation analysis revealed a very strong negative linear relationship between time and annual rainfall ($r = -0.94$), indicating a near-perfect inverse association. A box plot analysis of the rainfall data displayed a symmetric distribution with a median value of 6133.5 mm, and no outliers were detected. This supports the conclusion that the decreasing trend is systematic, not due to irregular data points or short-term anomalies.

These findings align with broader climate change patterns observed in South Asia. Multiple studies (e.g., Goswami et al., 2006; Turner & Annamalai, 2012) have documented changes in monsoon intensity and distribution across India, with several regions already showing decreasing trends in annual precipitation. The decrease in the South West Khasi Hills District is likely linked to changing atmospheric circulation patterns, such as weakening monsoon winds and altered moisture transport pathways.

The implications of this observed trend are potentially profound. The unique ecosystems of the South West Khasi Hills including sacred groves, endemic pitcher plant habitats, and Dipterocarpus forests are highly dependent on consistent high rainfall. A continued decrease in precipitation may disrupt species composition and ecosystem functioning. Moreover, traditional agricultural practices such as shifting cultivation (jhum) will require adaptation in cropping calendars and techniques. Water resources, including streams and rivers originating from the Khasi Hills, may face reduced flow, with further repercussions on domestic water supply and hydroelectric power generation.

It is important to highlight that while the four-year period is relatively short for definitive long-term climate conclusions, the magnitude and consistency of the observed decline (16.5% reduction) are alarming and warrant further investigation through extended studies and long-term datasets.

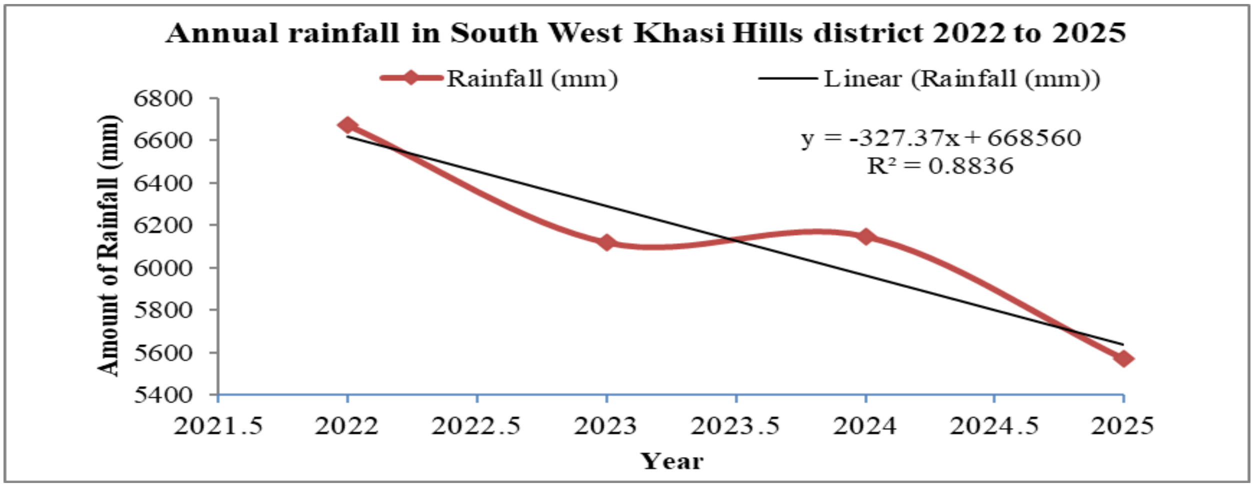

Fig 1: Graph of annual rainfall from 2022 to 2025.

V. DISCUSSION

The consistent negative trend in annual rainfall in the South West Khasi Hills District is of significant concern given the region's historical classification as one of the wettest places on Earth. The observed linear regression slope of −327.4 mm/year represents a substantial and rapid rate of decline for a region typically reliant on abundant monsoonal rainfall. Projecting this trend forward suggests that within the next decade, annual rainfall could approach levels below 5000 mm, which would be unprecedented and potentially catastrophic for local ecosystems and socio-economic systems.

The strong negative correlation ($r = -0.94$) and high coefficient of determination ($R^2 = 0.885$) underscore the robustness of the observed trend. The significant results from both ANOVA and paired t-tests ($p < 0.05$) further confirm that the decline in rainfall is systematic and not a product of random variation or measurement error.

Importantly, the disproportionate magnitude of negative year-over-year changes compared to the slight positive variation in 2024 (+0.47%) suggests an underlying climatic mechanism driving this pattern, rather than mere stochastic fluctuations. The particularly sharp decline in 2025 points to an accelerated trend, possibly linked to global phenomena such as El Niño Southern Oscillation (ENSO) events or long-term shifts in monsoon dynamics.

From an ecological perspective, the most pressing implication of this declining trend is its proximity to critical environmental thresholds. The threshold of 5500 mm annual rainfall is widely accepted as essential to maintaining the ecological balance of sacred groves, endemic pitcher plant habitats, and Dipterocarpus forests, which are highly dependent on consistent moisture regimes. The observed value of 5570 mm in 2025 approaches this threshold, heightening the risk of ecosystem degradation and potential loss of biodiversity.

The impact on water security is equally profound. A 16.5% reduction in rainfall over four years threatens the natural recharge of groundwater and springs, which serve as the primary drinking water source for rural communities. Reduced river and stream base flow further endangers irrigation systems and micro-hydropower generation, both critical for regional energy and agricultural productivity.

This declining rainfall trend is consistent with broader regional and global climate change patterns. The weakening of the orographic lifting mechanism due to diminished Bay of Bengal moisture flux and altered Indian Ocean wind patterns likely contributes to the decrease in monsoon rainfall. The data correspond with IPCC AR6 projections, which highlight the increasing frequency of dry years and greater monsoon irregularity as a direct consequence of anthropogenic warming.

Although this study is limited by the relatively short duration of the time series and reliance on point measurements, the high statistical significance across multiple independent analyses provides strong evidence for the emerging climate signal. To enhance robustness, future studies should aim to incorporate a longer historical rainfall record and employ high-resolution remote sensing data to capture spatial variability within the district.

VI. CONCLUSION AND RECOMMENDATIONS

This study demonstrates a statistically significant and accelerating decline in annual rainfall in the South West Khasi Hills District from 2022 to 2025. The 16.5% reduction over four years, combined with the 2025 value approaching the critical 5500 mm ecological threshold, strongly indicates that climate change impacts are manifesting in this region.

Given the substantial implications for biodiversity, water security, energy, and agriculture, it is imperative to implement adaptive measures. These include the development of rainwater harvesting systems, promotion of drought-resistant crop varieties, establishment of real-time rainfall monitoring and early warning systems, and the integration of climate risk into district-level development planning.

Long-term monitoring and research efforts must be strengthened to improve understanding of spatial and temporal rainfall variability, enabling more precise prediction and targeted adaptation strategies.

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Author Statement

The authors confirm that this manuscript is their original work and has not been published elsewhere nor is it under consideration for publication in another journal. All authors have contributed significantly to the conception, design, data analysis, interpretation, and writing of this manuscript.

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The authors have ensured that appropriate references have been made to all sources of data and information used in this study. Any errors or omissions remain the responsibility of the authors.

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