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Rainfall Trend Analysis of the Meghalaya Plateau: A Case Study of Ri Bhoi District

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ABSTRACT
Ri Bhoi district, located on the northern slopes of the Meghalaya plateau, has a complex climate ranging from pleasant summers and cold winters in the Highland zone closer to the Shillong plateau to hot and humid summers and cool winters in the Lowland zone, which merges with the Brahmaputra plains. Climate change, which is a reality at present, adversely impacts the marginalised section of the farmers more, especially those in the developing economies who depend on the vagaries of the climatic elements, and their crop production depends on the success or failure of seasonal rains. The present work attempts to analyse the rainfall trend on an average monthly, seasonal, and annual basis for the last 20 years for the Ri Bhoi district. The techniques followed for this analysis are the Mann-Kendall test at a 95% confidence level and Sen's slope estimate. The findings suggest an erratic rainfall pattern in the highland and lowland zones of Ri Bhoi district that could impacts agriculture and agro-based livelihoods.

Key words: Climate change, Trend analysis, Rainfall, Mann-Kendall test, Sen's slope estimate, Ri Bhoi district

INTRODUCTION

Precipitation is an important climatic parameter that affects the availability of water resources, the agriculture sector, the power sector and society as a whole (Deshmukh and Lunge 2012). The changing pattern and distribution of precipitation over time and space require urgent attention as it impacts food supply (Dore 2005), agricultural productivity, and rural livelihoods. Erratic precipitation affects the mean run-off, intensity and frequency of hazards like floods and drought (McCarthy et al. 2001). Precipitation is an integral part of the hydrological cycle, and the changes in the rainfall impact the pattern and volume of stream flow, groundwater reserves and soil moisture, which compel the authorities to review the water resource management policies and act accordingly. Trend analysis on rainfall offers a better understanding of the variation and pattern of rainfall, enabling the stakeholders to manage the available water resource effectively and deal with various mitigation measures relating to extreme and hazardous climatic events such as floods and drought (Bisht et al. 2017).

Abeysingha et al. (2015), while analysing the rainfall trend in the districts of the Gomti River basin of India, found that the trend in annual average rainfall was significantly higher in the districts closer to the upstream area when compared to the districts lying closer to the downstream area of the Gomti River basin suggesting a decreasing trend in annual average rainfall distribution. While analysing the rainfall trend and its magnitude at a regional scale with the help of the Mann-Kandell test and Sen's slope estimate across the Mandya district, Karnataka, Madhusudhan et al. (2021) found that the majority of the stations under survey indicated a statistically insignificant negative annual rainfall trend, forecasting a decrease in rainfall in the years to come. However, the annual rainfall series suggested no significant trend at any selected stations at a 95% confidence level.

As climate change on a global scale does not affect all regions equally, it becomes essential to assess micro-level trend analysis of the climatic elements, including rainfall, to check crop failure and soil moisture loss, depletion of underground water, etc., by adapting to the changes in the trend and magnitude of rainfall over an area.

Non-parametric test viz the Mann-Kandell and Sen's slope estimate are preferred to other statistical tests due to their applicability in time-series data that does not follow a random statistical distribution (Mohammed and Santhana Krishnan 2021). Numerous studies and research have focused on the trend analysis of rainfall at global, national, and regional levels (Rao et al. 2022). However, a survey of the literature suggests that the trend analysis of average monthly, seasonal and annual rainfall for the northern slopes of the Meghalaya plateau, where Ri Bhoi district is located, is yet to be conducted, which is an essential physiographic zone as it connects the Meghalaya plateau, especially Shillong plateau region with the Brahmaputra plains. The present work aims to analyse the rainfall trend and its magnitude on an average monthly, average seasonal and average annual basis for both the Highland and Lowland zones of Ri Bhoi district from 1999 to 2019.

MATERIAL AND METHODS

Study area

The Ri Bhoi district is located on the northern slopes of the Meghalaya plateau and extends between 91°20’30" to 92°17’00" East longitude and 25°40' to 26°20' North latitude (Fig. 1). It covers an area of 2448 km^2, and its elevation varies from 100 to 1300 m above mean sea level (Kharkongor 2012). Ri Bhoi district is comparatively drier and experiences erratic rainfall due to the rain shadow effect (Daimari 2013, Choudhury et al. 2012). The average yearly temperature ranges between 18 to 30°C, and the average rainfall ranges between 1242 to 1500 mm. The district is dominated by indigenous communities who live close to nature following subsistence agriculture with few technological innovations, and here, their agricultural activities depend on the vagaries of the climatic elements, including rainfall and temperature.

Data sources and methodology

To analyse the rainfall trend of Ri Bhoi district at a micro level, firstly, the district has been divided into two altitudinal zones, namely the Highland zone, marked by the contour of above 700 m located closer to the Shillong plateau and the Lowland zone, marked by the contour of below 700 m lying closer to the Brahmaputra plain as different climatic conditions prevail over these two zones. The Highland zone experiences a pleasant summer and cold winter; on the other hand, the Lowland zone experiences a hot and humid summer and cool winter.

The monthly rainfall data have been retrieved from the Indian Meteorological Department, the Department of Agriculture, the Government of Meghalaya, and NASA Data Access Viewer. Besides this, monthly rainfall data has also been collected from four stations, namely Umiam and Umsning stations, representing the Highland zone and Nongpoh and Byrnihat stations, representing the Lowland zone from 1999-2019.

The rainfall trend of both the zones of Ri Bhoi district has been computed, analysed and discussed on average monthly, seasonal and average annual scales with the help of the Mann-Kendall test at 95% confidence level and Sen slope estimate statistical

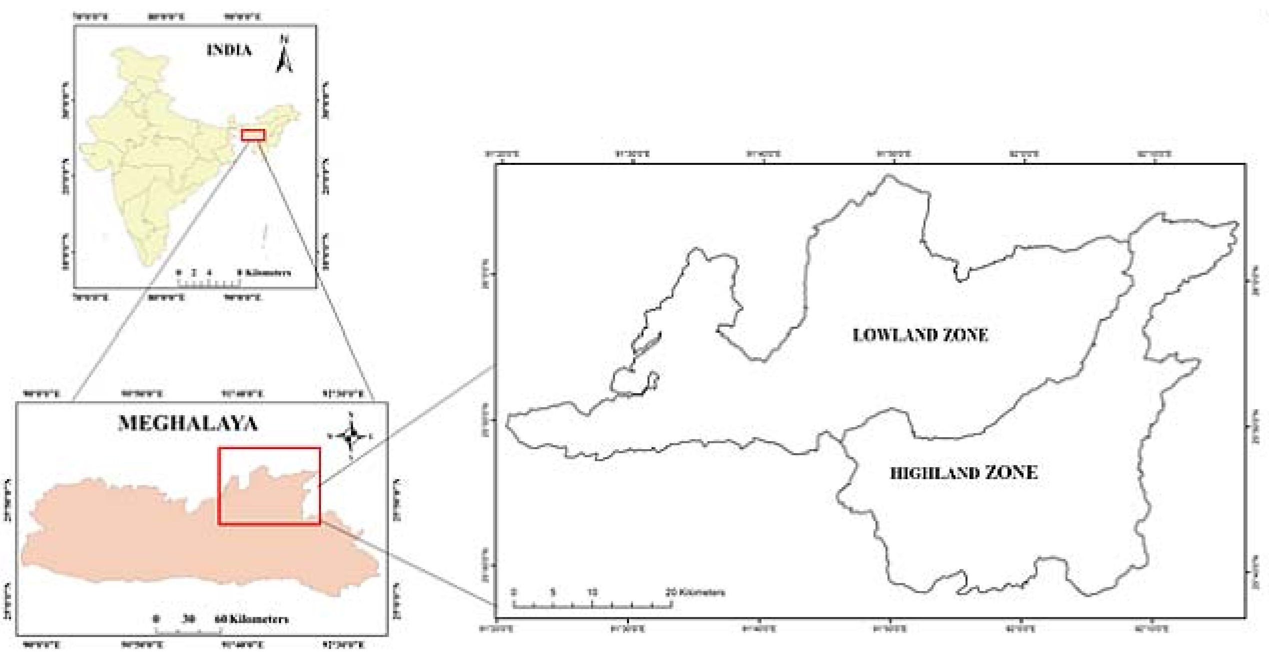

Figure 1. Study Area (Ri Bhoi District)

techniques. The Mann-Kandell test is used to check the alternative hypothesis (Ha) of the existence of an increasing or decreasing trend against the null hypothesis (Ho) of no trend in the time series data.

Another non-parametric method for trend analysis of the hydrological and hydro-meteorological data set is Sen's Slope Estimate (Alemu and Dioha 2020). The Sen's estimator tends to determine the magnitude of the trend and this test calculates the slope and intercept of the linear rate of change (Sen 1968). All the analyses are done using XLSTAT version 5.01.22 and R Software version 4.2.1.

RESULTS

Trend analysis of the average monthly rainfall in the Highland and Lowland zones

The trend analysis of the average monthly rainfall from 1999 to 2019 in the Highland zone suggests all the months show both insignificant increasing and decreasing rainfall trends at a 95% confidence level, accepting the null hypothesis (Ho), suggesting no marked change in the average monthly rainfall trend (Table 1). However, in the Lowland zone, only October depicts a statistically significant increasing trend with a P-value of 0.01, thereby accepting the alternative hypothesis (Ha) indicating the presence of a monotonic trend in the rainfall time series data in October from 1999–2019 (Table 2).

The magnitude of the average monthly rainfall in the Highland zone showed a decreasing trend as seen from Sen's slope estimate (Table 1) during the months of March and October, while no trend emerges for January and November. Similarly, in the Lowland zone a decreasing trend in the magnitude of rainfall for all the months except for August and December was seen (Table 2), which highlights an increasing trend in the magnitude of the average monthly rainfall.

Trend analysis of the average seasonal and average annual rainfall in the Highland and Lowland zones

The average winter, pre-monsoon and monsoon rainfall, and average annual rainfall for the past two decades showed an insignificant increasing trend, while the post-monsoon season showed an insignificant decreasing trend, thus accepting the null hypothesis (Ho) and suggesting no marked change in the average seasonal and average annual rainfall in the Highland zone in the past two decades (Table 3). The average winter, pre-monsoon, and monsoon seasons and average annual rainfall during 1999-2019 showed an increasing trend in the magnitude of rainfall. However, the average post-monsoon season, with a Sen's slope estimate value of -7.93 mm, shows a decreasing trend in the magnitude of rainfall (Table 3).

Conversely, in the Lowland zone, the average winter and monsoon rainfall, as well as the average annual rainfall, indicate an insignificant decreasing rainfall trend (Table 4), thereby accepting the null hypothesis (Ho). On the other hand, the average pre-monsoon and post-monsoon seasons with a P-value of 0.04 and 0.001, respectively, depict a statistically significant decreasing trend, accepting the alternative hypothesis (Ha), which suggests a marked change and the presence of a monotonic trend during these seasons. Similarly, the average seasonal and average annual rainfall exhibit a decreasing trend in the magnitude of rainfall from 1999–2019 (Table 4).

DISCUSSION

Trend analysis of the rainfall in the Highland zone

The analysis of the monthly average rainfall data from 1999-2019 in the Highland zone suggests that January, March, and October had an insignificant decreasing trend, while February, April to September, and November to December exhibit an insignificant increasing trend, thus accepting the null hypothesis (Ho) suggesting no marked change in the average monthly rainfall trend. Similar result of no significant trend at a 5% significant level has been observed by Dabral and Tabing (2020) while accessing the monthly rainfall trend of the Umiam region, a Highland zone of Ri Bhoi district, for the periods 1983–2012. Further, the results also reveal that the Z-statistic values correspond with the Kandell Tau values.

The analysis of the magnitude of the rainfall trend computed from the average monthly rainfall using Sen's slope estimate suggests that March and October depict a decreasing trend in the magnitude of rainfall. Meanwhile, February, April, May, June, July, August, September, and December depict an increasing trend

Table 1. Mann Kandell and Sen's slope estimate of the average monthly rainfall (1999-2019) in the Highland zone

Month	MK statistic (S)	Kendall Tau	Var (S)	P-value (two tailed)	Z statistic	Alpha value	Sen's slope
January	-6.00	-0.01	1031.33	0.88	-0.16	0.05	0.00
February	22.00	0.11	1088.00	0.52	0.64	0.05	0.22
March	-1.00	-0.01	1095.67	1.00	0.00	0.05	-0.02
April	22.00	0.11	1095.67	0.53	0.63	0.05	3.58
May	2.00	0.01	1095.67	0.98	0.03	0.05	0.14
June	11.00	0.05	1095.67	0.76	0.30	0.05	4.16
July	18.00	0.09	1095.67	0.61	0.51	0.05	7.39
August	28.00	0.13	1095.67	0.42	0.82	0.05	3.84
September	62.00	0.30	1095.67	0.06	1.84	0.05	10.35
October	-44.00	-0.21	1095.67	0.20	-1.30	0.05	-5.81
November	5.00	0.02	1087.00	0.90	0.12	0.05	0.00
December	45.00	0.24	971.68	0.16	1.41	0.05	0.02

Table 2. Mann Kandell and Sen's slope Estimate of the average monthly rainfall (1999-2019) in the Lowland zone

Month	MK statistic (S)	Kendall Tau	Var (S)	P-value (two tailed)	Z statistic	Alpha value	Sen's slope
January	-29.00	-0.14	1068.33	0.39	-0.86	0.05	-0.14
February	-20.00	-0.10	1080.00	0.56	-0.58	0.05	-0.18
March	-45.00	-0.22	1080.00	0.18	-1.34	0.05	-1.19
April	-32.00	-0.15	1080.00	0.36	-0.94	0.05	-3.46
May	-44.00	-0.21	1080.00	0.20	-1.31	0.05	-5.51
June	-44.00	-0.21	1080.00	0.20	-1.31	0.05	-11.26
July	-44.00	-0.21	1080.00	0.20	-1.31	0.05	-7.13
August	14.00	0.07	1080.00	0.70	0.40	0.05	2.12
September	-40.00	-0.19	1080.00	0.24	-1.19	0.05	-3.45
October	-92.00	-0.44	1080.00	0.01	-2.77	0.05	-8.03
November	-41.00	-0.21	1052.33	0.22	-1.23	0.05	-0.10
December	48.00	0.23	1080.00	0.15	1.43	0.05	0.13

in the magnitude of rainfall. However, no trend in rainfall magnitude is observed for January and November for the said two decades, as the Sen's slope estimate values are zero.

The analysis of the average seasonal and average annual rainfall of the Highland zone suggests that the average winter, pre-monsoon, and monsoon seasons, as well as the average annual rainfall, depict an insignificant increasing trend as the P-value is greater or equal to á (alpha) at a 95% confidence level accepting the null hypothesis (Ho). However, the average post-monsoon season shows an insignificant decreasing rainfall trend, thereby accepting the null hypothesis (Ho), suggesting the absence of a monotonic trend in the time series. Consequently, the rainfall trend analysis conducted by Kuttippurath et al. (2021) over the Shillong plateau, which lies closer to the Highland zone, depicts a similar result suggesting a changing rainfall trend on a seasonal and annual scale from 1973 to 2019, especially during the pre-monsoon and post-monsoon, revealing a significant increasing and an

Table 3. Mann Kandell and Sen's slope estimate of the average annual and average seasonal rainfall (1999-2019) in the Highland zone

Month	MK statistic (S)	Kendall Tau	Var (S)	P-value (two tailed)	Z statistic	Alpha value	Sen's slope
Annual	28.00	0.13	1087.00	0.42	0.82	0.05	1.73
Winter	11.00	0.05	1093.00	0.76	0.30	0.05	0.23
Pre-monsoon	2.00	0.01	1093.00	0.98	0.03	0.05	0.37
Monsoon	32.00	0.15	1093.00	0.36	0.94	0.05	31.04
Post-monsoon	-50.00	-0.24	1093.00	0.14	-1.48	0.05	-7.93

Table 4. Mann Kandell and Sen's slope estimate trend of the average annual and average seasonal rainfall (1999-2019) in the Lowland zone

Month	MK statistic (S)	Kendall Tau	Var (S)	P-value (two tailed)	Z statistic	Alpha value	Sen's slope
Annual	-60.00	-0.29	1052.33	0.08	-1.82	0.05	-2.67
Winter	-18.00	-0.09	1052.33	0.61	-0.52	0.05	-0.34
Pre-monsoon	-68.00	-0.32	1052.33	0.04	-2.07	0.05	-13.50
Monsoon	-30.00	-0.14	1052.33	0.39	-0.89	0.05	-8.67
Post-monsoon	-108.00	-0.51	1052.33	0.001	-3.30	0.05	-10.94

insignificant decreasing trend. The increasing rainfall trend during the pre-monsoon in the Shillong region from 1973–2019 is largely due to the influence of the El Niño–Southern Oscillation (ENSO) and sea surface temperature (SST) of the Bay of Bengal. While a decreasing rainfall trend during the post-monsoon is attributed to the least influence of the ENSO and the equatorial wind that blows during this season (Kuttippurath et al. 2021). The average winter, pre-monsoon, and monsoon seasons and the average annual rainfall depict an increasing trend in the magnitude of rainfall; however, the average post-monsoon season showed a decreasing rainfall magnitude trend in the Highland zone from 1999–2019.

Trend analysis of the rainfall in the Lowland zone

The average monthly rainfall in the Lowland zone reveals that January to July, September, and November indicate an insignificant decreasing trend. However, August and December months exhibit an insignificantly increasing rainfall trend at a 95% confidence level, thereby accepting the null hypothesis (Ho), which suggests the absence of a monotonic trend in the time series. Interestingly, October shows a statistically significant decreasing trend as the P-value is less than or equal to á (alpha), accepting the alternative hypothesis (Ha), depicting a monotonic trend in the time series for the two decades in the Lowland zone of the Ri Bhoi district. Further, the Z-statistic values also correspond with the Kandell Tau values. The computed Sen's Slope Estimate reveals that the months of January–July and September–November showed a negative trend in the magnitude of rainfall. However, August and December showed an increasing or positive trend in the magnitude of rainfall.

The analyses of the average seasonal and average annual rainfall of the Lowland zone reveal that the average winter and monsoon rainfall, as well as the average annual rainfall, suggest a statistically insignificant decreasing rainfall trend as the P-value greater than or equal to á (alpha) at a 95% confidence level accepting the null hypothesis (Ho). On the other hand, the pre-monsoon and post-monsoon seasons suggest a statistically significant decreasing rainfall trend, as depicted in Table 4, accepting the alternative hypothesis (Ha) suggesting a monotonic trend in the time series. A decreasing rainfall trend in the average seasonal and average annual rainfall, especially in the winter season from 1999–2019 in the northernmost tip of Ri Bhoi district, comprising the

Lowland zone, may be attributed to the topographic conditions, mainly the altitude of the region, and anthropogenic activities, including the setting up of industrial units, unmonitored emission of toxic gases in the air, and illegal deforestation (Phawa et al. 2022), ultimately affecting the agricultural sector, crop productivity, and rural livelihoods (Deshmukh et al. 2013, Ray et al. 2014). Conversely, while analysing the magnitude of the rainfall trend with the help of Sen's slope estimate depicts the average seasonal and average annual rainfall depict a decreasing trend in the Lowland zone of Ri Bhoi district from 1999–2019.

CONCLUSIONS

The Highland and Lowland zones of Ri Bhoi district are characterised by distinct climatic conditions that are greatly influenced by the south-west monsoon, altitude, and latitude. The analysis of the rainfall trend over a period of two decades is significant as it influences agricultural productivity, primary livelihoods, and the wellbeing of the people.

The main purpose of this research is to examine and analyse the rainfall trend and its magnitude on an average monthly, average seasonal, and average annual basis from 1999–2019 in both zones of Ri Bhoi district by using a non-parametric statistical technique, i.e., the Mann-Kendall test and Sen's slope estimate at a 95% confidence level. The results indicate the average monthly rainfall depicted an insignificant increasing and decreasing trend for all the months in both the Highland and Lowland zones, except for October in the Lowland zone, which showed a statistically significant decreasing trend from 1999–2019. The test results of the average annual as well as the average pre-monsoon, monsoon, and winter seasons in the Highland zone reveal an insignificantly increasing trend along with an increasing magnitude of rainfall, as both the Z-Statistics and the Q-Statistics (Sen's slope estimate) are positive.

In the Lowland zone, the average winter and monsoon seasons, as well as the average annual rainfall from 1999–2009, showed an insignificant decreasing rainfall trend with a decreasing trend in the magnitude of rainfall during the above-mentioned seasons. On the other hand, the average pre-monsoon and post-monsoon season rainfall in this zone indicates a statistically significant decreasing rainfall trend, suggesting the presence of a monotonic trend in the time series.

Consequently, the micro-level study of rainfall in the Ri Bhoi district, where agriculture is still a predominant sector, will enable policymakers and the local population to understand the pattern and trend of rainfall over the years, enabling them to develop a robust framework for adapting to climate change and grow new crops that are resistant to the changing trend and magnitude of rainfall so that the primary livelihoods and the overall progress of the population in general and Ri Bhoi District, in particular, are not hampered by climate change.

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