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Probability and Trend Analysis of Rainfall Data of Shillong District

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Abstract

This study analyses 15 years (2002–2016) of daily rainfall data for Shillong, located in northeastern India, obtained from the Global Weather Data repository developed for the SWAT model. The primary objective was to evaluate the variability, trends, and statistical characteristics of annual and seasonal rainfall. Descriptive statistical analysis was carried out to determine annual maximum and minimum rainfall, monthly rainfall variability, standard deviation, and coefficient of variation. The annual rainfall exhibited substantial variability, ranging from 0.04 mm to 1609.38 mm. The lowest mean monthly rainfall occurred in 2006 (115.3 mm), followed by 2013 (123.4 mm) and 2005 (151.2 mm), whereas the highest was recorded in 2004 (255.3 mm). The computed standard deviation (326.6) and coefficient of variation (127.9%) indicated a high degree of variability in rainfall distribution. Return-period analysis classified Shillong under normal rainfall conditions, with the maximum rainfall event corresponding to a return period of 24 years. Trend analysis based on slope (m) values revealed an increasing rainfall trend during August (18.257 mm/year) and September (11.537 mm/year), while June (–19.338 mm/year), July (–25.535 mm/year), and October (–13.815 mm/year) exhibited declining trends. The annual slope value (–28.894 mm/year) indicated an overall decreasing trend in annual rainfall over the study period.

Keywords: Shillong: Northeast India: Rainfall variability: Trend analysis: Statistical analysis.

Introduction

Rainfall is an important part of India's hydrological and climatic system, affecting agriculture, water resources, and the economy of the country. Rainfall dictates the humidity, aridity, and agricultural yield of the region and has a significant impact on flood and drought evaluation. Shillong, situated at an elevation of 1471 m, has a warm temperate climate with the average annual rainfall being approximately 3636 mm and temperature 18°C. Although it receives high rainfall, the area exhibits considerable spatial and temporal variability because of topographical limitations, influencing water storage capacity and irrigation potential. It is crucial for proper management of water resources and agricultural planning to identify rainfall variability and long-term trends. Hence, this research intends to examine the probability distribution and space-time pattern of mean rainfall, and evaluate rainfall variability and trends in Shillong district.

For understanding hydrological variability and supporting water resource planning, the analysis of rainfall frequency plays a critical role, as rainfall patterns are inherently complex and non-linear. Numerous studies have applied probability distribution models such as Normal, Log-Normal, Gamma, Gumbel, Weibull, and Log-Pearson Type III to identify the most suitable models for rainfall estimation and prediction. Kumar (2017) reported that Gamma, Log-Normal, and Extreme Value Type-I (Gumbel) distributions were appropriate for analyzing daily and annual rainfall. Similarly, several other researchers demonstrated that Log-Normal and Log-Pearson Type-III distributions often provide the best fit for maximum rainfall analysis and flood frequency estimation in hydrologic studies (Kite, 1977; Rao and Hamed, 2000; Bhakar et al., 2006; Hailegeorgis and Alfredsen, 2017). Overall, these studies highlight that probabilistic rainfall modelling is essential for accurate rainfall estimation, hydrologic design, and sustainable water resource planning and management.

Material and Methods

Study Area

The location for the study is Shillong, the capital city of Meghalaya, situated at an altitude of 1471 m with a warm temperate climate. The area receives approximately 3636 mm average annual rainfall and has a mean temperature of 18°C. The daily rainfall for 2002–2016, collected from a nearby weather observatory (2 km away from the site), was analysed for the experiment (Fig. 1). The population statistics were obtained from the 2011 Census of India, which recorded a population of 143,229 in Shillong. The study area is 1471 m above sea level and has a warm and temperate climate with an average temperature of 18°C and annual rainfall of around 3636 mm. The maximum rainfall occurs in the city during July, whereas December is the most arid month. Majorly, Red loamy and sandy soils are dominant in the area, and varied forms of agriculture like shifting and terrace cultivation are adopted.

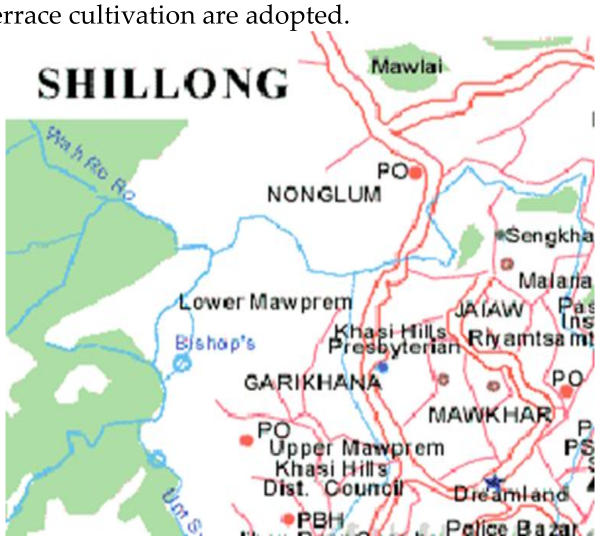

Fig.1 A Map of the District Shillong Showing the Boundaries

Data Collection and Analysis

For the present study, precipitation data for the time period from 2002 to 2016 were collected. Daily rainfall records were taken from the global online weather portal Global Weather Data for SWAT. The analysis included a number of statistical and hydrological techniques to predict rainfall variability and trends. Monthly series of rainfall for each station were organized from daily rainfall data, and district and state-level values of rainfall were intended by arithmetic average and area-weighted methods. The disparity of rainfall was forecasted through Mean, Standard Deviation, and Coefficient of Variation to measure central tendency, dispersion, and variability.

For the long-term trends in rainfall. Least squares method was castoff to get the line of best fit and estimate direction and rate of change, whereas Slope Method (Sen's method) defined the magnitude of the trend. Furthermore, Probability analysis using Hazen's Formula was used to calculate the probability of rainfall occurrence and recurrence interval, thus classifying weather conditions as dry, normal, or humid as per the FAO guidelines. These examines gave a comprehensive description of rainfall behaviour and its temporal variability, which is serious for agricultural planning and water resource management in the Shillong area.

Results and Discussion

The Statistical analysis of rainfall data at selected years were done using mean and the dispersion of data from mean was done using standard deviation and coefficient of variance. Statistical analysis of rainfall data at selected years in Table 1 demonstrated that minimum mean monthly rainfall (mm) occurred in the Year 2006 (115.3 mm) for all these 16-year data followed by 2013 (123.4 mm) and 2005 (151.2 mm), while maximum mean monthly rainfall (mm) occurred in the 2004 (255.3mm) also the values of standard deviation and coefficient of variance of rainfall data are 326.6 and 127.9, correspondingly.

The rainfalls and associated return period analysis from 2002 to 2016 showed substantial interannual variability. The maximum monthly rainfall varied from 338.5 mm in the year 2005 to 1044.4 mm in 2004 with each having a return period of 24 years, suggesting infrequent and severe rainfall events. On the other hand, the lowest monthly rainfall fluctuated between 0.3 mm and 11.7 mm, typically equivalent to return periods of 1 to 1.4 years, indicating more frequent low-rainfall events. In general, the trend indicates that although the very high rainfall events were rare in individual years, low-rainfall events were frequent for all years, implying considerable temporal variability in the distribution of rainfall during the 2002–2016 period. Depending upon Tabular Classification of Table 2 and 3Shillong has only one type of weather condition according to rainfall return periods i.e., the normal weather condition.

Based on the rainfall–frequency data for Shillong from 2002 to 2016, the annual rainfall shows moderate inter-annual variability with values ranging from the lowest of 2752.9 mm in 2006 to the highest of 6098.1 mm in 2004. The mean annual rainfall over the 15-year period is approximately 4110 mm, with a noticeable decline in rainfall in the later years compared to the earlier part of the record. The year 2004 stands out as an extreme wet year with a return period of 24 years, indicating that such a high rainfall event is statistically rare, whereas years like 2005, 2006, 2008, and 2013 represent relatively dry conditions with high exceedance probabilities and return periods close to one year. Most years fall within the normal rainfall range, indicating that while extremes do occur, the general pattern is one of moderate variability around the long-term mean.

A decreasing pattern in annual rainfall is evident when comparing the early period (2002–2008) with the later period (2009–2016), suggesting a downward trend in rainfall over time. Although the computed return periods align with the magnitude of rainfall events, some of the reported percentage probabilities exceed 100, indicating a need to refine the plotting-position formula, particularly to distinguish between exceedance and non-exceedance probabilities. Overall, the analysis indicates a predominance of normal rainfall years punctuated by occasional wet and dry extremes, with an emerging signal of declining annual rainfall in recent years. Statistically, trend analysis was tested in two steps. In the first step, whether a monotonic increasing or decreasing trend exists was checked with the Least Square Method, and the slope of the trend line will reflect the rate as well as direction of the change in rainfall (Helsel and Hirsch, 2002; Drapela and Drapelova, 2011; Choudhury et al., 2012). In the second stage, the nature and intensity of these trends were assessed for various time series, and below are discussed the findings.

The least-squares trends indicate a seasonal redistribution of monsoon rainfall at Shillong: early-monsoon months are drying while the mid-monsoon is intensifying. Specifically, June (–19.338 mm yr^{-1}) and July (–25.535 mm yr^{-1}) show clear declines, equivalent to about –193 mm/decade and –255 mm/decade, respectively, whereas August (+18.257 mm yr^{-1}) and September (+11.537 mm yr^{-1}) are increasing by roughly +183 mm/decade and +115 mm/decade**;** October resumes a decline (–13.815 mm yr^{-1}, –138 mm/decade). The annual slope (–28.894 mm yr^{-1}) aggregates these monthly signals and implies a net –289 mm/decade decrease in June–October rainfall over 2002–2016. The intercepts (June 584.99; July 600.31; August 189.53; September 177.11; October 308.75; annual 1860.7) simply reflect the fitted baseline under the chosen time coding and are not directly interpretable as means; a more meaningful baseline would be obtained by centering time at the series midpoint (e.g., 2009) to yield intercepts close to period-average rainfall. Together, the results suggest a weakening onset and retreat of the monsoon (June, July, October down) with shifting intensity toward the core months (August–September up), producing an overall seasonal total decline; for publication, report slopes with units (mm yr^{-1} or mm $month^{-1}$ yr^{-1} as appropriate) and complement OLS with a Mann–Kendall/Sen's slope test to assess significance over this relatively short (15-year) record.

Table 1 Statistical analysis of rainfall data of Shillong

Year	Max. Rainfall	Min. Rainfall	Mean Rainfall	S. D.	C.V.
2002	769.7	0.4	206.6	228.9	110.82
2003	733.8	1.7	742.2	630.8	85
2004	1044.4	0.9	255.3	326.6	127.9
2005	338.5	2.0	151.2	207.7	137.3
2006	355.1	0.0	115.3	116.5	101
2007	763.4	0.0	246.3	249.1	101.1
2008	353.2	4.9	160.2	221.6	138.4
2009	452.3	0.0	168.6	179.53	106.5
2010	603.0	0.0	167.9	181.7	108.2
2011	749.4	2.5	171.7	210.2	122.4
2012	382.3	0.0	160.1	285.6	178.4
2013	376.2	0.0	123.4	54.4	44.1
2014	633.7	0.0	158.6	204.6	129
2015	752	2.5	182.8	218.2	119.4
2016	505.4	2.2	163.1	12.77	101.3

Table 2 Probabilities of exceedance

Year	Rainfall	% Probability	Return Time Period
2002	4879.7	21	4.8
2003	4167.6	38	2.7
2004	6098.1	4	24.0
2005	3481.5	104	1.0
2006	2752.9	121	0.8
2007	5838.8	13	8.0
2008	3747	96	1.0
2009	3984.2	63	1.6
2010	4003	54	1.8
2011	4034.7	46	2.2
2012	3821.2	79	1.3
2013	2912.1	113	0.9
2014	3760.6	88	1.1
2015	4319.5	29	3.4
2016	3853	71	1.4

Table 3 Meteorological events classification based on rainfall return periods

Classification	Return Periods (Years)
Normal	<6
Abnormal	6-10
Very Abnormal	10-30
Exceptional	30-100
Very Exceptional	>100

Table 4 Values of Least square method

	Jun	Jul	Aug	Sept	Oct	Annual
Slope	-19.338	-25.535	18.257	11.537	-13.815	-28.894
Intercept	584.99	600.31	189.53	177.11	308.75	1860.7

Conclusions

The analysis of rainfall data for Shillong district from 2002 to 2016 revealed a declining trend in annual rainfall, as evidenced by the negative slope obtained through the Least Square Method. Seasonal assessment showed that August and September contributed the highest rainfall during the monsoon period, whereas July exhibited comparatively lower rainfall over the study years, indicating a shift in peak monsoon intensity. Variability analysis demonstrated that 2013 recorded the lowest coefficient of variation, signifying relatively stable rainfall distribution, while 2012 showed the highest variability, reflecting greater fluctuations in precipitation. Probability analysis carried out using Hazen's formula indicated that extreme rainfall events have a return period of approximately 24 years, while average rainfall events recur every 4 to 5 years, suggesting a predominantly normal rainfall regime for the region. Overall, the findings suggest that although Shillong continues to receive substantial monsoon rainfall, there is a perceptible declining trend over time. Such a shift may have critical implications for agriculture, water supply, and long-term water resource planning and management in the region.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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