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Rainfall Variability and Extreme Rainfall Events in Coastal Guyana (1981–2025)

Bibi Sherriza Ali*, Jason Phillips**, Shemuel Carmichael***
*(Department of Mathematics, Physics & Statistics, University of Guyana, Guyana
Email: bibi.ali@uog.edu.gy)
** (Department of Computer Science, University of Guyana, Guyana
Email: jason.phillips@uog.edu.gy)
*** (Data Analysis Unit, Bureau of Statistics, Guyana
Email: shemuelcarmichael7@gmail.com)

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Abstract:

Water resources, agriculture, flood risk and climate adaptation are the sectors and issues greatly impacted by rainfall variability and extreme rainfall events, especially in low lying coastal areas. The current study investigates the variability and extremes of rainfall over coastal Guyana for the period 1981 to 2025. Rainfall characteristics, long-term trend, structural breaks, and extreme rainfall behaviour were assessed using descriptive statistics, rainfall anomaly analysis, Mann–Kendall trend test, Sen's slope estimator, Bai–Perron structural break analysis and the Generalized Extreme Value (GEV) model. The results revealed that there is a significant variation in time, mean annual rainfall of 2278.91 mm and coefficient of variation of 21.79%. The rainfall showed a distinct bimodal seasonal distribution with main wet season between May and July and secondary wet season between November and December. Trend analysis showed a weak positive trend (Sen's slope = 4.03 mm year−1) but not significant at the Mann–Kendall p level (> 0.286), indicating that the longitudinal variability is the prevailing feature of the behaviour of rainfall. The results of the structural break analysis showed that the year 2003 was the year of a major shift in rainfall pattern. There were further changes in 1985 and 1987 as detected by the PELT change-point detection, which reveals episodic changes in rainfall pattern. The GEV analysis revealed that high magnitude rainfall events are possible and that estimated return periods of 2,958.66 mm, 3,390.99 mm and 3,731.46 mm for 10 year, 25 year and 50 year rainfall return periods respectively. The results of this study provide a detailed understanding of the rainfall characteristics over coastal Guyana and are of great value for monitoring climate conditions, flood risk management, water resources planning, and climate adaptation.

Keywords — Rainfall variability, Extreme rainfall, Generalized Extreme Value (GEV), Mann–Kendall trend test, Structural break analysis; Coastal Guyana.

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I. INTRODUCTION

Rainfall is an integral part of the climate system, affecting water availability, the production of food for human consumption and nutrition, ecosystem processes and hydrological hazards. Rainfall fluctuations in quantity, timing and intensity can have a significant impact on socioeconomic systems, especially in areas where rainfall seasonality plays a key role in agricultural, infrastructure and water resource management. It is becoming an important concern related to variability and extreme precipitation events in view of its implications for flood risk, climate resilience and sustainable development concerns. Rainfall intensity is particularly significant as it can trigger responses at the hydrological level and cause major consequences.

Therefore, rainfall intensity is an important area of climate research [1].

Seasonal climate systems and linkages between atmospheric and oceanic conditions cause significant rainfall variations over the Caribbean at the regional level. The Greater Caribbean region shows that there are temporal shifts in precipitation patterns and extreme rainfall events, justifying detailed regional assessments to better understand how precipitation is changing and how this will affect risks in the future [2]. Statistical hydrological methods are widely applied to quantify rainfall extremes and support risk-based planning by estimating the probability and magnitude of rare events [3].

Seasonal rainfall patterns significantly affect rainfall in Guyana, especially in coastal areas where a bimodal rainfall regime exists, namely a primary wet season and a secondary wet season [4]. The coastal region is significant because it has a dense population, high production of agricultural crops and is highly vulnerable to flooding. The difficulty of the rainfall processes in Guyana and the difficulties of accurately representing the local rainfall behaviour have been highlighted in previous studies. For example, the spatial and temporal variations in the region have been found to be difficult to capture, in rainfall modelling studies [5]. Moreover, rainfall variability has been observed to have substantial impacts on agricultural systems, especially on rice, as variability in precipitation has direct impacts on productivity and planning [6]. Besides, statistical modelling techniques have been employed to gain insights into rainfall occurrence and distribution in Guyana, highlighting the significance of quantitative methods in the analysis of rainfall [7].

Despite these contributions, rainfall behaviour in coastal Guyana has not been sufficiently examined using a fully integrated long-term approach. Existing studies have largely focused on individual aspects such as seasonal patterns, modelling techniques, or sector-specific impacts. However, fewer studies have simultaneously examined long-term variability, trend behaviour, structural changes, and extreme rainfall characteristics within a unified analytical framework. This limits a comprehensive understanding of how rainfall patterns evolve over time and whether observed changes are gradual or occur as abrupt shifts.

II. STATEMENT OF PROBLEM

Rainfall in coastal Guyana is highly variable and plays a critical role in agriculture, water resource management, and flood risk. However, its long-term behaviour remains inadequately understood when assessed using an integrated statistical approach [7]. While previous research has examined rainfall distribution, modelling techniques, and sectoral impacts, these studies have not collectively evaluated long-term trends, structural breaks, and extreme rainfall behaviour within a single coherent framework . This creates a gap in understanding whether rainfall patterns in coastal Guyana are stable, gradually changing, or experiencing abrupt shifts over extended periods. As a result, decision-making for flood management, agricultural planning, and climate adaptation is limited by incomplete knowledge of long-term rainfall dynamics.

Therefore, this research investigates rainfall variability and extreme rainfall events in coastal Guyana over the period 1981–2025.

III. OBJECTIVES OF THE STUDY

This research offers a detailed characterization of rainfall variability in coastal Guyana and brings evidence to inform climate monitoring, flood hazard assessment, hydrologic planning for agriculture and climate adaptation planning. The following are the objectives of the study:

- To assess the temporal variability of monthly and annual rainfall in coastal Guyana from 1981 to 2025.
- To determine the existence and magnitude of long-term trends in rainfall patterns over the study period.
- To identify structural breaks and regime shifts in rainfall patterns during 1981–2025.
- To analyze the frequency, intensity, and occurrence of extreme rainfall events in coastal Guyana.

IV. REVIEW OF LITERATURE

Rainfall variability and extreme precipitation have been widely studied due to their strong influence on water resources, agricultural productivity, and climate-related hazards. Understanding how rainfall behaves over time is essential for interpreting climate dynamics and improving planning in regions exposed to hydrological risks. Research has increasingly focused on both gradual changes in rainfall patterns and abrupt shifts, as well as the growing intensity of extreme rainfall events.

At the global level, extreme rainfall has been widely recognized as an important indicator of climate change impacts. Studies highlight that short-duration and high-intensity rainfall events are becoming more severe in many regions, increasing the likelihood of flooding and associated environmental and socio-economic impacts [1]. In hydrological science, statistical approaches have been developed to quantify the probability and magnitude of such extreme events, with extreme value theory forming a core analytical framework [3] [9]. These methods allow researchers to estimate return levels and assess risk associated with rare but high-impact rainfall events.

In the Caribbean region, rainfall variability is strongly influenced by ocean-atmosphere interactions and regional climate drivers, leading to significant spatial and temporal differences in precipitation patterns. Evidence shows that extreme precipitation behaviour in the Greater Caribbean is changing, with links to large-scale sea surface temperature variability and broader climate system changes [2]. This highlights the importance of regional-scale analysis to understand how global climate processes translate into local rainfall impacts.

In Guyana, rainfall plays a central role in agriculture, hydrology, and socio-economic development. The Bureau of Statistics Guyana (2023) provides essential long-term meteorological data that support climate analysis and planning [10]. Historical studies have shown that Guyana's coastal rainfall regime is characterized by strong seasonal variability and bimodal distribution patterns [4]. More recent research has extended this understanding by examining rainfall processes using statistical and modelling approaches. For example, rainfall modelling studies in Guyana have demonstrated the complexity of precipitation occurrence and distribution, highlighting the need for more refined analytical approaches [5] [7]. In addition, rainfall variability has been shown to have direct implications for agricultural systems such as rice cultivation, where fluctuations in rainfall significantly influence productivity outcomes [6].

Beyond seasonal variability, rainfall patterns may also experience gradual trends and abrupt structural changes over time. Non-parametric trend analysis methods are widely used to assess long-term changes in hydro-climatic variables, while structural break techniques help identify shifts in underlying rainfall regimes. The Bai–Perron methodology provides a robust statistical framework for detecting multiple structural changes in time series data [11]. Similarly, change-point detection methods such as the PELT algorithm offer efficient tools for identifying abrupt changes in rainfall behaviour over time [12]. These methods are particularly useful for understanding whether rainfall systems remain stable or undergo episodic shifts.

Extreme rainfall analysis also forms a key component of hydrological research in Guyana and similar regions. The application of extreme value theory enables the estimation of rainfall magnitudes associated with different return periods, which is essential for flood risk assessment and infrastructure design [3] [9] . Such analyses are particularly important in low-lying coastal environments where intense rainfall events can have severe consequences for drainage systems and agricultural land.

The literature indicates that rainfall behaviour is influenced by a combination of seasonal variability, long-term trends, structural shifts, and extreme event dynamics. However, most studies tend to focus on individual aspects of rainfall analysis rather than integrating variability, trend detection, structural change analysis, and extreme value modelling within a single long-term framework. This highlights the need for comprehensive assessments that combine these approaches to better understand rainfall dynamics in coastal Guyana over extended periods.

V. METHODOLOGY

This study was conducted for coastal Guyana, a region characterized by a bimodal rainfall regime with distinct primary and secondary wet seasons [4]. The coastal region is particularly vulnerable to rainfall variability because of its low-lying topography, agricultural importance, and susceptibility to flooding. Monthly rainfall records for the period 1981–2025 were obtained from the Bureau of Statistics Guyana [10] and aggregated into annual rainfall totals where required for statistical analyses.

Temporal rainfall variability was assessed using descriptive statistical techniques. Measures including the mean, median, standard deviation, coefficient of variation, minimum, and maximum rainfall were calculated to summarize the characteristics of annual rainfall over the study period. Annual rainfall time series, rainfall anomaly plots, and monthly rainfall boxplots were used to examine inter-annual variability, seasonal rainfall distribution, and the occurrence of unusually wet or dry periods. Seasonal rainfall characteristics were further evaluated by calculating the mean monthly rainfall and the percentage contribution of each month to the annual rainfall total.

Long-term rainfall trends were evaluated using the non-parametric Mann–Kendall trend test together with Sen's slope estimator. The Mann–Kendall test was applied to determine whether a statistically significant monotonic trend existed in the annual rainfall series, while Sen's slope estimator was used to estimate the magnitude and direction of change expressed in millimetres per year. These methods are widely applied in hydro-climatic studies because they are robust for environmental time-series data and are not highly sensitive to departures from normality.

Structural changes in rainfall behaviour were investigated using the Bai–Perron multiple structural break test and the Pruned Exact Linear Time (PELT) change-point detection method. The Bai–Perron procedure was used to identify statistically significant shifts in the rainfall time series by detecting changes in the underlying regression structure [11]. The PELT algorithm was applied to detect abrupt changes in the statistical properties of the rainfall series, providing an efficient method for identifying rainfall regime shifts within long-term climate records [12]. The combined application of these methods allowed the identification of periods where rainfall behaviour differed from the long-term pattern.

Extreme rainfall characteristics were analysed using the Generalized Extreme Value (GEV) distribution. The GEV model provides a statistical framework for modelling annual rainfall extremes and estimating the probability of rare precipitation events [3] [9]. The location (μ), scale (σ), and shape (ξ) parameters were estimated to describe the distribution of annual rainfall extremes, while model adequacy was assessed using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Return levels were subsequently estimated for selected return periods to evaluate the expected magnitude of extreme rainfall events and their implications for hydrological risk.

A. DATA ANALYSIS

All statistical analyses were undertaken to address the study objectives by examining rainfall variability, evaluating long-term rainfall trends, identifying structural breaks and regime shifts, and assessing the frequency and magnitude of extreme rainfall events. The combination of descriptive statistics, non-parametric trend analysis, structural break detection, and extreme value modelling provided a comprehensive assessment of rainfall behaviour in coastal Guyana during the period 1981–2025. This analytical framework is consistent with approaches commonly used in rainfall and climate variability studies (Rao et al., 2012; Bernard et al., 2025).

VI. RESULTS AND DISCUSSION

This section presents the results of the rainfall analyses conducted for coastal Guyana during the period 1981–2025. The findings describe patterns of rainfall variability, long-term trends, structural changes, and extreme rainfall characteristics, together with their implications for understanding rainfall behaviour in the study area.

A. *Temporal Variability of Monthly and Annual Rainfall*

TABLE I
DESCRIPTIVE STATISTICS

Statistic	Value
Mean annual rainfall (mm)	2278.91
Median rainfall (mm)	2324.9
Standard deviation (mm)	496.65
Coefficient of variation (%)	21.79
Minimum annual rainfall (mm)	1592.2
Maximum annual rainfall (mm)	3541.8

The descriptive statistics indicate that the mean annual rainfall in coastal Guyana during 1981–2025 was 2,278.91 mm, while the median was 2,324.9 mm, suggesting that annual rainfall totals were generally clustered around the central tendency, with a few low-rainfall years slightly reducing the mean. The standard deviation of 496.65 mm demonstrates considerable year-to-year variation in annual rainfall totals, indicating that rainfall fluctuated substantially over the study period. The coefficient of variation of 21.79% further reflects a moderate level of inter-annual rainfall variability, suggesting that although annual rainfall remained relatively consistent overall, noticeable fluctuations occurred between years. Annual rainfall ranged from a minimum of 1,592.2 mm to a maximum of 3,541.8 mm, a difference of 1,949.6 mm, highlighting both relatively dry and exceptionally wet years during the study period. These results demonstrate that rainfall variability in coastal Guyana is characterized by substantial inter-annual fluctuations and strong seasonal differences, indicating that both annual and monthly rainfall patterns must be considered when assessing long-term rainfall behaviour.

Fig. 1 Annual Rainfall time series.

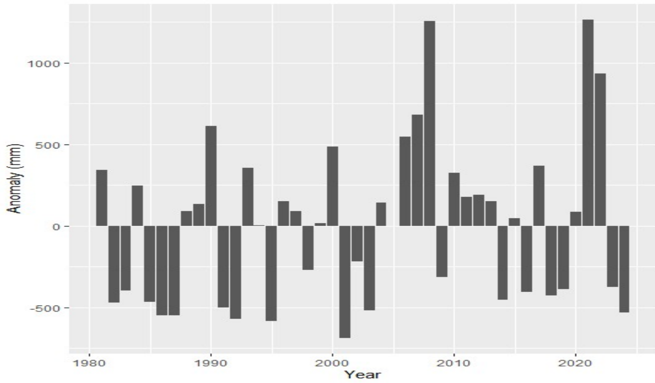

Fig. 2 Rainfall anomaly plot

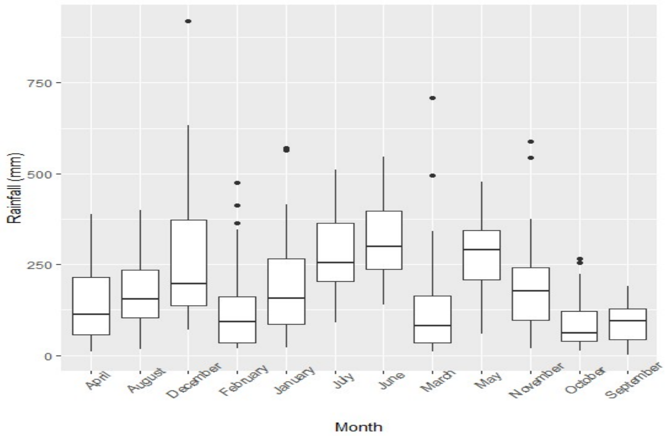

Fig. 3 Monthly rainfall boxplots

The annual rainfall record for coastal Guyana during 1981–2025 exhibits substantial year-to-year variability, with annual totals fluctuating between approximately 1,600 mm and 3,550 mm. Several years experienced exceptionally high rainfall, particularly around 2007 and 2023, while

Comparatively low rainfall totals occurred during the early 1980s, early 1990s, early 2000s, and in 2025. Although annual rainfall varied considerably, no consistent upward or downward trend is visually evident over the study period. The rainfall anomalies further demonstrate this variability by showing alternating positive and negative departures from the long-term mean, indicating that wet and dry years occurred intermittently rather than as prolonged periods of above - or below - average rainfall. Positive anomalies were most pronounced around 2007 and 2023, whereas marked negative anomalies were observed during the early 1980s, early 2000s, and 2025. At the monthly scale, rainfall exhibits a distinct seasonal pattern, with the highest median rainfall occurring during May, June, and July, reflecting the major rainy season, while September and October recorded the lowest median rainfall, representing the driest period of the year. Monthly rainfall variability was greatest during the wetter months, as evidenced by wider interquartile ranges and longer whiskers, indicating greater dispersion in rainfall amounts. Several extreme monthly rainfall events are also apparent, particularly in December, March, May, and November, where outliers indicate rainfall totals that were substantially higher than the typical monthly distribution. These patterns highlight the pronounced seasonal nature of rainfall in coastal Guyana, together with considerable inter-annual fluctuations and the occurrence of occasional extreme rainfall events.

B. *Long-Term Rainfall Trend*

TABLE II
MANN–KENDALL TEST

Statistic	Value
Sen's slope (mm/year)	4.03
95% Confidence Interval (Lower)	-5.85
95% Confidence Interval (Upper)	17.49
Z statistic	1.068
p-value	0.286

TABLE III.
SEN'S SLOP

Statistic	Value
Kendall's Tau (τ)	0.114
S statistic	103
Variance of S	9130.33
Z statistic	1.068
p-value	0.286
Number of years (n)	43

The annual rainfall trend plot indicates a slight upward trend over the study period (1981–2025), as evidenced by the positive slope of the trend line. This observation is supported by the Mann–Kendall trend test, which produced a positive Kendall's Tau ($\tau = 0.114$) and S statistic ($S = 103$), suggesting a weak increasing trend in annual rainfall. However, the calculated Z statistic ($Z = 1.068$) was not statistically significant ($p = 0.286 > 0.05$), indicating that the observed increase in rainfall is insufficient to reject the null hypothesis of no monotonic trend. The Sen's slope estimator further quantified the rate of change as 4.03 mm year^{-1}, implying that annual rainfall increased by approximately 4 mm per year over the study period. Nevertheless, the 95% confidence interval for Sen's slope ranged from −5.85 mm year^{-1} to 17.49 mm year^{-1}, encompassing zero, indicating that the true rate of change could be a slight decrease, no change, or a modest increase in annual rainfall. The results indicate that annual rainfall in coastal Guyana exhibited a weak increasing tendency over the study period; however, the absence of statistical significance suggests that rainfall variability rather than a consistent long-term trend has been the dominant feature of rainfall behaviour between 1981 and 2025.

C. *Structural Breaks and Rainfall Regime Shifts*

TABLE IV
STRUCTURAL BREAK AND CHANGE-POINT DETECTION RESULTS FOR ANNUAL RAINFALL IN COASTAL GUYANA (1981–2025)

Method	Change Point Number	Detected Year
Bai-Perron Structural Break Test	1	2003
PELT Change-Point Detection	1	1985
PELT Change-Point Detection	2	1987

The structural break analysis identified different change points in rainfall patterns depending on the detection method applied. The Bai–Perron Structural Break Test detected one major structural break in 2003, indicating a statistically identified shift in the rainfall series at this point. The PELT (Pruned Exact Linear Time) change-point detection method identified two change points occurring in 1985 and 1987, suggesting earlier variations in the rainfall sequence. The variation in detected years between the two approaches reflects differences in their statistical procedures, with Bai–Perron focusing on changes in the overall regression structure and PELT identifying shifts based on changes in the characteristics of the time series. The detection of multiple change points indicates that rainfall behaviour in coastal Guyana has not remained completely stable throughout the study period. Instead, rainfall patterns have experienced episodic shifts, suggesting that changes in rainfall characteristics occurred through periods of altered variability rather than through a continuous long-term trend.

D. *Extreme Rainfall Characteristics and Return Period Analysis in Coastal Guyana*

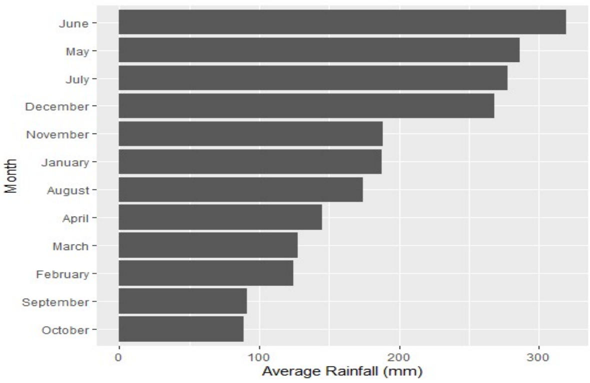

Fig. 4 Average Monthly rainfall

TABLE V
SEASONAL RAINFALL CHARACTERISTICS AND WETTEST MONTHS IN COASTAL GUYANA (1981–2025)

Category	Period/Month	Mean Rainfall (mm)	Contribution (%)
Wet Season	May–July	—	—
Wettest Month	June	319.31	14.01
Wettest Month	May	286.18	12.56
Wettest Month	July	277.91	12.19
Secondary Wet Period	November–December	—	—
Wettest Month	December	268.17	11.77
Wettest Month	November	188.62	8.28

The analysis of monthly rainfall distribution indicates a clear seasonal pattern in coastal Guyana, with the highest rainfall concentrations occurring during the primary wet season from May to July. Among all months, June recorded the highest mean rainfall of 319.31 mm, contributing 14.01% of the total annual rainfall, followed by May (286.18 mm; 12.56%) and July (277.91 mm; 12.19%). This period represents the peak rainfall season, accounting for the largest proportion of rainfall accumulation within the study period. A secondary wet period was observed during November–December, with December recording a mean rainfall of 268.17 mm (11.77%) and November recording 188.62 mm (8.28%), indicating another period of increased rainfall activity. The monthly rainfall distribution further shows lower rainfall totals during September and October, which recorded the smallest contributions, suggesting a relatively drier period within the annual cycle. These patterns demonstrate the seasonal variability of rainfall across coastal Guyana from 1981–2025, with rainfall concentrated mainly during the mid-year wet season and a secondary increase toward the end of the year.

TABLE VI
GENERALIZED EXTREME VALUE (GEV) MODEL PARAMETERS FOR ANNUAL RAINFALL EXTREMES (1981–2025)

Parameter	Estimate	Standard Error
Location(μ)	2043.98	72.22
Scale (σ)	374.23	57.96
Shape (ξ)	0.072	0.198
AIC	654.36	—
BIC	659.65	—

TABLE VII
ESTIMATED EXTREME RAINFALL RETURN LEVELS FOR COASTAL GUYANA (1981–2025)

Return Period	Estimated Rainfall (mm)
10-year	2958.66
25-year	3390.99
50-year	3731.46

The analysis of annual rainfall extremes using the Generalized Extreme Value (GEV) model provides an assessment of the magnitude and probability of extreme rainfall events in coastal Guyana during the period 1981–2025. The annual rainfall series shows considerable year-to-year variability, with several years recording rainfall totals above the long-term average, including notable peaks exceeding 3500 mm. The fitted GEV model produced a location parameter (μ) of 2043.98 mm, representing the central tendency of annual rainfall extremes, while the scale parameter (σ) of 374.23 mm indicates the variability associated with extreme rainfall values. The estimated shape parameter ($\xi = 0.072$) suggests a slightly positive tail behaviour, indicating the potential for unusually high rainfall events beyond the observed range. Model performance statistics showed an AIC value of 654.36 and BIC value of 659.65, which were used to evaluate the suitability of the fitted distribution. The return level estimates indicate that rainfall events of approximately 2958.66 mm may occur over a 10-year return period, increasing to 3390.99 mm for a 25-year return period and 3731.46 mm for a 50-year return period. These estimates demonstrate that while extreme rainfall events occur less frequently, their magnitude increases considerably over longer return periods, emphasizing the importance of incorporating extreme rainfall characteristics into flood risk assessment and climate adaptation planning in coastal Guyana.

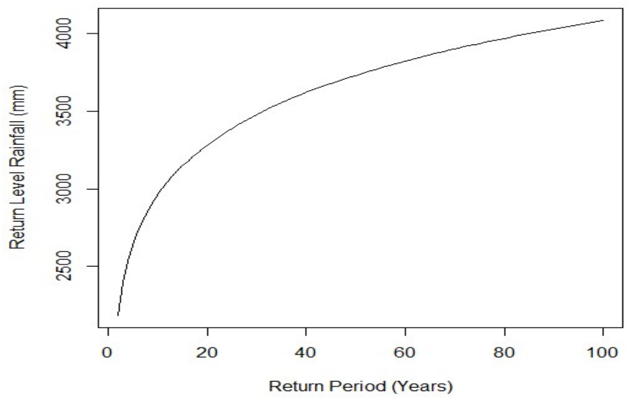

Fig. 5 GEV Return Level Plot for Annual Extreme Rainfall

The return level plot shows a positive, nonlinear relationship between return period and estimated rainfall magnitude, with return levels increasing from approximately 2,200 mm at a 2-year return period to about 4,100 mm at a 100-year return period. The curve exhibits a steep increase at shorter return periods, indicating that relatively small increases in recurrence interval are associated with substantial increases in rainfall depth for more frequent events. As the return period becomes longer, the slope gradually decreases, producing a concave downward pattern that reflects diminishing incremental increases in estimated rainfall for increasingly rare events. This behaviour is consistent with the statistical characteristics of extreme rainfall frequency analyses, where the estimated magnitude of rare events continues to increase with return period but at a progressively slower rate. The return level analysis confirms that coastal Guyana is exposed to potentially high-magnitude rainfall events, with increasing rainfall intensity associated with longer recurrence intervals. These findings highlight the importance of understanding extreme rainfall behaviour for improving flood preparedness, drainage planning, and climate resilience strategies.

VII. CONCLUSION

Rainfall patterns in coastal Guyana during the period 1981–2025 were characterized by considerable temporal variability, marked seasonality, episodic structural shifts, and the occurrence of extreme rainfall events. Rainfall varied substantially between years while maintaining a distinct bimodal seasonal pattern, with the primary wet season occurring from May to July and a secondary wet period during November and December. Although a slight upward tendency in annual rainfall was detected, statistical analyses indicated that this trend was not significant, suggesting that inter-annual variability remains the dominant characteristic of rainfall behaviour in the region.

The analyses further demonstrated that rainfall patterns have not remained constant over time. Structural break and change-point detection methods identified periods of altered rainfall behaviour, indicating that rainfall variability has occurred through episodic shifts rather than a continuous long-term trend. In addition, extreme rainfall analysis showed that the magnitude of rainfall events increases with longer return periods, highlighting the potential for infrequent but severe rainfall events that may increase the risk of flooding and place greater demands on drainage systems, agriculture, infrastructure, and water resource management.

These findings provide a comprehensive assessment of rainfall dynamics in coastal Guyana by integrating rainfall variability, trend analysis, structural break detection, and extreme value modelling within a single framework. The research contributes to the limited body of literature on long-term rainfall behaviour in Guyana and provides evidence that can support climate monitoring, flood risk assessment, infrastructure planning, water resource management, and the development of climate adaptation strategies. Continued monitoring of rainfall patterns and extreme rainfall events will be essential for improving resilience to future climate variability and informing sustainable environmental and development planning in coastal Guyana.

VIII. ACKNOWLEDGEMENT

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