Characterizing Daily Precipitation Extremes in North Central of Nigeria

*Umar Alfa[1], Abubakar Haruna[2]
[1]Department of hydraulic and Civil Engineering Université Grenoble Alpe, France
[2]Université Grenoble Alpe, France

Corresponding author: *Umar Alfa[1]

Abstract:- Extreme rainfall events pose significant challenges to communities, infrastructure, and ecosystems in North Central Nigeria. This research investigates the characteristics and trends of extreme rainfall in the region to enhance our understanding of precipitation variability and its implications for flood risk management. A comprehensive literature review reveals the need for local-scale analysis, distribution fitting, climate change considerations, and community engagement in flood risk mitigation. Mann-Kendall trend tests are conducted across multiple locations (Ilorin, Minna, Jos, and Makurdi) and various time periods (daily, monthly, and annually) to assess significant trends in extreme rainfall. Results indicate a lack of statistically significant trends in daily and monthly rainfall for Ilorin, Jos, and Minna, suggesting the stationarity of the data. In contrast, both daily and monthly rainfall data for Minna and Makurdi exhibit significant upward trends, emphasizing the increasing intensity of rainfall events in these areas.

Furthermore, the study applies the Generalized Extreme Value (GEV) distribution using different method (Maximum likelihood method, L-moment and Method of moment), the L-Moments method, to fit extreme rainfall data. The methodological approach demonstrates superior goodness-of-fit measures, supporting its preference for modeling extreme events in North Central Nigeria.

The return level analysis based on the L-Moments method highlights increasing return levels with longer return periods, indicating a heightened potential for extreme precipitation. Return level estimates provide valuable insights for flood risk assessment and infrastructure planning.

Keywords:- *Precipitation, Time Series, North Central and Nigeria.*

I. INTRODUCTION

Extreme rainfall events play a pivotal role in instigating devastating floods, emerging as a major global natural disaster with severe implications for human lives, infrastructure, and the environment. The escalating frequency and intensity of extreme weather phenomena, particularly heavy rainfall, have heightened the risk of flooding across numerous regions. In North Central Nigeria, a region renowned for its agricultural productivity and exposed communities, comprehending the characteristics of daily precipitation extremes holds paramount importance for effective flood risk assessment and decision-making.

Floods inflict catastrophic consequences, encompassing loss of life, infrastructural devastation, and livelihood disruption. North Central Nigeria faces a heightened vulnerability to flooding due to its geographic attributes, including rivers and low-lying areas, coupled with a dense population. This region experiences dual rainfall seasons, characterized by intense rainfall events during the long rainy season from April to October and the short rainy season from March to November, resulting in flash floods and river overflow.

Effective flood risk management necessitates an in-depth understanding of the statistical attributes of extreme rainfall occurrences. The endeavor to characterize daily precipitation extremes in North Central Nigeria seeks to provide critical insights into the magnitude, frequency, and return periods of such events. The research's significance lies in its potential to enhance flood risk assessment and management strategies. By elucidating the features of daily precipitation extremes, encompassing their spatial and temporal dynamics, decision-makers can judiciously plan land use, design infrastructure resilient to flooding, and formulate emergency preparedness measures. Accurate knowledge of extreme rainfall events is instrumental in establishing criteria for drainage systems, dams, reservoirs, and developing early warning systems to mitigate floods' impact on vulnerable communities.

To accomplish these research objectives, an extensive dataset of daily precipitation records will be meticulously collected and subjected to rigorous quality control measures. The study area encompasses North Central Nigeria, encompassing states like Benue, Plateau, Nasarawa, and Kogi, characterized by diverse climatic conditions and land cover types. The research methodology encompasses data preprocessing, exploratory data analysis, and the application of extreme value analysis techniques. The Generalized Extreme Value (GEV) distribution, along with estimation methods and goodness-of-fit assessments, will be employed to model extreme events and estimate return levels.

Moreover, uncertainty analysis will be conducted to quantify the uncertainty associated with return level estimations, providing a comprehensive understanding of potential extreme precipitation scenarios and associated risks. In conclusion, comprehending daily precipitation extremes in North Central Nigeria is instrumental in improving flood risk assessment and decision-making. This research endeavors to unravel the statistical properties of extreme rainfall, shedding light on their temporal and spatial patterns. Ultimately, this knowledge will empower enhanced flood risk management strategies, fostering better planning and decision-making to safeguard vulnerable communities and infrastructure.

II. STUDY AREA

The research area is North Central Nigeria, it comprises of the seven states situated physically in the center belt region of the country, ranging from the west, near the confluence of the River Niger and the River Benue. The region itself is rich in natural land features, and boasts some of Nigeria's most fascinating scenery. The study focuses on four states, which are, Niger, Plateau Makurdi and Kwara State (Figure 1.).

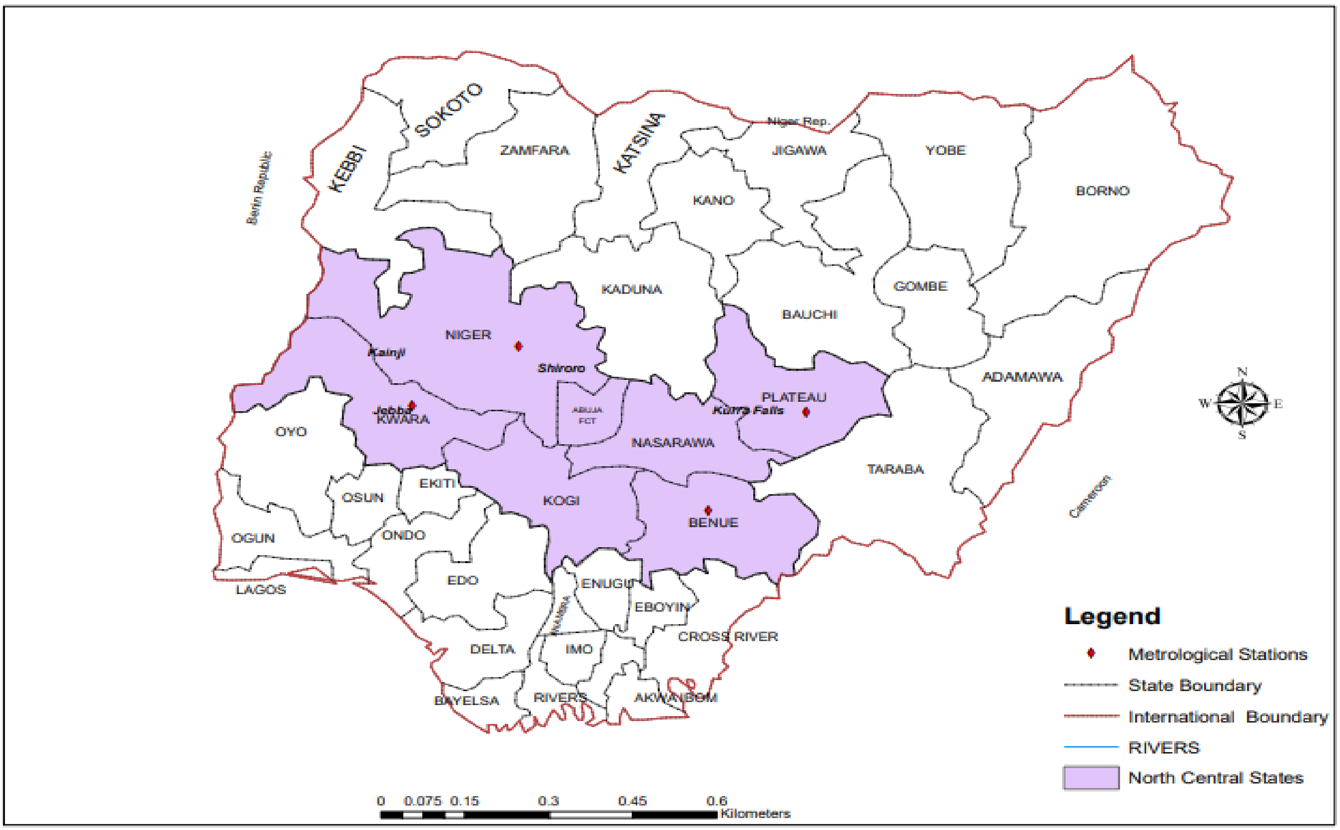

Fig 1 Location of Selected States in North Central Nigeria

III. MATERIALS AND METHODS

A. *Materials*

The data used in this study include monthly rainfall (mm) for four synoptic stations in north central parts of Nigeria from the Nigerian Meteorological Agency for the period of 1981 to 2020. Interpolation and averaging for missing data were done for Minna, Jos, Makurdi and Ilorin.

B. *Method*

➢ *Stationarity Test*

In order to satisfy the stationarity assumption required for Generalized Extreme Value (GEV) distribution analysis, the Mann-Kendall (MK) test was employed to investigate potential trends over different selection periods within the data. The Mann-Kendall trend test is a widely accepted non-parametric method for assessing monotonic trends in time series data. Its applicability extends to datasets with non-normal distribution, making it particularly suited for analyzing datasets with missing or tied data. In this study, we focused on the annual maximum daily rainfall series.

For a given variable "m," with "t" denoting the year index ranging from 1 to T (total number of years in the dataset), the differences in data values between different time steps were calculated as:

$$(t1, t2) = Mt2 - Mt1$$

where "t2" > "t1."

The test statistic "N" was then computed as:

$$N = \sum \sum sgn[dt\ ,t]$$

Here, $[dt, t]$ denotes the sign of dt, t. The test statistic "N" represents the number of times "mt2" is greater than "mt1" minus the number of times "mt1" is greater than "mt2" for all possible combinations of "mt1" and "mt2" with "t2" > "t1." A positive value of "N" implies that the time series increased more frequently than it decreased (and vice versa for a negative value of "N"). The value of "N" is bounded by "T(T-1)/2."

Kendall's τ is a normalized version of this statistic, obtained by dividing by this upper bound:

$$\tau = 2N / [(T - 1)]$$

Assuming the data are serially independent, the null hypothesis can be approximated by a normal distribution. H0 is rejected when the test statistic is less than the critical value corresponding to a 5% two-sided significance level.

- *Stationary Generalized Extreme Value Distribution (GEV)*

The Generalized Extreme Value (GEV) distribution is a family of continuous probability distributions employed within extreme value theory (EVT), encompassing the Gumbel, Fréchet, and Weibull families. It is characterized by three parameters: shape (ξ), location (μ), and scale (σ). The choice of which type of GEV distribution to use depends on the underlying behavior of the data's tails.

The cumulative distribution function (CDF) of the GEV distribution is defined as:

$$(x; \mu, \sigma, \xi) = \{\ \exp(-1 + \xi(x - \mu)/\sigma)\ \text{ if } \xi \neq 0$$

$$\exp(-\exp((x - \mu)/\sigma)) \quad \text{ if } \xi = 0\}$$

The parameters of the GEV distribution are typically estimated using the method of maximum likelihood (MLE), L-Moments, or the Method of Moments.

- *L-Moments*

The L-Moments method involves calculating linear combinations of order statistics from the data to estimate the parameters of the GEV distribution:

- L-CV (Coefficient of Variation): Estimates the scale parameter (σ) and is calculated as L2 / L1.
- L-Skewness: Estimates the skewness parameter (ξ) and is calculated as L3 / L2.
- L-Kurtosis: Estimates the kurtosis parameter (κ) and is calculated as L4 / L2.
- L-Moments are derived from order statistics of the dataset.

- *Method of Moments*

The Method of Moments estimates the GEV distribution parameters by matching the theoretical moments of the distribution with the sample moments from the data.

- Estimating the Location Parameter (μ): $\mu = \bar{X}$ (sample mean).
- Estimating the Scale Parameter (σ): σ = s (sample standard deviation).
- Estimating the Shape Parameter (ξ): ξ is determined by solving an equation involving sample skewness (G3) and the gamma function.

C. Model Selection

To select the best-fitting GEV model among the different estimation methods (MLE, L-Moments, and Method of Moments), several criteria are employed, including the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Likelihood Ratio Test (LRT). These criteria help identify the model that balances goodness of fit with model complexity, thereby preventing overfitting.

- *Akaike Information Criterion (AIC):*

AIC quantifies the relative quality of statistical models and is calculated as AIC = -2 * log-likelihood + 2 * number of model parameters. Lower AIC values indicate better fit.

- *Bayesian Information Criterion (BIC):*

Similar to AIC but with a stronger penalty for complexity, calculated as BIC = -2 * log-likelihood + log(n) * number of parameters, where "n" is the sample size. Lower BIC values suggest better fit.

- *Likelihood Ratio Test (LRT):*

A statistical test that compares nested models by assessing whether the more complex model significantly improves the fit compared to the simpler model. It relies on the difference in log-likelihood values and uses the chi-square distribution for hypothesis testing.

D. Return Level

Once the best-fitting GEV model has been determined, the return level of extreme daily rainfall is derived. The return level represents the level of extreme rainfall expected to be exceeded with a certain probability (typically expressed as a return period, e.g., 100 years). The return level is estimated by inverting the cumulative function of the GEV distribution.

- When $\xi \neq 0$: $z = \sigma(1 - (-\log(1 - p))^{\wedge}(1/\xi)) + \mu$

For GEV model:

- When $\xi = 0$: $z = \mu - \sigma * \log(-\log(1 - p))$

Where "p" is the desired probability of occurrence (e.g., 1/100 for a 100-year return level). The parameters of the GEV distribution, estimated using the selected method, are used in this computation.

IV. RESULTS AND DISCUSSION

A. Stationary Test

Table 1 Stationary Test

LOCATION	PERIOD	TEST STATISTIC	P-VALUE	DESCRIPTION
	Daily	-0.00416	0.51179	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series
Ilorin	Mothly	0.0555	0.073225	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series
	Annually	0.160000	0.14851	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series
	Daily	3.784699	0.000153895	Reject the null hypothesis. There exists a trend in the extreme rainfall series.
Minna	Mothly	3.784699	0.000153895	Reject the null hypothesis. There exists a trend in the extreme rainfall series.
	Annually	3.784699	0.3051931	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series.
	Daily	1.666579	0.09559805	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series.
Jos	Mothly	1.666579	0.09559805	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series.
	Annually	1.666579	0.1053411	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series.
	Daily	3.083626	0.002044943	Reject the null hypothesis. There exists a trend in the extreme rainfall series
Makurdi	Mothly	3.083626	0.002044943	Reject the null hypothesis. There exists a trend in the extreme rainfall series.
	Annually	3.083626	0.09801394	Fail to reject the null hypothesis. There is no significant trend in the extreme rainfall series

The Mann-Kendall trend analysis examined extreme rainfall patterns in North Central Nigeria. Ilorin had no significant trends in daily, monthly, or annual rainfall. Minna showed a significant upward trend in daily and monthly rainfall but not annually. Jos displayed no significant trends. Makurdi had significant upward trends in daily and monthly rainfall but not annually. These findings suggest that extreme rainfall in these areas is generally stationary, supporting the use of the Generalized Extreme Value (GEV) distribution for risk assessment and management of extreme weather events.

B. Data Analysis and Interpretation

The analysis of daily precipitation extremes across different stations in North Central Nigeria revealed significant insights into rainfall patterns and their implications for flood risk management. In Ilorin Station, mean daily precipitation ranged from 1.91 mm to 6.97 mm, with extreme events like the 194.3 mm recorded in 2014 emphasizing the need for further investigation into intense rainfall factors. Jos Station exhibited mean daily precipitation ranging from 2.23 mm to 6.97 mm, with a peak of 149.4 mm in 2016, indicating susceptibility to intense rainfall and flood risks. Minna Station's analysis showed mean daily precipitation between 2.24 mm and 4.82 mm, with a maximum of 107.2 mm in 2020, underlining the potential for intense rainfall and consequent flooding. Makurdi Station displayed mean daily precipitation ranging from 2.09 mm to 4.83 mm, with a peak of 174.1 mm in 2015, highlighting the potential for intense rainfall events contributing to flooding risks. These findings underscore the importance of understanding long-term precipitation patterns for effective flood risk management, resilient infrastructure, and adaptive planning in North Central Nigeria.

C. Fitting Gev Distribution

➢ *Ilorin Station*

Table 2 Fitted Gev Distribution for Ilorin Station

Station	METHOD	PARAMETER		INFORMATION CRITERION	
	Maximum Likelihood Estimation (MLE)	Location	56.97796250	AIC	326.5213
		Scale	11.09994224	BIC	331.5879
		Shape	0.03213858		
		Location	56.52862736	AIC	326.792

Jos Station	L-Moments Estimation	Scale	10.76460997		
				BIC	331.8586
		Shape	0.08996581		
	Method of Moments (MME)	Location	56.97796250	AIC	326.5213
		Scale	11.09994224		
				BIC	331.5879
		Shape	0.03213858		
Minna Station	Maximum Likelihood Estimation (MLE)	Location	74.0452756	AIC	342.5711
		Scale	14.9478424		
				BIC	347.6378
		Shape	-0.1466402		
	L-Moments Estimation	Location	73.8052456	AIC	342.7806
		Scale	15.6941802		
				BIC	347.8473
		Shape	-0.1418801		
	Method of Moments (MME)	Location	74.0452756	AIC	342.5711
		Scale	14.9478424		
				BIC	347.6378
		Shape	-0.1466402		
Makurdi Station	Maximum Likelihood Estimation (MLE)	Location	77.73213274	AIC	375.714
		Scale	20.94646718		
				BIC	380.7806
		Shape	0.00251628		
	L-Moments Estimation	Location	77.09239668	AIC	375.8628
		Scale	20.52476005		
				BIC	380.9295
		Shape	0.04510151		
	Method of Moments (MME)	Location	77.73213274	AIC	363.714
		Scale	20.94646718		
				BIC	358.6474
		Shape	0.00251628		
Ilorin Station	Maximum Likelihood Estimation (MLE)	Location	79.55126842	AIC	387.0671
		Scale	23.14908719		
		Shape	0.06810165	BIC	392.1337
	` L-Moments Estimation	Location	79.46030761	AIC	386.9118
		Scale	24.22303146		
				BIC	391.9784
		Shape	0.04520654		
	Method of Moments (MME)	Location	79.55126842	AIC	387.0671
		Scale	23.14908719		
				BIC	392.9784
		Shape	0.06810165		

Across all the four (4) other stations, the Maximum Likelihood Estimation (MLE) and Method of Moments (MME) methods yield similar parameter estimates for location, scale, and shape. However, the L-Moments method's parameter estimates slightly differ, indicating its unique approach to characterizing the distribution.

Regarding model fit and complexity, the L-Moments method consistently demonstrates lower AIC and BIC values compared to MLE and MME. This suggests that the L-Moments method strikes a favorable balance between model fit and complexity, highlighting its effectiveness in accurately capturing extreme rainfall behavior while maintaining relative simplicity.

These trends hold true across different stations, underlining the robustness of the L-Moments method for extreme value analysis. The L-Moments method's ability to offer accurate parameter estimates and superior goodness-of-fit measures positions it as a preferred choice for fitting the Generalized Extreme Value (GEV) distribution to the given rainfall data.

In summary, the L-Moments method emerges as a consistent and suitable choice across stations, showcasing its potential for accurately characterizing extreme rainfall patterns. The method's preference is reinforced by its superior AIC and BIC values, affirming its crucial role in achieving the research objectives related to extreme value analysis and hydrological risk assessment.

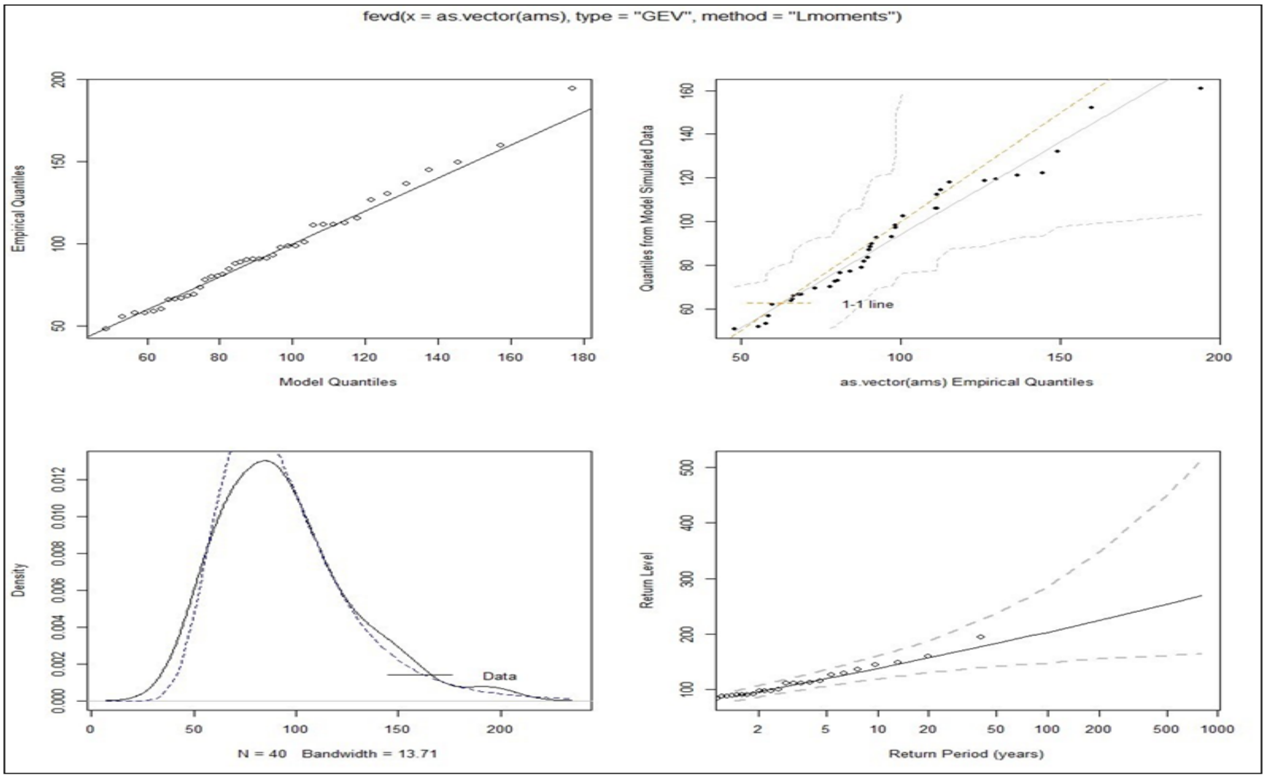

Fig 2 Plots and Analysis (L-Moments Method) for Ilorin.

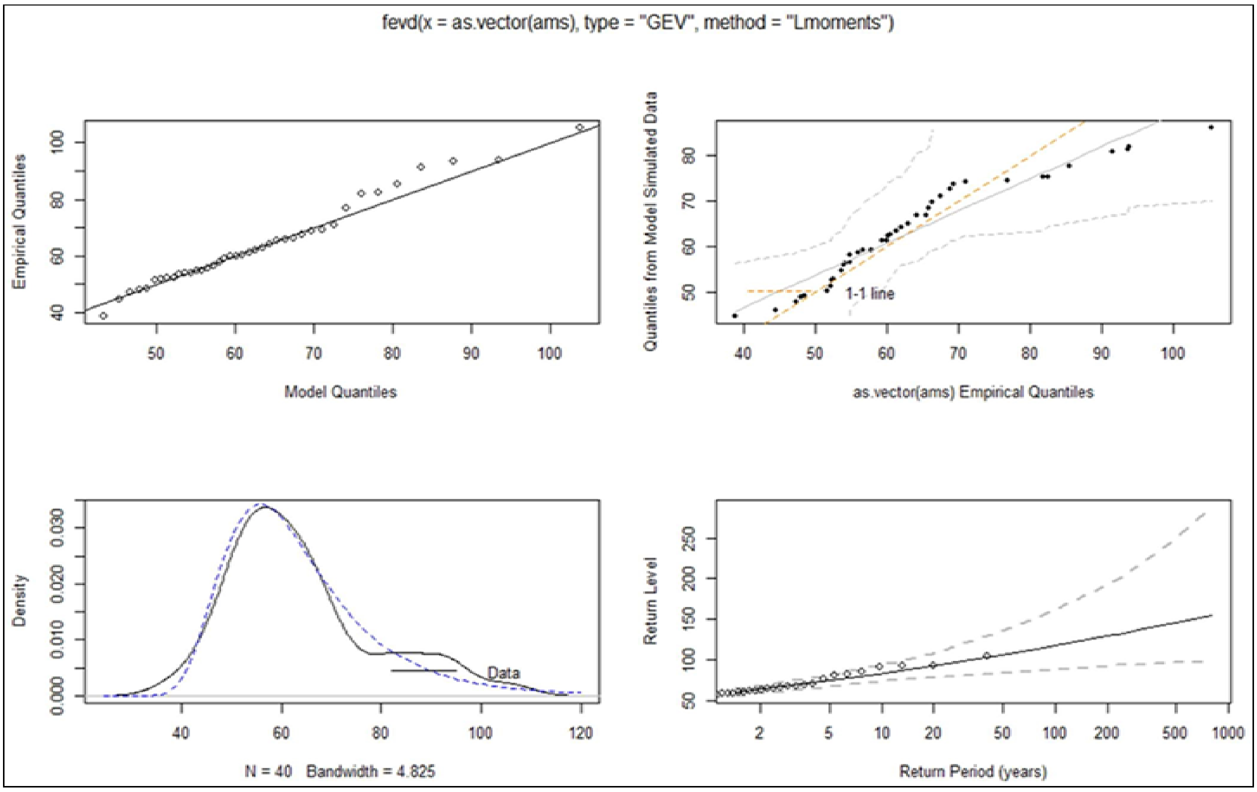

Fig 3 Plots and Analysis (L-Moments Method) for Jos

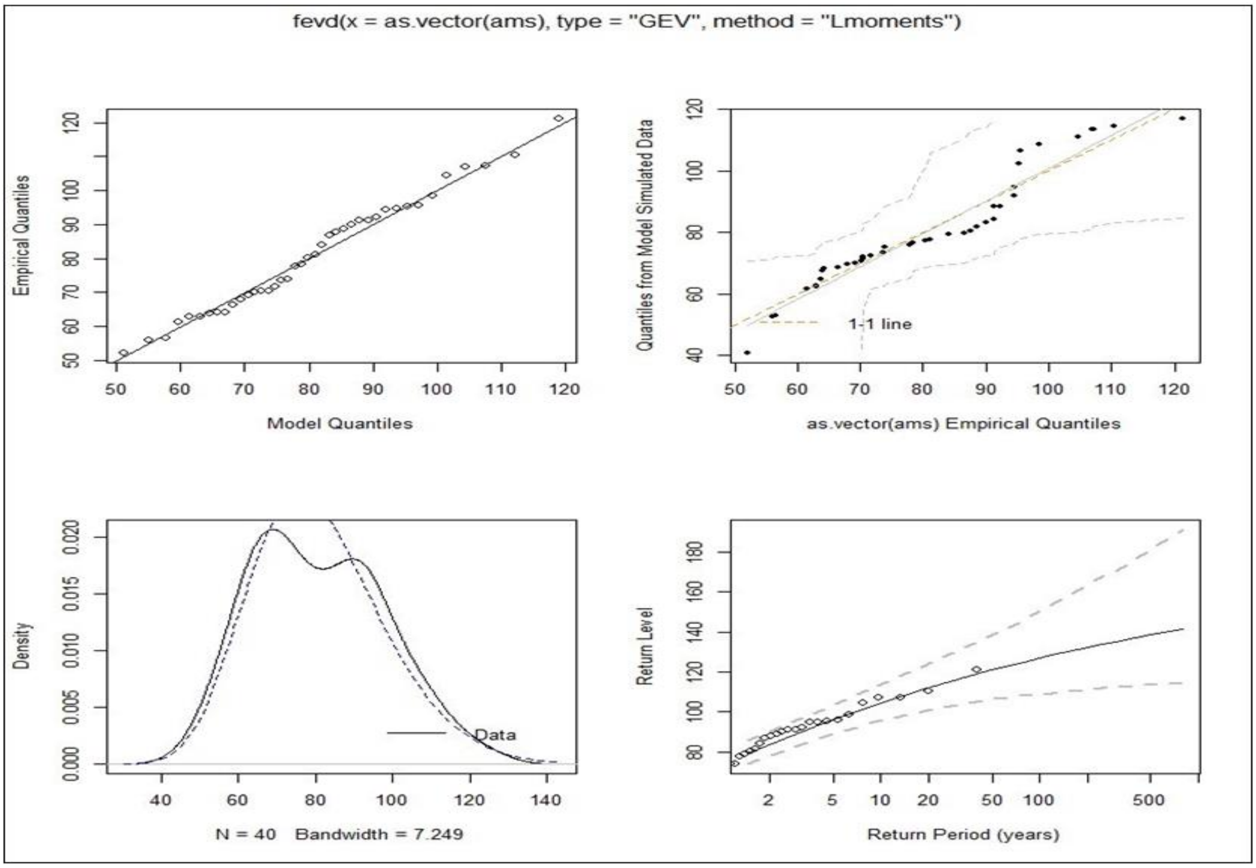

Fig 4 Plots and Analysis (L-Moments Method) for Minna Station

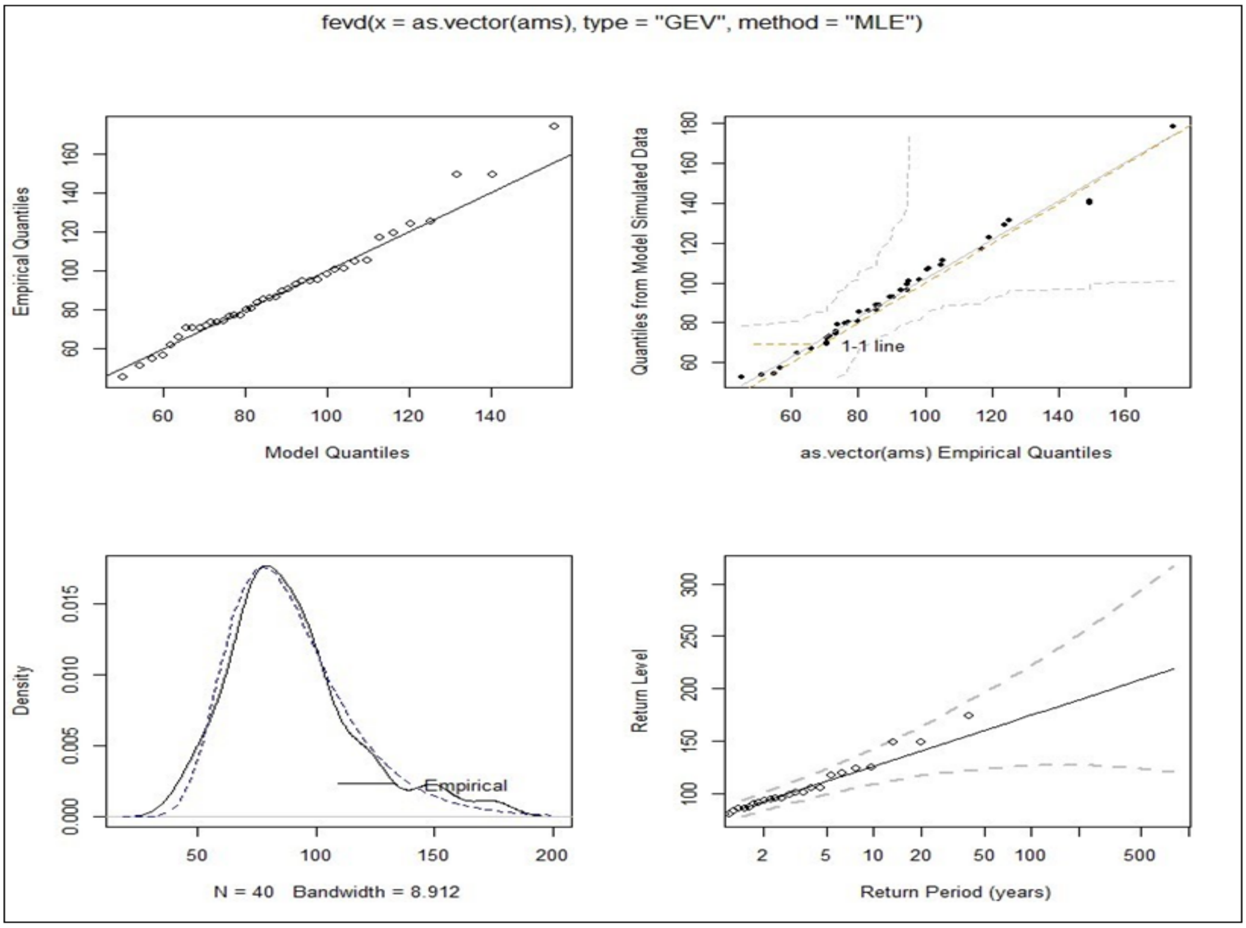

Fig 5 Plots and Analysis (L-Moments Method) for Makurdi

Summary Evaluation of Plots and Analyses for Study area (Jos, Minna and Makurdi and ilorin) using L-Moments Method.

Upon meticulous examination of this comprehensive diagnostic plot, a notable pattern emerges. The Q-Q plot, P-P plot, Return Level Plot, and Empirical Density Plot collectively exhibit a remarkable harmony between the fitted GEV distribution and the observed data. The S-shaped curve in the P-P plot aligns gracefully, indicative of a strong agreement between the CDFs. The return level plot establishes a coherent link between return periods and extreme values, while the empirical density plot showcases a commendable concurrence between the two distributions.

The culmination of these positive indicators, substantiated by rigorous statistical evaluation, lends credence to the appropriateness of the L-Moments-based GEV distribution for modeling extreme values at the Jos, Minna, and Makurdi stations. This diagnostic plot underscores the effectiveness of the chosen method in capturing the extreme behavior within the data. However, it's imperative to acknowledge that a holistic assessment should encompass additional statistical tests and diagnostic tools to fortify the reliability of the selected distributional model.

Table 3 Estimated return levels for extreme rainfall events, calculated using the L-Moments method for Jos station, Minna Station, Ilorin Station and Makurdi Station

Return Period (Years)	Estimated Return Level (mm) (Jos station)	Estimated Return Level (mm) (Minna Station)	Estimated Return Level (mm) (Markurdi Station)	Estimated Return Level (mm) (Ilorin)
2	60.5	79.4	84.7	88.4
5	73.8	95.0	108.9	117.1
10	83.4	104.0	125.7	136.8
20	93.2	111.8	142.3	156.5
50	106.8	120.8	164.7	182.8
100	117.9	126.8	182.0	203.3

This table showcases the summary estimated return levels in millimeters for various return periods at three different stations: Jos, Minna ilorin and Makurdi. As the return period increases, there's an escalation in the estimated return levels, illustrating the heightened potential for extreme precipitation. Among these stations, ilorin consistently records the highest return levels, indicating its elevated susceptibility to intense rainfall events and potential flooding. Makurdi follows with moderately elevated levels, while Jos and Minna displays relatively lower return levels. This information offers valuable insights for flood risk assessment, infrastructure planning, and disaster management tailored to the unique conditions of each station.

V. CONCLUSION

In conclusion, the outcomes and discussions outlined in this chapter offer a comprehensive analysis of extreme rainfall patterns across distinct North Central Nigeria locations. Through the utilization of Mann-Kendall trend tests, significant and non-significant trends in precipitation extremes have been identified, shedding light on the diverse behaviors exhibited in various areas.

An in-depth examination of three fitting methods - Maximum Likelihood, L-Moments, and Method of Moments - for the Generalized Extreme Value (GEV) distribution has highlighted the superior performance of the L-Moments approach. This method has showcased its robust adaptability to the observed extreme rainfall data, a validation strengthened by the visualization provided by several diagnostic plots, such as the Quantile-Quantile (Q-Q) plot, ProbabilityProbability (P-P) plot, and Return Level plot.

Furthermore, the estimation of return levels through the L-Moments method hasfurnished invaluable insights into the intensity and recurrence of extreme rainfall events across various return periods. Notably, Ilorin stands out with consistently elevated return levels, signifying its heightened vulnerability to heavy rainfall and potential flooding. Similarly, Makurdi exhibits moderately increased levels, whereas Jos displays comparatively lower return levels. These estimations offer a profound understanding of the region's susceptibility to intense rainfall and its implications for effective flood risk management, strategic infrastructure planning, and proactive disaster preparedness strategies

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