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Analysis of Annual Maximum Daily Rainfall at Selected Locations in Central Nigeria.

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a b s t r a c t

In recent times, there has been an intensification in the occurrence of extreme rainfall events, necessitating the need for a deeper understanding of the behaviour of these extreme events. Using the Generalised Extreme Value distribution, this study analysed the probability of occurrence and behaviour of annual maximum daily rainfall at Abuja, Lafia, and Lokoja in the central region of Nigeria between 1989 and 2023. The parameters of the Generalised Extreme Value distribution were estimated using the maximum likelihood method, and the return levels were computed 2, 5, 10 and, 25, 50, 100 and 200 years return period. The results of the Mann-Kendall trend test and Sen's slope estimator revealed significant declining and increasing trends of 1.1 mm/yr and 2.0 mm/yr at Abuja and Lafia, respectively and no trend at Lokoja. The Augmented Dickey-Fuller test indicated non-stationarity in the time series of annual maximum daily rainfall at Abuja and Lafia, while stationarity was accepted for Lokoja. The results of the distribution fitting showed that the Weibull distribution was the best fit distribution for Abuja, while the Fréchet distribution was the most appropriate for Lafia, and Lokoja. Relative to the return periods, the estimated return level for the 2-year return varied between 75.4 mm and 103.3 mm of rainfall, while the 200-year return period varied between 168.3 mm and 224.8 mm of rainfall. These findings emphasize the need for further deepening of the understanding of extreme rainfall events to improve community resilience to hydrometeorological hazards such as flooding.

1. Introduction

Accurate information on rainfall extremes is of great importance due to its applicability in flood assessment, mitigation and risk management. The knowledge on rainfall extremes is also important for agricultural planning and loss prevention, and general water resources management. In the absence of this information, the attainment of SDG 11.5 (water-related disaster management), SDG 13 (climate action), and SDG 2 (Zero hunger) by 2030 would be difficult to achieve.

On a global scale, Westra et al (2013) have shown that many locations around the world are exhibiting increasing trends in annual maximum daily precipitation. Such increasing trends can result in adverse environmental and socio-economic impacts such as flooding and increased sedimentation of rivers, soil erosion, loss of crops, damage to infrastructure, and displacement of the vulnerable population. These adverse conditions are likely to be exacerbated under increasing global temperatures as most regions of the world are projected to experience an increase in extreme precipitation based on the sixth assessment report of the Intergovernmental Panel on Climate Change [IPCC] (Seneviratne et al., 2021).

Across several states and communities in Nigeria, extreme daily rainfall has sometimes resulted in severe flooding, with concomitant loss of lives and properties, as well as displacement of people and loss of livelihoods.

According to Umar and Gray (2022), between 2011 and 2022, Nigeria recorded 103 flood incidents, with a total flood-related fatalities of   1, 187 persons and damage to properties worth $940.5 million. Within the same period, the central states of the country recorded a total of 20 flooding incidents.

The increasing trends of extreme rainfall events in different parts of the world (e.g., Rajeevan et al., 2008; Olafsdottir, et al., 2021) and the need for adequate mitigation measures and provision of resilient hydraulic structures have prompted some studies aimed that analysing the probability of occurrence of specific maximum daily rainfall in different countries across the world using different Extreme Value Distribution models. Such models include the Normal, Log-Normal, Pearson Type III, Log-Pearson Type III, Exponential, Gumbel, Weibull, Halpen Types A, B and B^{-1}, Generalised Logistic, Generalised Pareto (GPD), and the Generalised Extreme-Value (GEV) distribution Models (Stedinger et al., 1993). Among these distribution models GEV is one of the most widely used for the modelling of extreme hydrometeorological events for various reasons. These include its flexibility and adaptability making it effective in modelling different datasets with different statistical characteristics (Anghel and Ianculescu, 2025). Others include its suitability in fitting bock maxima data (Towler et al., 2020), its descriptive and predictive abilities without any a priori constraint, and its robustness in estimating quantiles of distribution as well as its capacity for allowing predictions about return levels of extreme hydrometeorological events (de Carvalho et al., 2014). Furthermore, its emphasis on the upper tail of a distribution, compared with other statistical approaches makes it more accurate for estimating the probability of low-frequency high magnitude

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rainfall events (Renteria, 2026). Despite these advantages the GEV model is beset with uncertainty in the estimation of GEV parameters for rainfall data due to the challenges in fitting the distribution which could further be compounded by factors such as complex topography and changes in climatic conditions (Hossain et al., 2021).

In different parts of the world the GEV distribution has been used to model extreme rainfall for various return periods and different return levels. For example, Feng et al., (2007) used the GEV distribution to model annual maximum rainfall for daily, 2-day, 5-day, and 10-durations in China. The results of the study indicated that the 50-year return level in some parts of the country was becoming less frequent than the 25-year return levels. Using the GEV distribution, Carvalho et al (2014), analysed the annual maximum daily rainfall across three regions in Brazil. The results of the study revealed a decline in the return period of rainfall greater than 100mm in all the regions. The results also indicated that the best fit distribution for the Midwest and southeast regions of the country was the Weibull distribution, while the Fréchet distribution was the best fit for the southern region. Ahammed et al., (2014) estimated the return periods of extreme rainfall events for 57 years in Dhaka, Bangladesh. Their findings show that, amongst others that, annual daily maximum rainfall that is equal to or exceeds 425mm has a return period of 100 years.

Within the African continent there are a number of studies that have modelled and estimate the return periods and return levels of extreme rainfall using the GEV model (or the GEV model in combination with other models). Modelling the maximum daily annual rainfall received in northern Algeria between 1936 and 2009, the results obtained by Boudrissa et al., (2017) indicated that Gumbel and Fréchet type distributions were the best fit distributions for the analysed locations within the region. The study further showed increases in estimated return levels with increasing return periods. In a study to identify the most effective covariates of extreme daily rainfall of different durations in the Southern highland region of Tanzania, Kyojo et al., (2024), identified local temperature changes and urbanisation as the most effective covariates for 1-day duration rainfall dataset, while Global Temperature Anomaly, El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) were considered most suitable covariates for the 3-, and 5-day duration rainfall. The study also showed that the return levels for extreme rainfall events in the area exhibited a rising trend with increasing return period. Over the northwestern highlands of Ethiopia, Shang et al., (2010) found no evidence of increasing trends in extreme rainfall and concluded that the 100-year return level had not increased significantly

In the West African sub-region, a number of studies based on the GEV distribution as a model for extreme value analysis of rainfall exists in literature. In Benin Republic, Obada et al., (2025) modelled the maximum daily rainfall over 15-gauge stations for a 100 year period. The results obtained indicated that non-stationary GEV distribution model were well suited for rainfall time series that exhibited significant trends while the stationary GEV distribution model was the best fit for rainfall dataset with non-significant trends.

For a study modelling extreme rainfall along the coastal and northern parts of Ghana using the GEV and the GPD models, Twumasiankrah et al., (2024) found that the GEV model exhibited the best fit for extreme rainfall in the northern part of the country. Using a combination of spatial interpolation of GEV distribution parameters and spatial maximum estimation, Panthou et al., (2012) modelled and interpolated the parameters of extreme rainfall in the central Sahel covering Niamey (Niger Republic) and Quagadougou (Burkina-Faso). The results showed amongst others that the spatial maximum likelihood approach performed better in predicting extreme rainfall within the region.

In Nigeria, Agbonye and Izinyon et al., (2017) used six probability distributions to model annual maximum daily rainfall for three cities in the south-eastern part of the country. The findings from the study indicated that the GEV distribution was the best-fit distribution model for the three cities. Similarly, Awode et al., (2025) modelled extreme rainfall events over south-western Nigeria using both the GEV and Gumbel distributions. A major finding from their study is that the GEV distribution provided a better fit compared to Gumbel distribution. The study also showed that estimated return levels from the Gumbel distribution was higher in magnitude than the estimates from GEV distribution. In addition, Kane et al., (2023) employed the GEV and GPD to model and forecast maximum annual rainfall over Katsina in Northwest Nigeria. Their findings showed that while the Fréchet distribution was the best-fit distribution within the GEV model, the ordinary Pareto distribution performed better for rainfall above a certain threshold.

A major similarity among the literatures cited above is that at most of the locations studied, the return levels of extreme rainfall generally increase with return period. This seems to suggest that time progresses, the return levels of extreme rainfall will continue to increase across different regions of the world.

Despite the vulnerability of certain locations within the central region of Nigeria to flooding, which is sometimes triggered by extreme rainfall events, there is limited information on the probability of occurrence and behaviour of extreme rainfall in this region, especially within the selected study locations. Insights provided by such information is very important for the development of early warning systems, which could help in boosting livelihood resilience and preventing the loss of lives and properties. In light of these, this study aims to model the annual maximum daily rainfall at selected locations in central Nigeria using the GEV distribution to understand the behaviour of maximum rainfall in the region.

Materials and Methods
Study Area
The three selected locations (Fig.1) representing Nigeria's central region are geographically located approximately between Longitudes 5º29'39.98"E to 9º41'58.64"E and latitudes 6º31'47.99"N to 9º22'11.13"N.

The topography and terrain of the study domain is made up of a combination of hills and undulating plains of varying elevations. At the Federal Capital Territory (FCT) Abuja, the elevation varies between 70 m above sea level (a.s.l) in the extreme south-western parts in the Gurara River floodplains to over 760 m a.s.l in the northern part of the territory. The landscape features different hills which occur in clusters or long ranges, as well as several inselbergs. The most prominent of these hills are the Gawu range of hills in the northwest, the Gurfata range southwest of Suleja, the Bwari-Aso range in the northeast, the Idon Kasa range northwest of Kujeand the Wuna range north of Gwagwalada. In between the major hills are extensive plains such as the Gwagwa plains, the Iku-Gurara plains, the Robo plains, and the Rubochi plains (Abumere, 1993). At Lafia, the terrain is dominated by undulating lowlands, with the lowest elevation around 132 m a.s.l and the highest at about 224 m a.s.l. (Ma'aji et al., 2019). The area comprises of a few large and small disconnected hills such as the Konakancae, Monkar, Shishem and Ngolo which are located along the north-eastern boundary of the city. At Lokoja, the landscape is made up of undulating plains dotted with residual hills of varying shapes and sizes. These hills which are characterised by irregularly shaped peaks include the Agbaja hill and Mount Patti (Ukoeje and Achegulu, 2021). The elevation of Lokoja between 45 and 125 m a.s.l.

Hydrologically, the study area lies entirely with the catchment of Rivers Niger and Benue, and their various tributaries. Within the FCT and environs, several rivers which include Gwagwalada, Usmanu, Wupa and Wosika drains the landscape. The drainage pattern of the area varies from trellis to dendritic. (Akoachere et al., 2019). At Lafia, much of the city is drained by Rivers Gwayaka and Mada, and their tributaries which include Feferuwa, Ntirim and Rafin Gora which drain the eastern part of the area, and Lange, Ehula, and Agbabija which drain the western part. The drainage pattern is dendritic, reflecting the geomorphic and geologic uniformity of the area (Ifediegwu, 2022). At Lokoja, a post confluence river formed by Rivers Niger and Benue flows downstream for 350 km before emptying into the Niger Delta and subsequently into the Gulf of Guinea (Lawal and Omosanya, 2023). The location on the bank of the confluence of the River Niger and Benue makes it vulnerable to flooding (Buba et al., 2021).

According to Iloeje (1981), the climate of the region is a tropical continental type or Koppen's Aw. It is characterised by two seasons, namely the dry season and the rainy season. Rainfall in the region, just like the rest of the country, is subject to the circulation of the tropical maritime (mT) air mass and the equatorial easterlies (Odekunle, 2006). Furthermore, seasonal fluctuation of the Intertropical Discontinuity (ITD) plays an important role in the receipt over the region, just like the rest of the country.
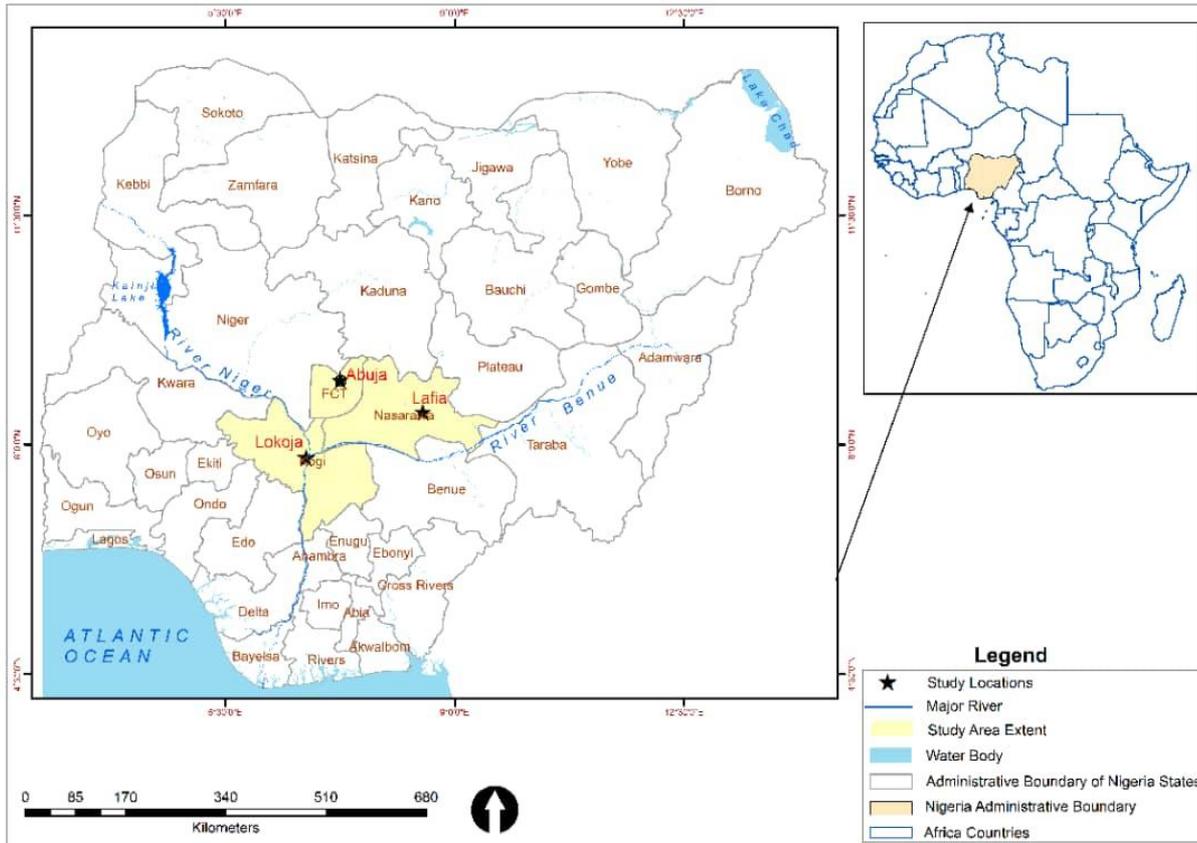
Fig.1: The study locations within the central region of Nigeria.

Table 1: Metadata of the Meteorological Stations used in the Study

Station Name	Station Abbrev	WMO ID No	Longitude (°E)	Latitude (°N)	Elevation a.s.l (m)	Data Availability
Abuja	ABJ	65125	7.00	9.00	343.1	100 Per cent
Lafia	LAF	65124	8.52	8.51	135.0	100 Per cent
Lokoja	LOK	65243	6.73	7.78	62.5	100 Per cent

In areas located north of the ITD, the atmosphere is usually dry and rainless preventing the formation of clouds while in area located south of the ITD moist and rainy conditions prevail due to the presence of conditions that favour the development of clouds of significant vertical extent such as the disturbance lines also known as the West African line squalls and the monsoons which are embedded in zones C and D weather (Olaniran, 1990). In the same vein, the rainy season within the central region of Nigeria is subject to sea surface temperature anomalies in the global oceans (Ibebuchi and Abu, 2023). In addition, the intensity and duration of extreme rainfall in the country and by extension the study locations are generally influenced by the adequacy of moisture carried by the south-westerly winds from the south Atlantic Ocean (Olaniyan et al., 2021).

In Abuja, the onset of the rainy season is usually around March in the southern extreme and April at the northern limits, while the cessation of the rains is around October in the northern parts and November in the southern limits. A major feature of the rainy season in the FCT is the frequent occurrence of squall lines, which may last for 30 minutes and are usually followed by drizzle which could last for several hours. In addition, the presence of inselbergs generates convectional activity which results in intense relief rainfall in their immediate vicinity (Abumere, 1993). At Lafia and Lokoja, the rainy season lasts from April to October, with a mean annual rainfall ranging between 1, 290 mm and 1, 595 mm at Lafia (Ma'aji et al., 2019) and an annual rainfall of about 1, 500 mm at Lokoja (Oluwatimilehin et al., 2022).

The identifiable vegetation type in the region is the Guinea savannah. Within the study domain, the species of vegetation comprises the mixed deciduous woodland in the Niger and Benue troughs and the *Afzelia Africana* and semi-deciduous forest around Abuja (Nigerian Environmental Study/ Action Team [NEST], 1991). A significant proportion of this vegetation has been lost due to changes in land use and rapid urbanisation, which has resulted in an increase in impervious surfaces, with potential increase in peak runoff, time to peak and volume of flood.

Data and Methods

The annual maximum daily rainfall for Abuja, Lafia, and Lokoja meteorological stations was obtained from the daily rainfall dataset for the period between 1st of January 1989 to 31st December, 2023. The rainfall dataset was obtained from the archives of the Nigerian Meteorology Agency (NIMET). Information on the three meteorological stations used for the study is presented in Table 1.

The time series of the annual maximum daily rainfall was subjected to the following analyses: trend tests, stationarity tests, analysis of extreme values, goodness of fit tests and estimation of return period. These tests were carried out using XLSTAT software. The trend and stationarity tests were carried out using the time series module, while the distribution fitting module was used for the GEV modelling.

Trend Test

The non-parametric Mann-Kendall (MK) trend test (equations 1 to 5) was used for trend detection. The null hypothesis (H_0) of no trend in the rainfall time series was tested against the alternative hypothesis (H_1) that there is a trend in the rainfall time series at the 0.05 level of significance. The MK trend test is expressed as follows (Adeyeri et al., 2019; Animashaun et al., 2020):

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} sgn(X_j - X_i)$$ (1)

A positive S value indicates an increasing trend, and a negative value indicates a decreasing trend in the data time series. The sign function is expressed as:

$$Sgn(X_J - X_i) = \begin{cases} 1 \; if \; X_j - X_i > 0 \\ 0 \; if \; X_j - X_i = 0 \\ -1 \; if \; X_j - X_i < 0 \end{cases}$$ (2)

Where the sample size n > 10, the statistics S is approximately a standard normal distribution with a mean that equals 0 and a variance denoted by:

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18}$$ (3)

Where n is the number of data points, t_j is the ties of the sample time series, and m is the number of tied values. The test statistic, Z, is given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \; S > 0 \\ 0 & if \; S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \; S < 0 \end{cases}$$ (4)

The estimation of the slope of the trend was based on Sen's slope estimator expressed in equation 5 as:

$$\beta = Median\left(\frac{x_j - x_k}{j-k}\right)$$ (5)

The non-parametric Mann-Kendall trend test was employed due to its suitability for analysing non-normally distributed time series such as hydrometeorological data, which are normally skewed, and also due to its insensitivity to outliers, which may be contained in the data (Yue et al., 2022; Hammed, 2008). However, it is important to acknowledge that the Mann-Kendall trend test has some limitations, which include the assumption that the data are independently and identically distributed (Blain, 2013). For annual maximum rainfall series, the impact of this limitation is often minimal or negligible due to serial independence or randomness that is often exhibited by the data series.

Stationary Tests

In order to examine if temporal independence exists in the statistical characteristics of the annual maximum daily rainfall series, the Augmented Dickey-Fuller (ADF) test was used to test for stationarity. The test was carried out at a 0.05 level of significance. The ADF test is expressed as (Masingi and Maposa, 2021; Ng et al., 2024):

$$y_t = \beta + \beta_1 t + \delta\gamma_{t-1} + \sum_{i=i}^{m} \alpha_i \Delta\gamma_{t-1} + \varepsilon_t$$ (6)

Where β is a constant, β1 is the coefficient of a linear trend if present, γ is the coefficient of the lagged dependent variable, δ represents the lag operator, and ε_t is the error term. The ADF test was used to test the null hypothesis (H_0) that there exists a unit root and non-stationarity in the time series against the alternative hypothesis (H_1) that the time series is stationary. The choice of the ADF test is based on its ability to identify trends and seasonality that may affect the reliability of statistical models (Ng et al., 2024).

Analysis of Extreme Values and Goodness of Fit Tests

The Generalised Extreme-Value distribution is an extreme value theory method that represents the Gumbel, Fréchet, and Weibull distributions in a single parametric form as proposed by Jenkinson in 1955 (de Carvalho et al., 2014). The GEV distribution is expressed in equation 7 by the density distribution and equation 8 by the cumulative distribution function (Beijo and Avelar, 2010; de Carvalho et al., 2014) as:

$$f(x) = \left(\frac{1}{\sigma}\right) exp\left\{-[1 + \xi Z]^{-(1/\xi)}\right\}(1 + \xi Z)^{(-1-1/\xi)}$$ (7)

$$F(x) = exp\left\{-[1 + \xi Z]^{-(1/\xi)}\right\}$$ (8)

Where $\xi \neq 0$ and $Z = (x - \mu)/(\sigma)$. The μ, σ, and ξ are the parameters of position, scale, and form. When the shape parameter (ξ) is less than zero, the distribution translates to the Weibull distribution; when it is greater than zero, it is a Fréchet distribution; and when it is zero, it is a Gumbel distribution (Carvalho et al., 2014).

The maximum likelihood method was used to estimate the shape parameters in equation 8, while the Kolmogorov-Smirnov goodness of fit test was used to evaluate the degree of adjustment of the x series (i.e, the time series of annual maximum daily rainfall) to the probability density function.

The derivation of the D statistic (equation 9) of the Kolmogorov-Smirnov test is based on the maximum vertical difference between the theoretical and empirical cumulative distribution function. The D statistic is stated as:

$$D = \frac{max}{1 \leq i \leq}\left(F'(x_i)\frac{i-1}{n}, \frac{i}{n} F(x_i)\right)$$ (9)

Where F' (x) is the empirical cumulative frequency of the values of the annual maximum daily rainfall series, and F (x) is the cumulative frequency as shown in equation 9. The Kolmogorov-Smirnov test was used due to some of the advantages it offers. Firstly, the test does not depend the on underlying cumulative distribution function, and secondly, since, it is an exact test, it does not depend on the sample size for the approximations to be valid (National Institute of Standards and Technology [NIST] / Semiconductor Manufacturing Technology [SEMATECH], 2012). The GEV distribution was selected for this study due to its descriptive and predictive abilities and its robustness in estimating quantiles (Zalina et al., 2002).

For the GEV model, the hypothesis regarding its distribution is stated as:

H_0: The annual maximum daily rainfall follows a GEV distribution.

H_1: The annual maximum daily rainfall does not follow a GEV distribution.

The null hypothesis is accepted if the computed p-value is greater than the significance level α = 0.05

Estimation of Return Period

The return period was estimated using (equation 10) as shown below (Boudrissa et al., 2017):

$$F_x(x_T) = P(X \leq x_T) = 1 - \frac{1}{T} \Rightarrow x_T = F^{-1}\left(1 - \frac{1}{T}\right)$$ (10)

Where $P(x \leq x_T)$ represents the probability of occurrence, T is the return level, and x_T represents the magnitude of the event. The annual maximum daily rainfall associated with the 2-year, 5-year, 10-year, and 25-year return periods was estimated.

Results and Discussion
Trend of Annual Maximum Daily Rainfall
The results of the Mann-Kendall trend test (Table 2) show a declining trend of -1.1mm/yr in annual maximum daily rainfall at Abuja and an increasing trend of 2.0mm/yr in Lafia. At Lokoja, the annual maximum daily rainfall exhibited no significant trend.

Despite the declining trend shown in the results of the Mann-Kendall trend test for Abuja, Ibebuchi and Abu (2023) argue that the region is generally shifting towards a wetter regime, with some locations showing significant positive trends in rainfall. According to the authors, such positive trends, such as those exhibited at Lafia, can be attributed to a temporal shift in the asymmetric circulation pattern towards a wet regime occasioned by positive sea surface temperature anomalies over the North Atlantic, Mediterranean and Western Pacific Oceans.

The increasing trend at Lafia is an indication of the likelihood of more frequent and severe flooding, which could result in the disruption of socio-economic activities and damage to public infrastructure such as roads and bridges. Furthermore, the increasing trend of annual maximum daily rainfall, especially the high-intensity type, has the potential to aggravate soil erosion and increase the sediment load of rivers in the area.

In Abuja, where the annual maximum daily rainfall shows a declining trend, and by implication, less frequent and less severe flooding events, various anthropogenic factors have been found to be responsible for the flooding within the city. These include building on green areas, which are meant to serve as natural buffers in retaining stormwater and preventing flooding, building on flood-prone areas, dumping of refuse into drainage channels and contravention of the city's master plan, amongst others.

For Lokoja, the result is an indication that the annual maximum daily was variable with no established clear pattern during the period of study. This situation makes the prediction of future water availability difficult and also poses a challenge to the design of hydraulic infrastructure such as dams, reservoirs, and irrigation systems.

Within the context of climate change, the West African sub-region, where Nigeria is located, is generally projected to experience more extreme precipitation. According to the Sixth Assessment Report of the IPCC (Seneviratne et al., 2021), the West African domain is projected to experience increases in the intensity and frequency of extreme rainfall under 1.5 ºC, 2 ºC and 4 ºC global warming.

Stationarity of Annual Maximum Daily Rainfall
The results of the Augmented Dickey-Fuller (ADF) test presented in Table 3 shows that the null hypothesis (H_0) of non-stationarity was accepted for Abuja and Lafia as the computed P-value is greater than the significance level $\alpha = 0.05$ while the alternative hypothesis (H_1) of stationarity was accepted for Lokoja as the computed P-value is lower than the significance level $\alpha = 0.05$.

The non-stationarity of the annual maximum daily rainfall at Abuja and Lafia suggests non-constancy in its statistical characteristics with time, while the stationarity at Lokoja implies that there is no systematic change in the statistical parameters of the time series of the annual maximum daily rainfall. The non-stationary characteristics of annual maximum daily rainfall at Abuja and Lafia have consequences for flood risk and hydraulic infrastructures. According to Ng et al., (2024), the evaluation of non-stationarity could assist in avoiding the underestimation of extreme rainfall, therefore preventing design failure for hydraulic structures.

Generalised Extreme Value Modelling
The estimated position (μ), scale (σ), and shape (ξ) parameters for the annual maximum daily rainfall for the study locations are shown in Table 4.

For Abuja, the best fit distribution was the Weibull distribution ($\xi < 0$), while for Lafia, and Lokoja, the Fréchet distribution ($\xi > 0$) was the best fit distribution. This indicates that the rainfall in Abuja can be modelled using the Weibull distribution, whereas the rainfall at Lafia and Lokoja can be modelled using the Fréchet distribution. The suitability of the positive-shaped Fréchet distribution for Lafia and Lokoja may be due to a number of reasons. According to Lliopoulou et al (2018), the positive-shaped parameter could be caused by multiple types of synoptic patterns or the influence of large-scale circulation patterns. The results of the best fit distribution for Lafia and Lokoja align with those obtained for the modelling of annual maximum rainfall at Akure, southwest Nigeria, by Ilesanmi et al., 2024). Likewise, the Weibull distribution for the annual maximum daily rainfall at Abuja is consistent with the result obtained by Samuel et al., (2020), who found that the Weibull distribution was the best-fit distribution for Kaduna, a state contiguous to Abuja.

The results of the Kolmogorov-Smirnov Goodness of Fit Test, which shows the degree of adjustment of the time series of annual maximum daily rainfall to the probability density of the GEV distribution, are shown in Table 5.

Table 2. Results of MK Trend Test for Annual Maximum Daily Rainfall

Location	τ	s	Sen's Slope (mm/yr)	P-value (Two-tailed)	Interpretation
Abuja	-0.3230	-192.0	-1.1125	0.0064	Negative trend
Lafia	0.3902	232.0	1.9625	0.0010	Positive trend
Lokoja	0.0825	49.0	0.2714	0.4864	No Trend

Table 3. Results of the ADF for Annual Maximum Daily Rainfall

Location	ADF Statistic	P-value	Interpretation
Abuja	-2.7389	0.2140	Unit Root; Non-Stationary
Lafia	-2.7076	0.2244	Unit Root; Non-Stationary
Lokoja	-4.4322	0.0059	No Unit Root; Stationary

Table 4. Estimates of the Position (μ), Scale (σ), and Shape (ξ) parameters of the Extreme Values Probability Density Function

Location	μ	σ	ξ
Abuja	67.9740	20.2367	-0.0718
Lafia	92.7390	28.7092	0.2344
Lokoja	79.3984	16.7904	0.1515

Table 5. Results of the Kolmogorov-Smirnov Goodness of Fit Test

Location	D_{max}	P-value
Abuja	0.0920	0.9154
Lafia	0.1132	0.7358
Lokoja	0.0971	0.8802

Table 6. Estimated Annual Maximum Daily Rainfall for Different Return Periods

Return Period and Estimated Rainfall (in mm)						
Station	2-year	5-year	10-year	25-year	50-year	100-year	200-year
Abuja	75.4	98.5	113.8	133.1	147.4	161.6	175.8
Lafia	103.3	135.8	157.4	184.6	204.8	224.8	224.8
Lokoja	85.6	104.6	117.2	133.1	144.9	156.6	168.3

As shown in the table, the computed p-values at the three locations are greater than the significance level $\alpha = 0.05$; therefore, the null hypothesis that the annual maximum daily rainfall follows a GEV distribution was accepted. Similar results were obtained by Awode et al., (2025), which showed that the Kolmogorov-Smirnov Goodness of Fit Test was a highly significant fit for extreme rainfall in southwest Nigeria. In addition, the acceptance of the null hypothesis suggests that the GEV distribution is suitable for predicting and describing the statistical behaviour of the annual maximum daily rainfall in the study domain.

Return Period

The estimated annual maximum daily rainfall for different periods is presented in Table 6.

From the results presented in Table 6, the estimated annual maximum daily rainfall increases with the return period. For instance, while it is expected that a period of 2 years must have elapsed before annual maximum daily rainfall of 75.4 mm, 103.3 mm, and 85.6 mm would be recorded at Abuja, Lafia, and Lokoja, respectively. Higher magnitudes of 175.8 mm, 224.8 mm, and 168.3 mm are expected for the 200-year return period. As shown by the results, the annual maximum daily rainfall at Lafia is associated with the highest return levels, suggesting a high level of vulnerability to flooding and subsequently posing challenges for agriculture, infrastructure, and resilience. These results are similar to those obtained from other parts of the world, such as Algeria, Boudrisa et al., (2017), Sri-Lanka, Mayooran and Laheetharan (2014), Bangladesh, Ahammed et al., (2014), Malaysia, Ng et al., (2024), aand Ghana Angbing et al., (2020).

Given the return levels associated with each return period, there is a need for extreme rainfall climatology to be factored into the development of mitigation and water resources management strategies, as well as environmental and public safety regulations.

Conclusion

Hydrometeorological hazards such as extreme rainfall have potential catastrophic consequences; hence underscoring the need to adequately understand their behaviour and predict their future occurrences. This study applied the GEV distribution in describing the annual maximum daily rainfall in parts of central Nigeria for 35 years. Using the maximum likelihood approach, the Weibull and Fréchet distributions were found to be the best- fit distributions. The estimation of the return levels for the various return periods indicated that the return levels of the annual maximum daily rainfall increase with the return period, suggesting increased vulnerability to flooding in the future.

The insights offered by these findings can assist policy makers in making informed policies geared towards the development of early warning systems, flood risk mitigation, and strengthening community resilience to hydrometeorological hazards. To achieve this, there is a need for governments at the federal and state levels to strengthen the existing relevant policy frameworks and initiatives such as the National Flood Emergency Preparedness Response Plan and the National Policy on Environment to bolster resilience. In the same vein, there is a need for the strengthening of local governance to assist in monitoring and enforcing land-use planning regulations.

Within the study domain, there is a need for holistic floodplain management that effectively combines spatial planning and structural measures to enhance the safety and resilience of the populace. Similarly, the adoption of nature-based solutions, such as afforestation and restoration of wetlands, would assist in reducing the flood risk and some of its adverse consequences.

In addition, location- specific risk management can be deployed in scenario planning for emergency response, thereby reducing human and material loss. A deeper understanding provided by the estimation of the probability of extreme rainfall events could serve as a framework for insurance companies to develop better models for quantifying and managing risks associated with climate- related hazards.

References

Abumere, S.I. (1993). The Federal Capital Territory, Abuja. In Udo, R.K., and Mamman,

A.B. (eds), Nigeria. Giant in the Tropics. Volume 2. Gabumo Publishing, Lagos, Nigeria, pp. 15-32.

Adeyeri, O.E., Lawin, A.E., Laux, p., Ishola, K.A., and Ige, S.O. (2019). Analysis of climate extreme indices over Komadugu-Yobe basin, Lake Chad region: Past and future occurrences. *Weather and Climate Extremes,* 23(2019), 100194. https://doi.org/10.1016/j.wace.2019.100194.

Agbonaye, A.I., and Izinyon, O.C. (2017). Best-fit probability distribution model for rainfall frequency analysis of three cities in southern Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 1(1), 34-42.

Ahammed, F., Hewa, G.A., and Argue, J.R. (2014). Variability of annual maximum rainfall of Dhaka, Bangladesh. *Atmospheric Research*, 137, 176-182.

Akoachere, R.A., Yaya, O.O., Eyong, A.T., Ayuk, E.O., and Egba, E.S. (2019). Hydrogeology of Abuja FCT-Nigeria: A GIS evaluation. *Access Library Journal*, 6:e5649, 1-32. DOI:10.4236/oalib.1105649.

Angbing, I., Abubakari, A., Nasiru, S. (2020). Extreme analysis of maxima rainfall in the upper east region of Ghana: a case study of Navrongo municipality. *Applied Mathematics and Information Sciences*, 14 (4), 645-653. http:dx.doi.org/10.18576/amis/140413.

Anghel, C.E., and Ianculescu, D. (2025). Application of the GEV distribution in flood frequency analysis in Romania: An in-depth analysis. *Climate*, 13, 152. https:/.doi.org/10.3390/cli3070152.

Animashaun, I.M., Oguntude, P.G., Akinwumiju, A.S., and Olubanjo, O.O. (2020). Rainfall analysis over the Niger Central Hydrological Area, Nigeria: Variability, trend and change point detection. *Scientific African, 8* (2020), e00419. https://doi.org/10.1016/j.sciaf.2020.e00419.

Awode, A.E., Adewunmi, J.R., Obiora-Okeke, O, Komolafe, A.A. (2025). Analysis of rainfall variability and extreme events in south-western Nigeria. Implications for water resources management and climate resilience. *Bulletin of the National Research*, 49 (31), 1-17. https://doi.org/10.1186/s42269-025-01324-4.

Beijo, L.A., and Avelar, F.G., (2010). Distribuição generalizada de valores extremos noestudo de dados climáticos: Uma breve revisão. *Revista Estatística UFOP* 1,10–16.

Blain, G.C. (2013). The Mann-Kendall test: the need to consider the interaction between serial correlation and trend. *Acta Scientiarum. Agronomy*, 35(4), 393-402. Doi:10.4025/actasciagron.v35iv4.16006.

Boudrissa, N., Cheraitia, H., and Halimi, L. (2017). Modelling maximum daily yearly rainfall in northern Algeria using generalised extreme value distributions from 1936 to 2009. *Meteorological Applications*, 2, 114-119. DOI:10:1002/met.1610.

Buba, F.N., and Orofin, Z.O. (2021). Assessment of flood vulnerability in some communities in Lokoja, Kogi State, Nigeria, using participatory geographic information systems. *International Journal of Disaster Risk Reduction,* 55, 102111. https;//doi.org/1016/j.ijdrr.2021.102111.

de Carvalho, J.R.P., Assad. E.D., de Oliveira, A.Y., and Pinto, H.S. (2014). Annual maximum daily rainfall trends in the Midwest, southeast and

southern Brazil in the 71 years. *Weather and Climate Extremes*, 5-6 (2014), 7-15. http:dx.doi.org/10.1016/j.wace.2014.10.001.

Douville, H., Raghavan, K., Renwick, J., Allan, R.P., Arias, P.A., Barlow, M., Cerezo-Mota, R., Cherchi, A., Gan, T.Y., Gergis, J., Jiang, D., Khan, A., Pokam Mba, W., Rosenfeld, D., J Tierney, J., and Zolina, O. (2021). Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A., Pirani, S.L., Connors, C., Péan, S., Berger, N., Caud, Y., Chen, L., Goldfarb, M.I., Gomis, M., Huang, K., Leitzell, E., Lonnoy, J.B.R., Matthews, T.K., Maycock, T., Waterfield, O., Yelekçi, R.Y., and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1055–1210, doi:10.1017/9781009157896.010.

Feng, S., Nadarajah, S., and Hu, Q. (2007). Modelling annual extreme precipitation in China using the generalised extreme value distribution. *Journal of the Meteorological Society of Japan,* 85(5), 599-613.

Hammed, K.H. (2008). Trend detection in hydrologic data: the Mann-Kendall trend test under scaling hypothesis. *Journal of Hydrology,* 349,350-368.

Hossain, I., Khastagir, A., Aktar, M.N., Imteaz, M.A., Huda, D., and Rasel, H.M. (2024). Comparison of estimation techniques for generalised extreme value (GEV) distribution parameters: a case study with Tasmanian rainfall. *International Journal of Environmental Science and Technology*. https://doi.org/10.1007/s13762-021-03693-5.

Ibebuchi, C.C., and Abu, I. (2023). Rainfall variability patterns in Nigeria during the rainy season. *Scientific Reports*, 13: 7888, 1-12. https://doi.org/10.1038/s41598-023.

Ifediegwu, S.I. (2022). Assessment of groundwater potential zones using GIS and AHP technology: a case study of the Lafia district, Nasarawa state, Nigeria. *Applied Water Science,* 12 (10), 1-17. https://doi.org/10.1007/s13201-021-01556-5.

Ilesanmi, A.O., Halid, O.Y., Adejuwon, S.O., Odukoya, E.A., and Olayemi, M.S. (2024). Application of generalised extreme value distribution to annual maximum rainfall. *FUDMA Journal of Sciences,* 8(2), 118-122.

Iloeje, N.P. (1981). A New Geography of Nigeria. Longman Group Limited, United Kingdom.

Kane, I.L., Umar, K.T., and Rabe, A. (2023). Extreme rainfall modelling through the lens of extreme value theory: a case study of Katsina city, Nigeria. *UMYU Scientifica,* 2(3), 092-099. https://doi.org/10.56919/usci.2323.015.

Kyojo, E.A., Mirau, S., Osima, S.E., Masanja, V.E. (2024). Modelling non-stationarity in extreme rainfall data and implications for the climate adaptation : a case study from southern highlands region of Tanzania. *Scientific African*, 25, 1-23. https://doi.org/10.1016/j.sciaf.2024.e02321.

Lawal, M.A., and Omosanya, K.O.L. (2023). Multidecadal changes in Planform morphology of the confluence of River Niger and River Benue, West Africa. *Journal of Hydrology*, 623, 129764. https://doi.org/10.1016/j.hydrol.2023.

Lliopolou, T., Koutsoyiannis, D., Monanari, A. (2018). Characterising and modelling seasonality in extreme rainfall. *Water Resources Research,* 54, 6242-6258. https://doi.org/10.1029/2018WR023360.

Maáji, U.M., Maina, M.B., and Sarki, M.U. (2019). Lineaments analysis and interpretation for assessment of groundwater potential of Lafia and environs, north central Nigeria. *IOSR Journal of Applied Geology and Geophysics*, 7(1), 22-28. DOI:10.97900/0990-0701012228.

Masingi, V.I., and Maposa, D. (2021). Modelling long term monthly rainfall variability in selected provinces of South Africa: trend and extreme value analysis approaches. *Hydrology,* 8, 1-27. https://doi.org/10.3390/hydrology8020070.

Mayooran, T., and Laheetharan, A. (2014). The statistical distribution of annual maximum rainfall in Colombo District. *Sri Lankan Journal of Applied Statistics*, 15(2), 107-130.

National Institute of Standards and Technology/ SEMATECH (2012). E-handbook of Statistical Methods. https://doi.org/10.18434/M32189.

Nigerian Environmental Study Action Team. (1991). Nigeria's Threatened Environment. A

National Profile. NEST Publications, Ibadan, Nigeria, pg. 148.

Ng, J.L., Huang, Y.F., Yong, S.L.S., Lee, J.C., and Ahmed, A.N. (2024). Analysing the variability of non-stationary extreme rainfall events amidst

climate change in east Malaysia. *Water Infrastructure, Ecosystems and Society*, 73(7), 1494-1509. doi: 10.2166/aqua.2024.132.

Obada, E., Hounnondaho, F.Z., Yarou, H., Mampo, O.M.G., Alamou, A.E. (2025). Trend and frequency analysis of long term daily rainfall in Benin. *Journal of Geoscience and Environmental Protection*, 13(12), 260-278.

Odekunle, T.O. (2006). Determining rainy season onset and retreat over Nigeria from precipitation amount and number of rainy days. *Theoretical and Applied Climatology*, 83, 193-201. DOI:10.1007/s00704-005-0166-8.

Odekunle, T.O., Orimoogunje, I.O.O. and Ayanlade, A. (2007). Application of GIS to assess rainfall variability impacts on crop yield in Guinean savannah parts of Nigeria. *African Journal of Biotechnology*, 6(18), 2100-2113. http:www.academicjournals.org/AJB.

Oguntunde, P.G., Abiodun, B.J., and Lischeid, G. (2012). Spatial and temporal temperature trends in Nigeria, 1901-2000. *Meteorology and Atmospheric Physics*, 118: 95-105. DOI 10.1007/s00703-012-0199-3.

Olafsdottir, H.K., Rootzen, H., and Bolin, D. (2021). Extreme rainfall events in the north-eastern United States become more frequent with rising temperatures, but their intensity remains stable. *Journal of Climate*, 34, 8863-8876. DOI: 10.1175/JCLI-D-20-0939.1.

Olaniran, O.J. (1990). Changing patterns of rain days in Nigeria. *Geojournal,* 22(1), 99-107.

Olaniyan, O.A., Ajayi, V.O., Lawal, K.A., Akeh, U.P. (2021). Impact of Moisture Flux and Vertical Wind Shear on Forecasting Extreme Rainfall Events in Nigeria. In: Oguge, N., Ayal, D., Adeleke, L., da Silva, I. (eds) *African Handbook of Climate Change Adaptation*. Springer, Cham. https://doi.org/10.1007/978-3-030-45106-6_98.

Oluwatimilehin, I.A., Akerele, J.O., Oladeji, T.A., Omogbehin, M.J., and Atai, G. (2022). Assessment of the impact of climate change on the occurrences of Malaria, Pnemonia, Meningitis, and Cholera in Lokoja city, Nigeria. *Regional Sustainability*, 3, 309-318. https://doi.org/10.1016/j.regsus.2022.11.007.

Panthou, G., Vischel, T., Lebel, T., Blanchet, J., Quantin, G., and Ali, A. (2012). Extreme rainfall in West Africa: a regional modelling. *Water Resources Research*, 48, 1-19. doi:10.1029/2012WR01252.

Rajeevan, M., Bhate, J., and Lawal, A.K. (2008). Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. *Geophysical Research Letters*, 35, L18707, 1-6. doi:10.1029/2008GLO35143,2008.

Renteria, R., Aquino, R., and Polanco, M. (2026). Modelling extreme rainfall using the generalised value distribution and exceedance analysis in Colina, Mexico. *Sensors*, 26, 1-12. https?doi.org/10.3390/s26020532.

Samuel, B.S., Samuel, A.N., Peter, N., Abdulateef, M., and Kwaghdoo, A.G. (2020).

Modelling extreme rainfall in Kaduna using the generalised extreme value distribution. *Science World Journal*, 15(3), 73-77.

Seneviratne, S.I., Zhang, X., Adnan M., Badi W., Dereczynski, C., Di Luca A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S.M., Wehner, M., and Zhou, B. (2021). Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., and Zhou, B. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766, doi:10.1017/9781009157896.013.

Shang, H., Yan, J., Gebremichael, M., and Ayalew, S.M. (2010). Trend analysis of extreme precipitation in northwetern highlands of Ethiopia with a case study of Debre Markos. *Hydrology and Earth System Sciences Discussions*, 7, 8587-8605. doi:10.5194/hessd-7-8587-2010.

Stedinger J.R., R.M. Vogel, R.M., and Foufoula-Georgiou, E. (1993). Frequency Analysis of Extreme Events. In Maidment, D.R. (ed), Handbook of Applied Hydrology (Chapter 18 pp. 1-66). McGraw-Hill, New York.

Towler, E., Llewellyn, D., Prein, A., Gilleland, E. (2020). Extreme-value analysis for the characterisation of extremes in water resources: a generalised workflow and case study in New Mexico monsoon precipitation. *Weather and Climate Extremes*, 29, 1-11. https://doi.org/10.1016/j.wace.2020.100260.

Twumasiankrah, S., Pels, W.A., and Nadarajah, S. (2024). Modelling rainfall along the coastal and northern parts of Ghana. Mausam, 75 (2), 433-442. DOI:https:doi.org/10.54302/mausam.v755i25875.

Ukoje, J.E., and Achegbulu, E.O. (2021). Assessment of urban expansion and flood vulnerability in Lokoja town, north central Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 15 (2), 125-139. doi:https://ejesm.org/doi/v15i2.1.

Umar, N., and Gray, A. (2022). Flooding in Nigeria: a review of its occurrence and impacts and approaches to modelling flood data. *International Journal of Environmental Studies.* https://doi.org/10.1080/00207233.2022.2081471.

Westra, S., Alexander, L., and Zwiers, F. (2013). Global increasing trends in annual maximum daily precipitation. *Journal of Climate*, 26, 3904-3918. http:dx.doi.org/10.11751/JCLI-D-12-00502.1.

Yue, S., Pilon, P., Phinney, B., and Cavadias, G. (2002). The influence of autocorrelation on the ability to detect trend in hydrological series. *Hydrological Process*, 16, 1807-1829.

Zalina, M.D., M. Desa, M.N., Nguyen, V.T.N., M. Kassim, A.H. (2002). Selecting a probability distribution for extreme rainfall series in Malaysia. *Water Science Technology Journal,* 45 (2), 63-68.