**Original Research Article**

**Modeling Rainfall Intensity-Duration-Frequency (IDF) and Establishing Climate Change Existence in Abakaliki-Nigeria Using a Non-Stationary Approach**

**Abstract**

This study aimed to develop non-stationary Intensity-Duration-Frequency (IDF) curves for Abakaliki, Nigeria, using a 31-year rainfall record (1992-2022) obtained from the Nigerian Meteorological Agency. The study utilised trend analysis via the Mann-Kendall test and change point detection using CUSUM and Sequential Mann-Kendall tests to identify non-stationarity in rainfall patterns. Three distinct General Extreme Value (GEV) distribution models were assessed to find the best-fitting non-stationary model according to the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The analysis showed a notable increasing trend in rainfall intensity (p-value = 0.0059), with change points observed in 2010 and 2012. Among the models, the GEVt-III displayed the best performance across most duration intervals (10-1440 minutes) indicated by its lowest AIC values, while the GEVt-I excelled for the 5-minute duration. A generalized non-stationary IDF model was created, demonstrating exceptional predictive ability (R² = 0.996, MSE = 37.00). These results emphasize the necessity of incorporating non-stationary methods in infrastructure design in Abakaliki, as conventional stationary approaches may significantly underestimate rainfall intensities in the era of climate change.

**Keywords**: Rainfall Intensity-Duration-Frequency (IDF), Non-stationary modeling, Climate change, General Extreme Value (GEV) distribution, Mann-Kendall trend analysis, Change point detection

**1. Introduction**

The rising occurrence and severity of extreme precipitation events are critical issues in hydrology and civil engineering, especially regarding infrastructure design and urban drainage management. Rainfall Intensity-Duration-Frequency (IDF) curves provide relationships between rainfall intensity, storm duration, and their occurrence frequency, making them essential in the design of hydraulic structures (Endreny & Imbeah, 2009; Ganguli & Coulibaly, 2017). Traditionally, these IDF relationships have been established based on the assumption of stationarity, which means that the statistical characteristics of extreme rainfall are assumed to remain constant over time. However, this foundational assumption has come under increased scrutiny as climate change continues to alter precipitation patterns globally (Milly et al., 2008; Tramblay et al., 2013; Ekwueme et al., 2025).

Climate change is anticipated to intensify the hydrological cycle, as the Clausius-Clapeyron relationship states that the atmospheric capacity to hold water increases by about 7% for every 1°C of warming (Trenberth, 2011; Lenderink & van Meijgaard, 2008). This physical relationship directly influences precipitation intensity, potentially increasing the frequency and severity of extreme rainfall events (Cheng & AghaKouchak, 2014; Westra et al., 2013). The changes in precipitation patterns lead to nonstationary, meaning that the statistical characteristics of extreme rainfall vary over time, which necessitate a time component to be introduced to IDF model development to account for the variations of the statistical parameters over time.

In Nigeria, especially in the southeast around Abakaliki, the effects of climate change are becoming more apparent through changes in rainfall patterns and intensities (Ekwueme et al., 2024). Traditional IDF curves that do not account for nonstationarity can significantly underestimate future rainfall extremes. The utilisation of a stationary IDF model for design could result in insufficient infrastructure design and a heightened flood risk (Cheng & AghaKouchak, 2014). Cheng and AghaKouchak (2014) showed that conventional stationary methods for IDF development may underestimate extreme precipitation by up to 60% in areas undergoing substantial climate change. This difference underscores the essential requirement for nonstationary methods considering temporal variations in rainfall patterns. Several researchers have proposed frameworks for developing nonstationary IDF curves, incorporating time-varying parameters in extreme value distributions (Cheng & AghaKouchak, 2014; Agilan & Umamahesh, 2016; Ganguli & Coulibaly, 2017; Ekwueme et al., 2024). The General Extreme Value (GEV) distribution has emerged as a particularly useful model for incorporating nonstationarity, as it allows for temporal changes in distribution parameters (Tramblay et al., 2013; Ganguli & Coulibaly, 2017). Studies have employed various approaches to model nonstationary, including linear trends in distribution parameters and incorporating covariates such as global temperature anomalies, urbanisation indicators, and climate indices (Agilan & Umamahesh, 2016; Ali & Mishra, 2017).

Despite the progress in nonstationary IDF model development, nonstationary IDF methods are still not widespread in Nigeria, especially in the southeast. Nwaogazie and Sam (2020) found that most IDF studies in Nigeria continue to depend on stationary methods, even as evidence of climate change's effects becomes more apparent. This study aims to address this knowledge gap by developing nonstationary IDF curves for Abakaliki, Nigeria, using a 31-year rainfall record spanning from 1992 to 2022.

**2. Materials and Methods**

**2.1 Study Area**

Abakaliki, the capital of Ebonyi State, is in southeastern Nigeria, specifically in the South-Eastern region, at coordinates 6.3231°N latitude and 8.1120°E longitude. The city has a tropical climate with a rainy season from March to October and a dry season from November to February. Its climate is shaped by its position in the Guinea Forest-Savanna mosaic ecoregion, which typically yields substantial annual rainfall, rendering it prone to flooding and other rain-related issues. The city's rapid urbanisation in recent years has increased its exposure to climate change effects, particularly regarding alterations in rainfall patterns.



**Figure 1**: Map of the study Area

**2.2 Data Collection**

The research employed long-term historical rainfall data spanning nearly thirty years. A 31-year rainfall dataset covering the period from 1992 to 2022 was acquired from the Nigerian Meteorological Agency (NIMET) for analysis in Abakaliki. The data obtained was the 24-hour monthly rainfall record for Abakaliki. Smaller rainfall duration records were obtained by downscaling the 24-hour rainfall record utilizing the Indian Meteorological Department (IMD) model, which is given by Equation (1). The shorter duration records obtained included 5, 10, 20, 30, 60, 120, 360, and 720 minutes.

= (1)

Where = Downscaled rainfall precipitation, = daily rainfall precipitation (mm), t = time.

**2.3 Development of Non-Stationary IDF model**

The trend and change point analysis was done before developing the rainfall intensity duration frequency models. The trend analysis was carried out to determine how the statistical parameters of rainfall fluctuated over time and to support the development of a non-stationary IDF model. Change point analysis was performed to pinpoint significant shifts in the rainfall data. The Mann-Kendall test assessed the trend changes, while the distribution-free CUSUM and Sequential Mann-Kendall methods identified the change point year.

The development of the non-stationary IDF model was based on the General Extreme Value (GEV) distribution. The GEV distribution was adapted for modeling different behavioural extremes with three distribution parameters, notably location, scale, and shape parameters (Cheng et al., 2014). Equation (2) presents the standard cumulative distribution function (CDF) of the GEV as given by Coles et al. (2001).

 (2)

Where F(x) = Cumulative distribution function, = mean (location), = standard deviation (scale) and, = shape parameter are three behavioural parameter extremes.

The maximum likelihood estimator served as the statistical method for estimating distribution parameters, as it can be readily adapted for non-stationary evaluations. Non-stationarity arises from expressing one or more statistical parameters of the GEV as a function of time (Coles et al., 2001; Katz, 2013). Three linear non-stationary expressions were used to develop the IDF models, as shown in Table 1. The optimal non-stationary model was chosen based on the goodness of fit indicated by AIC and BIC. Among these, the model exhibiting the lowest AIC and BIC was considered the best match for the rainfall's non-stationarity. R-studio facilitated the retrieval of model parameters and the calculation of rainfall intensity.

**Table 1:** Types of Selected GEV Linear Parameter Models

|  |  |  |
| --- | --- | --- |
| **Model Type** | **Parameter Combination** | **Remark** |
| (i) GEVt – 0 |  | Stationary parameter model |
| (ii) GEVt – I |  | Non-stationary parameter model |
| (iii) GEVt – II |  | Non-stationary parameter model |
| (iv) GEVt – III |  | Non-stationary parameter model |

Source: Silva and Simonovic (2020)

**3. Results**

Table 2 shows the trend and change point analysis outcomes for Abakaliki. The Mann-Kendall test indicated a statistically significant upward trend in rainfall, with a test statistic of 2.7534 and a p-value of 0.0059. The result from the Mann Kendall provides sufficient evidence that the rainfall at Abakaliki is on the rise and the statistical parameters of the rainfall will change over time. The result prompts the use of a non-stationary approach for modelling the rainfall. The change point analysis results in Table 2 demonstrate that both methods yield similar findings. The CUSUM test pinpointed 2010 and 2012 as potential change point years, though these points were not statistically significant at 90% and 95% confidence levels. This was further supported by the Sequential Mann Kendall (SQMK) test, which identified 2010 as a change point. The close occurrence of these change points (2010-2012) indicate a potential shift in rainfall patterns during this timeframe for Abakaliki. The results from both the Mann-Kendall and change point analyses strongly suggest that climate change is impacting rainfall precipitation in Abakaliki; therefore, a non-stationary method should be applied to develop the IDF model.

**Table 2**: Mann Kendall and Change Point for Abakaliki

| **Test Type** | **Statistic** | **p-value** | **Trend/Change Point** | **Remark** |
| --- | --- | --- | --- | --- |
| Mann-Kendall | 2.7534 | 0.0059 | Increasing | Significant |
| CUSUM | 5.0 | - | 2010 and 2012 | Not Significant (CI: 90%, 95%) |
| SQMK | - | - | 2010 | Steady positive increase from 2013 to 2019 |

Table 3 presents the development of the non-stationary IDF model. Analysing the GEV parameters uncovers intriguing patterns across various time durations from 5 to 1440 minutes. For 5-minute duration, the GEVt- I model exhibited the best fit, achieving an AIC of 207. 946 and a BIC of 213. 682. However, as durations extended to 10 minutes or more, the GEVt- III model consistently outperformed others with the lowest AIC values- such as 218. 897 for the 10- minute duration versus 223. 555 for GEVt- I. In the intermediate range of 20 to 60 minutes, the GEVt- III model continued to show superiority. Specifically, for the 20- minute duration, the model performed optimally with an AIC of 238. 470. This trend persisted for the 30- minute period (AIC = 247. 691) and the 60- minute duration (AIC = 262. 103). The adjustments in both the location and scale parameters over time indicate that both the central tendency and variability of extreme rainfall events in Abakaliki are evolving.

For the longer durations of 120 to 1440 minutes, the trend remained with GEVt- III consistently yielding the best fits. The analysis for the 720- minute duration recorded an AIC of 314. 329 for GEVt- III, while the 1440- minute duration showed an AIC of 328. 818, both representing the lowest values in their respective duration categories. Figure 2 shows the calculated rainfall intensity for all durations and return periods. This figure serves as a practical resource for engineers to determine rainfall intensity for any duration and return period relevant to Abakaliki. A general IDF model was created to facilitate ease in obtaining rainfall intensity for any duration and return period, as shown in Table 4. This model demonstrated exceptional predictive capability with a high coefficient of determination (R ² = 0. 996) and a relatively modest Mean Square Error (MSE = 37. 00). The elevated R² value indicates that the model accounts for approximately 99.6% of the variability in rainfall intensity, suggesting high reliability for predicting rainfall intensities across various durations and return periods.

**Table 3:** Evaluation of the performance of GEV parameters used for non-stationary and stationary models for Abakaliki

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Time (mins)** | **Models** | **Location Parameter** | **Scale** | **Shape Parameter** | **BIC** | **AIC** |
| 5 | GEV₍t₎ – I | -67.764 + 0.038t | 4.703 | 0.209 | 213.682 | **207.946** |
| GEV₍t₎ – II | 8.443 | 5.158 - 0.0002t | 0.185 | 215.689 | 209.953 |
| GEV₍t₎ - III | -145.167 + 0.076t | -3.348 + 0.004t | 0.31 | 215.269 | 208.099 |
| 10 | GEV₍t₎ – I | -24.522 + 0.018t | 5.846 | 0.193 | 229.292 | 223.555 |
| GEV₍t₎ – II | 10.638 | 6.50- 0.0002t | 0.185 | 230.022 | 224.286 |
| GEV₍t₎ - III | -390.026 + 0.199t | -13.12 + 0.009t | 0.177 | 226.067 | **218.897** |
| 20 | GEV₍t₎ – I | -136.164 + 0.075t | 7.457 | 0.167 | 241.987 | 236.251 |
| GEV₍t₎ – II | 13.402 | 8.190 - 0.0007t | 0.219 | 244.343 | 238.607 |
| GEV₍t₎ - III | -118.461 + 0.066t | -0.115 + 0.004t | 0.203 | 245.64 | **238.47** |
| 30 | GEV₍t₎ – I | 6.277 + 0.005t | 8.948 | 0.1841 | 252.609 | 246.873 |
| GEV₍t₎ – II | 15.342 | 9.376 - 0.0003t | 0.1847 | 252.726 | 246.99 |
| GEV₍t₎ - III | -82.163 + 0.049t | 3.017 + 0.003t | 0.1624 | 254.861 | **247.691** |
| 60 | GEV₍t₎ – I | 9.759 + 0.005t | 10.961 | 0.188 | 266.934 | 261.198 |
| GEV₍t₎ – II | 19.329 | 11.813 - 0.003t | 0.228 | 267.044 | 261.3 |
| GEV₍t₎ - III | -86.316 + 0.0528t | 4.843 + 0.0029t | 0.187 | 269.27 | **262.103** |
| 120 | GEV₍t₎ – I | 17.533 + 0.004t | 14.119 | 0.1791 | 281.315 | 275.58 |
| GEV₍t₎ – II | 24.355 | 14.89 - 0.0005t | 0.1848 | 281.372 | 275.636 |
| GEV₍t₎ - III | -180.216 + 0.102t | 1.492 + 0.0060t | 0.2055 | 282.945 | **275.775** |
| 360 | GEV₍t₎ – I | 35.417-- 0.00011t | 20.081 | 0.1836 | 304.081 | 298.345 |
| GEV₍t₎ – II | 35.119 | 21.47 - 0.0007t | 0.1849 | 304.08 | 298.344 |
| GEV₍t₎ - III | -0.1703 + 0.017t | 19.0 + 0.0004t | 0.1954 | 307.297 | **300.127** |
| 720 | GEV₍t₎ – I | 44.635-- 0.0002t | 25.296 | 0.183 | 318.406 | 312.67 |
| GEV₍t₎ – II | 44.252 | 27.05 - 0.0009t | 0.2336 | 318.405 | 312.669 |
| GEV₍t₎ - III | -24.449 + 0.0343t | 22.28 + 0.0011t | 0.2072 | 321.499 | **314.329** |
| 1440 | GEV₍t₎ – I | 56.244 - 0.0002t | 31.872 | 0.3669 | 332.73 | 326.994 |
| GEV₍t₎ – II | 55.759 | 34.08 - 0.0011t | 0.2321 | 332.728 | 326.993 |
| GEV₍t₎ - III | 12.572 + 0.0215t | 31.23 + 0.0003t | 0.1949 | 335.987 | **328.818** |



**Figure 2: Computed Rainfall Intensity Duration Curves for Abakaliki**

**Table 4: GEV fitted General Non-stationary IDF (GNS-IDF) model for Abakaliki**

| **S/N** | **Station** | **IDF Model** | **R²** | **MSE** |
| --- | --- | --- | --- | --- |
| 1 | **Abakaliki** | I =  | 0.996 | 37.00 |

**4. Discussion**

The analysis of rainfall patterns in Abakaliki revealed that there would be significant implications for infrastructure design if stationary models are utilised in developing IDF models. The Mann-Kendall test results show a significant increasing trend (p-value = 0.0059), and the identification of potential change points in 2010 and 2012 indicate non-stationarity in rainfall patterns. The development of IDF models utilizing non-stationary models revealed that the GEVt-III was the best non-stationary model for Abakaliki for most durations, with GEVt-I performing best for 5-minute duration. The GEVt-III model that best represents the rainfall pattern in Abakaliki suggests that both the location and scale parameters varied over the 31 years study duration. This indicates that the rainfall precipitation gradually increases from year to year, and the variation within each year also changes over the study duration. The utilisation of a stationary model will significantly underestimate the rainfall intensities as both the increase in the rainfall precipitation and its variability are not captured in the stationary models.

Underestimating rainfall intensity could lead to the design of inadequate drainage infrastructure, thereby increasing the risk of flooding in Abakaliki. Cheng and AghaKouchak (2014) demonstrated that stationary models could underestimate the 50-year precipitation by as much as 60% in some regions. The global trend towards non-stationary analysis is evident in the literature. Sugahara et al. (2009) found that non-stationary models better captured the increasing intensity of extreme rainfall events. The use of the non-stationary model for developing the IDF model has been embraced in other parts of the world. However, the adoption of non-stationary approaches in Nigeria has been relatively slow. Very limited studies have been done on non-stationary models in Nigeria. Nwaogazie and Sam (2020) found that most IDF studies in Nigeria still relied on stationary approaches despite growing evidence of climate change impacts. The implications of using stationary instead of non-stationary approaches in Abakaliki are particularly of concern, given its location in the South-Eastern region. AghaKouchak et al. (2018) emphasised the importance of non-stationary approaches in regions experiencing rapid climate change. Willem et al. (2012) noted that incorporating such non-stationary patterns in urban drainage design could reduce infrastructure vulnerability by up to 30%. These findings suggest an urgent need to update design standards and infrastructure planning approaches in Abakaliki. Continuing to use stationary approaches would underestimate future rainfall intensities and lead to systemic infrastructure inadequacies, particularly in urban drainage system.

**5. Conclusion**

This study aimed to create non-stationary Intensity-Duration-Frequency (IDF) curves for Abakaliki, Nigeria, utilizing a 31-year rainfall dataset (1992-2022) sourced from the Nigerian Meteorological Agency. Trend and change point analyses indicated that climate change affects rainfall patterns in Abakaliki. The identified significant increasing trend in rainfall intensity and the change points detected in 2010 and 2012 provide compelling evidence of non-stationarity in local precipitation patterns. The GEVt-III model outperformed in most duration intervals, while the GEVt-I model excelled at 5-minute duration, highlighting the limitations of traditional stationary methods for modeling rainfall in this area. The findings correspond with global trends regarding climate change's impact on precipitation patterns and emphasize the urgent need to revise design standards and infrastructure planning in the region. The results indicate that relying on stationary IDF curves for infrastructure design in Abakaliki may lead to substantial underestimation of rainfall intensities, potentially resulting in inadequate infrastructure capacity.

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