Analysing Rainfall Trends and Flood Risk in Coastal Nigeria: A Case Study of Calabar Using Mann-Kendall and Sen's Slope Methods

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ABSTRACT

This study investigates long-term patterns in rainfall and related flood frequencies in Calabar, southeastern Nigeria, using the Mann-Kendall trend test and Sen's slope estimator. Covering twenty years (2003–2022), it utilises daily rainfall data from the Nigerian Meteorological Agency (NiMET) to examine changes in rainfall intensity and seasonality. The results reveal no statistically significant trend in annual rainfall ($p = 1.0$), although Sen's slope indicates a slight downward trend (+7.907 mm/year). August was the only month with a statistically significant decrease in rainfall, with a Sen slope of – 0.387. The findings suggest increasing flood vulnerability despite the lack of statistical significance, emphasising the need for proactive flood management measures such as improved drainage, urban planning, and public awareness in the region.

Keywords: Rainfall trends, Mann-Kendall test, Sen's slope, Calabar, flood risk, climate variability.

INTRODUCTION

Rainfall variability, especially in tropical coastal cities like Calabar, significantly affects urban infrastructure and public safety due to elevated flood risks. Despite receiving over 2,900 mm of annual rainfall (Amadi et al., 2021), recent flood events indicate that traditional assumptions about rainfall patterns may no longer be accurate. This paper utilises non-parametric statistical methods to analyse temporal rainfall trends and their implications for flooding in Calabar. The study fills a gap in regional empirical data, supporting the development of adaptive climate and disaster policies. Globally, rainfall variability and flooding present significant environmental challenges, particularly in areas experiencing intense climate change and human impact. In many tropical regions, including Nigeria, highly variable rainfall patterns have serious consequences for water resource management, agriculture, and disaster preparedness. Calabar, situated in south-eastern Nigeria, experiences high annual rainfall due to its coastal proximity to the Atlantic Ocean. However, this abundance of rain also makes the region susceptible to frequent flooding (Amadi et al., 2021). Such floods often cause extensive damage, displacing residents, destroying infrastructure, and resulting in economic losses. A primary cause of flooding in Calabar is poorly designed drain sizing and distribution, along with the use of existing slopes to establish drain invert levels during construction (Antigha et al., 2018). The Mann-Kendall method and Sen's slope estimator are two established non-parametric techniques used to identify trends in environmental data (Yue & Wang, 2002). The Mann-Kendall test is widely adopted in hydrology to determine whether a statistically significant trend exists in time-series data. It is advantageous for rainfall data because it can detect increasing or decreasing trends without assuming a specific data distribution (Ekwueme & Agunwamba, 2021). Meanwhile, Sen's slope estimates the rate of change over time, offering insights into how quickly rainfall patterns are shifting (Sen, 1968). The Mann–Kendall and Sen's slope methods are frequently employed together in rainfall and flood studies because they complement each other in trend analysis. The Mann–Kendall test effectively detects the presence of a statistically significant monotonic trend but does not quantify the change's magnitude. Sen's slope, on the other hand, provides an estimate of the rate and direction of that change, offering practical insights into how swiftly rainfall or flood patterns are evolving. When used together, these methods deliver a more thorough assessment by identifying both the existence of a trend and its intensity, making them particularly useful in hydrological and climate research.

METHOD

Study Area

The Calabar region, located in southeastern Nigeria, is notable for its unique geographical and climatic features that significantly influence its hydrology and flood patterns. Calabar acts as the capital of Cross River State. Geographically, the city is situated between two major rivers: the Calabar River to the west and the Great Kwa River to the east. These rivers converge at the Cross River estuary, which flows into the Atlantic Ocean (Efiong et al., 2024). Covering approximately 137 km², Calabar's distinctive geographical and geomorphic characteristics considerably impact its vulnerability to flooding. Key features include the Marina escarpment, two parallel ridges, and a geosyncline passing through the city, creating physical and drainage challenges. The Marina escarpment, on the city's western edge, faces the winding Calabar River and extends from Calcemco Beach to Nsidung Beach. This cuesta-like formation encourages surface water runoff towards low-lying areas. Two prominent ridges run parallel: one along the western side from Ikot Ekpo/Tinapa in the north to Mbukpa in the south, covering about 40% of the city, and another along the eastern side near the well-known Eastern Highway, rising roughly 60 meters above sea level. Both ridges drain into a central geosyncline or depression, which extends north-south through key parts of the city, including Big Qua Town and Otop Abasi Barracks. This geosyncline is the lowest zone in Calabar, making its areas prone to periodic flooding because of poor drainage (Efiong et al., 2024). Calabar has a tropical rainforest climate with year-round rainfall, exhibiting a double-peaked pattern in June/July and September/October. Total annual rainfall often exceeds 2,000 mm, while average temperatures hover around 27°C, seldom dropping below 19°C (CRBDA, 1982). According to Koppen's classification, Calabar is designated as a humid tropical climate. Urban growth and land use changes have displaced much of the original vegetation, especially in the eastern and southern wetlands, which face threats from encroachment. These climate and environmental factors increase the city's flood risks. Geologically, Calabar forms part of the Benin Formation in the Niger Delta Basin, mainly composed of coarse sands, gravels, and minor clay layers. Although this porous geology allows water to infiltrate easily, urban development has substantially altered the landscape, leading to increased surface runoff. Along with topographical and drainage challenges, this heightens the risk of sheet and gully erosion (Efiong et al., 2024). The city's expansion is primarily directed northward, constrained by the rivers on the east and west and the swampy mangrove forests to the south. Calabar is divided into two administrative areas: Calabar Municipality and Calabar South Local Government Area. It is an interfluvial settlement situated on higher ground between the two river valleys. While its strategic location between the Calabar and Great Kwa rivers boosts economic and cultural activities, it also makes the city vulnerable to frequent flooding, a problem worsened by inadequate drainage infrastructure and urban encroachment. Despite these challenges, Calabar has grown into a vibrant urban centre, attracting migrants and tourists with its rich cultural heritage and aesthetic appeal (Yaro et al., 2016).

Data Collection

- The primary source of rainfall data for this study is historical records obtained from the Nigerian Meteorological Agency (NiMET). NiMET operates various meteorological stations across Nigeria, including in the Calabar region, and is responsible for collecting, processing, and disseminating meteorological data. The rainfall data spans several decades, enabling analysis of long-term trends and seasonal variations. The dataset includes daily, monthly, and yearly rainfall measurements, which are vital for understanding rainfall timing and recognising patterns of variability.
- Flood data were gathered from various sources to thoroughly evaluate flood events and their impacts in the Calabar region. The primary source of flood data includes reports and records from the National Emergency Management Agency (NEMA) of Nigeria. The research also incorporated flood-related data from peer-reviewed articles and studies that have previously examined flooding in Calabar. This secondary data source is vital for cross-verifying information and supporting findings from primary sources.

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Analytical Tools

- Mann-Kendall Test: The Mann-Kendall test is a non-parametric statistical method commonly used to detect trends in time series data without assuming a specific distribution (Hirsch et al., 1982). This method is beneficial for hydrological data, such as rainfall and flood records, which often do not follow a normal distribution and may contain outliers. The Mann-Kendall test evaluates whether there is a monotonic trend in the data, meaning it can identify if the variable consistently increases or decreases over time (Hamed, 2008). The approach works by comparing the ranks of data points in a time series. For each pair of observations, the test calculates the difference in ranks. If a later observation exceeds an earlier one, it adds a positive value; if smaller, it adds a negative value. The sum of these differences is the Mann-Kendall statistic (S), which can be used to derive a Z statistic for hypothesis testing. A significant positive Z indicates an upward trend, while a significant negative Z indicates a downward trend (Kendall, 1975).

- Limitations of the Mann-Kendall Test

The Mann–Kendall test is valuable for identifying monotonic trends in hydrological and climatic data, but it has notable limitations. It is sensitive to serial correlation, cannot detect non-linear or cyclical standardised variations, and does not provide the magnitude of change without supplementary methods like Sen's slope. Its reliability is also influenced by sample size; it does not explain the causes of trends, and it assumes spatial independence, which may not hold in correlated systems.

- Sen's Slope Estimator: Sen's Slope Estimator is a widely used non-parametric method that estimates the slope of the trend line in a time series dataset, providing a measure of the rate of change over time (Sen, 1968). This approach is helpful in hydrological studies because it offers a simple way to interpret changes in variables such as rainfall and flood frequencies. Sen's Slope calculates the slope between all pairs of data points in the dataset. For each pair (x_i, y_i) and (x_j, y_j), where x represents time and y the variable of interest, the slope (Q) is computed as:

$$Q = \frac{y_j - y_i}{x_j - x_i}$$

This process generates a set of slope estimates, which are then ranked to identify the median slope, providing a dependable measure of the overall trend (Hamed, 2008). This approach performs well with datasets containing outliers, as extreme values have less influence on the median than the mean.

- Software used: The analysis of rainfall patterns and flood frequencies in the Calabar region required advanced software and tools to support data management, statistical analysis, and visualisation. These tools combined enabled a comprehensive approach to the research, ensuring that both data processing and analytical techniques were carried out efficiently and accurately.

Microsoft Excel was primarily used for initial data organisation and exploratory analysis. Its user-friendly interface enables straightforward data entry and management, making it an ideal tool for early data preprocessing. Excel's features, such as sorting, filtering, and basic statistical calculations, are utilised to perform an initial pass of data validation, ensuring that the datasets are complete and correctly formatted before being imported into R for advanced analysis. Furthermore, Excel's charting capabilities aid in visualising initial data patterns, including basic time series plots of rainfall and flood occurrences.

RESULTS AND DISCUSSION

Rainfall Pattern Overview

The rainfall data for the Calabar region over 20 years for this study were obtained online from the Nigerian Meteorological Agency (NiMET), covering 2003 to 2022. This data was collected as monthly averages and measured in mm/day. The precipitation data used are presented in Table 1 below.

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Table 1: Average Daily Precipitation for Calabar Region between 2003 and 2022 (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	mm/day												
2003	3.08	4.9	1.51	6.32	11.29	9.36	5.1	11.29	10.79	9.68	2.55	1	6.41
2004	2.45	0.55	0.87	8.42	10.8	14.72	9.86	17.97	15.27	6.24	6.5	0.46	7.85
2005	0.59	1.68	4.95	5.02	6.43	10.88	8.86	16.49	27.41	10.39	2.16	0.26	7.94
2006	2.27	2.91	4.83	7.63	7.01	3.95	19.3	29.98	26.25	7.8	3.1	0.1	9.64
2007	0.05	2.76	1.91	6.37	5.08	26.8	23.9	20.69	18.64	12.73	7.55	1.56	10.69
2008	0.41	0.91	4.05	7.5	6.26	10.83	7.79	14.59	15.58	8.17	3.6	1.59	6.78
2009	2.34	1.86	6.59	4.97	5.7	11.83	9.72	14.4	12.95	7.52	3.66	0.29	6.84
2010	2.78	4.35	5.4	6.54	8.86	8.55	19	16.44	11.67	9.43	3.39	0.87	8.14
2011	0.44	3.1	3.18	4.71	7.37	13.15	18.57	22.99	16.94	12.18	1.87	0.15	8.76
2012	0.42	3.74	2.84	7.52	4.92	19.49	13.65	14.95	17.1	11.94	6.5	1.36	8.69
2013	0.47	1.78	6.27	6.29	7.64	10.19	11.84	11.11	19.27	12.59	9.74	2.07	8.29
2014	0.3	2.2	4.02	4.96	6.01	5.03	10.59	14.07	12.3	8.51	2.83	0.06	5.93
2015	0.2	3.02	3.61	3.59	7.36	17.32	12.99	11.51	11.86	12.73	7.76	0.08	7.68
2016	0.24	0.75	9.45	5.86	8.93	14.31	11.39	20.14	12.62	14.53	2.67	1.35	8.56
2017	0.75	0.41	7.03	7.7	9.88	10.57	16.77	15.1	11.68	15.3	8.74	0.13	8.73
2018	0.28	7.01	3.73	3.67	5.5	18.92	10.18	10.95	7.78	8.83	6.97	0.16	6.97
2019	1.97	1.08	3.45	1.44	2.97	6.13	13.05	14.8	10.62	9.21	7.79	0.44	6.12
2020	0.02	0.41	10.86	4.45	9.49	10.63	16.26	8.9	18.86	10.39	6.74	0.55	8.15
2021	0.66	0.39	2.32	11.34	12.04	7.11	7.94	8.56	11.57	10.35	6.19	1.99	6.73
2022	2.15	0.33	3.47	7.08	5.76	9.13	16.25	14.96	37.8	8.7	4.13	0.78	9.23

Mann-Kendall Trend and Sen's Slope Result

The statistics, including the mean and standard deviation of the data, are shown in Table 2 below.

Table 2: Statistics of Rainfall Data over the Study Area

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
JAN	20	0.020	3.080	1.094	1.047
FEB	20	0.330	7.010	2.207	1.795
MAR	20	0.870	10.860	4.517	2.534
APR	20	1.440	11.340	6.069	2.120
MAY	20	2.970	12.040	7.465	2.383
JUN	20	3.950	26.800	11.945	5.497
JUL	20	5.100	23.900	13.151	4.766
AUG	20	8.560	29.980	15.495	5.093
SEP	20	7.780	37.800	16.348	7.141
OCT	20	6.240	15.300	10.361	2.421
NOV	20	1.870	9.740	5.222	2.459
DEC	20	0.060	2.070	0.763	0.671
ANN	20	5.930	10.690	7.907	1.241

The analysis shows that September records the highest rainfall intensity, averaging 37.8 mm/day, making it the wettest month within the study period. Conversely, January experiences the lowest rainfall, with only 0.02 mm/day, indicating a distinctly dry season. Other months with relatively high rainfall include August (29.8 mm/day), June (26.8 mm/day), and July (23.9 mm/day), all of which significantly contribute to the city's hydrological pattern. The concentration of heavy rainfall during these peak months, combined with the city's low-lying geomorphic setting and inadequate drainage infrastructure, worsens the occurrence of flash floods, often leading to severe urban flooding (Ojikpong et al., 2016; Bassey & Effiong, 2021). This emphasises the

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urgent need for effective stormwater management strategies, such as improved drainage systems, retention basins, and sustainable urban planning, to reduce flood risks during these critical months.

Mann-Kendall Test

The Mann-Kendall Two-Tailed Test Result for the Annual Rainfall of Calabar Region is shown in Table 3

Table 3: Mann-Kendell Two-Tailed Trend Test for Annual Rainfall

Kendall's tau	0
S	0.000
Var(S)	950.000
p-value (Two-tailed)	1.000
alpha	0.05

Test interpretation

H_o: There is no significant trend in the series

H_a: There is a significant trend in the series

The computed p-value is greater than the significance level $\propto = 0.05$; therefore, we do not reject the null hypothesis, indicating that there is no significant trend in the annual rainfall data for the 2 decades between 2003 and 2022 used in this study in the Calabar Region.

Sen's Slope

For the duration of the rainfall data obtained, the graph showing Sen's Slope is depicted in Figure 1 below.

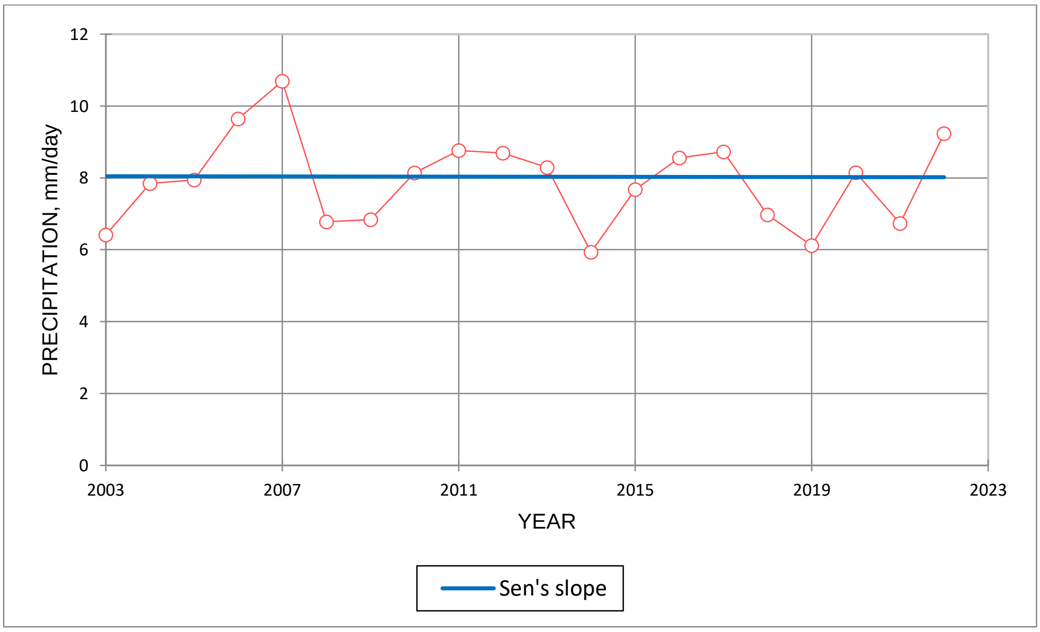

Figure 1: Sen's Slope of Annual Rainfall of Calabar Region between 2003 and 2022

This shows that the Sen's Slope of annual precipitation data over the study area from 2003 to 2022 is near zero (-0.001), indicating no significant trend in the series.

Kendall's Tau, Sens's Slope, And P-Value for Annual Rainfall

The Kendall Tau Parameter, Sen's Slope, and ρ-value for each month of the obtained rainfall data, as well as the annual rainfall over the study area, are shown in Table 4.

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Table 4: Kendall Tau, ρ-value, and Sen's Slope for Monthly Annual Rainfall between 2003 and 2022

Series\Test	Kendall's tau	p-value	Sen's slope
JAN	-0.242	0.144	-0.032
FEB	-0.322	0.051	-0.117
MAR	0.158	0.347	0.106
APR	-0.200	0.230	-0.084
MAY	-0.032	0.871	-0.032
JUN	-0.105	0.538	-0.106
JUL	0.084	0.626	0.166
AUG	-0.347	0.035	-0.387
SEP	-0.189	0.256	-0.227
OCT	0.201	0.229	0.139
NOV	0.248	0.135	0.140
DEC	0.021	0.922	0.004
ANN	0.000	1.000	-0.001

Between 2003 and 2022, rainfall trends across the months exhibit varying patterns. January, February, April, May, June, and September show no statistically significant trend. Although both Sen's slope and Kendall's tau indicate a weak downward tendency, the p-value greater than 0.05 suggests that this decline is not statistically significant and may be due to random variation. In contrast, March, July, October, November, and December also display no significant trend; however, both Kendall's tau and Sen's slope point to a slight upward direction. Since the p-value remains above 0.05, this increase is considered statistically insignificant, representing only a weak, non-reliable upward tendency. Even though the trend within this period is weak, the city of Calabar can still experience floods due to the geomorphology of the land (Okon et al. 2015). Notably, August stands out, exhibiting a significant decreasing trend in rainfall. Here, both Kendall's tau and Sen's slope are harmful, and with $p < 0.05$, the result confirms a robust and statistically reliable downward trend during the study period. The graph of the ρ-value for each month and annual rainfall is shown in Figure 2.

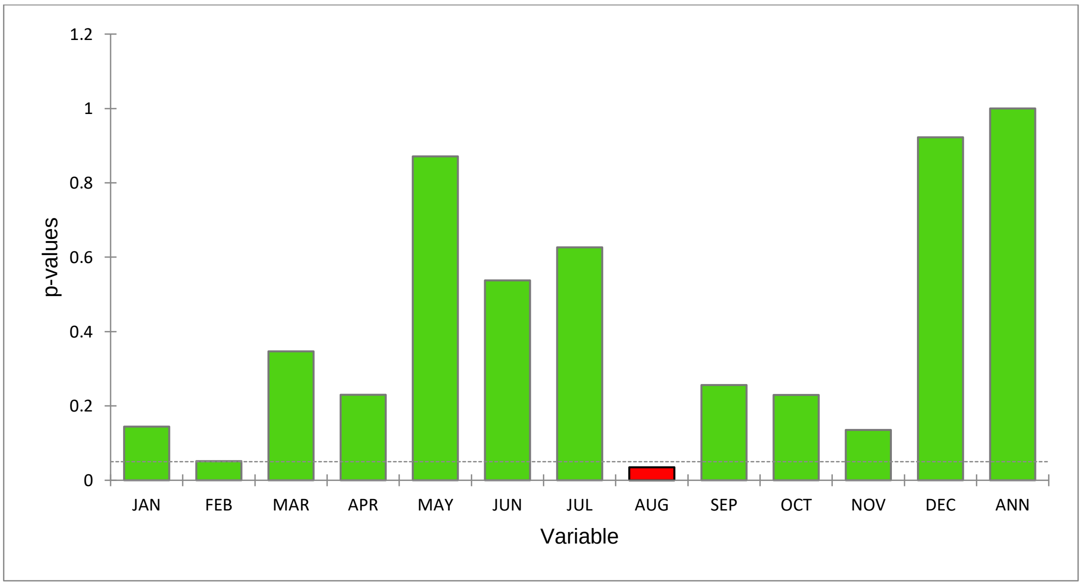

Figure 2: $\rho - value$ of each month and the annual rainfall between 2003 and 2022

Within the 2003–2022 study period, August is the only month exhibiting a statistically significant trend, with a p-value of 0.035. This value falls below the 5% significance threshold, leading to the rejection of the null hypothesis and confirmation of a significant rainfall trend in that month. February, with a p-value of 0.051, lies very close to the 5% threshold, suggesting a near-significant result that warrants attention but does not meet the conventional criterion for significance. For all other months, p-values are well above 0.05, indicating insufficient evidence to reject the null hypothesis and thus no statistically significant rainfall trends in those periods.

CONCLUSION

This study investigated rainfall variability and flood risk in Calabar, a coastal city in southern Nigeria, using the Mann–Kendall test and Sen's slope method from 2003 to 2022. The results show that September has the highest rainfall (37.8 mm/day), while January remains the driest month (0.02 mm/day). Other months with high rainfall, such as August (29.8 mm/day), June (26.8 mm/day), and July (23.9 mm/day), also significantly influence the city's hydrology. The concentration of heavy rainfall during these months, combined with the city's low-lying terrain and inadequate drainage infrastructure, heightens its vulnerability to flash floods, often causing severe urban flooding. Statistical analysis reveals no significant long-term trend in annual rainfall, indicated by a near-zero Sen's slope (-0.001) and p-values above the 0.05 threshold. Most monthly trends, whether marginally increasing or decreasing, are weak and statistically insignificant, with August being the only month showing a statistically significant decreasing trend ($p = 0.035$). February's near-significant value ($p = 0.051$) suggests a borderline case that requires further investigation.

The findings show that, even without strong long-term rainfall trends, Calabar remains highly vulnerable to flood hazards because of its geomorphic setting and infrastructural issues. This has broader implications for tropical coastal cities, where localised rainfall extremes and poor urban planning often combine to raise flood risks. To reduce vulnerability, practical strategies such as upgrading drainage systems, integrating green infrastructure, and enforcing land-use regulations are urgently needed.

Future research should build on this analysis by incorporating climate model projections to evaluate how long-term changes in rainfall patterns under climate change could influence flood risk dynamics in Calabar and similar coastal areas. Additionally, spatial analyses and hydrological modelling could offer more detailed insights into flood-prone regions and help shape effective adaptation strategies. By combining statistical trend detection with predictive modelling, policymakers and planners will be better prepared to develop sustainable, climate-resilient systems for managing floods in tropical coastal cities.

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