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Innovative trend analysis of precipitation changes over Nigeria: A case study of locations across the Niger and Benue Rivers

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Abstract

Precipitation has become a major topic of discussion in the subject of climate change. Studies have presented correlative relationships between climate change and the existing alterations in the global water cycle, leading to more extreme precipitation events, including both droughts and floods. This has shown severe impacts on agriculture, water resources, ozone levels, and human settlements. Accordingly, this study analyzes the trends in 40 years (1981-2020) of total monthly and annual precipitation data from six selected locations in Nigeria, using both the Mann-Kendall (MK) and new Sen's innovative trend analysis (ITA) method. The stations were chosen because of their close proximity to the Niger or Benue Rivers. The data were visually analyzed using boxplots to identify seasonal patterns and outliers, and the results of the MK test show that four of the six locations detected trends for annual and wet season precipitation variations. However, this was not applicable to dry season variations. The ITA test results show that only Kainji has an increasing trend in total annual and wet season precipitation, especially for high precipitation values, whereas other locations show decreasing trends for maximum precipitation values. A comparison of the two tests suggests that, the ITA test is more sensitive in detecting trends in precipitation data for the study locations. Overall, this study provides useful information for understanding the precipitation patterns in Nigeria, and can assist in planning and implementing appropriate water resource management strategies, with regards to the major rivers in the region.

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1. Introduction

1.1. Background

Climate change is a global phenomenon, and a major concern in recent times [1]; encompassing fields such as sustain-

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able development [2], health impacts [3], mental well-being and environmental impact assessment [4]. The result is severe weather conditions with adverse impact on ecosystems, economies and human lives. A key environmental component affected by climate change is precipitation, and its rate of change significantly affects agriculture, water resources and hydrological systems [5].

In Refs. [6, 7] it was demonstrated that there was a change in global precipitation patterns due to climate change, and Nigeria is not an exception. In Nigeria, variations in precipitation patterns over time have induced flooding, droughts, and other water-related risks; according to a study by Chinwendu *et al.* [8] and Akpodiogaga-a and Odjugo [9]. This has resulted in the nation experiencing significant socioeconomic impacts including decreased agricultural output, infrastructure damage, and population displacement [10, 11]. Nigeria's major rivers, the River Niger and the River Benue, are crucial to the nation's management of natural water supplies and agricultural endeavors [12]. Thus, making the effect of climate change on precipitation patterns along both rivers rivers a core focus of numerous research. For instance, a study by Aich *et al.* and Oguntunde and Abiodun [13, 14] discovered that rainfall over the Niger River basin has increased significantly whereas rainfall over the Benue River basin has dropped.

1.2. Literature review

The literature review presentation in Table 1 evaluates previous studies including the methods employed, research outcomes, the implications of the findings revealed, and its consequences concerning climate change. Concerning rainfall variability analysis in Ref. [15], a few common techniques are the coefficient of variation (COV), the standardised anomaly index (SAO), and the precipitation concentration index (PCI). These methods provide some considerable insight into the existing temporal patterns of rainfall variations in diverse regions. However, these techniques are limited in their ability to detect trends across specific data ranges. Trend analysis in rainfall or temperature variation is suitably examined in several studies [15–24] using the Mann-Kendall (MK) test and Sen's slope estimators (SSE). Nevertheless, even the MK test and SSE have certain limitations as they are incapable of detecting non-monotonic trends and clusters, and are only suitable to identifying monotonic trends.

Specifically, the MK test is a non-parametric test capable of detecting monotonic trends in a time series data. However, the aforementioned limitation and its de-sensitivity to outliers has shown an underestimation of significance in some analysed trends. For instance, Alifujiang *et al.* [17] study on the Upper Wabe Shebelle River Basin in Southern Eastern Ethiopia shows that the MK test was limited in detecting significant trends in only 19.4% of the assessed stations, whereas the ITA method was able detect significance in 36.1%. Additionally, the Sen's slope estimators (SSE) is suited to estimating the magnitude of the trend [15, 16, 18–21].The SSE is a non-parametric method, that is less sensitive to detecting outliers compared to the MK test. A unique characteristic of the SSE is its leanings towards a linear trend. However, such a behaviour is not always accurate, and can induce an overestimation or underestimation of the trend's magnitude; this is bound to vary. Thus, the Innovative Trend Analysis (ITA) method is used in overcoming such limitations as employed in the following studies [15–19, 21, 23–29].

The ITA method has been seen to be more efficient in detecting low, medium and high clusters, including monotonic and non-monotonic trends in rainfall; as observed in Ref. [17]. Moreover, Cui *et al.* [16] study on the Yangtze River Basin in Western China reveals the ITA's competency in distinctly identifying, low, medium and high trends in the river flow. An outcome unavailable in the MK test; nevertheless, the ITA is not without certain limitations. For instance, Caloiero [22] highlighted that the ITA method does not facilitate an identification of differences between each point and the 1:1 line. Such constraints can skew the accuracy in interpreting the magnitude of change in rainfall trends. Furthermore, in certain situations the ITA method has displayed an over-sensitivity to certain choice of parameters, namely, the significance level and number of bootstrap replications. Aside rainfall assessments, temperature trends analysis requires the utilisation of the MK test, SSE and the ITA method according to Refs. [18, 20, 26, 28]; these four studies have shown a similar outcome of significant increasing trends in temperature, specifically in the hot and dry seasons. The interpretation of such findings imply a significant influence of climate"chan'e on agricultural productivity and water availability in the assessed regions.

Crucial to study's analysis and decision-making, is the reliability of the data used in the study. The quality of such data is dependent on the source and time period of the study. Evidence from most reviewed studies shows a collection of data spanning several decades, 30 to 118 years [15–29]. However, a closer inspection of the datasets as explained in each individual study's methodology reveals a considerable variation in its number of locations/stations. For instance, Danandeh *et al.* [26] employed data from a single station while Marak *et al.* [23] utilised data from about 6,955 stations. This distortion in spatial coverage may affect the generalisability of the findings for a larger region in which the assessed results are sourced from sub-regions. Moreover, the choice of the most suitable statistical method of analysis is a choice that requires careful consideration, due to the intended outcome. Seceral studies, including Refs. [19–23, 25, 29] combine methods, in order to facilitate a comparison of results. Mallick *et al.* [19] study of the Asir region in Saudi Arabia revealed that the ITA method identified significant decreasing trends in annual rainfall at 25 stations. Whereas, the MK test was only able to detect trends at 20 stations. Thus, emphasising the importance of multiple methods in informing a comprehensive understanding of trends in both temperature and rainfall.

To conclude this review, the choice of analysis method holds significant import over the accuracy of results. An accuracy-basis examination of previous studies reveals the ITA method as the most suitable, primarily due to its detection of both monotonic and non-monotonic rends, as well as low, medium and high clusters. Regardless, the underlying research

Table 1. Literature review of studies across the world that applied the ITA method alongside other methods. The presented studies employed numerous methods in temperature, precipitation, rainfall and flow trends analysis across diverse study areas and timeframes.

Author	Technique Used	Study Area	Data Set (Provision & Timeframe)	Observation
[15]	*Rainfall variability analysis*: coefficient of variation (COV), precipitation concentration index (PCI), standardised anomaly index (SAI) *Spatio-temporal trends*: Mann-Kendall test (MK), Sen's slope estimators (SSE) *Rainfall clusters*: Innovative Trend Analysis (ITA)	Upper Wabe Shebelle River Basin; South Eastern Ethiopia	Rainfall data for obtained from 19 stations; spanning 1989-2018 (30 years)	ITA is better than MK, due to its detection of low, medium and high clusters, monotonic and non-monotonic trends in rainfall; wherein the MK is limited.
[16]	*Annual and Seasonal River flow*: Linear regression (LR) analysis, MK test, Sen's method, ITA	Yangtze River; Western China	Data was obtained from 214 meteorological stations; spanning 1960 to 2015 (56 years)	The ITA covers assumptions such as test number, serial relationship and non-normality; which cannot be done by Sen and MK's methods. Also, permits the distinct identification of high, medium and low tends in the flow.
[17]	*Monthly features of the Precipitation*: MK test *Inherent details on monthly precipitation and temporal trends*: ITA method	Lake Issy-Kul basin; Kyrgyzstan	Monthly precipitation data from 3 stations surrounding the Lake Issy-Kul (Balykchy, Cholpon-Ata and Kyzyl-Suu); spanning 1951-2012 (62 years)	The MK test recorded a 19.4% significance trend, while the ITA recorded a 36.1% significant trend, more positive than the MK test. The ITA results are more detailed than the MK's in its identification of hidden variations of precipitation trends and the graphical depiction of extreme events trend possibilities.
[18]	*Annual and Seasonal variations in air temperature and precipitation:* MK test, ITA and Sen's slope estimator	Kashmir Valley; North-West Himalayas	Data was obtained from 6 ground-based stations; spanning 1980-2019 (40 years)	Investigations into minimum and maximum air temperature (T_{min} and T_{max}) and precipitation over Kashmir Valley shows increased T_{min} and T_{max} trends. Furthermore, decreased precipitation trends makes the region prone to drier climatic weather.
[19]	*Historical Rainfall trend analysis*: MK test, trend free pre-whitening Mann-Kendall (TFPW MK) test, and ITA *Serial Correlation detection*: Modified Mann-Kendall (MMK) test *Future rainfall trend and long-term temporal relation between future and past annual rainfall trends:* Detrended Fluctuation Analysis (DFA)	Asir region; Saudi Arabia	Monthly and Annual rainfall data was obtained from 30 meteorological stations; spanning 1970-2017 (47 years)	The ITA detected 25 stations, MMK detected 23 stations, TFPW MK detected 21 stations, and the MK detected 20 stations revealing significant decreasing trends in the region's annual rainfall. The ITA detected significant negative trends in some stations which could not be detected at all by other methods Regarding the DFA, most stations showed a decline in future rainfall
[26]	*Monthly, seasonal and annual trends in temperature and precipitation*: MK test, Sen's slope methods. *Seasonal and annual trend*: ITA *Annual trend*: successive average methodology (SAM)	Osijek, Croatia	Data was collected from 1 station; the Osijek meteorological station; spanning 1900-2018 (118 years)	Revealed significant increasing trends of air temperature in the hot and dry seasons. Temperature and precipitation trends highlight potential risk to agricultural production

[27]	*Partial trends in Rainfall*: ITA	North-Eastern Algeria	Data was obtained from 16 meteorological stations; spanning 1982-2019 (38 years)	The climate change impact is seen the region's increased precipitation and recurring extreme rainfall episodes
[28]	*Air Temperature and Precipitation*: ITA	Jinsha River Basin; China	Data was obtained for 40 meteorological stations; spanning 1961-2016 (57 years)	Significant increasing trends were observed for annual and seasonal temperatures at a 99% confidence level Annual precipitation showed an increasing trend in the Jinsha River Basin
[20]	*Annual temperature and precipitation time series reliability:* ITA, MK test and Sen's slope test estimator	Upper Huai River Basin; China	Data was obtained from 6 meteorological stations; spanning 1960-2016 (57 years)	Weak correlative relationship between temperature and precipitation (r = -0.17) Results imply a significant change in temperature and rainfall; a result of climate change in the region
[21]	*Annual and seasonal rainfall analysis*: ITA, MK test and Sen's slope estimator *Normal distribution test of rainfall time series*: Shapiro-Wilk tests	Sri Lanka	Data obtained from 37 meteorological stations; spanning 1987-2017 (31 years)	MK results showed an increasing trend for 65% of the stations and a decreasing trend for the remaining 35%. Whereas, ITA showed increasing trend for 67% and a decreasing trend for 33% Both MK and ITA showed rainfall increased during the First Inter-Monsoon and decreased during the South-West Monsoon
[30]	Monthly precipitation analysis: Innovative Polygon Trend Analysis (IPTA) method	Susurluk Basin; Turkey	Data was obtained from 10 meteorological stations; spanning 2006-2017 (12 years)	Precipitation varies by years as there is no regular polygon display in the IPTA graphics, which were created for each station.
[22]	*Seasonal and Annual Rainfall trend analysis*: MK test, ITA and Sen's method	South Island; New Zealand	Data obtained from 152 rain gauges; spanning 1951-2010 (59 years)	When statistically significant, ITA limitation does not permit determination of difference between each point and the 1:1 line The South-West area of the Island is forecasted to be wetter and the North-East area of the island to be drier
[23]	*Spatial and Temporal Rainfall Variations*: MK test, ITA	Umiam and Umtru watersheds in Meghalay; India	Data provided by the Indian Meteorological Department; obtained daily rainfall data from 6955 rain gauge stations; spanning 1901-2018 (117 years)	Low and medium rainfall decreased from 1901 to 2018 The MK test detected significant trends in 60% of the grids, whereas the ITA detected 90% of the grids as having significant trends In the two watershed, Annual, winter, pre-monsoon and monsoon rainfall is decreasing, whereas post-monsoon rainfall is increasing
[29]	*Spatial Patterns of Rainfall regimes*: Precipitation Concentration Index (PCI) and Seasonality Index (SI) *Trend analysis:* ITA and percent bias (P_{BIAS}) *Reliability*: MK tests, Modified Mann-Kendall (MMK) test	Bangladesh	Data was obtained from 23 meteorological stations; spanning 1966 to 2019 (53 years)	The study shows a significant change in the climate within the examined timeframe, with drastic precipitation levels.

[24]	*Precipitation trend analysis*: ITA	Cheliff Watershed, Northern Algeria	Data was obtained from 28 meteorology stations; spanning 1959-2019 (60 years)	90% of stations have a medium slightly downward trend condition and 3% of the stations have a strong downward trend. No upward trend was observed
[25]	*Rainfall Trend Analysis Comparison*: MK, ITA and IPTA	Vu Gia-Thu Bon River Basin; Vietnam	Data was obtained from 15 selected rainfall monitoring stations; spanning 1979-2016 (38 years)	Significant increasing trend in March IPTA detected 88% significant trends in all months MK detected 26% and ITA with significance test detected 93% An observed regular natural equilibrium due to the polygon nesting around the global regression line

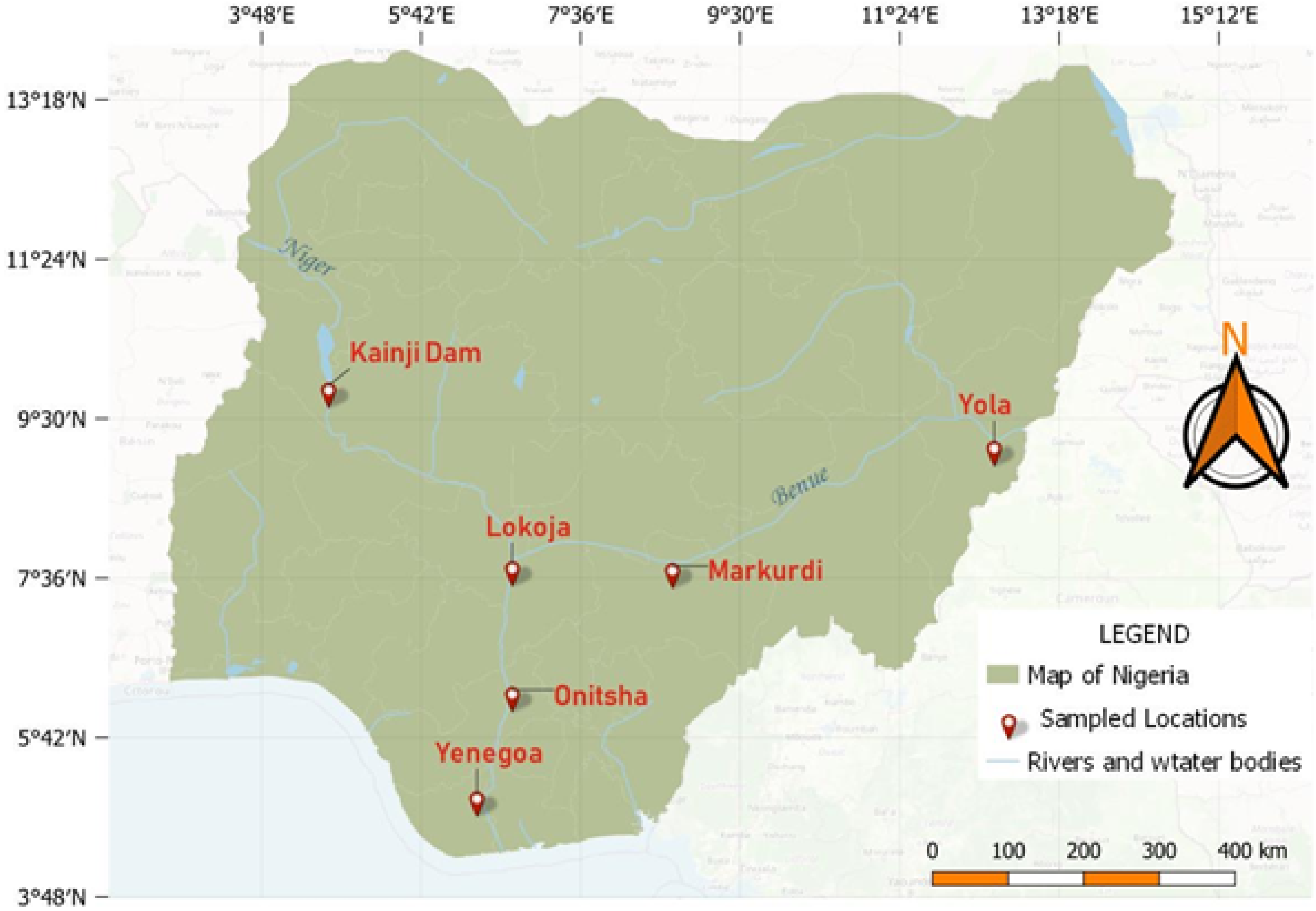

Figure 1. Study area (Nigeria) showing the six locations.

significance for such studies demands an action to necessary adaptive strategies suitable in mitigating against risks posed by climate change. Hence, a crucial objective remains informing the decision-making and policy development aimed at improving agricultural productivity and water availability. Lastly, integrating study results with other relevant climate related informarion offers the opportunity of developing climate change region-focused strategies.

1.3. Justification of methodology / Research questions

This study utilises statistical techniques and precpitation data across six major locations along the River Niger and the River Benue in analysing the trend of changing precipitations in key Nigerian locations. This study builds on the findings of earlier studies [9, 31], that demonstrated the effects of climate change on regional precipitation patterns, by adopting the innovative trend analysis (ITA) technique proposed in Ref. [32], and the non-parametric Mann-Kendall (MK) trend test for result comparison and in-depth evaluation. Table 1 provides a detailed literature review on the application of Sen's ITA test, drawing inferences from over 15 studies to highlight the advantages of using the ITA test alongside other conventional time-series analysis techniques. The rationale is adopting a fresh look in examining how the region's precipitation patterns has changed over time, identifying the influencing variables that are responsible for these trends, the trend patterns across data ranges (low, medium and high values), and discussing the impact these changes have on water resources and agriculture. Thus, the following research questions will be answered.

1. How have the annual and seasonal precipitation levels changed in the study locations over the past 40 years, are there any significant trends or patterns in the data? and what are the implications for water resources and agriculture?
2. How can the observed precipitation trends be related to river flow/water levels?
3. How does the innovative trend analysis (ITA) used in this study compare to traditional methods of trend analysis when applied to 40 years of seasonal and annual precipitation data?

The importance of these research questions is that they enable the study to bridge key gaps in understanding how climate change affects rainfall patterns in Nigeria's riverine zones. It intends to determine fluctuations in seasonal and yearly precipitation levels throughout critical areas along the Niger and Benue rivers by examining long-term precipitation trends using both innovative and traditional methodologies. These insights are critical for anticipating the effects on water resources, agriculture, and hydrological systems. Another objective of the study is to provide actionable data for policymakers and resource managers in the face of climatic variability by improving the accuracy of trend detection using ITA and comparing it to the Mann-Kendall test. The study's premise is that, as a result of climate change, precipitation patterns along the Niger and Benue Rivers are changing, with important ramifications for water resource management and agriculture; this has necessitated the utilization of a more conventional analysis method in understanding key precipitation inducing variables The study will add to the expanding body of knowledge about how climate change affects precipitation patterns and offer policymakers, managers of water resources, and farmers insightful information.

2. Study area and data

Nigeria, a Sub-Saharan country, located between lattitudes 4 degrees and 14 degrees and longitude 3 degrees and 14 degrees [33]. The climate becomes progressively drier as we approach the north from the coastal regions of the south [9]. Nigeria features diverse vegetation/climatic zones by the Atlantic Ocean to the south and the Sahara desert to the north [34, 35]. Numerous zones exhibit distinctive traits, and the climatic cover relies significantly on a location's proximity to the Sahara Desert, the Rivers Niger and Benue, or the Atlantic Ocean [36]. Moreover, altitude has a noticeable impact on vegetation, and Nigeria is not an exception [37]; however, meteorological variables are always affected by the afrementioned factors [38]. That is why this study is focused on six distinct locations from different regions , in close proximity to any or both of the Rivers Niger and Benue. Figure 1 shows the exact locations of these stations, their obviuos proximity to the rivers and also the confluence of these rivers. Table 2 shows the six locations, their exact cordinates, and a description of their climatic characteristics and effects it has on anthropogenic activities in general.

Forty years total monthly precipitation data from 1981 to 2020 were obtained from the NASA POWER DATA repository (https://power.larc.nasa.gov/data-access-viewer/) for all locations in each of Nigeria's vegetation zones as indicated in Figure 1.

3. Methodology

3.1. The Mann-Kendall (MK) trend test

The MK test is a non-parametric test used in analysing time-series data. In this test, the data must not fit into a particular distribution [48]. When a set of data fits into a linear relationship, this test is applied. When studying climatological, meteorological, and hydrological time series, the test is typically used [52–54]. The test statistic (S) of this test is calculated using the following equations:

$$S = \sum_{k=1}^{n-1} \sum_{j=k=1}^{n} sgn(x_j - x_k), \tag{1}$$

where;

$$sgn\left(x_j - x_k\right) = \left\{ \begin{array}{ll} +1; & if\left(x_j - x_k\right) > 0 \\ 0; & if\left(x_j - x_k\right) = 0 \\ -1; & if\left(x_j - x_k\right) < 0 \end{array} \right) . \tag{2}$$

where 'n' is the number of data values. A positive S value denotes an upward trend, while a negative S value denotes a

Table 2. Showing all stations in Nigeria, the cordinate, as well as their various characteristics.

Location (Exact Coordinates)	Elevation	Characteristics	Source(s)
Kainji dam *Lat*: 9.873 *Long*: 4.6229	65m	Approximately 300 km from Minna, Niger State, 250 km from Ilorin, Kwara State, and 500 km from Abuja, Nigeria. The Kainji dam contains a reservoir estimated at 136 km long, while the main dam is approximately 550 m long and 64 m tall. Contains live and dead reservoir storages of 12,109m^3 of water and 3,109m^3 of water,respectively. The reservoir's maximum and lowest operational levels are 141.73m and 129.0m, respectively	[39].
Lokoja *Lat*: 7.7848 *Long*: 6.7539	45m	Known as the "confluence town", because it is the meeting point of the Rivers Niger and Benue. The town has a steep slope, with the ground elevation varying from 35 to 428 meters above mean sea level. The region has relative humidity of about 60%, and annual rainfall ranges between 1,100 mm and 1,300 mm. Heavy rainfall may cause the river and its tributaries to overflow their banks, inundating the town. Flood occurrences in 2012 and 2018 were recognized as the most destructive floods in the research region.	[40, 41].
Makurdi *Lat*: 7.734 *Long*: 8.6463	95m	Situated on the banks of the Benue River. Two air masses impact the weather conditions in this location: the warm, moist south westerly air mass and the warm-dry north-easterly air mass. The south-westerly air mass is a rain-bearing wind that provides rain from May through October. From November to April, a dry north-easterly air mass flows across the area, causing seasonal dryness. The average annual rainfall in Makurdi is around 1,290 mm. However, temperatures in the region are normally high throughout the year, with February and March being the warmest months. The lowest and maximum temperatures vary from 17 to 25 ^{0}C and 30 to 38 ^{0}C, respectively; with a monthly rainfall of around 200 mm.	[42, 43]
Onitsha *Lat*: 6.1339 *Long*: 6.7635	65m	The region is known to be seated on Eocene Nanka Formation clastic sediments and alluvium deposits. It is located within the rain forest area and serves as the final gauging station along the Niger River basin, before it empties into the Atlantic Ocean. It has a typical Nigerian tropical climate, affected by three major wind currents: the tropical maritime (MT) air mass, the tropical continental (CT) air mass, and the equatorial easterlies. The annual rainfall averaged 1200 mm, with a high temperature of 34.7 ^{o}C and a relative humidity of 65%. As the commercial headquarters of the country's eastern region, the city's natural landscape and hydrological processes have been drastically affected by human activities such as urbanization, river dredging, and road building.	[44–46]
Yenagoa *Lat*: 4.8859 *Long*: 6.2504	10m	The area is primarily rural and suburban, encompassing a variety of settlements. It has a tropical climate, with rain falling virtually every month of the year. The average monthly temperature ranges from 25 to 31^{o}C. Located in the transition zone of the Coastal sedimentary lowlands hydrogeologic province, the wetlands are vegetated tidal flats produced by a reticulate network of interconnecting meandering Niger River streams and tributaries. A rich series of sedimentary strata underpins the region, as a result, the region has been taken for granted as a reliable supply of copious groundwater. Because of this mindset, the conventional approach to water delivery is indiscriminate borehole drilling without prior geological, hydrogeological, and environmental concerns.	[47–49]
Yola *Lat*: 9.2279 *Long*: 12.5231	599m	With an average annual rainfall of 850-1000 mm, and more than 41% of this rain falling in August and September, the region is not known for high precipitation. Temperature also varies significantly over time in Yola, with an average maximum temperature of 42^{o}C and a relative humidity of roughly 29%.	[50]

downward trend. Higher positive values in S on the other hand, indicates an upward trend, while lower negative values indicate a declining trend. Usually, if the number of data values (n) is greater than 10, the normal approximation (Z statistic) is always utilized. It's also worth noting that when there are tied/equal values, the Z statistic's accuracy reduces if the data values are

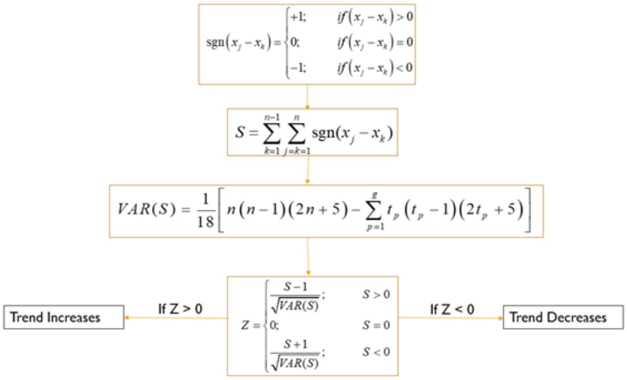

Figure 2. Mann-Kendall Trend Test Methodology.

close to 10. The variance of S '*VAR(S)*' is used to calculate the value of the Z statistic [51].

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right]. \quad (3)$$

We can now obtain the test statistic Z, using the values of *VAR(S)* and *S*;

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

Figure 2 shows a flowchart MK trend test methodology in brief. To interpret results; when the Z value is negative, a decreasing trend is recognized, and when the Z value is positive, a rising trend is discerned. If and when the data's p-value is less than the significance level (in this case, 5% = 0.05), both interpretations can be considered to have a significant trend and the null hypothecs (H_o) is rejected. If the p-value is greater than the level of significance, the trend is not significant and H_o is accepted [55, 56].

3.2. Şen, (2012)ITA test

This method which was proposed by Şen [32, 57] was first applied to hydro-meteorological tine series data and has since been used in various trend tests of various parameters, as observed from the literature review in Table 1. The technique is based on:

1. Dividing a series of data into two equal halves: first and second half. With each sub-series being sorted independently in ascending or descending order. The first sub-series (x_i) is positioned on the X-axis, while the second sub-series (y_i) is located on the Y-axis
2. Plotting them as a scatter plot against each other which will result in a scatter of data points along the 1:1 (45°) line on the Cartesian coordinate system, as seen in the Figure 3. From Figure 3, based on the Cartesian coordinate system.
3. When there is no trend in the series, the data points fall on the 1:1 line [32].
4. A monotonically increasing trend is observed when all the data points from the plot are above the 1:1 line; the same way, a monotonically decreasing trend is observed when all the data points are below the 1:1 line. In unique cases, some data points can fall below, above and on the 1:1 line; this will be separated into the low, medium, and high values as shown in Figure 2.

To buttress on the trend's significance, Sen proposed a statistical appraoch encompassing the calculation of important parameters as follows:

$$S = \frac{2\left(\overline{x_2} - \overline{x_1}\right)}{N} \quad (5)$$

$$\rho_{\overline{x}_1\overline{x}_2} = \frac{E\left(\overline{x}_1\overline{x}_2\right) - E\left(\overline{x}_2\right)E\left(\overline{x}_1\right)}{\sigma_{\overline{x}_2}\sigma_{\overline{x}_1}} \quad (6)$$

$$\sigma_s = \frac{2\sqrt{2}}{N\sqrt{N}}\sigma\sqrt{1 - \rho_{\overline{x}_1\overline{x}_2}} \quad (7)$$

In equation (5) s stands for the slope of trend; $\overline{x}_1$ and $\overline{x}_2$ for the mean of the first half and second half of the time series, respectively; and N is the number of data. In equation (6), the stochastic process for the calculation of the correlation coefficient, $\rho_{\overline{x}_1\overline{x}_2}$, is indicated and in this regard, $\sigma_{\overline{x}_1}$ and $\sigma_{\overline{x}_2}$ denotes the standard deviation of the first half and second half of the time series, respectively. In Equation (7), σ_s is the standard deviation of the slope, and σ is the standard deviation of the whole time series x. For further details regarding the ITA test, Şen [59] should be consulted.

3.3. Strength's and weaknesses of the MK trend test and Şen, (2012) ITA Test

The Mann-Kendall (MK) trend test is known for its ability to discover monotonic trends in time series data, such as precipitation patterns across decades in Nigeria's riverine zones. Its non-parametric nature enables it to effectively handle data with non-normal distributions and outliers, making it appropriate for climate investigations in which data normality assumptions may not apply. By measuring the presence and importance of trends without assuming specific distributions, MK provides a reliable way for determining whether precipitation amounts are regularly increasing, decreasing, or remaining stable over time. However, MK test has limitations in that it does not quantify the amount or direction of trends, nor does it distinguish between trends over different precipitation value ranges. This may limit its usefulness in understanding how variations in precipitation influence distinct parts of the population or ecosystems, limiting nuanced insights into localized effects.

Sen's Innovative Trend Analysis (ITA) test complements MK by increasing sensitivity to trends over a wide variety of precipitation data. ITA divides trends into low, medium, and high-value segments, allowing for a more detailed examination of how different aspects of the precipitation distribution are changing over time. This level of granularity enables researchers to spot subtle trends that older methods may miss,

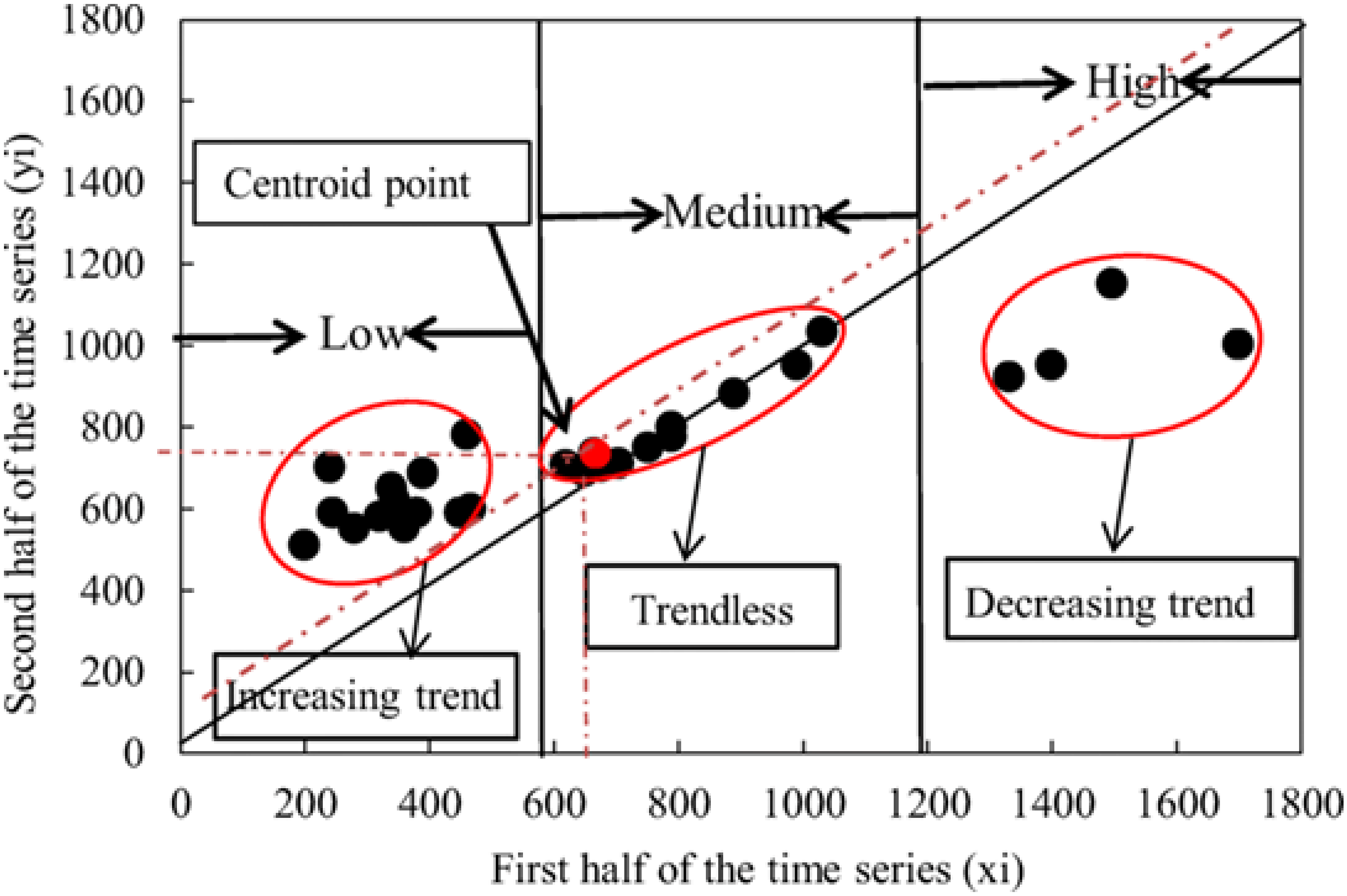

Figure 3. Illustration of the innovative trend method showing low, medium and high values [58].

as well as gain a better knowledge of how climate change affects specific sectors such as agriculture or water resources. The quality and completeness of the data, as well as the subjective setting of threshold values, can all have an impact on ITA's effectiveness. Furthermore, ITA may necessitate thorough preprocessing to determine relevant data ranges, which might inject uncertainty into trend detection and analysis.

3.4. Data analysis process

Data was analyzed and results visualized using the Python programming language and the methodology described in Section 3 Box plots were used to show data distribution, the MK and Sen's ITA test was used to detect for trends in the data, tables were presented to easily show results. The code for the analysis have been provided through a link at the end of this study.

With respect to the MK-test, the data in this investigation were not subjected to any pre-whitening or homogeneity test processes. In order to preserve the authenticity of the time series in the trend algorithms, only original recorded data were taken into account. Because precipitation measurements are frequently strongly autocorrelated, pre-whitening may not be appropriate when applied to precipitation data [60]. As a result, the values in the time series rely on earlier values, and the data's autocorrelation structure can include crucial information regarding the underlying mechanisms that cause the precipitation patterns [61].

The ITA trend test has been applied to precipitation data for the six study locations and presented in scatter graphics (Figures 6 - 17). The meteorological stations in Nigeria are shown in Figure 1. As earlier buttressed, these locations were chosen due to their close proximity to the two major rivers; River Niger and River Benue. Total precipitation time series was assessed for the monthly and annual timescale, and trend analysis was carried out using the ITA method for 40 years 1981 - 2020. The ITA approach's findings were compared to those of the monotonic Mann-Kendall test conducted on the original series.

Before conducting the MK and Şen's ITA trend tests, the data from the stations were visually analyzed, using the Box-Whisker plot. Also, known as boxplot, it is frequently used to illustrate the pattern of distribution (right or left skewness) of data values in a variety of problems [62]. It is based on the values for the minimum, maximum, median, quartiles (25th and 75th percentiles), extreme values, and outliers. The boxplots demonstrate how the data deviates from a normal distribution not only in terms of skewness, but also in terms of the number of outliers and the extreme values [63]. This justifies the selection of non-parametric tests for trend analysis because they are resistant to outliers, seasonality, and non-normal data.

4. Results

4.1. Data distribution of total monthly precipitation over selected locations in Nigeria

Therefore, box plots for all study locations, for all months and seasons are displayed in Figure 4 and Figure 5 respectively. This serves the purpose of summarizing the data distribution of precipitation data over the study period presented in Table 3. The plots identified seasonal patterns and outliers in the data. Each subplot in Figure 5 shows how each of the six study locations have their distinct, but almost related distribution. The monthly pattern can be clearly seen from Figure 4, and this justifies the decision in choosing the dry season to fall between November and March, and the wet season to fall between April and October (in Figure 5). Careful observation of Figure 4 and Table 3 will show that the wet months have a higher range of data values when compared to the dry season. Furthermore, the locations that are around Northern Nigeria have maximum precipitation values that are almost comparable to the minimum precipitation values in some locations in Southern Nigeria.

4.2. The Mann-Kendall (MK) trend test for analyzing seasonal and annual total precipitation over selected location in Nigeria

The results for the MK test for the precipitation data between 1981 and 2020 are shown in Table 4. It can be observed that the annual trend of four locations, namely, Kainji, Yola, Lokoja and Makurdi; detected trends as p-values that are lower than the significance level (α) = 0.05. The same is applicable to the wet season variations. For the dry season variations, the MK test did not detect any significant trend. The MK test only detected a positive/increasing trend for the annual and wet season trends in Kainji after the Z values were positive (2.16 and 2.38 respectively).

4.3. Sen's ITA trend test for analyzing seasonal and annual total precipitation over selected location in Nigeria.

Figures 6 – 11 show the ITA results for all 6 stations during the dry and wet seasons. Also, Table 5 shows the interpretation of these results using the scatter points that are divided into low, medium and high values. The slope of these plots, correlation and deviation in slope has been indicated in the table after being calculated using equations (5), (6), and (7) respectively. From the slope, we have been able to identify the overall trend type (increasing or decreasing), which will be compared to the MK test. For the seasonal (wet and dry season) ITA results, only Kainji (Figure 6) had increasing overall trends, and this was specifically observed in the wet season and especially in the higher precipitation values. High values across all seasons for other locations had decreasing trends; these shows that the maximum values for precipitation across 5 locations are decreasing (Figures 7 – 11). The same was observed for medium values for all locations apart from Kainji (Figure 6). Only Makurdi and Onitsha (Figure 9 and Figure 10) had increasing trends for their low values. Figures 12 – 17 show the ITA scatter graphics for the annual precipitation data. The plots show that only Kainji (Figure 12) has an increasing total annual precipitation trend, especially across its high values (1000mm and above), which may be attributed to the presence of the dam and increased evaporation from high temperature as evidenced in Ogunjo *et al.* [64]. This is not the case for the other 5 locations as majority of their precipitation data points are in the lower triangle showing reducing annual precipitation.

4.4. Comparison of MK test and ITA test for seasonal and annual precipitation over selected locations in Nigeria

A summary and comparison of the MK test and ITA technique results are provided in Table 5. The ”high” values and ”low” values of each station were independently assessed using the ITA method, as indicated in Table 5. This table shows that, despite the Mann-Kendall test showing no trend in most locations on a seasonal and annual basis, both upward and downward trends may be seen using the ITA approach for low, medium and high precipitation values. For locations where the MK indicated no trends, the ITA test indicated diverse trends across all precipitation data ranges. This shows that the results of the Sen's ITA trend test show greater sensitivity in identifying trends across different precipitation data ranges compared to the Mann-Kendall (MK) test. While the MK test detected significant trends only in four locations for annual and wet season variations, the ITA test revealed additional trends, particularly in high and low precipitation values. This comparison demonstrates the ITA test's effectiveness in capturing nuanced trends that the MK test may overlook, providing a more comprehensive analysis of seasonal and annual rainfall trends in Nigeria.

5. Discussion

Research and evaluation are crucial since evidence shows that Nigeria's water resources are being impacted by climate change [9, 65, 66]. Since precipitation is the main source of both surface water and groundwater, changes in rainfall have a direct impact on the available amount of water resources [67]. Therefore, it is crucial to understand the characteristics and factors governing changes in precipitation in order to better utilize water resources. However, such assessments are rarely taken into account when attempting to understand precipitation changes. Thus, for improved water resource planning and management, in-depth knowledge of the fluctuations in precipitation over key locations near Nigeria's major rivers is required. However, the majority of earlier studies in Nigeria focused on the variability of annual precipitation trends, which did not take into account seasonal-scale aspects of precipitation. Earlier studies show that, the ITA method has not been applied in the region of study for the characteristics of the trends of precipitation data over time, and this section will seek to give answers to the earlier outlined objectives.

Table 3. Data description of all study locations.

LOCATION		Mean	Std	min	25%	50%	75%	max
Kainji	Annual	994.30	217.45	653.91	859.57	965.04	1054.69	1837.59
	Dry Season	5.82	13.14	0.00	1.05	3.16	5.27	83.45
	Wet Season	137.89	25.75	92.66	120.54	134.10	148.41	202.91
Yola	Annual	945.34	201.59	675.00	806.84	933.40	1033.59	1719.14
	Dry Season	2.30	4.04	0.00	0.00	0.00	3.16	16.87
	Wet Season	133.41	27.65	96.43	114.51	129.58	146.90	233.54
Lokoja	Annual	1203.42	344.00	247.85	1038.87	1191.80	1402.73	2000.55
	Dry Season	11.14	17.44	0.00	3.16	7.38	11.60	106.62
	Wet Season	163.96	44.05	35.40	141.63	164.23	193.61	241.07
Makurdi	Annual	1332.70	321.25	769.92	1133.79	1291.99	1492.38	2262.30
	Dry Season	14.36	14.10	0.00	8.44	11.60	16.87	89.94
	Wet Season	180.13	44.95	103.21	152.35	176.28	203.40	311.13
Onitsha	Annual	1873.07	568.36	885.94	1492.38	1840.43	2257.03	3174.61
	Dry Season	35.87	21.24	0.00	18.99	35.86	51.68	87.54
	Wet Season	241.96	74.31	119.03	193.61	232.79	292.30	424.89
Yenagoa	Annual	2685.61	921.84	1186.52	2040.82	2499.61	3243.16	5605.66
	Dry Season	72.08	39.53	0.00	44.30	66.45	88.59	177.08
	Wet Season	332.18	118.89	147.66	247.85	303.60	394.00	702.87

Table 4. MK results for all study locations.

LOCATION		Calculated Z-Value	MK test statistic (S)	P-Value	Slope	Test Interpretation
Kainji	Annual	2.16	193	0.031	5.27	YES (+)
	Dry Season	0.41	37	0.683	0.00	NO
	Wet Season	2.38	213	0.018	-0.85	YES (+)
Yola	Annual	-2.21	-198	0.027	-5.67	YES (-)
	Dry Season	-1.06	-88	0.291	0.00	NO
	Wet Season	-2.37	-212	0.018	-0.85	YES (-)
Lokoja	Annual	-2.51	-224	0.012	-10.95	YES (-)
	Dry Season	-1.55	-139	0.120	-0.13	NO
	Wet Season	-2.46	-220	0.014	-1.29	YES (-)
Makurdi	Annual	-3.14	-280	0.002	-12.76	YES (-)
	Dry Season	-0.42	-38	0.677	-0.07	NO
	Wet Season	-3.52	-314	0.000	-1.93	YES (-)
Onitsha	Annual	-1.26	-113	0.208	-10.16	NO
	Dry Season	0.35	32	0.727	0.08	NO
	Wet Season	-1.40	-126	0.160	-1.59	NO
Yenagoa	Annual	-1.06	-95	0.291	-12.94	NO
	Dry Season	-0.02	-3	0.982	-0.00014	NO
	Wet Season	-1.61	-144	0.108	-2.43	NO

5.1. Annual and seasonal trends in precipitation

The popular MK trend test was applied to show the monotonic trends of the six study locations for all seasons, on an annual basis, and it depicted increasing precipitation trends for Kainji. Yola, Lokoja and Makurdi; furthermore, reducing trends while Onitsha and Yenagoa did not show trends. For the ITA test, in the overall results Kainji showed an increasing annual precipitation trend. This pattern was also observed for the seasonal trends as all other locations apart from Kainji did not have positive (increasing) trend results for the MK test. However, slight variations were observed for the low, medium and high values. These seasonal and annual changes may have some physical implications on the availability of water resources, agriculture, vegetation patters and ecosystem dynamics as well as infrastructure. A location like Kainji with increasing precipitation in spite of having lower maximum values of precipitation when compared to other locations could have a positive impact on the availability of water in that location. The observed increasing trend could be attributed to localized climatic conditions or microclimates around the Kainji dam area, which could promote more regular precipitation. Features such as the presence of the dam itself, surrounding vegetation, and water

Table 5. Results for ITA test, in comparison with MK test.

LOCATION		Low	Medium	High	Slope (s)	Correlation	Deviation in slope	MK Results
Kainji	Annual	NO	NO	YES (+)	9.55	0.95	1.22	YES (+)
	Dry Season	YES (-)	NO	NO	-0.07	0.86	0.05	NO
	Wet Season	YES (-)	NO	YES (+)	1.41	0.96	0.14	YES (+)
Yola	Annual	YES (-)	YES (-)	YES (-)	-18.93	0.92	1.79	YES (-)
	Dry Season	NO	YES (-)	YES (-)	-0.18	0.88	0.04	NO
	Wet Season	YES (-)	YES (-)	YES (-)	-2.57	0.94	0.21	YES (-)
Lokoja	Annual	NO	YES (-)	YES (-)	-34.94	0.85	3.88	YES (-)
	Dry Season	YES (-)	YES (-)	YES (-)	-0.65	0.91	0.08	NO
	Wet Season	NO	YES (-)	YES (-)	-4.52	0.86	0.51	YES (-)
Makurdi	Annual	YES (-)	YES (-)	YES (-)	-33.06	0.98	1.53	YES (-)
	Dry Season	YES (+)	NO	YES (-)	-0.18	0.96	0.05	NO
	Wet Season	YES (-)	YES (-)	YES (-)	-4.59	0.97	0.24	YES (-)
Onitsha	Annual	YES (-)	YES (-)	YES (-)	-46.17	0.98	2.62	NO
	Dry Season	YES (+)	YES (-)		-0.81	0.97	0.12	NO
	Wet Season	YES (-)	YES (-)	YES (-)	-6.02	0.96	0.47	NO
Yenagoa	Annual	YES (-)	YES (-)	YES (-)	-75.38	0.94	7.22	NO
	Dry Season	NO	YES (-)	YES (-)	-1.28	0.97	0.21	NO
	Wet Season	YES (-)	YES (-)	YES (-)	-9.86	0.94	0.95	NO

bodies can influence local weather patterns, contributing to sustained precipitation which could result in a more constant and reliable water supply. This consistent influx of water can help the Kainji dam maintain acceptable reservoir levels, increasing its capability for hydroelectric power generation, irrigation, and other water-dependent operations. As a result, it promotes sustainable water resource management, reduces the danger of water scarcity, and increases agricultural output in the surrounding areas. According to Stromberg *et al.* [71], the increasing water availability can lead to a slow and gradual change in vegetation cover or changes in plant species composition. It's important to bear in mind that not all physical effects of variations in precipitation depend on how much precipitation falls in each location's absolute terms. Changes in precipitation can have an impact on the ecology and society in the area, depending on the local geography, soil types, and other factors [72]. Despite the observed decreasing trends in high precipitation values for locations other than Kainji, drought may not occur due to sustained precipitation in most months of the year. Additionally, the decreasing trend in high precipitation values in these regions might reduce the likelihood of flooding. If this continues, the vegetation in the area will have to adjust to the frequency of this change. By incorporating both the Mann-Kendall and Sen's ITA trend tests, the study has presented a detailed examination of how precipitation patterns change within the year, and even annually. This technique improves our understanding of seasonal dynamics, providing insights vital for water resource management and climate adaption strategies tailored to Nigeria's different climatic locale. These findings are particularly important due to the fact that annual precipitation variations have little or no effects on decisions on sustainable water management when compared with seasonal variations.

5.2. Potential impact of precipitation trends on water levels/River flow

Both the MK test and ITA test show that Kainji (Table 5 and Figure 12) has an increasing total annual precipitation trend, especially across its high values (1000mm and above). Furthermore, ITA results for the seasonal (wet and dry season) in Figure 6 supports this. It should be noted that river Niger flows through the Kainji dam area. It is clear as to why this location was chosen to build the largest dam in Nigeria, generating over 582 MW of electricity, with a current installed capacity of about 760MW [73]. From this discovery and supporting evidences [74, 75], precipitation levels could have an effect on the water levels in the area and consequently river flow. According to Tarpanelli *et al.* [76], the Rivers Niger and Benue pose the risk of floods due to river discharge in rainy seasons. Evidently river flow and water levels can be significantly impacted by rising and falling precipitation amounts. But the connection between precipitation and river flow is intricate and subject to a variety of influences, including regional topography, soil composition, and land use. For instance, more precipitation will run off into rivers and may result in flash floods if there are many impermeable surfaces in the watershed, such as paved roads and buildings [77]. A quick increase in precipitation, on the other hand, may not be absorbed into the soil if the soil is extremely dry and compacted, which may also result in flash floods. The reverse may be the case for the locations with reducing precipitation from our results. Albeit, evidences from Akinbobola *et al.* [78] show that with locations around the Niger River basin are increasingly kin risk of floods.

5.3. Comparison of ITA method with other traditional methods

From the results, we have been able to identify increasing or decreasing trends using the ITA test for all locations and for

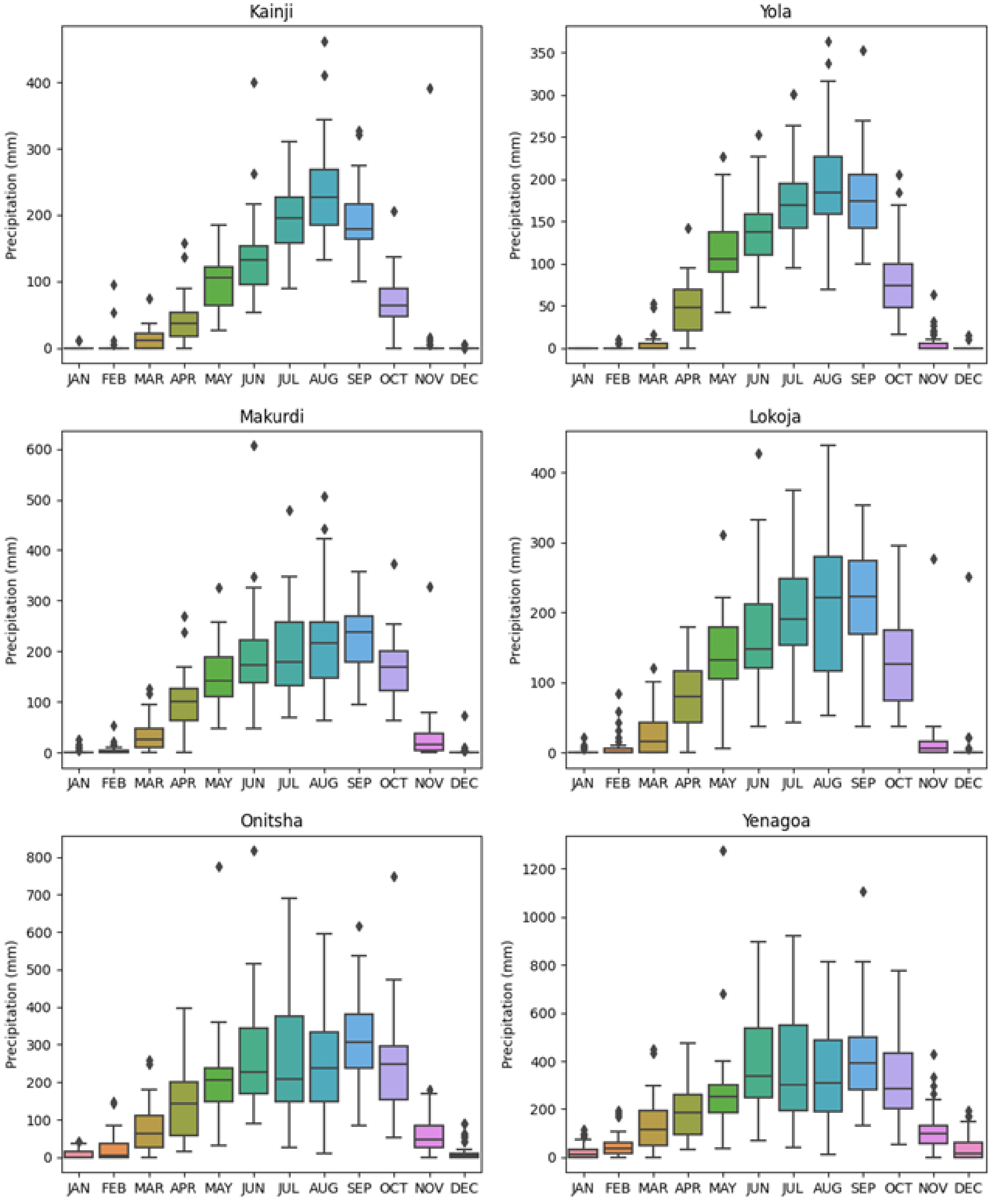

Figure 4. Box plots showing the monthly data distribution across all years for all study locations.

specific data ranges (low, medium and high values); the MK test however, only identified monotonic trends for only the annual and wet seasons of four locations. No dry season precipitation trend eas identified by the MK test. The ITA test which is applied to this study is crucial in the identification of precipitation trends across various ranges of data. For locations where no trend is observed for the MK test, changes are observed across precipitation data ranges (low, medium and

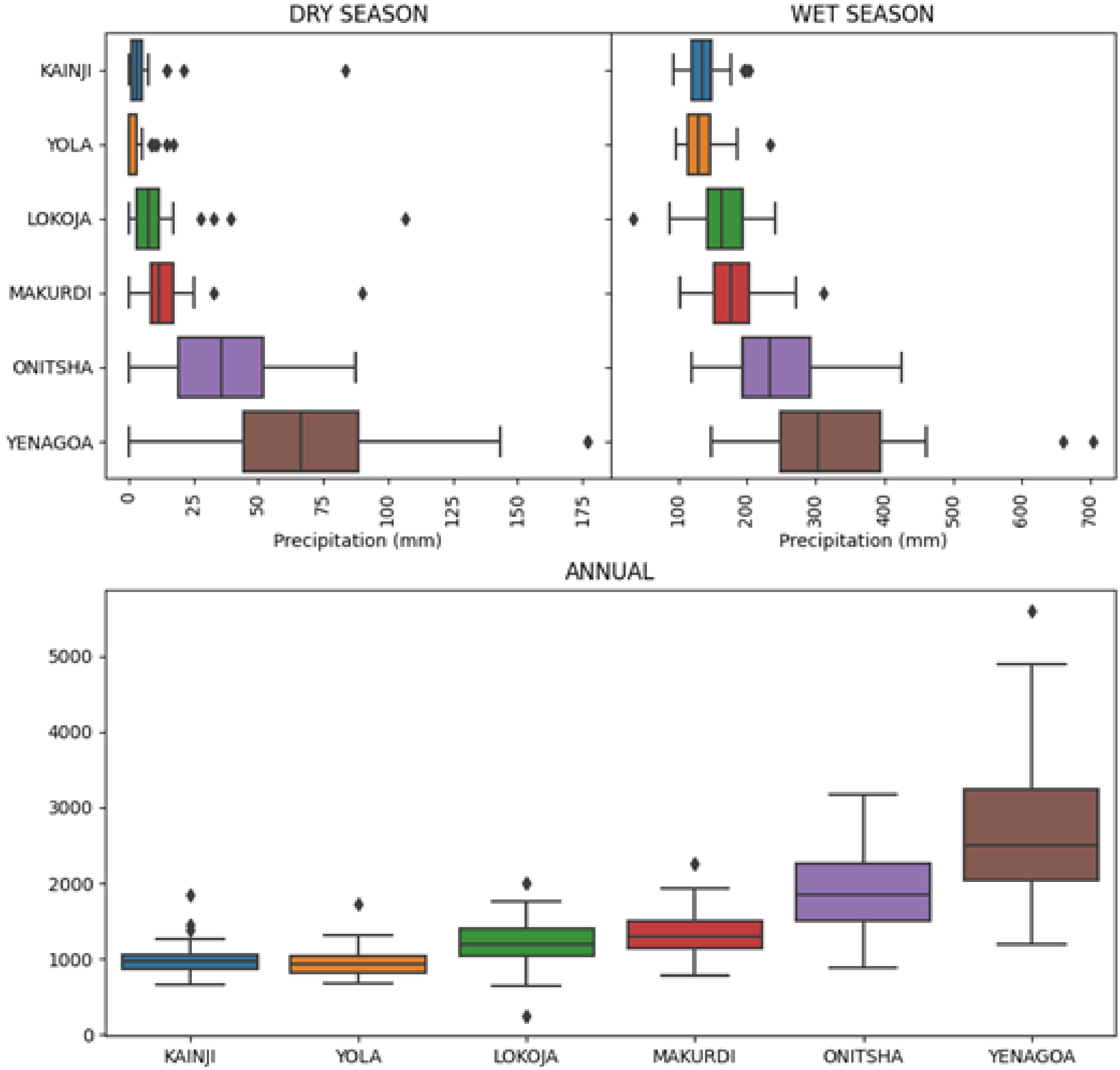

Figure 5. Box plots showing the data distribution for dry season, wet season, and the annual trend across all years for all study locations.

high) when adopting the ITA test. ITA can assist researchers and decision-makers in prioritizing their work and efficiently allocating resources by ident ifying patterns in this manner. For instance, trends with high values that are increasing or decreasing may be given priority for additional study and possibly local infrastructural development to adapt to these changes, whereas trends that have low values may be given less attention or even be completely abandoned. This is a helpful aspect of the ITA technique and it will enable enables more effective and efficient decision-making based on the expected impact and likelihood of a given trend.

6. Recommendations

Based on the findings of this study, the following are the recommendations for policy development and future research:

1. Based on the results of the study, it is necessary to undertake further studies on the application of the innovative trend analysis (ITA) technique to find precipitation trends across different data sets in Nigeria. These studies may compare ITA to other well-established trend analysis techniques.

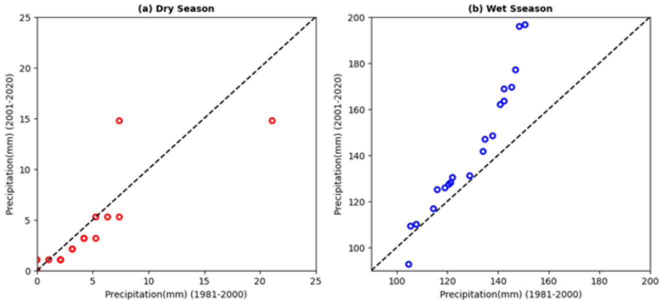

Figure 6. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Kainji from 1981-2020 .

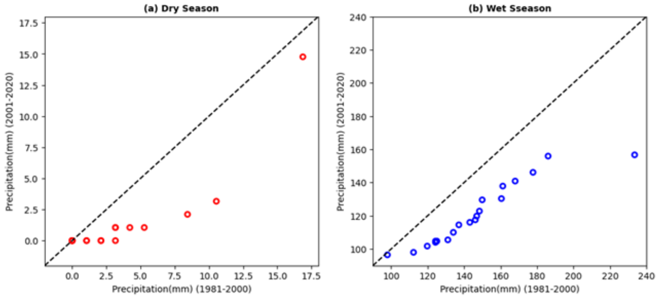

Figure 7. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Yola from 1981-2020.

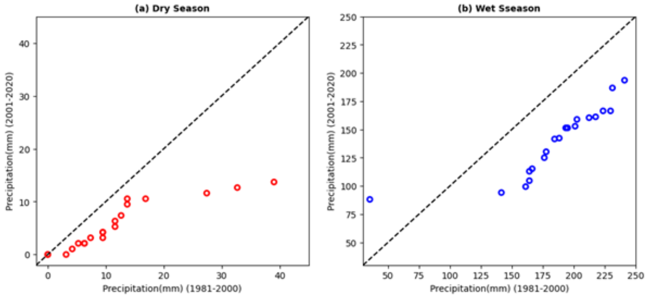

Figure 8. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Lokoja from 1981-2020.

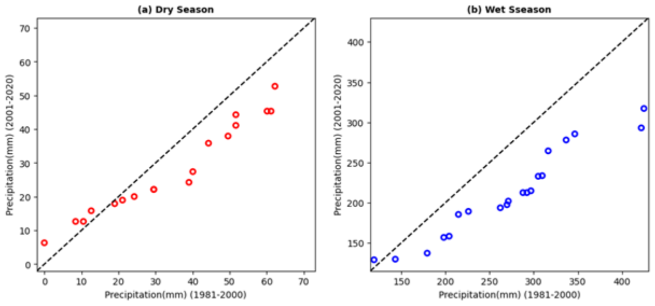

Figure 9. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Makurdi from 1981-2020.

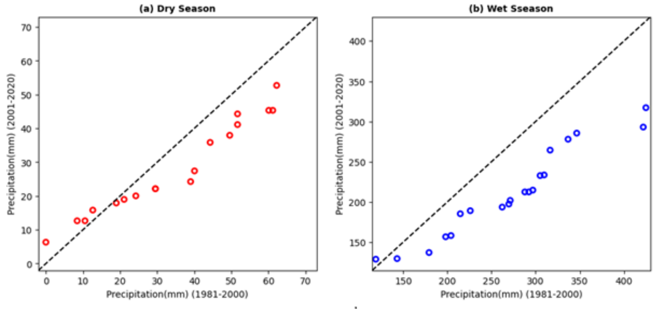

Figure 10. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Onitsha from 1981-2020.

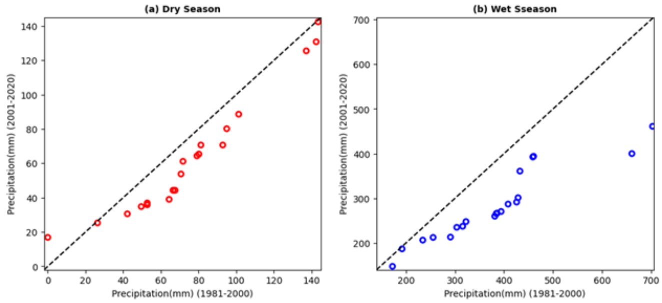

Figure 11. Results of innovative trend analysis (ITA) for precipitation over for dry and wet season over Yenagoa from 1981-2020.

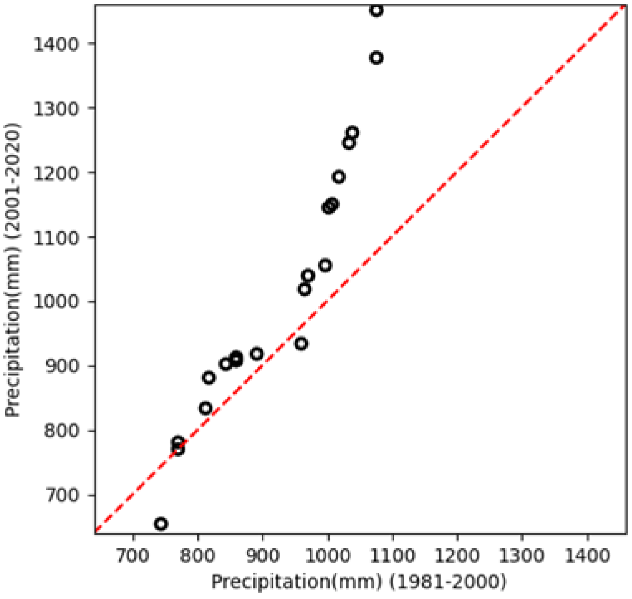

Figure 12. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Kainji from 1981-2020.

2. To better understand the patterns of precipitation changes and its consequences for water resources and agriculture, there should be a greater emphasis on the application of ITA to seasonal precipitation trends rather than just annual trends. This will strengthen policies that will con-

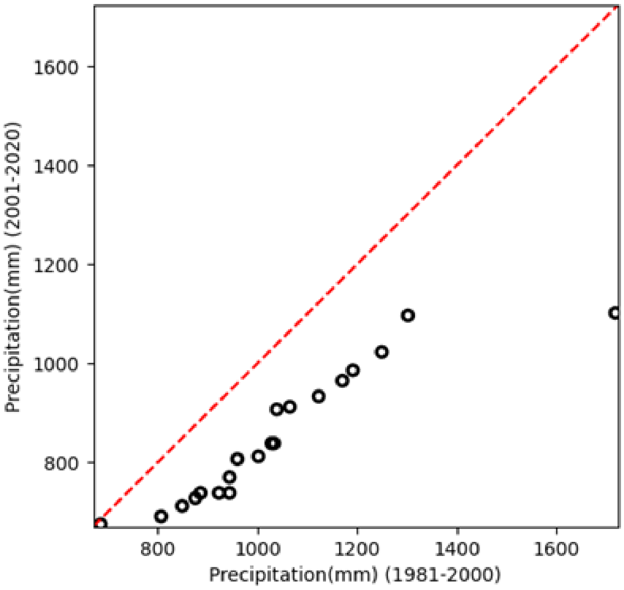

Figure 13. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Yola from 1981-2020.

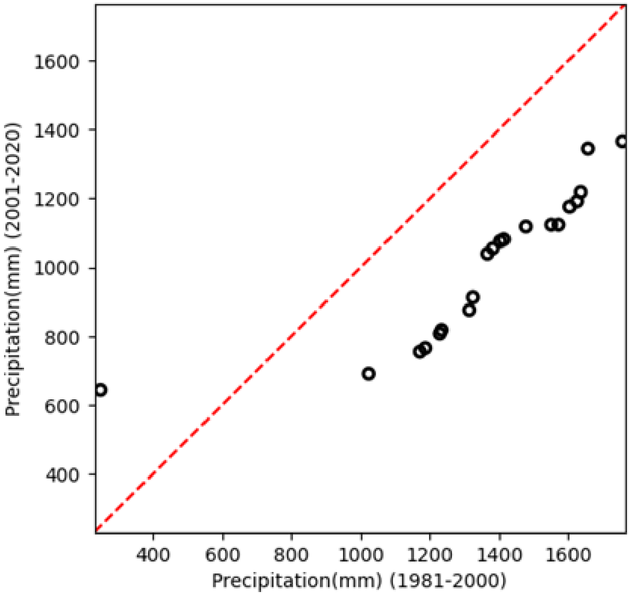

Figure 14. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Lokoja from 1981-2020.

centrate on strengthening the planning and management of water resources, which could entail the creation of more effective irrigation systems, the building of fresh dams or reservoirs in locations with better river flow, and the adoption of strategies to cut down on water wastage.

3. Based on the study which shows seasonal increase in precipitation for a location like Kainji which is predominantly dominated by the dry season, the correlation of these results with other studies that seeks to directly measure and understand the dynamics of river flow is pertinent.

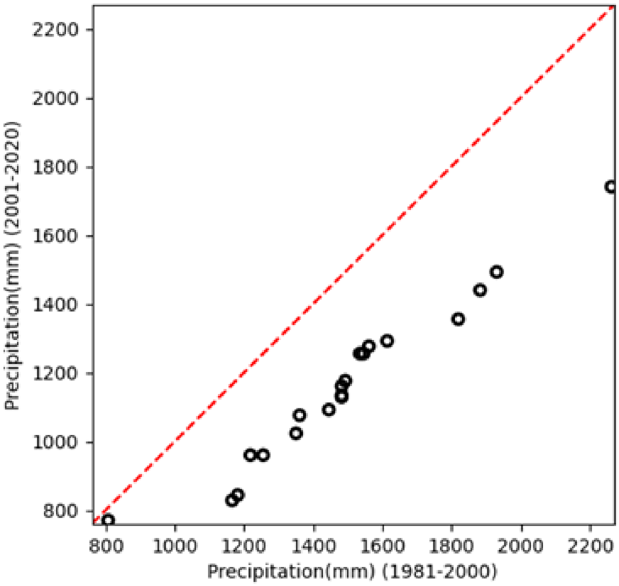

Figure 15. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Makurdi from 1981-2020.

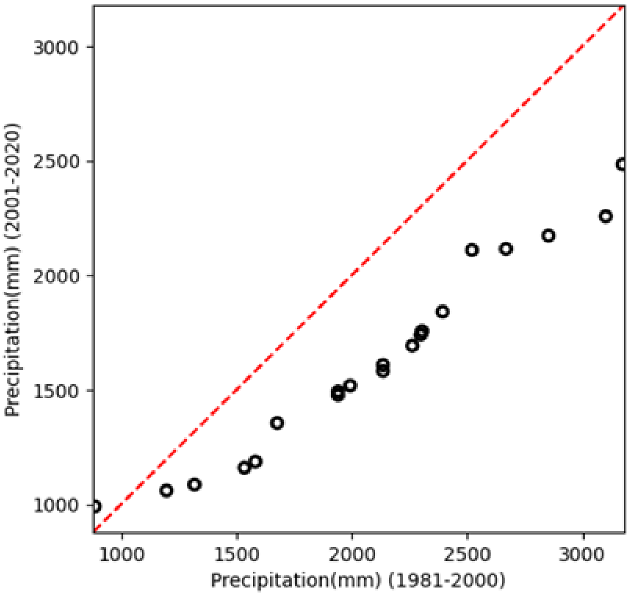

Figure 16. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Onitsha from 1981-2020.

4. Based on the decreasing annual and seasonal precipitations levels for the high values in most of the locations, there should be a greater emphasis on climate change adaptation and mitigation strategies. This could entail creating climate-smart agriculture methods, preserving and restoring ecosystems, and putting policies in place to modify infrastructure to suit changing the weather pat-

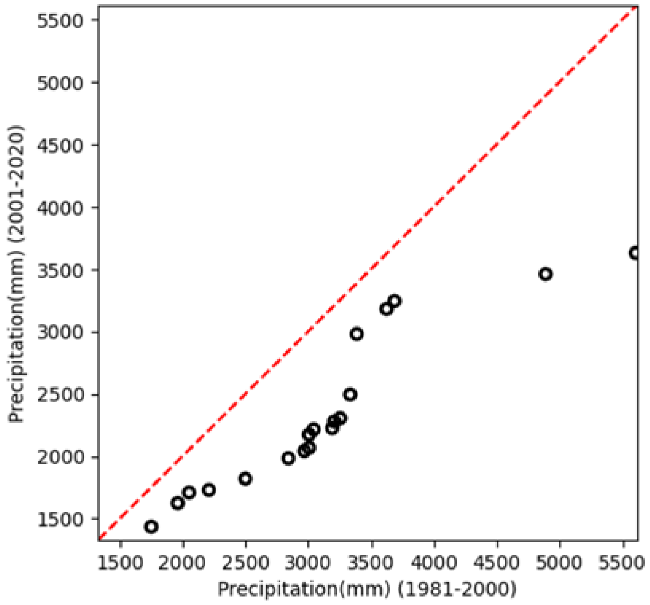

Figure 17. Results of innovative trend analysis (ITA) for the annual variations of precipitation over Yenagoa from 1981-2020.

terns.

7. Conclusion

This study applied the ITA method to evaluate trends in the annual and seasonal precipitation in six locations in close proximity to River Niger and River Benue. The main conclusions follow:

1. The MK test detected significant trends in four locations for the annual and wet season variations but did not detect any significant trend for the dry season variations across all locations. Only Kainji has increasing significant trends after the p-value of the data was lower that the significant level ($\alpha = 0.05$).
2. On the other hand, the ITA test identified an increasing overall trend in Kainji for the wet season and annual precipitation trends; the same was discovered for the high values of precipitation in this location too. For the other five locations, the ITA test detected decreasing trends in the maximum precipitation values across all seasons. For the annual precipitation data, only Kainji had an increasing trend, especially across its high values.
3. The comparison between the MK and ITA tests showed that the ITA test was more sensitive to detecting trends in the precipitation data than the MK test.

The findings will prove useful for water resource managers who are attempting to forecast the probability of disasters like floods and droughts in the study area. By statistically assessing trends in the ”low,” ”medium,” and ”high” value categories of time series, this study also makes a contribution to trend detection techniques. The ITA method brings various improvements that are recommended to be applied in the trend analysis. Further recommendations were provided for policy development and future research. Reduced precipitation patterns in some areas may have an influence on water supplies, perhaps causing water stress and reducing agricultural productivity, especially if this reduction is in an area with a relatively low average precipitation value. Conversely, locations with increasing rainfall, such as Kainji, may suffer increased flood hazards, altering infrastructure and ecosystem dynamics; perhaps this explains why the dam was built in that location. These findings highlight the importance of adaptive water management methods, climate-resilient agriculture practices, and ecosystem conservation initiatives to minimize the various effects of shifting rainfall patterns throughout Nigeria’s diverse geographies.

Data availability

Data used for this study was obtained from the NASA POWER repository at https://power.larc.nasa.gov/data-access-viewer/.

Code availability

Codes for the analysis and visualization (ipynb/python files), as well as the cleaned data (xlsx/Excel files) can be seen from the GitHub repository at https://github.com/Emmaestro001/ITA_analysis_of_precipitation_across_Niger_and_Benue_Rivers/tree/main/JNSPS_ITA_OF_PRECIPITATION%20(NIGER%20AND%20BENUERIVERS).

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