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Trend Analysis and Variability of Air Temperature and Rainfall in Regional River Basins

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Abstract

Global warming and climate variability are emerging as the foremost environmental problems in the 21st century, especially in developing countries. Full knowledge of key climate change variables is crucial in managing water resources in river basins. This study examines the variability of air temperature and rainfall in the five states of South-Eastern region of Nigeria, using the trend analysis approach. For this purpose, temporal trends in annual rainfall and temperature were detected using non-parametric Mann-Kendall test at 5% significance level. The time series rainfall and temperature data for the period 1922-2008 were analyzed statistically for each state separately. The results of Mann Kendall test showed that there is trend in rainfall in all the capital cities in South-East except Owerri and Awka. It is also observed that the trend of rainfall is decreasing for all the study areas in South-East with the lowest trend rate of -0.1153 mm rainfall occurring in Umuahia. In the case of air temperature, it is observed that the trend is increasing for all the study areas in South-East with the highest trend rate of 0.04698 °C/year occurring in Enugu. These findings provide valuable information for assessing the influence of changes on air temperature and rainfall on water resources and references for water management in the South-Eastern river basin of Nigeria. It also proved that Mann-Kendall technique is an effective tool in analyzing temperature and rainfall trends in a regional watershed.

Keywords: Climate Change; Mann-Kendall; Rainfall; Temperature; Trend Analysis.

1. Introduction

Climate change together with the variability of climatic conditions has constituted huge adverse effects on water resources as well as the agriculture of countries that rely on agriculture [1, 2]. The study on climate change is basically centred on the likely changes in the climatic variables like temperature and rainfall, thus, the variability of these variables is of much significance. The temperature increase can cause incidents of heat wave, sicknesses, and death in affected areas. Moreover, a change in temperature can lead to a change in the species of animals and plants. As the earth's temperature increases, the rate of cloud formation and evaporation increases, and subsequently the rate of rainfall also increases [3]. Rainfall is important in the management as well as the planning of irrigation and agricultural projects. Thus, a change in rainfall can affect the sustainability of water availability and food production. The irregular spatial and temporal availability together with its uncertainty causes flooding in one hand, and droughts in the other hand. An increase in rainfall could equally lead to a corresponding increase in frequency of floods which in turn could have an adverse effect on the water quality. Rainfall commences around March, reaching its peak during July to September and finally stopping in November. Mean annual rainfall ranged between 1200 mm and 2000 mm

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with a maximum temperature of 34.7 ºC and a relative humidity of 65%. South-Eastern Nigeria, as the commercial nerve centre of the country, have witnessed severe synthetic alteration of their natural landscape and hydrological processes in the cities from human activities, such as urbanization, dredging of rivers and construction of roads [4].

Uchechukwu et al. (2018) [5] used the log-Pearson type III distribution method to study various parameters namely: rainfall, elevation, latitude, and the distance from sea. Their study obtained regional coefficient of variation of 22% showing that the area has low variability which indicates consistent high rainfall values. Their findings put the annual average rainfall of South Eastern Nigeria as 1744 mm with bi-modal double peaks in July and September, which reflect the condition in most part of Southern Nigeria. They opined that the high rain bearing wind speed of the area with escarpment may obviously have affected the rainfall pattern in the area. However, data from their Udi study may not be sufficient to conclude the hydro-meteorological pattern of the South-Eastern Nigeria.

Ayanlade et al. (2018) [6] studied rainfall variability and drought characteristics in two agro-climatic zones, with their assessment focusing on climate change challenges in Africa, their results revealed high spatial and temporal variability in rainfall within the two stations. Their findings show anomalies in rainfall over the past years but much more in the locations around the Guinea savannah. Their control stations are not sufficient to arrive at their conclusion of Africa. A more transnational survey and controls could have validated their claim.

Rainfall trends and variability in Onitsha, Anambra State, Nigeria has been reported. The study was based on the need for information required for water resources planning and management within the region and focused on monthly, annual and seasonal variability in rainfall between 1971 and 2008. Their result revealed low annual variability compared to seasonal and monthly series [4]. Focal point of the study was on rainfall only. The research recommended that farmers and water resources managers should develop adequate management strategies such as construction of structures for water storage and diversion as in reservoirs and dams. Such structure can help prevent recurrent flooding experiences and water scarcity in the area.

The negative effects of climate change will drastically affect ecosystems in the world. The severity of the negative impacts, conversely, would certainly vary in different countries or around ecosystems. Nigeria is seriously affected by unfavourable climatic conditions which affect millions of the citizens negatively. Incessant flooding, droughts and irregular rainfall have changed the traditional planting seasons unknown to the farmers. In South-East zone, an excessive flooding has been experienced, giving rise to gully erosion in some areas, destruction of properties and even death in other locations.

Amadi et al. (2019) [7] examined the possible effects of climate change on agricultural sustainability in Enugu, South-eastern Nigeria using lessons drawn from trend analysis of historical time series of meteorological variables in monthly time step in the area. The research analysed trends and variations of selected climatic parameters that influence agriculture using integrated statistical method. The study was motivated by the incidence of poor crop productivity in the area, and it revealed that the climate may be changing at rates that hamper agricultural productivity and sustainability. Data on rainfall, air temperature, sunshine duration, relative humidity, and wind speed spanning over 63 years obtained from Nigerian Meteorological Agency, Oshodi, Lagos, Nigeria was used. The result of the study however did not address the management of water resources infrastructural question in the catchment area.

Several other research works have attempted to determine the trend and variability of air temperature and or rainfall in some cities in Nigeria, but a comprehensive analysis have not been carried out specifically for any entire regional basin, including South-Eastern river basin which is considered the temperate region of Nigeria

Numerous physical models have been proposed for studying long term changes in the climatic variables on spatial as well as temporal scales. The study of spatial and temporal variability of climatic parameters can equally be done by analysing the long-term data with the aid of statistical tools. The investigation of the climatic variability involving time - series can also be done using parametric and non-parametric statistical techniques. The parametric approach is based on the assumption that the data is free from outliers and that it has a normal distribution, however, the non-parametric approaches does not [8]. Among all the non-parametric approaches used in the analysis of time-trends, the Mann-Kendall test is most common [8, 10]. Many scientists have relied on this approach for investigating various hydro-meteorological variables [11].

The pattern of the wet season in Nigeria has been examined in various studies; some of them focused on decennial, periodical or cumulative annual rainfall assessment whereas others just identify the beginning and the end of wet season. Due to the extremely unpredictable beginning of rainy season coupled with the increasing duration of dry seasons, a clear understanding of the trend of seasonal changes is vital. This research seeks to analyse the data in all the state capital cities namely: Owerri, Abakaliki, Umuahia, Enugu and Awka, of South Eastern Nigeria to establish the trend and pattern of these climatic variables over a prolonged period. However, limited research data, lack of awareness, and information on climate change risk factors and its impacts to the stakeholders are the constraints encountered in the study.

2. Research Methodology

2.1. Study Area

The South-Eastern region of Nigeria is an area which covers about 76,358 km^2 south of the Benue valley and east of the lower Niger. In terms of geo-political zones, the region consists of five states out of 36 states in Nigeria, and they include Abia, Anambra, Ebonyi, Enugu and Imo states. The region is situated between longitudes 7^{0}E and 9 ^{0}E and latitudes 4^{o}N and 7^{o}N and. In terms of relief, the land surface of eastern part of Nigeria can be classified as plains, highlands, and the lowlands [12]. Applying spatial data extraction as suggested by Karimi and Khorrambakht (2018) [12], produced Figure 1(b). The plains and Climate of South-Eastern Nigeria is characterized by seasonal distribution of rainfall, which depends on the interaction of the Equatorial Easterlies, Tropical Maritime air mass and Tropical Continental air mass. The rainfall pattern is characterized by long rainy season as well as short dry season, and it is controlled by the movement involving inter-tropical convergence. The long rainy season starts from April to July, while the short dry season occurs in August, and it is followed by a short rainy season which occurs between September to October [4].

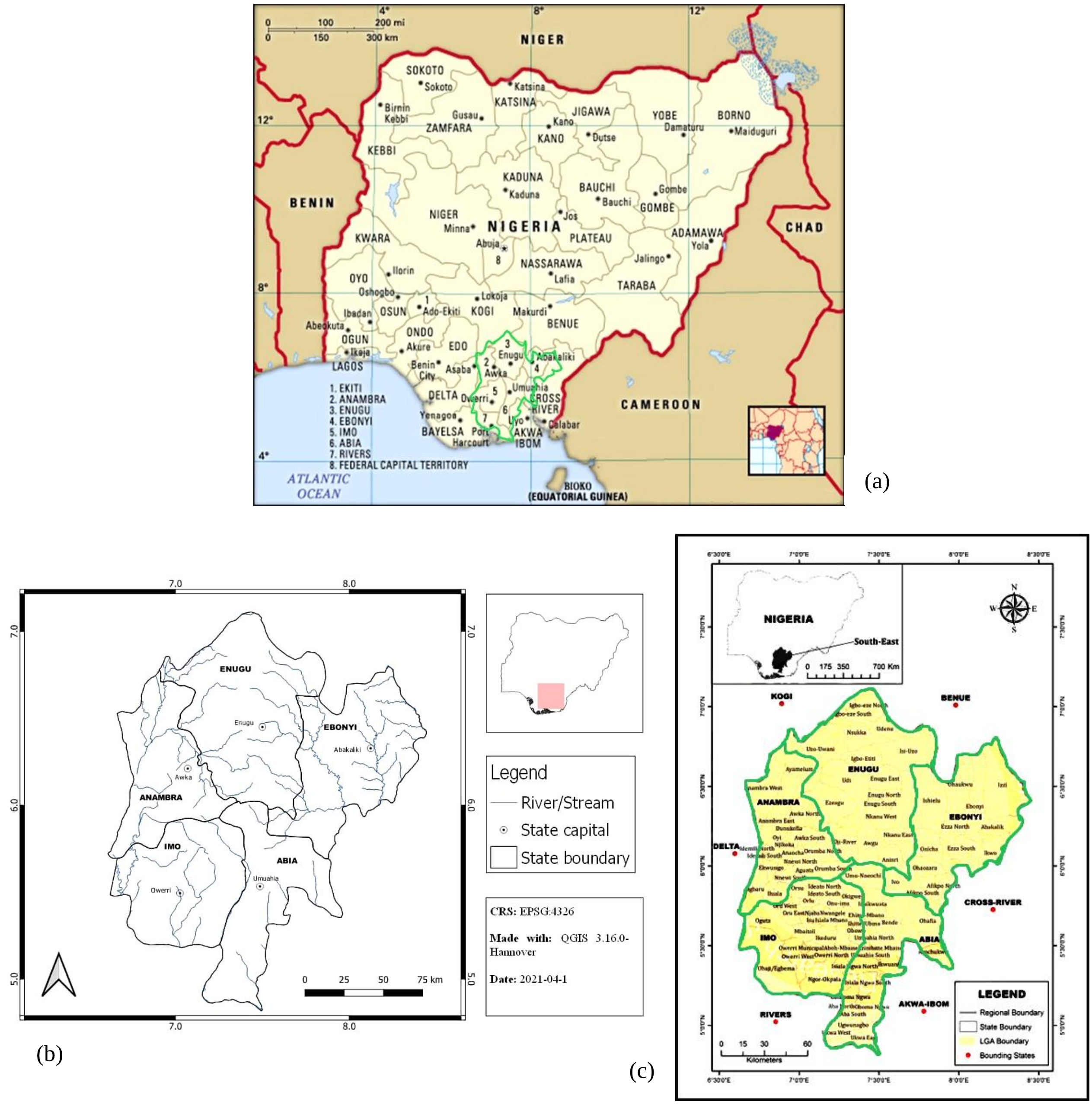

Figure 1. a) Map of Nigeria showing all the states and their capital with the study area outlined; b) Map of the South-Eastern region (study area) showing the rivers and waterways in the basin; c) Map of the South-Eastern River Basin with their major State capitals and major cities.

2.2. Sources and Method of Data Collection

The data for the minimum and maximum temperature as well as the monthly rainfall for Abakaliki, Awka, Enugu, Owerri, and Umuahia were obtained from the Nigerian Meteorological Agency, Lagos, Nigeria. The minimum and maximum air temperature (°C) together with the rainfall depth (mm) were recorded monthly on a yearly basis. The data was obtained for all stations for a period of 86 years, ranging from 1922-2008. The mean daily temperature was calculated as the arithmetic mean of the minimum and maximum temperature measured for a particular day. The mean monthly temperature was computed as the arithmetic average of the mean daily temperatures of all the days in the month. The study adopted uniform time frame in data collection. This means that only data collected at the same moment in every state simultaneously was used for the analysis. All monthly data were averaged to obtain time series of annual averages for all the climatic data used.

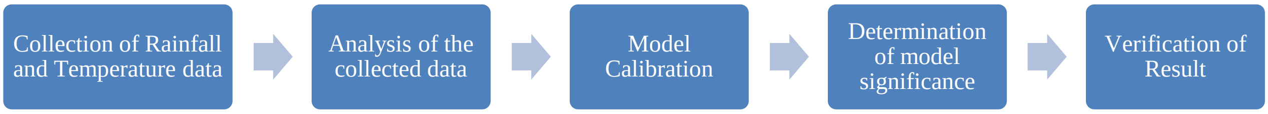

Figure 2. Flow Chart of the Research Methodology

2.3. Trend Analysis of Climatic Data

The trend analysis for climate variability was performed in two stages. First and foremost, the existence of a monotonic decrease or increase was investigated using the non-parametric Mann-Kendall test. After this, the computation of the regression coefficients for the meteorological time and parameters was done to obtain the strength of the linear interactions existing between the parameters. The monotonic trends were detected using the non-parametric based Mann-Kendall test. To determine the Mann-Kendall test statistic (*S*), Equation 1.

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

Where x_j, and $x_{k,}$ are the annual values in years respectively.

Simplifying Equation 1 gives Equation 2:

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \tag{2}$$

A high positive value of the statistic (S) signifies an increase in the trend, whereas a negative low value signifies a decrease in the trend. Nevertheless, the computation of the probability (p) having the statistic(S) with the sample size (n) is necessary because it helps in the statistical quantification of the significance existing in the trends [17]. The variance of S was computed using Equation 3.

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

Where tp and q are the number of data values and tied groups in the p^{th} group respectively. The test statistic (Z) was computed with *VAR(S)* and *S* values using Equation 4.

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

The test statistic (Z) obeys a Gaussian distribution. The value of Z value was tested at 95% confidence limit ($Z_{0.025}$=1.96). If the value obtained for p was lower than the significance limit (α = 0.05), the null hypothesis (H0) would be rejected. The rejection of H0 indicated the existence of a trend, while the acceptance of H0 indicated non-existence of trend. The rejection of H0 implies that the result is statistically significant. These computations were done using Microsoft Excel software application. The trend component of a time series is usually described with a trend line especially if the amount of increase or decrease in the series from one period to the other is constant. The trend line was expressed by using Equation 5.

$$Y_t = a + b_t \tag{5}$$

Where: t, a, Y_t and b are the unit of time, the values of the trend when the time t is 0, the trend for a given time and the change in Y_t per unit period of time.

The least square approach was adopted in finding the equation relating to the trend line. The constants: a and b, in the linear trend functions were computed using Equation 6 with the aid of Minitab software.

$$a = \frac{\sum y \sum t^2 - \sum t \sum ty}{n \sum t^2 - (\sum t)^2} \quad (6)$$

$$b = \frac{n \sum ty - \sum t \sum y}{n \sum t^2 - (\sum t)^2} \quad (7)$$

3. Results and Discussion

3.1. Rainfall Trend Analysis Conducted for South-East Nigeria

The result obtained from Mann-Kendall test is shown in Table 1, while the variability in rainfall is presented in Figures 3 to 7.

Table 1. Result of Mann-Kendall Test for Rainfall (mm)

State Capital	Mann- Kendall Statistic	Kendall Tau	p-value (2-tailed test)	Alpha	Test Interpretation	Trend rate	Trend Equation	Trend
Enugu	-1100	-0.281	0.00001	0.05	Reject H0	-0.3492	171.9-0.3492t	Decreasing
Owerri	-497	-0.107	0.112	0.05	Accept H0	-0.773	221.6-0.773t	Decreasing
Umuahia	-835	-0.18	0.00933	0.05	Reject H0	-0.1153	186.35-0.1153t	Decreasing
Abakaliki	-1128	-0.243	0.000444	0.05	Reject H0	-0.1463	179.62-0.1463t	Decreasing
Awka	-597	-0.109	0.112	0.05	Accept H0	-0.773	178.1-0.652t	Decreasing

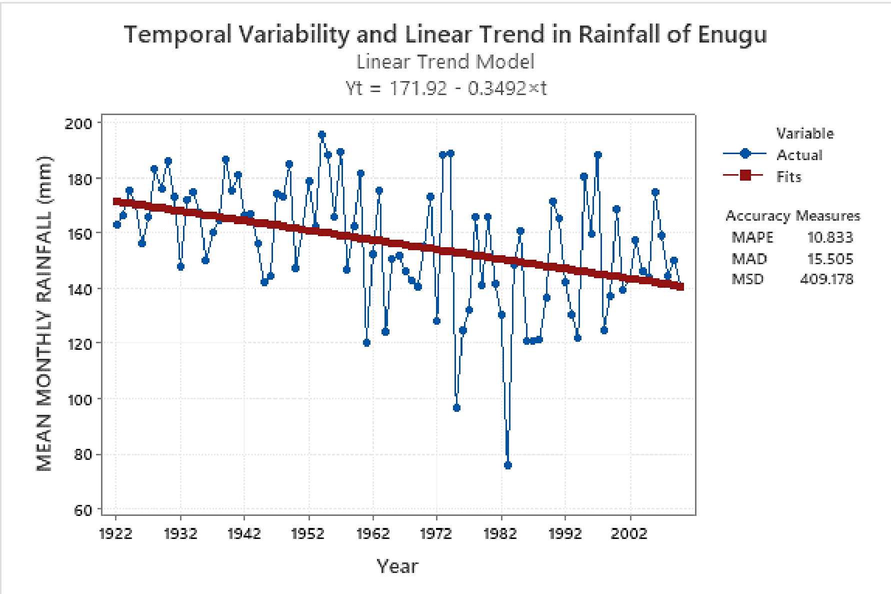

Figure 3. Linear trend line of rainfall data for Enugu, Nigeria

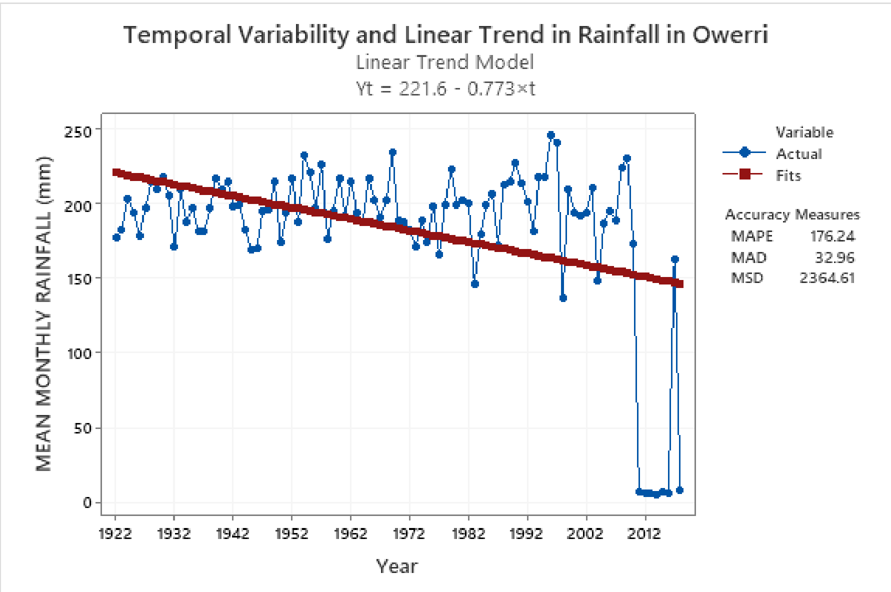

Figure 4. Linear trend line of rainfall data for Owerrri, Nigeria

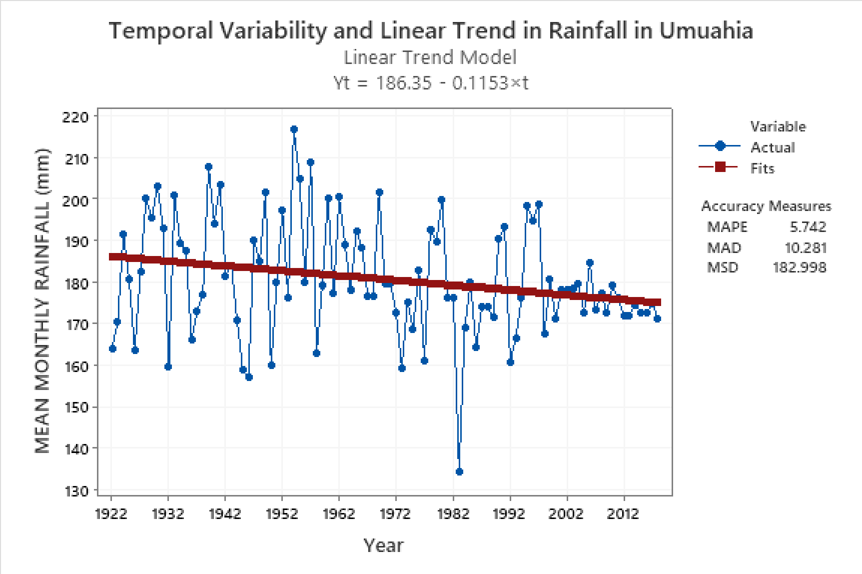

Figure 5. Linear trend line of rainfall data for Umuahia, Nigeria

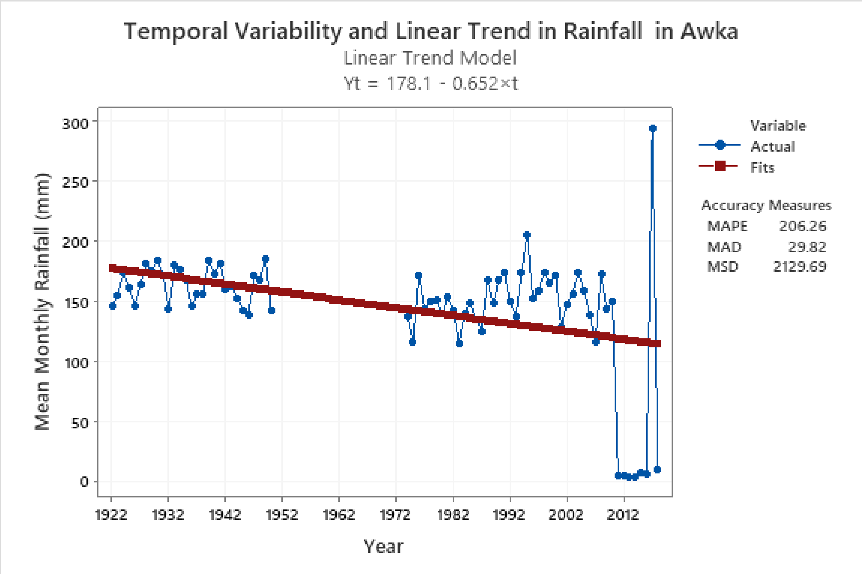

Figure 6. Linear trend line of rainfall data for Awka, Nigeria

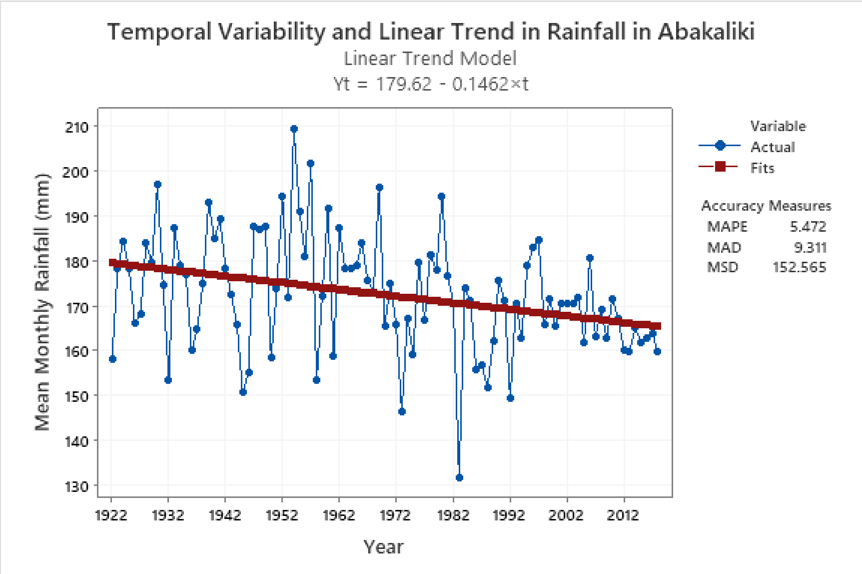

Figure 7. Linear trend line of rainfall data for Abakaliki, Nigeria

From the Mann-Kendell test of rainfall results shown in Table 1, H0 was rejected in three states of the region namely: Abia, Enugu and Ebonyi states. This means that these three states manifested statistically significant ($p < 0.05$) downward trend in rainfall while the other two states of Imo and Anambra, shows no significant downward trend. A decreasing trend in all the states were observed throughout the period under investigation, with value at Enugu (-0.3492 mm/year), Umuahia (-0.1153 mm/year), Owerri (-0.773 mm//year) Abakaliki (-0.1463 mm/year) and Awka (-0.773 mm/year). This signifies that between 1922 and 2008, annual rainfall has constantly decreased, and the observed trend implies increased period of dryness and possible drought [4] as revealed in Figures 3 to 7. Much of the decreasing trend in rainfall could be attributed to low rain during the period. The fluctuations in years in which the maximums amount of rainfall occurred followed a zigzag pattern. The same hold for minimums amounts of rainfall throughout the region. The rainfall regime in South-Eastern Nigeria, varied between seasons but with longer period of dry season. The wet months do not have equal amount of rainfall and neither through the years, this is in line with the previous studies [13, 14]. Continuous decrease in rainfall could lead to a reduction in the availability of water resources in Nigeria just as research findings were reported for other regions of the world such as in Sahel zone [15], sub-Saharan Africa [16], Chad area [17], West African region [18], Sudan-Sahel zone of Nigeria [19], and in Logone drainage basin [20]. Moreover, significant variation in rainfall could affect the quality, volume and availability of surface water [21], and could have adverse consequences on generation of hydropower [22]. In a related research conducted by Akinbile et al. (2020) and Onyeneke et al. (2020) [23, 24] there is an observed increase in rainfall trends throughout the main agro-ecological regions, with the exception of the Sahel Savannah.

3.2. Trend Analysis for Air Temperature in Southeast Nigeria

The result of Mann-Kendall test conducted for air temperature is shown in Table 2, while the temporal variability and linear trend is shown in Figures 8 to 12.

Table 2. Result of Mann-Kendall Test for Air Temperature (°C)

State Capital	Mann- Kendall Statistic	Kendall Tau	p-value (2-tailed test)	Alpha	Test Interpretation	Trend rate	Trend Equation	Trend
Enugu	2136	0.488	2.22e-16	0.05	Reject H0	0.04698	25.785 + 004698t	Increasing
Owerri	1877	0.409	2.22e-16	0.05	Reject H0	0.01600	26.008 + 001600t	Increasing
Umuahia	1213	0.267	0.00015283	0.05	Reject H0	0.004153	26.3204 + 0.004153t	Increasing
Abakaliki	1034	0.229	0.0012356	0.05	Reject H0	0.003295	26.2342 + 0.03295t	Increasing
Awka	1888	0.400	2.00e-16	0.05	Reject H0	0.01859	26.126+0.01859t	Increasing

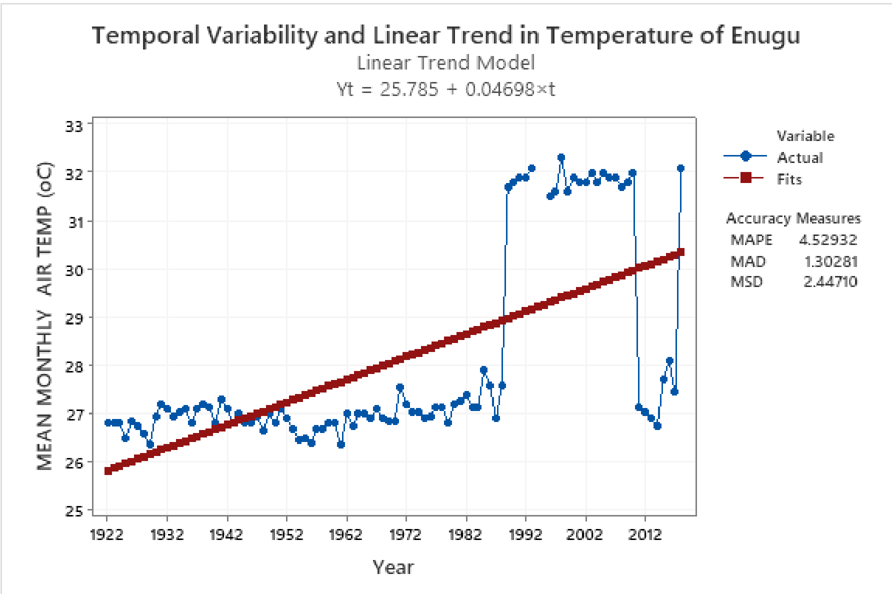

Figure 8. Linear nature of trend line of Air Temperature in Enugu, Nigeria

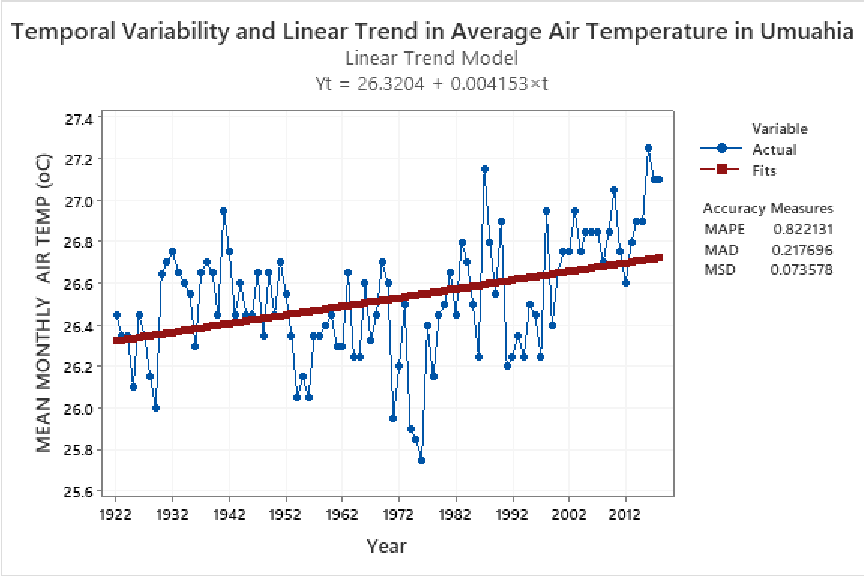

Figure 9. Linear nature of trend line of Air Temperature in Umuahia, Nigeria

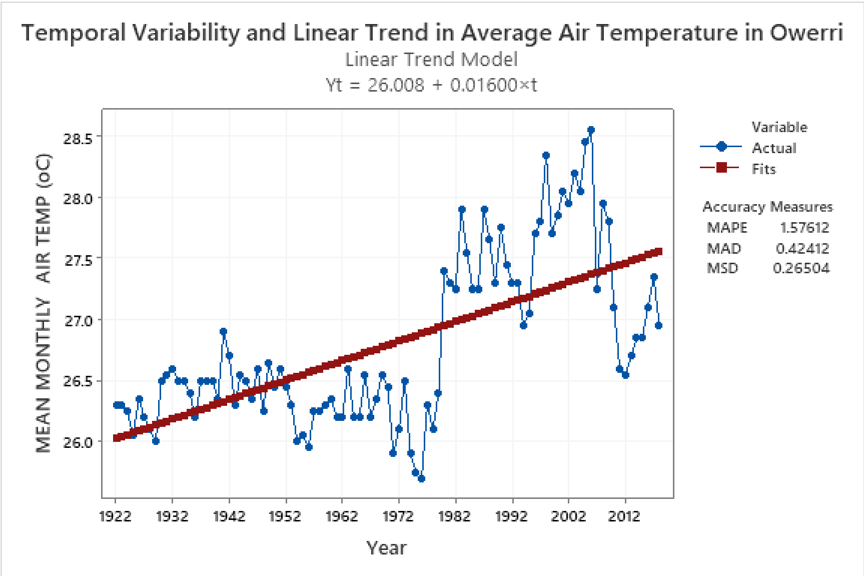

Figure 10. Linear nature of trend line of Air Temperature in Owerri, Nigeria

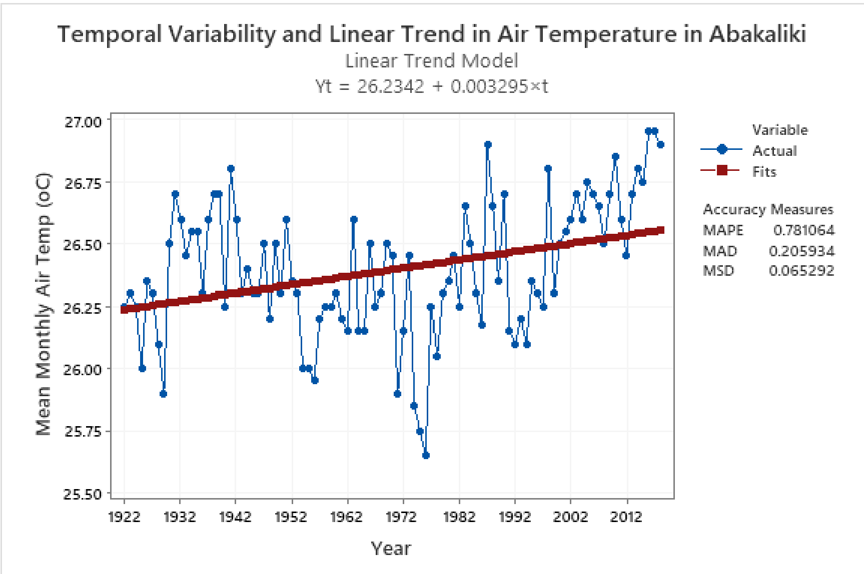

Figure 11. Linear nature of trend line of Air Temperature in Abakaliki, Nigeria

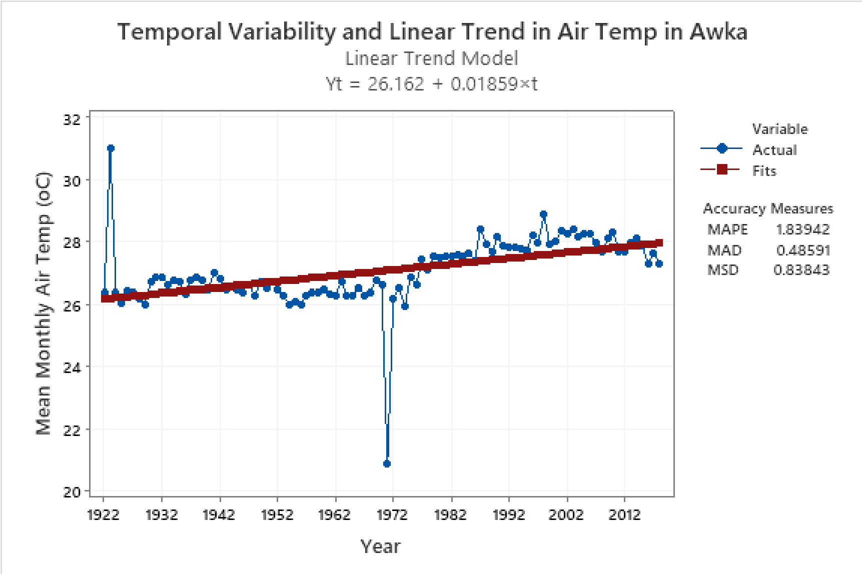

Figure 12. Linear nature of Trend Line of Air Temperature in Awka, Nigeria

The result of Mann-Kendall test on air temperature, indicates that H0 is rejected in all the states of South-Eastern Nigeria (Table 2). This means that there is trend in air temperature for all South-East capital cities.

A significant increase of mean air temperature was observed at Enugu, Umuahia, Owerri Abakaliki and Awka with an increased air temperature value of 0.04698, 0.01600, 0.004153, 0.003295, and 0.01859 ^oC/year, respectively. All the states were statistically significant ($p < 0.05$) upward trend in temperature. A maximum value of 32.2, 27.21, 28.1, 27.8 and 28.2 ^oC/year were observed at Enugu, Umuahia, Owerri, Abakaliki and Awka respectively as Figures 8 to 12 indicates. The most notable observation based on the results is that all the States have rising temperature. The rate of rise in air temperature could lead to more evaporation in the area. The S statistics is strongest in Enugu since it has the most significant trend among the capital cities of South-East with the recorded highest rate of increasing trend in air temperature value of 0.04698^oC/year. This signifies that the region has continuously become hotter in the last century. A rise in temperature is among the indicators of climate change [25]. Onyeneke et al. (2020) [24] reported that temperature increased substantially over time across all main agro-ecological regions in Nigeria. The rise in temperature can cause scorching of crops as well as reduced crop yield.

Research conducted by Freduah et al. (2019) [26] shows an increase in temperatures of the Savannah areas of Guinea and Sudan. These agrometeorological areas equally showed evidence of decreasing precipitation, which, along with rising temperatures, decreases crop yield. According to Freduah et al. (2019) [26] study, weather-related decline in crop yield tends to occur via variables like higher seepage, reduced grain-filling period, as well as higher atherosclerosis rate, which reduces the capacity of the maize plant to cover the grains effectively. Also Akinbile et al. (2020) [23] reported an increase in temperature across Nigeria's main agro-ecological regions between 1971-2010.

Sylla et al. (2016) [27] conducted a research using the RCM multi-model method to predict temperature across the Sahel zone and projected an average temperature rise of 1.8 °C till 2035. Various studies such as Fitzpatrick et al. (2020), Engelbrecht et al. (2015) and Serdeczny et al. (2016) [28-30] predicted a rise in temperature in some areas of Africa, particularly in Sahel region. This prediction provides information for better agricultural practices, which have direct impact on food availability and also help make decisions regarding availability of land and water resources in a given region [24]. Continuous increase in temperature is a strong characteristic of increase in global warming.

4. Conclusion

This study saw an improvement in the accuracy and reliability of the result obtained from those of previous work conducted in some cities of Nigeria by other researchers. Analysing the air temperature and rainfall trends for the five cities of the region all at the same time eliminated some of the constraints in the previous research works. In general, there was conformity in the results obtained from the Mann-Kendall test and the linear trend line for the five South-Eastern states for the 86-year time. Trends in 86-year climatic data do confirm climate change is occurring in South-Eastern Nigeria. The trend analysis proved to be a qualitative description of the impact of climatic factors on runoff changes. The high rate of trend in climatic variables consistently generated the high impact of climate change on climatic variables. The trends in climatic variables seen for each state could imply that the changes are more pronounced for certain locations and less for others, or the changes in climatic patterns could be affected seasonally. Previous Mann-Kendal statistics study shows that there is no trend in solar radiation and atmospheric pressure in most cities of the South-Eastern region. During this period, linear trend line showed that there is increasing trend in air temperature in all the capital cities in South-Eastern river basin. The adoption of uniform period of reading (use of only data collected at the same time in every state) increases the acceptability of the results from this study. For an instance, data used in the analysis was those collected from each of the gauging stations of Owerri, Abakaliki, Umuahia, Enugu and Awka at the same period of the day and week simultaneously. This approach resolves some limitations contained in the previous research works. This method should be adopted in determining impacts of climate parameters for bigger catchment area. It is critical to understand here that the estimates for climate change should be analysed from a local perspective and conclusions are not to be drawn from a global level. Policy makers and planners should appropriately consider climate change effects in water management activities. It is recommended that timely measures and institutional changes should be employed in reducing the irreparable damages that can be caused by climate change.

5. Declarations

5.1. Author Contributions

Conceptualization, B.N.E. and J.C.A.; methodology, B.N.E. and J.C.A.; software, B.N.E.; validation, B.N.E. and J.C.A.; formal analysis, B.N.E.; investigation, B.N.E.; data curation, B.N.E.; writing—original draft preparation, B.N.E. and J.C.A.; writing—review and editing, B.N.E. and J.C.A.; supervision, J.C.A.; project administration, B.N.E.; funding acquisition, BNE. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

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