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Research Article

Establishing Climate Change on Temperature Trend, Variation and Change Point Pattern in Warri, Nigeria

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Abstract

The study aimed to establish climate change on temperature trends, variation and change point patterns in Warri, Nigeria, using 31-year daily temperature data (1992-2022). The primary data were obtained from the Nigerian Meteorological Agency (NIMET) for Warri to understand the temperature dynamic in the city. Both the annual maximum and minimum temperatures were extracted from the dataset and also the mean temperature was obtained by getting the mean temperature of the maximum temperature values. Mann-Kendall trend tests, linear regression, change point detection through CUSUM analysis, and Sequential Mann-Kendall tests were used for the trend and change point analyses. Results revealed statistically significant increasing trends in annual maximum temperature (0.02 ℃/year) and mean temperature (0.025 ℃/year), while minimum temperature showed a non-significant positive trend. Change point analysis identified significant shifts in maximum and mean temperatures around 2005-2006. The average annual maximum temperature was 36.35 ℃, with temperature yearly projections suggesting potential increases to nearly 40 ℃ over the next century if current trends continue. These findings have important implications for urban infrastructure and industrial operations in Warri, particularly given its significance as a major oil and gas hub. The study provides crucial insights for climate adaptation planning in coastal industrial cities experiencing warming trends.

Keywords

Temperature Trends, Change Point Detection, Mann-Kendall Test, CUSUM Analysis, Climate Change, Urban Heat Island, Warri

1. Introduction

Temperature is one of the important climate indicators used to track global warming and has a tremendous effect on the hydrology cycle [24, 5, 15, 21]. The global temperature has significantly increased especially in the past three decades and is projected to increase more in the coming decades [11]. Intergovernmental Panel on Climate Change (IPCC) reported a 50% chance that the global temperature will rise to 1.5 ℃ or above 2 ℃ from 2021 to 2040 [13]. Such an increment in the global temperature will result in significant warming of the earth's surface. Suhaila & Yusop stated that even a 1 ℃ change in the global temperature is significant because a vast amount of heat would be required to warm all the oceans and the atmosphere for a 1 ℃ temperature change to occur [27, 18, 29]. Therefore, detecting and analysing temperature trends is crucial for understanding climate change impacts at regional and local scales [12, 3].

Warri is one of the major cities in Nigeria and a region where heavy oil and gas exploration and production is done. Origho reported that Warri has become an Urban heat Island due to its urbanization [20]. Urban heat islands tend to expe-

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rience higher heat than its surrounding rural environs. Also, oil and gas exploration taking place in the city will result in the production of greenhouse gases which in turn will raise the surface temperature. International Energy Agency (IEA) stated that oil and gas production contributes about 15% of the total energy-related emissions globally which is about 5.1 billion tonnes of greenhouse gas emissions [10]. Changing temperature patterns in any location tend to have significant implications for urban infrastructure, industrial operations, and human well-being [8, 1, 2]. This is particularly relevant for Warri, a major oil and gas hub in Delta State, where temperature variations can be affected by both urban activities and petroleum activities [35].

Understanding of the variation and the effect of climate change on temperature is usually analysed using statistical methods. Many researchers have used trend analysis tests and change point tests to understand the effect of climate change on temperature. However, limited studies have been conducted on the trend of temperature and change points in Nigeria particularly Warri. Ragatoa et al. reported a significant increase in the temperature in Warri but the year when there was a significant change in the temperature was never identified [23]. Understanding temperature dynamics require consideration of both gradual temperature trends and when there is an abrupt shift in temperature trend. Recent research has emphasized the importance of detecting change points in temperature time series, as these can indicate significant transitions in climate regimes [24]. Suhaila & Yusop identified that the atmosphere in Malaysia is becoming warmer and the abrupt change in the temperature trend occurred from 1996 to 1998 [27]. The abrupt change from 1996 to 1998 was attributed to the El Nino events that occurred during that period. Zarenistanak et al. reported warmer atmosphere temperatures in most provinces in Iran and stated that most of the changes in the trend of the temperature occurred during the 1900s [35]. Identification of change points helps identify extreme events that might have caused the abrupt change in the atmospheric temperature. Identifying the change point year can be relevant for urban and industrial planning in rapidly developing regions like the Niger Delta. This study aims to ascertain if the atmospheric temperature in Warri is becoming warmer and when the abrupt change in the temperature trend occurred using a comprehensive statistical analysis of 31-year temperature data (1992-2022).

2. Materials and Methods

2.1. Study Area

Warri is a major city in Delta State, located in the Niger Delta region of southern Nigeria as shown in Figure 1. The city lies between Latitude 5°22' 19.2" to 6°8' 6" and Longitude: 5°0' 0" to 5°46' 48" with an average elevation of 4 meters above sea level. As one of the most significant urban centres in the Niger Delta region, Warri serves as a crucial hub for Nigeria's oil and gas industry, hosting numerous petroleum facilities including refineries, tank farms, and export terminals.

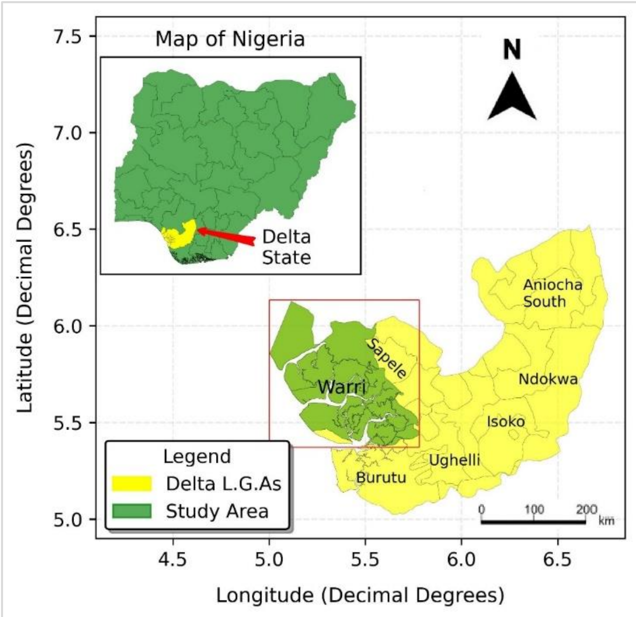

Figure 1. *Map of Study Area (Warri in South Central Nigeria).*

The city experiences a tropical monsoon climate which is characterized by two seasons namely: the rainy and dry seasons. The region receives substantial annual rainfall, typically ranging between 2,000 - 4,000mm. As shown in Figure 1, Warri is a coastal city and experiences relatively high relative humidity that often exceeds 80%. Mean monthly temperatures in Warri range between 25 - 32 ℃, showing minimal seasonal variation characteristic of its geographical location. Geologically, Warri is situated within the Niger Delta sedimentary basin, which began forming in the Early Cretaceous period. The local geology is characterized by thick sequences of deltaic sediments up to 12km in thickness. Warri's economic landscape is dominated by oil and gas activities, with numerous multinational petroleum companies operating in the area. This industrial presence has led to significant urban growth and development, resulting in substantial land-use changes over recent decades. The combination of intensive industrial activity, rapid urbanization, and its coastal location are factors that influence temperature dynamics making Warri an ideal location for studying the potential impacts of climate change on temperature.

2.2. Data Collection

Establishing trends in rainfall requires long historical data. A 31-year temperature record spanning from 1992 to 2022 were obtained from the Nigerian Meteorological Agency (NIMET) for Warri to understand the temperature dynamic in the city. The data obtained from NIMET were the daily maximum and minimum temperatures for Warri for the study duration. The data were further analysed to obtain the annual maximum temperature which is the maximum temperature in a particular year. Annual minimum temperature was also obtained which is the minimum temperature in a particular year. Then the mean temperature was obtained by getting the mean temperature of the maximum temperature values.

2.3. Statistical Test Methods

The temperature dynamics in Warri were analyzed using various statistical tests. For the trend analysis, both linear regression and the Mann-Kendall test were used for trend detection. Linear regression is the parametric test used for trend detection in time series data while Mann Kendall is the non-parametric version that does not require that the time series data should be normally distributed. Theil Sen's Slope Estimator was utilized in estimating the magnitude of the trend. Two change point tests namely: Distribution free CUSUM and Sequential Mann Kendall were used in identifying the year when an abrupt change was observed in the temperature trend.

2.3.1. Linear Regression

Linear regression which is a parametric test was used in identifying if there was a trend in the temperature data [19, 27]. The equation of the simple linear regression model is given in Equation (1). The slope of the equation can be used to identify the direction of the trend and the magnitude of the trend. If the slope model parameter is statistically significant then there is sufficient evidence to state that the temperature data of Warri has a positive or negative trend otherwise no trend exists.

$$T = a_o + a_1 t \tag{1}$$

Where t = time (year), a_o = intercept, a_1 = slope, and T = temperature (degree ℃)

2.3.2. Mann Kendall Test

The Mann-Kendall (MK) test, a non-parametric test was also used to detect the trend in hydrological and meteorological time series data [16, 14, 30, 17]. This test is preferred over linear regression for trend detection due to its robustness with non-normally distributed data. Zhang et al. highly recommended that Mann Kendall test should be used for trend detection [36]. However, only when the temperature data has serious outliers and is extremely skewed should Mann Kendall be preferred over linear regression. The Mann-Kendall test establishes two hypotheses namely:

a. Null hypothesis (H_0): No trend exists in the temperature data series.
b. Alternative hypothesis (H_1): A monotonic increasing or decreasing trend exists in the temperature data series.

The Mann-Kendall test statistic S is computed using Equations (2-5):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sig(x_j - x_i) \tag{2}$$

$$sig(x_j - x_i) = \begin{cases} +1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases} \tag{3}$$

$$V(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_q(t_q - 1)(2t_q + 5)\right] \tag{4}$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & If\ S > 0 \\ \frac{S+1}{\sqrt{V(S)}}, & If\ S < 0 \end{cases} \tag{5}$$

Where: t_q = number of ties for p^{th} values; q = number of tied value; and Z = Standardized Mann Kendall statistic. A trend is detected in the time series data if the absolute standardized Mann Kendall statistic $|Z|$ is greater than the critical z-score $Z_{1-\alpha/2}$ or if the p-value is less than the level of 5% significance.

Mann Kendall test result is seriously affected by autocorrelation in the data set, especially at lag 1. The existence of serial autocorrelation at lag 1 can result in a Type 1 error which results in the rejecting of the null hypothesis when it should not have been rejected [33, 7, 26]. This error causes one to judge the existence of a trend when in fact there is no trend in the temperature data. Before applying the MK test, the data were examined for serial correlation using autocorrelation function (ACF) analysis using the Python statsmodel library-pymannkendal. If autocorrelation is found at lag 1 in the temperature data, then correction should be applied to the temperature data. However, if no serial autocorrelation is found in the temperature data set, the Mann Kendall test can be applied without the need for correction. Yue et al. developed a correction for time series with serial correlation known as "Trend Free Pre-whitening (TFPW)" [34].

2.3.3. Theil Sen's Slope

The Sen's Slope Estimator (SSE) test was used to determine the magnitude and variation of the trend. The Sen' slope is estimated using the formula in Equation (6) [25, 32].

$$\beta = \text{Median}\left(\frac{x_i - x_j}{t_i - t_j}\right) \tag{6}$$

Where x_i and x_j are rainfall data values at time t_i and t_j (i > j) respectively.

2.3.4. Change Point Analysis

Two complementary non-parametric methods were employed for detecting change points in the temperature series data. Distribution-free CUSUM test was used to examine differences in mean values before and after potential change points. A change point is identified where the absolute

CUSUM value reaches its maximum.

Sequential Mann-Kendall test (SQMK) analyses the temperature data series in both forward and backward directions. The intersection point of these progressive and retrograde series indicates a potential change point. Both methods were implemented using the "trendchange" package in [31, 22]. This dual approach provides robust identification of significant changes in the temperature data pattern over the study period.

3. Results

3.1. Summary Statistics and Temperature Distribution & Analysis in Warri

The trend of the annual minimum, maximum, and annual mean temperatures for Warri from 1992 to 2022 are presented in Figure 2. The annual minimum temperature ranged from 11.20 - 20.50°C for the study duration. The annual minimum temperature demonstrates more pronounced fluctuations, with a noticeable dip in the annual minimum temperature to 11.20°C in 2015. The annual maximum and mean temperatures showed a relatively constant trend over the study period. The annual maximum temperature ranged from 35 - 38.50°C while the annual mean temperature ranged from 31.21 - 32.81°C.

The summary statistic and distribution of the temperature series are shown in Figure 3. The mean annual maximum temperature was 36.35°C while the mean annual minimum temperature was 17.98°C. For the average annual mean temperature, the temperature computed was 32.03°C. The boxplot showed that there were a few outliers in the annual maximum and minimum temperatures. In terms of the variation in the temperature, the annual minimum temperature had the highest temperature as indicated by the high coefficient of variation of 11.57%.

Both annual maximum and mean temperature series had low variation in the temperature data as indicated by their low coefficient of variation. However, the annual maximum temperature series had slightly higher variation in the temperature series than the annual mean temperature series. The distribution showed that the temperature series was kind of skewed to the left. Shapiro Wilk and Anderson-Darling test revealed that both the annual maximum and minimum temperatures series were not normally distributed. However, the annual mean temperature distribution was normally distributed. The normality of the temperature data was confirmed by the Z-skewness as presented in Table 1. The Z-skewness was obtained by dividing the skewness by the standard error of the skewness. Ghasemi & Zahediasl stated that series with absolute Z-skewness value greater than 1.96 violate normality [9]. The result showed that just the annual minimum temperature largely violated normality while annual maximum temperature was on the broad line of violating normality. The annual mean temperature of Warri was normally distributed and did not violate normality irrespective of the test used in checking for normality.

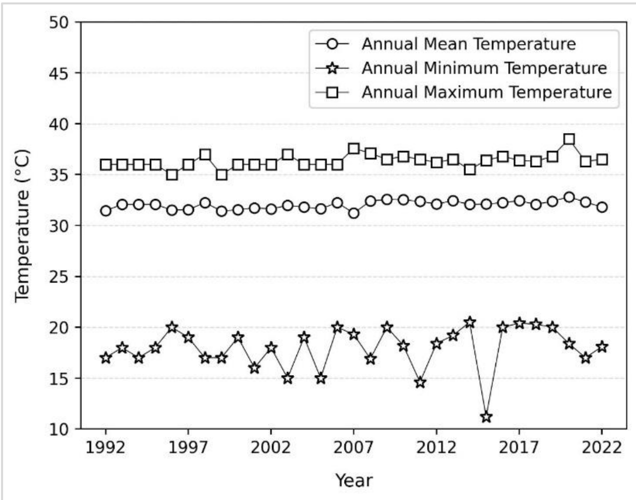

Figure 2. *Plot of annual temperature series for the study for Warri.*

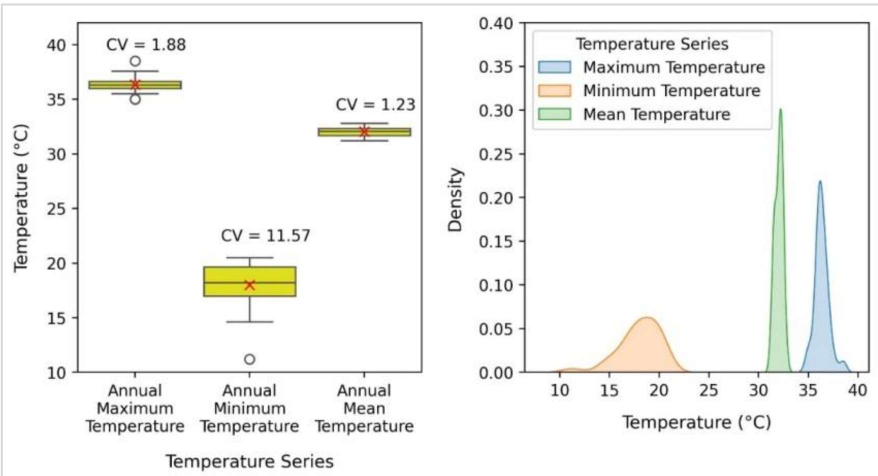

Figure 3. *Distribution and summary statistics of temperature series.*

Table 1. *Skewness and Normality tests.*

Annual Temperature Series	Shapiro-Wilk	Anderson-Darling	Skewness	Standard Error of Skewness	Z-skewness
Maximum Temperature	0.011	0.006	0.818	0.421	1.944089
Minimum Temperature	0.005	0.027	-1.295	0.421	-3.07957
Mean Temperature	0.431	0.222	-0.230	0.421	-0.54589

Note: When p-value is less than 0.05, then one should reject the null that the temperature series comes from a normal distribution

3.2. Trend Analysis Using Linear Regression

The trend analysis using linear regression for the annual minimum, maximum, and annual mean temperatures for Warri are presented in Table 2. The linear regression analysis revealed distinct trends in annual maximum, minimum, and mean temperatures in Warri over the study period. For annual maximum temperature, there was a statistically significant increasing trend (p = 0.011) with a rate of 0.034 ℃ per year. The result revealed that the annual maximum temperature would increase by 0.034 ℃ yearly. The result indicates that there would be a 3.4 ℃ increase in the annual maximum temperature in Warri 100 years from now. Considering that the current mean annual maximum temperature of Warri is 36.35 ℃, an increment of 3.4 ℃ will put the mean annual maximum temperature at 39.75 ℃ in 100 years from now. Temperature close to 40 ℃ might cause significant problems to the ecosystem of Warri. Annual mean temperature also exhibited a significant warming trend (p = 0.002) with an increase of 0.023 ℃ per year. The projected annual mean temperature increase in 100 years would be 2.3 ℃. In contrast, while annual minimum temperature showed a positive trend of 0.031 ℃ per year, this trend was not statistically significant (p = 0.465). These results indicate that Warri has experienced significant warming over the study period, particularly in maximum and mean temperatures, while changes in minimum temperature have been more variable and less certain.

Table 2. *Linear regression for temperature series in Warri.*

Statistic	Annual Maximum Temperature		Annual Minimum Temperature		Annual Mean Temperature	
	Intercept	Year	Intercept	Year	Intercept	Year
Value	-32.039	0.034	-44.492	0.031	-14.938	0.023
Standard error	24.998	0.012	84.471	0.042	13.653	0.007
t	-1.282	2.736	-0.527	0.740	-1.094	3.440
Pr > |t|	0.210	0.011	0.602	0.465	0.283	0.002
Lower bound (95%)	-83.166	0.009	-217.255	-0.055	-42.863	0.009
Upper bound (95%)	19.089	0.060	128.271	0.117	12.986	0.037

3.3. Trend Analysis Using Mann-Kendall (MK)

Before conducting the Mann-Kendall test, autocorrelation analysis was performed to examine the independence of the temperature observations. Figure 4 presents the correlogram showing the autocorrelation function (ACF) for different lag times. For the annual maximum temperature, the ACF at lag 1 was 0.151 which signifies that no autocorrelation was present in the annual maximum temperature data thereby indicating serial independence in the temperature series. Similarly, the ACF for annual minimum and mean temperature were -0.212 and 0.285 respectively. No autocorrelation was present in the annual minimum and mean temperature data. The lack of serial correlation in all three temperature series data suggests that Mann Kendall can be directly applied to the temperature data without the need for correction.

The result of the Mann Kendall for the temperature series in Warri is presented in Table 3. The Mann-Kendall trend analysis revealed significantly increasing trends across all temperature series. The Mann-Kendall result for annual maximum and mean temperature revealed that there was significant increasing trend in the temperature. However, there was an increasing trend in the annual minimum temperature, but the trend was not statistically significant. The Sen's slope estimator provided quantitative measures of the trend magnitudes. The result from the Sen slope showed that the annual maximum and mean temperature are expected to increase by 0.02 ℃/year and 0.025 ℃/year respectively. Projecting this increment for the next 100 years, the temperature in Warri would have increased by almost 2 ℃.

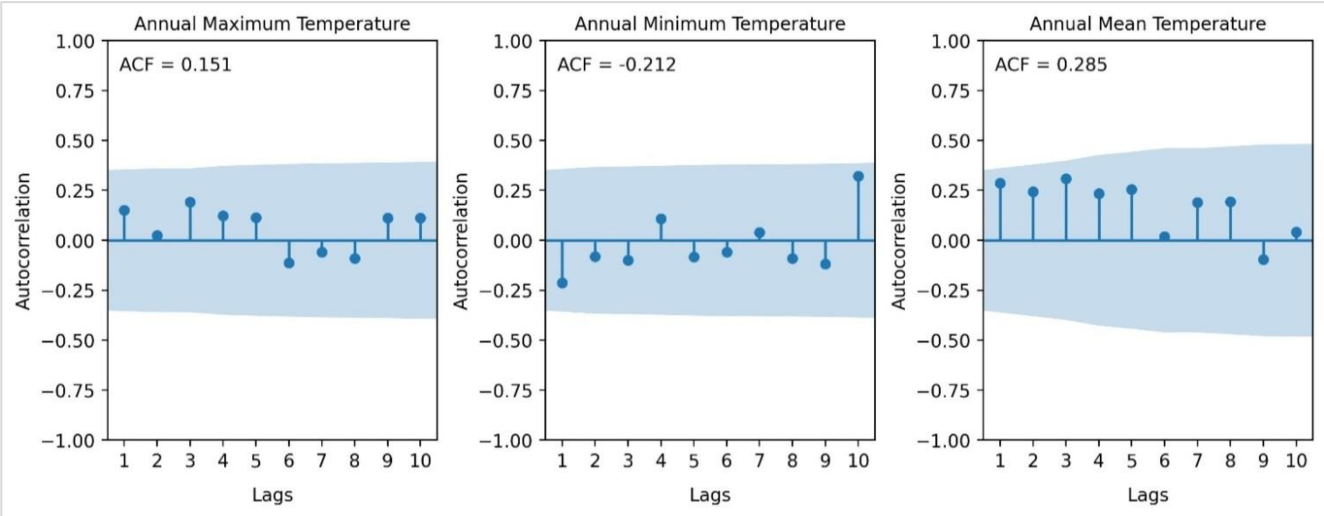

Figure 4. *Rainfall precipitation correlogram of ACF for Warri.*

Table 3. *Mann-Kendall Test Results for Different Time Scales in Warri (1992-2022).*

Statistic	Annual Maximum Temperature	Annual Minimum Temperature	Annual Mean Temperature
Kendall's tau	0.356	0.184	0.363
S	153.000	83	169
Var(S)	3280.333	3419	3461.667
p-value (Two-tailed)	0.008	0.161	0.004
Sen Slope	0.020	0.045	0.025
alpha	0.05	0.05	0.05

3.4. Trend Change-Point Analysis

The analysis of change points in the temperature series employed both Distribution-free CUSUM and Sequential Mann-Kendall tests to identify significant shifts in temperature patterns. The distribution-free CUSUM change point analysis is shown in Table 4. For the annual maximum temperature, the CUSUM analysis revealed a maximum CUSUM value of 11, which exceeded all critical values (6.7927, 7.5722, and 9.0755), providing strong evidence that the change point year for annual maximum temperature occurred in 2006. The CUSUM plot in Figure 5 visually confirms this significant shift, as the abrupt shift is located at the maximum CUSUM value of 11 in 2006. For annual mean temperature, a significant change point was also detected in 2005 with a maximum CUSUM value of 10. However, the annual minimum temperature showed no significant change point, with a maximum CUSUM value of 6 that fell below the critical thresholds as shown in Figure 5.

The Sequential Mann-Kendall (SQMK) analysis provided additional temporal insights through the progressive u(t) and retrograde u'(t) series. Figures 6 to 8 show the SQMK graph for the three-temperature series which are annual maximum temperatures, annual minimum temperatures, and annual mean temperature. For the annual maximum series, the prograde and retrograde crossed in the year 2016 as shown in Figure 6. The point of the crossing of the prograde and retrograde indicate the change point year. The annual mean temperature showed a significant crossing in 2006, aligning with the CUSUM results which indicated that the change point year was in 2005. For the annual minimum temperature, multiple crossings were observed around 2012 and 2021, suggesting no clear change point could be established.

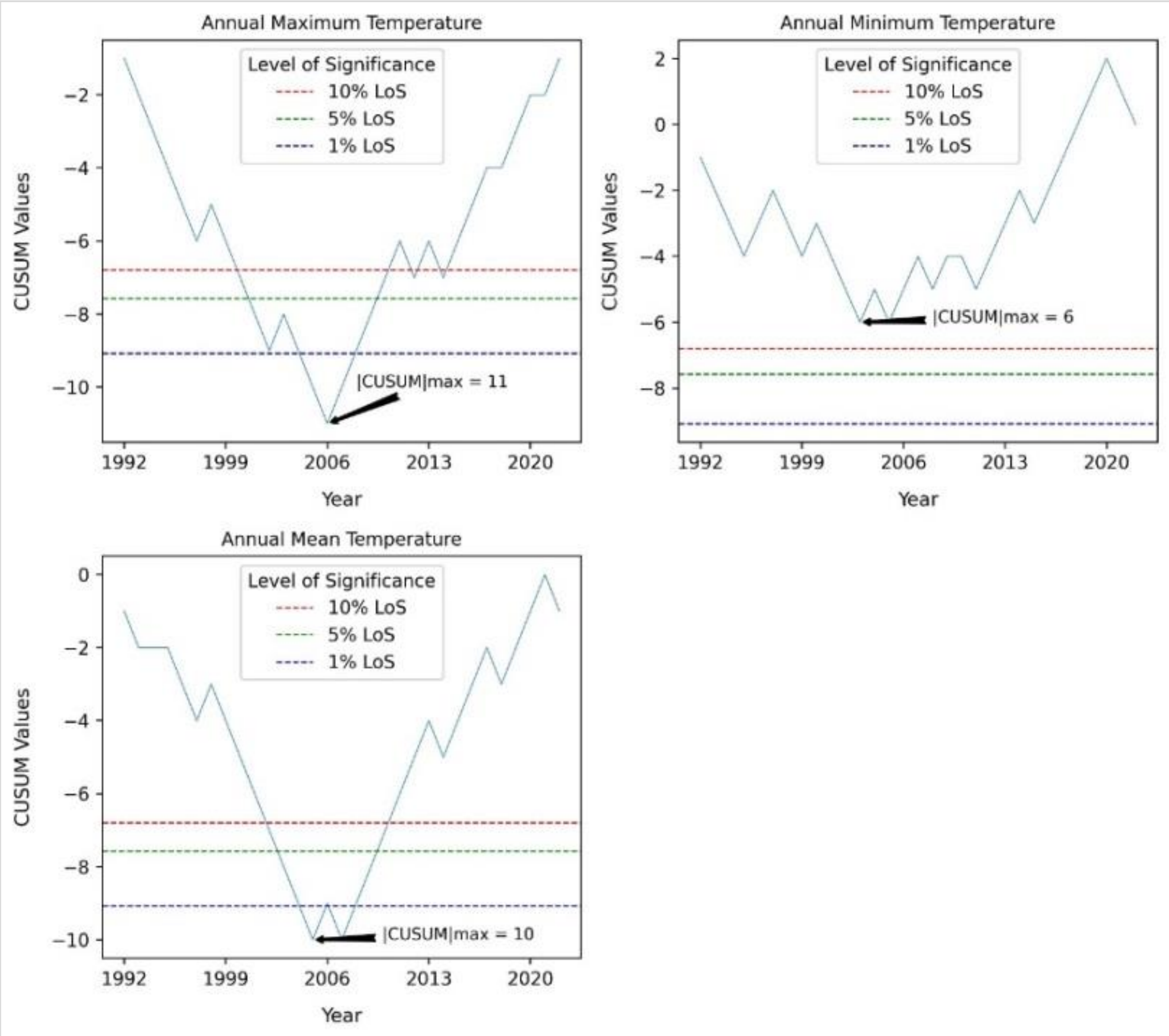

***Figure 5**. Distribution-free CUSUM plot for temperature series for Warri.*

***Table 4**. Distribution free CUSUM Change Point.*

Temperature Series	Maximum CUSUM Value	Critical Values	Change Point Year	Remark
Annual Maximum Temperature	11	CI @ 90%: 6.7927 CI @ 95%: 7.5722 CI @ 99%: 9.0755	2006	Significant change point
Annual Minimum Temperature	6	CI @ 90%: 6.7927 CI @ 95%: 7.5722 CI @ 99%: 9.0755	2003	No significant change point
Annual Mean Temperature	10	CI @ 90%: 6.7927 CI @ 95%: 7.5722 CI @ 99%: 9.0755	2005	Significant change point

The combined results from both methods indicate that Warri's temperature patterns have undergone significant changes, particularly in maximum and mean temperatures, with major shifts occurring between 2005-2006. The minimum temperature showed more variable patterns without clear change points. The identification of these change points aligns with the significantly increasing trends detected in the Mann-Kendall analysis, providing a more complete picture of how temperature patterns have evolved in Warri over the study period.

***Table 5**. Sequential Mann Kendall Change Point.*

Temperature Series	Change Point Year	Crossing Pattern	Remark
Annual Maximum Temperature	2016	Single crossing	Probable change point
Annual Minimum Temperature	2012	Multiple crossings	No change point
Annual Mean Temperature	2006	Single crossing	Probable change point

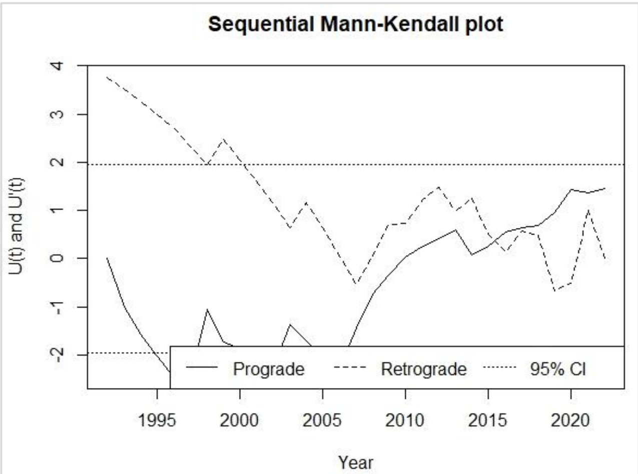

***Figure 6**. Sequential Mann-Kendall plot for Annual Maximum Temperature.*

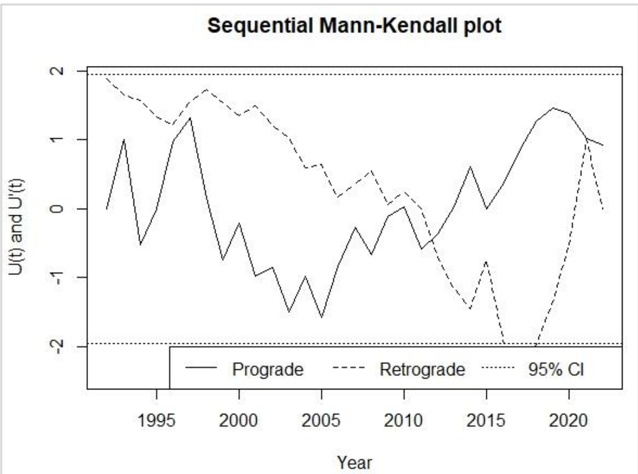

***Figure 7**. Sequential Mann-Kendall plot for Annual Minimum Temperature.*

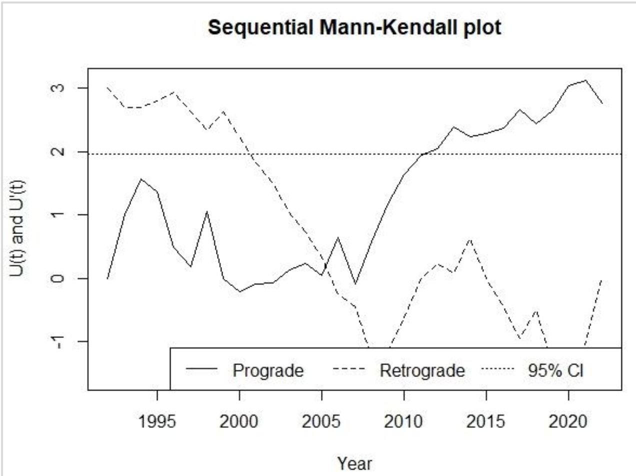

***Figure 8**. Sequential Mann-Kendall plot for Annual Mean Temperature.*

3.5. Temperature Difference pre and Post-Change Point Year

The differences in temperature patterns before and after the detected change points were examined through comparative statistical analysis and visualization. Figure 9 presents the distribution of annual maximum temperatures before and after the 2006 change point. The mean maximum temperature rose from 36.00℃ before 2006 to 36.629℃ afterwards. The increment recorded before and after the change point year was 0.629℃. Mann-Whitney test was used to investigate if the increment in the mean annual maximum temperature before and after the change point year was significant. The result of the Mann-Whitney test checking for significant differences in the mean annual maximum temperature is presented in Table 6. The result revealed that the mean annual maximum temperature before the change point year was statistically different from the mean record after the change point year (U=43.00, p-value = 0.002). The result confirms that an event might have commenced to occur from the year 2006 that brought about a significant increase in the mean. Figure 10 shows the mean annual minimum temperature before and after the change point year which occurred in 2003 but was not significant. While there was a slight increase from 17.818 - 18.075 ℃, the difference was relatively small as observed in Figure 10. The Mann-Whitney test results presented in Table 7 indicate this difference of 0.257 ℃ was not statistically significant (U= 80.00, p-value = 0.221). The mean annual mean temperature comparison is shown in Figure 11. The plot demonstrates a clear upward shift in the mean annual mean temperature before and after the change point year in 2005. It was observed that the mean annual mean temperature increased from 31.778 - 32.207 ℃. Mann-Whitney test presented in Table 8 revealed that the increase of 0.429 ℃ was statistically significant (U = 38.00, p = 0.002).

These findings reinforce the trend analysis and change point results, showing significant warming in Warri's annual maximum and mean temperatures after their respective change points, while minimum temperatures showed more modest and statistically insignificant changes. The magnitude of these changes, particularly in maximum temperatures, suggests meaningful shifts in Warri's temperature regime that may have important implications for urban planning and human comfort in the region.

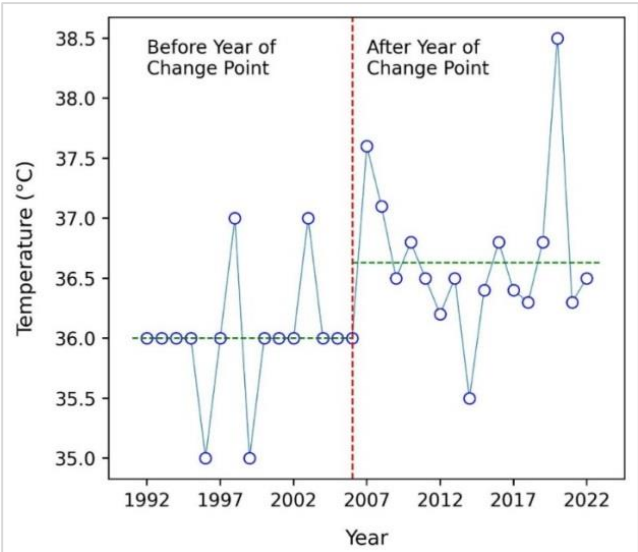

Figure 9. *Annual Maximum Temperature before and after change point year.*

Table 6. *Mann Whitney test of significance of annual maximum temperature before and after change point year.*

U	43.000
Expected value	119.000
Variance (U)	604.213
p-value (Two-tailed)	0.002
alpha	0.05

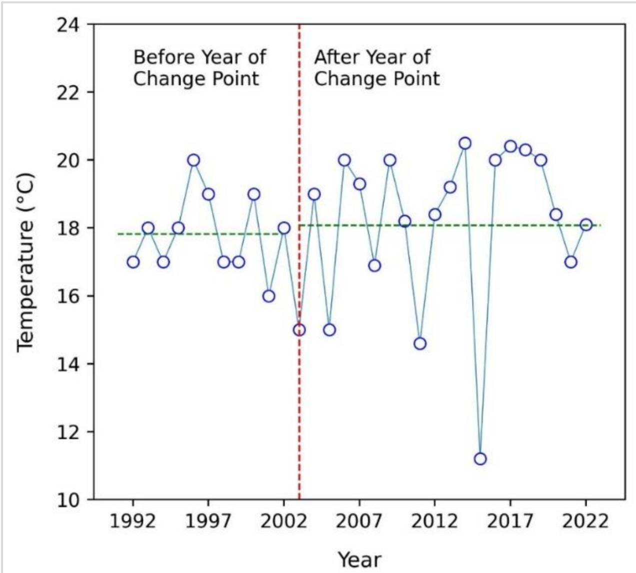

Figure 10. *Annual Minimum Temperature before and after change point year.*

Table 7. *Mann Whitney test of significance of annual minimum temperature before and after change point year.*

U	80.000
Expected value	110.000
Variance (U)	580.753
p-value (Two-tailed)	0.221
alpha	0.05

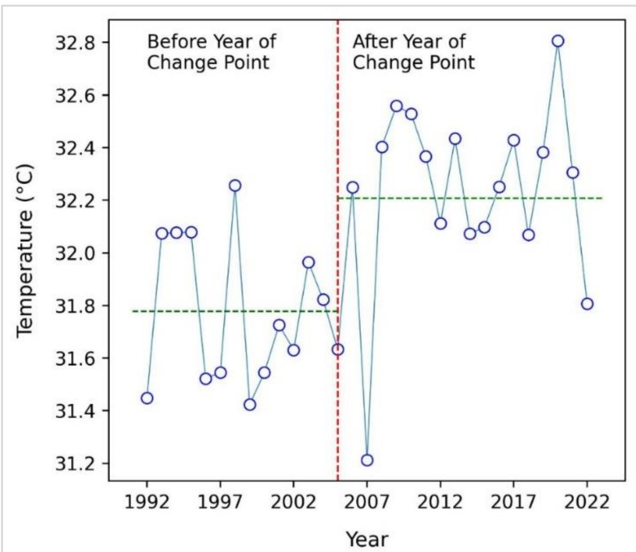

Figure 11. *Annual Mean Temperature before and after change point year.*

Table 8. *Mann Whitney test of significance of annual mean temperature before and after change point year.*

U	38.000
Expected value	117.000
Variance (U)	624.000
p-value (Two-tailed)	0.002
alpha	0.05

4. Discussion

The findings from the trend analysis study from 1992 to 2022 revealed significant warming of the Warri atmosphere. Both parametric (linear regression analysis) and non-parametric (Mann Kendall) tests confirmed statistically significant increasing trends in annual maximum and mean temperatures. However, no statistically significant trend was observed in the annual minimum temperatures, but a positive trend was revealed. The linear regression analysis indicated warming rates of 0.034 ℃/year for annual maximum temperature and 0.023 ℃/year for annual mean temperature, projecting potential increases of 3.4 and 2.3 ℃, respectively over 100 years if these trends continue. However, the Sen Slope estimated that the annual maximum temperature would increase by 0.02 ℃/year while the annual mean temperature would increase by 0.025 ℃ /year. Ragatoa et al. reported that the annual maximum temperature in Warri was significantly increasing by 0.02269 ℃/year similar to what was obtained in this study [23]. Judging from the 0.02 ℃/year increase in Warri, it would be estimated that the annual maximum temperature in 100 years in Warri will be above 2 ℃ of the current annual maximum temperature. The Intergovernmental Panel on Climate Change, IPCC projects that the global average surface temperature will increase between 1.4 - 5.8 ℃ from 1990 to 2100 [6, 4, 28]. The rate of annual maximum temperature found in Warri for the same duration was within the IPCC range. Suhaila & Yusop project that the trend of the annual maximum temperature in Peninsular Malaysia is expected to range from 1.4 - 5.8 ℃/100years [27]. The estimated annual maximum temperature for 100 years in Warri exceeded the lower boundary of what is obtainable in Peninsular Malaysia but did not exceed the upper limit. The change point year gives insight into why Peninsular Malaysia is experiencing a higher temperature rate than Warri. The change point detected for Warri for the annual maximum temperature was 2006 while that of Peninsular Malaysia was around 1996 to 1998. This indicated that the increasing trend of annual maximum temperature began almost a decade ago from the reported 2006 change point in Warri. Also, industrialization in Malaysia far exceeds what is obtainable in Warri. Origho stated that urbanization can significantly increase the temperature rate [20]. The more rapid warming in Warri aligns with the findings by Suhaila & Yusop who observed that accelerated temperature increases are noticed more in urban-industrial areas [27]. Efe & Ojoh also noted a significant temperature increase in Warri from 1907-2009 [8]. A more interesting finding in their study was the significant relationship they found between temperature increase and the number of malaria cases in Warri. Continuous increases in the temperature in Warri might further compound the number of cases of malaria experienced in the city. Judging from the projected 100-year annual maximum temperature, it is expected that the annual maximum temperature might rise to about 40 ℃. This high temperature will increase cooling demands and put significant stress on the inadequate power infrastructure in Nigeria presently. Also, the oil and gas sector may face increased cooling costs and potential operational constraints during peak temperature periods.

The lack of significant change points in the annual minimum temperatures in Warri despite an increasing trend suggests different driving factors may influence daily temperature extremes. Suhaila & Yusop found a significant increase in the annual minimum temperature in Peninsular Malaysia [27]. They reported that the warming rate in the minimum series was larger than those obtained in the maximum series. They attributed this finding to urbanization, stating that urbanization tends to affect annual minimum temperatures more than it affects annual maximum temperatures. The rate of warming of the annual minimum temperature in Warri (0.045 ℃/year) was also higher than what was obtainable for the annual maximum temperature, but it was not significant. However, the continued urbanization of Warri might result in the city experiencing significantly warmer minimum temperatures, a pattern commonly observed in rapidly developing industrial cities. Therefore, mitigation should be in place as urbanization continues to reduce the effect of the city experiencing warmer minimum temperatures. The increasing urban heat island signal suggests the need for climate-sensitive urban planning incorporating heat-mitigation strategies.

5. Conclusion

This study aimed to demonstrate if there were significant warming in Warri's atmospheric temperature over the past three decades (1992 to 2022). Both parametric and non-parametric tests were utilized for trend and change points which provided a robust approach to detecting temperature trends in Warri. The result revealed a statistically significant increase in the annual maximum and mean temperature but no significant increase in the annual minimum temperature. The analysis revealed substantial increases in the annual maximum temperature (0.02 ℃/year) and mean temperature (0.025 ℃/year). The detection of change points around 2005-2006 coincides with periods of intensive urban and industrial development in the region. The projected temperature increases, potentially reaching nearly 40 ℃ for annual maximum temperatures by century's end, raise serious concerns for human comfort, infrastructure resilience, and industrial operations in the city. The findings in this study emphasize the need for proactive climate adaptation strategies in Warri, particularly given its importance as an industrial hub.

Abbreviations

ACF	Autocorrelation Function
CUSUM	Cumulative Sum
IEA	International Energy Agency
IPCC	International Panel on Climate Change
MK	Mann-Kendall
NIMET	Nigerian Meteorological Agency
SQMK	Sequential Mann-Kendall
SSE	Sen's Slope Estimator
TFPW	Trend Free Pre-whitening

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Conflicts of Interest

The authors declare no conflicts of interest.

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