Trend Analysis of the Variations of Ambient Temperature Using Mann-Kendall Test and Sen’s Estimate in Calabar, Southern Nigeria

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Abstract. Studies have been made to understand the fluctuations of temperature in regions around the world because of an ever changing variation due mostly to man’s anthropogenic activities. This study is focused on analysing the temperature variations in Calabar, Southern Nigeria for 20 years (1998 – 2018) using the Mann-Kendall trend test and Sen’s slope estimator. Results from the Mann-Kendall test shows that the annual trends of the maximum and average ambient temperature are both increasing after showing positive Kendall Z-values (1.04 and 0.10 respectively). The minimum ambient temperature annual trend was observed to be decreasing after having a negative Kendall Z-value (-0.32); the estimations from Sen’s slope agreed with these results. The p-values were calculated to be 0.745, 0.299, and 0.922 for the minimum, maximum, and average ambient temperature trend respectively; these values were all found to be less than all significant levels used 0.1% (0.001), 1% (0.01), 5% (0.05), and 10% (0.1). This shows that the trends were not increasing or decreasing significantly, hence there is “no significant trend”. This may be due to the almost unchanging weather condition in the region arising from its closeness to the Atlantic Ocean.

Keywords: Trend analysis; ambient temperature; Mann-Kendall test; Sen’s slope estimate.

1. Introduction

There have been many applications of trend analysis which is being used to depict a change in the patterns; of, to a large extent climatic parameters. These patterns are always varying and this calls for a consistent application of trend analysis. One of the highest contributors to these variations is man’s anthropogenic activities [1-2].

This study seeks to analyze the temperature variation in the coastal region of the Southern Nigeria using the non-parametric Mann-Kendall test (MK-Test) and Sen’s slope Estimator. Various studies have been done to discern the variation of temperature [1-6] and all results obtained show that there is a dire need for a consistent analysis of this ever changing and evolving trend.

The cliché, which is true as proven from previous studies is that ‘meteorological parameters like temperature is and will always be increasing annually’ which brings the problem of climate change into play. A recent study by Agbo et al [4], shows that temperature in the region of study has been
increasing for 12 years, this was done by just observing the data, the non-parameter MK-test will show if the trend is truly increasing and also reveal the significance of the so-called “increasing trend”.

The test returns results by calculating the Kendall Z and S statistics values which shows an increasing trend if positive and a decreasing trend if negative [7]. By making use of the significance level ($\alpha$) we can determine the level of significance of the trend by noting that if the p-value (probability value) of the data is higher than the significance level, we can say that the null hypothesis $H_0$ is satisfied and there is “no trend”. The alternative hypothesis $H_1$ will show that there is a trend in the series with results showing that the p-value is lower than the significance level ($\alpha$).

### 1.1 The Non-Parametric M-K Test

The S statistics is usually used for a time series having below 10 data points calculated statistically as [8].

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

Where:

$$\text{sgn}(x_j - x_k) = \begin{cases} +1; & \text{if } (x_j - x_k) > 0 \\ 0; & \text{if } (x_j - x_k) = 0 \\ -1; & \text{if } (x_j - x_k) < 0 \end{cases}$$  \hspace{1cm} (2)

$n$ here is the number data values studied in the series, for this study that number is 20 years. If $n$ is 10 or more like in our case, the normal approximation is used (the Kendall Z-value). To get this value, we need to calculate the variance of $S$, $\text{VAR}(S)$ [9].

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

The equation takes into account the several tied values (equal values); $n$ is the number of data values, $g$ here is representing the number of these equal trend values or groups, $t_p$ represents the number of data values in the $P^{th}$ group.

We can now compute the Kendall test statistics (Z-value) by adopting $\text{VAR}(S)$ and $S$.

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

We have a decreasing trend if Z is negative and an increasing trend if Z is positive.
1.2 Sen’s Slope Estimator

Sen [10] derived a method for the estimation of the Kendall Tau. This method has its application in the estimation of the slope of a linear trend, which arises from a linear equation as;

\[ f(t) = Qt + B \]  

(5)

\( f(t) \) here is a function of time which represents the time series, which can be increasing or decreasing, \( t \) is the date (time) values, \( B \) is a constant and \( Q \) is the slope. \( Q \) can be gotten by the equation.

\[ Q_i = \frac{x_j - x_k}{j - k} \]  

(6)

Here at time \( j \) and \( k, j > k \) and \( i = 1, 2, \ldots, N \), the values of the data pairs are represented by \( x_j \) and \( x_k \). We can determine the median of the \( N \) values of \( Q \) by [5];

\[ Q = \begin{cases} Q_{(iN+1)/2}; & \text{if } N \text{ is odd} \\ \frac{1}{2}Q_{(N/2)} + Q_{(iN+2)/2}; & \text{if } N \text{ is even} \end{cases} \]  

(7)

When the value of \( Q_i \) is positive, one can discern that there is an increasing trend, and similarly a decreasing trend shows that the value of \( Q \) is negative. No trend is indicated by a zero value [5,7].

2 Methodology

Figure 1. Map of Study Area (Calabar).

Figure 2. NiMet Calabar at Margaret Ekpo International Airport.
2.1 The Study Area

Figure 1 shows the map of Calabar, a coastal (port) city in Southern Nigeria, the capital of Cross River State. The region is one of the cities in Nigeria having most of her boundaries ending at the Atlantic Ocean; making her elevation to be about 32m \[4\] above the sea level.

The region exhibits a rare climate called the tropical monsoon climate having a long wet season of about 8-10 months and a very short dry season of about 2 - 4 months. This shows that although there are variations, the variations throughout the year do not have a large deviation compared to other regions.

One of the main reasons why the region’s weather is almost uniform when observed physically is that it is coastal and conventional waves from the Atlantic Ocean makes the region humid. She has a land area of approximately 406 square kilometers or 157 square miles \[11\].

2.2 Data Acquisition and Analysis

The data used for this study was obtained from Nigerian Meteorological Agency (NiMet), Calabar. The average diurnal values of minimum and maximum ambient temperature were collected after being measured at an altitude of about 63m from the ground level at the weather station at the exact latitude of 04°58’N and longitude of 08°21’E. Figure 2 shows this location which is at the Margret Ekpo International Airport in Calabar.

The average value of the ambient temperature is calculated using the minimum and maximum value. The Mann-Kendall’s trend test, equations (1), (2), (3) and Sen’s slope estimator equation (6) have been used for this analysis. The analysis is being carried out by the Addinsoft XLSTAT which was used on the annual values of the minimum, maximum and average ambient temperature trends. The Kendall Z-value was calculated using equation (4) and its rules.

The results of the p-values were compared with all significant levels of the test to show the result interpretation at different levels of significance. Sen’s slope \(Q\) was obtained too, to show the nature of the increasing or decreasing trend. These results (p-value and significant levels) were compared for the null hypothesis \(H_0\), the results were organized in tables and charts and presented.

3 Analysis and Discussion

The results of the outcomes of the Mann-Kendall (M-K) trend test and Sen’s slope estimate for 20 years in Calabar, Southern Nigeria are presented in this section. We try to discern the existence or non-existence of a trend with quintessence using this non-parametric test. The M-K test is carried out with all levels of significance (0.1%, 1%, 5% and 10%) and results are presented to show that the test interpretation are the same for all levels of significance.
Variables $\tau$ S Var(S) Z $p$-value (Two-tailed) $Q$ Result Min Max $\bar{x}$ $\sigma$

| Minimum Ambient Temperature | -0.058 | -11.00 | 949.00 | -0.32 | 0.745 | -0.005 | $H_0$ \(\downarrow\) | 22.20 | 23.84 | 23.26 | 0.38 |
|-----------------------------|--------|--------|--------|-------|-------|--------|-----------|--------|--------|--------|-------|
| Maximum Ambient Temperature | 0.174  | 33.00  | 949.00 | 1.04  | 0.299 | 0.016  | $H_0$ \(\uparrow\) | 30.46 | 31.68 | 30.99 | 0.35 |
| Average Ambient Temperature | 0.021  | 4.00   | 950.00 | 0.10  | 0.922 | 0.002  | \(H_0\uparrow\) | 26.42 | 27.56 | 27.13 | 0.29 |

Table 1. The results of the M-K Test and Sen’s Estimate for Calabar showing Kendall tau ($\tau$), test statistic (S), the variance of S [Var(s)], test statistic (Z), probability value (p-value), mean ($\bar{x}$), standard
deviation ($\sigma$), test results [increasing (↑) or decreasing (↓)] after comparing with all significant levels [0.1% (0.001), 1% (0.01), 5% (0.05), and 10% (0.1)].

3.1 Results from M-K
We recall in the M-K test, a Z-value which is positive shows an increasing or positive trend while a negative Z-value showed a decreasing or negative trend. Higher Z-values show a more positive trend and vice versa. We have 2 hypotheses, $H_0$ which says the nature of the monotonically increasing or decreasing trend is not significant (no trend) this happens when the p-value > the level significance ($\alpha$). The alternative hypothesis $H_1$ explains that the nature of the monotonically increasing or decreasing trend is significant (there is a trend), this happens when the p-value < the level of significance ($\alpha$).

After analyzing the temperature trend from 1999-2018, with the M-K test and comparing with significant levels 0.1% (0.001), 1% (0.01), 5% (0.05), and 10% (0.1), from table 1, results show that the trend of the maximum ambient temperature and the average ambient temperature is positive and increasing, in other words, the trend for both shows a positive Kendall Z-value with 1.04 and 0.1 respectively. The maximum values were observed in 2016 and 2010, with a deviation from the mean of 0.35 and 0.30 for the maximum and average ambient temperature respectively. The Kendall Tau ($\tau$) value for maximum and average ambient temperature respectively is 0.174 and 0.021 respectively, the higher value shows a stronger association and vice versa [5].

Although both the average and maximum ambient temperature shows a positive trend, their p-values (0.299 and 0.922) are both less than all significant levels (0.001, 0.01, 0.05 and 0.1), this shows that both trends are not increasing significantly, although from the Z-value of the maximum ambient temperature (1.04; highest) and its p-value (0.299; lowest), we can clearly see that the trend, although not significant is the most increasing of all trends tested (table 1).

The minimum ambient temperature shows a negative or decreasing trend with a Z-value of -0.32. this trend has its minimum value far back in 1998 as 22.20, and its maximum value in 2010 as 23.84 with a deviation from the mean of 0.38. the Kendall Tau ($\tau$) value is -0.058 showing the lowest association for all trends.

As we can see from the Z-value of the minimum temperature trend, the trend is decreasing although we can discern from the test that the trend is not decreasing significantly because the p-value (0.745) is lower than all levels of significance (0.001, 0.01, 0.05, 0.1).

From these observations of all trends, we can say that all trends are not significantly increasing or decreasing as the case may be.

3.2 Results for Sen’s Slope Estimator Test
After applying this test, we observed that the highest magnitude of slope $Q = 0.016$ is that of the maximum ambient temperature (figure 3) followed by the average ambient temperature ($Q = 0.002$, figure 4) and the finally minimum ambient temperature ($Q = -0.005$, figure 5). The result shows that the slope magnitude corresponds to the results of the Kendall Z-value which shows an increasing trend for both the maximum and average ambient temperature, while the minimum ambient temperature was found to be decreasing all without significance.
4. Conclusion

Temperature is one of the major meteorological parameters affecting climate change as it is directly linked to solar energy; the primary source of renewable energy. This study shows from the results of the non-parametric Mann-Kendall test and Sen’s slope estimator that there were no significant trends in the variations of ambient temperature in the study area as the p-values for the maximum, minimum and average ambient temperature were all less than the significance levels. The existence of no significant trend may be attributed to the fact that Calabar is a coastal area, having an almost invariant weather condition.

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