



Trend Analysis of Hydro-meteorological variables in the coastal area of Lagos using Mann-Kendall trend and Standard Anomaly Index methods

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ABSTRACT; This paper presents the application of Mann-Kendall trend test and Standard Anomaly index on hydro-meteorological variables in the coastal area of Lagos state in order to determine the nature of trend and level of significance. The hydro-meteorological data such as air temperature, relative humidity, wind speed, rainfall and sea level rise were obtained from Nigeria meteorological agency (NIMET) Oshodi, Lagos. Variables such as rainfall, relative humidity, wind speed and sea level rise exhibited positive Kendall's (S) values indicate upward trend and imply an increase of the parameters over time. However, temperature showed negative Kendall's (S) which indicates downward trend and implies decrease over time. Sea level rise, rainfall, relative humidity and wind speed has mean statistics Zs of 3.9855, 1.9668, 3.0895 and 2.2553 respectively which are more than 1.96 (test statistics for a significant level of 5% that is ($Z_{0.025} = 1.96$), this implies that the upward trend is significance and there is tendency to continue. Temperature has statistic Zs of 0.0309 which is less than 1.96 and implies no significance, thus the reduction may not be noticed. The auto correlation factor values ranges from 0.59 to 0.99 for all the parameters, indicating a good fit. Standard Anomaly index (SIA) results showed that trends for the temperature depicts downward trend with the slope of the trend equations are negative, this implies that temperature has tendency to decrease. Rainfall, relative humidity and sea level rise exhibited upward trend which implies tendency to increase. However, the mean wind speed exhibited upward trend while both maximum and minimum wind speed exhibited downward trend, but not noticeable. It can be inferred that both Mann-Kendall trend test and standard anomaly index showed that there is tendency for trend increase in rainfall, humidity, windspeed and sea level rise, while temperature has tendency to decrease. This could be due to impact of climate variability which can influence flooding pattern in the coastline of Lagos State. ©JASEM

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Key Words: Climate variables, Mann-Kendall test, Standard Anomaly index, hydro-Meteorological variables, Lagos coast.

Global climate change is a sensitive subject that affects all key aspects of human existence, the socio-economic, political and the biophysical environments that dictate the quality of life on the earth. In effect, environmentalists in the last few decades have been sounding warnings on the uncontrolled emissions of pollutants into the atmosphere, enhanced greenhouse effect, and depletion of the ozone layer which are seriously threatening the life support system on earth. Simultaneously, pristine rainforests have been cleared at a tremendous rate in the pursuit of agricultural and timber products and fuel wood. This global climate change should be regarded as one of the greatest threats to the world. The past and current trend of the hydro-meteorological variables can assist in visualization and characterization of the past,

current and future water resource situation within the Lagos coastline. Reviews of related works include Inter-governmental Panel on Climate (2007), Raziell (2008), Salami et al., (2011), Mondal et al. (2012), Ojoye (2012), Ikpee (2015). From the review work a range of potential impacts of climate change and variability on the Hydrological regime for various geographic areas has been hypothesized and the Mann-Kendall non-parametric test (MKNT) and Standard Anomaly Index (SAI) was adopted to detect trends observed by most authors.

Mann-Kendall non-parametric test is widely used for the analysis of trends in meteorological and hydrological series. One of the advantages of this method is its applicability for a time series

distribution, which does not follow a typical statistical distribution. This method of analysis adopts two parameters such as the Kendall statistic, S and the normalized test statistic Z_s which are used to determine the nature and level of the significance of trends exhibited by the variables. Generally, a positive value of S is an indication of an upward trend, while a negative value indicates a downward trend. Also the value of Z_s greater than 1.96 at a selected confidence limit of 95% shows that the trends can be interpreted as statistically significant or otherwise.

Standard Anomaly Index (SAI) was first used by Karus (1997) to provide a synthesis of the average area behaviour of precipitation at a specified time. The index was found to be effective for rainfall variability in the Niger Basin area (Ojo, 1991). SAI was used to test for the trend and fluctuation of hydro-meteorological parameters in the study of climate change impact on water resources and adaptation strategies in the Sudano- Sahelian Ecological Zone (SSEZ) of Nigeria (Ojoye, 2012). It is used to investigate the annual rainfall trends in homogeneous rainfall of sub-divisions of western Iran in order to assess the variability during the last thirty five years (Raziel, 2008). The SAI is used for any hydro-meteorological parameter; the name of the index is adopted to suit the parameter under consideration (Ojoye, 2012). The climate data used for this study were subjected to standardized anomaly index (SAI) in order to depict the fluctuation and trend exhibited by each of the hydro-meteorological parameters. The anomaly index for fluctuation analysis with line bar above the reference zero line means that the year has a positive (or surplus) anomaly while those with line bars below the reference zero line means negative (or deficit) anomaly (Valt et al., 2005).

The purpose of this study is to investigate the variability of meteorological variables in the coastal area of Lagos Nigeria and to deduce the influence of variability on the meteorological variables within the coastline. In achieving this, the Mann-Kendall non-parametric test and Standard Anomaly Index (SAI) was explored to establish trends. The objectives of this study are to analyze the meteorological variables within Lagos coast using the Mann-Kendall trend analysis and Standard Anomaly Index in order to identify the nature of trend exhibited by the variables and the consequence of variability of climate change on the meteorological variables.

MATERIALS AND METHODS

Study Area: Adelekan (2009) reported that Lagos is the fifth largest city in the world and is the foremost manufacturing, port city in West Africa, and the hub of business and economic development in Nigeria. This coastal city is situated within latitudes $6^{\circ} 23'N$ and $6^{\circ} 41' N$ and longitudes $2^{\circ} 42'E$ and $3^{\circ} 42'E$ (Figure 1). The city has the largest concentration of multinationals and commercial institutions and is home to about 60 percent of Nigeria's non-oil economy. Lagos grew from 300,000 inhabitants in 1950 to 7.7 million people in 1990. United Nations estimates indicate that by 2000 the total population for Lagos had reached 13.4 million, projecting it to reach over 20 million by 2010 (LMDGP Project Appraisal Document, 2006). The growth of Lagos is primarily the result of its location on the west coast of Africa which has fostered the development of trade within its hinterland as well as with the neighboring international state. The role of Lagos as the administrative capital of Nigeria until December 1991 also contributed to its growth. The high population growth rate of Lagos has been largely attributed to rural-urban migration which accounts for up to 75% of the population increase (Abumere, 2004). Study conducted by Adelekan (2009) revealed that Lagos had an area of about 200 km^2 in 1960 and by the beginning of the 21st century the contiguously built-up area of Lagos was estimated to be about $1,140 \text{ km}^2$. For sections of the metropolis along the coastline large areas have been built-up with high population densities. Except for Eti – Osa local government area, the newly developing area of Lagos expansion, which presently has 43.45% of its total area built-up, other local government areas with coastlines have over 50% of their total area built-up. Shomolu local government has the most artificial land cover of about 90%. Much urban development has taken place in Eti-Osa local government area especially since 1983 when the Lagos state government began to allocate the Lekki Peninsula for urban development. Along with the planned development of this peninsular is the emergence of fast growing poor urban neighborhoods around existing rural settlements. This emerging development pattern has implications as the development of the Lekki Peninsular is with little or no consideration for sea level rise. This makes this rapidly urbanizing area and the growing population vulnerable to sea level rise and climate change.

Nigeria has a coastline of about 850 km, from the western border with the Benin Republic to the eastern border with the Republic of Cameroon. Geomorphologically, the Nigerian coast is divided into four main units: the Barrier Lagoon coast, the

Mud coast, the Niger Delta and the Strand coast (Nwilo, 1995 and Nwilo & Onuoha, 1993). The Barrier Lagoon coast of Nigeria is part of a series of Barrier Lagoon coasts along the West African coast starting from Cote d'Ivoire and ending in Nigeria. Within Nigeria, it is made up of a number of islands, lagoons and creeks including Lagos Island, Ikoyi Island, Victoria Island, Lekki, the Lekki and Lagos Lagoons, Badagry and Badagry Creeks. One common feature of the islands is that they are low

lying. In Lagos and Victoria islands for example, heights of 1.5-4.0 m a.m.s.l. are very common. This is despite the fact that these islands were sand filled. In addition to the low topography of these barrier islands, some of them such as Ikoyi, Lagos, Victoria Island and Lekki are either fully or partially developed commercial and residential areas and could be said to constitute the most important commercial and residential parts of the country (Nwilo & Onuoha, 1993).



Fig 1 Lagos Coastal Slum Communities (Adapted from Gandy, 2005)

Data Collection: The data required for this study are the meteorological variables which include rainfall, sea rise level, air temperature, relative humidity and wind speed which were all obtained from the Nigeria

Meteorological Agency (NIMET) Oshodi, Lagos. The sampling station for this study is the Victoria Island marine station. The details of meteorological variables and years of record is presented in Table 1

Table 1: Victoria Island Marine Station with meteorological Parameters with Years

S/No	Meteorological Parameters	Years of Record
	Air temperature	1992 - 2012
	Rainfall	1992 - 2012
	Relative Humidity	1992 - 2012
	Wind Speed	1992 - 2012
	Sea level rise	1992 - 2012

Source: Nigeria Meteorological Agency (NIMET) Oshodi, Lagos

Data Analysis: The Mann-Kendall non-parametric test was adopted in identifying trends in time series data. It compares the relative magnitudes of sample data rather than the data values. The major benefit of this test is that the data need not conform to any particular distribution. Moreover data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure for the

trend analysis assumes that there exists only one data value per time period. When multiple data points exist for a single time period the median value is used. The data values are evaluated as an ordered time series and each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic (S) is assumed to be 0, if there is no trend. If a data value from a later period is higher than a data value from an earlier time period,

then S is incremented by 1. Conversely, if the data value from a later period is lower than a data value sampled earlier, then S is decremented by 1. The net result of all the increments and decrements yield the final value of S . The expressions for the Mann-Kendall trend analysis are given in Equations 1 to 4. Let X_1, X_2, \dots, X_n represents n data points where X_j represents the data point at time j . Then the Mann-Kendall statistic (S) is given (Hirsch et al., 1982 and Gan, 1992) in Equations (1) and (2). A very high positive value of S is an indication of an increasing trend while a very low, negative value indicates a decreasing trend. However, it is important to compute

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

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

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

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

The test statistic Z_s is used as a measure of trend significance. In fact this analysis is used to test the null hypothesis, H_0 : There is no monotonic trend in the data if $|Z_s|$ is greater than $Z_{\alpha/2}$ where α represents the chosen significance level (usually 5% with $Z_{0.025} = 1.96$) then the null hypothesis is invalid, meaning that the trend is significant. Being significant implies that the trend has a causative factor and did not occur by chance. The Mann-Kendall statistical analysis has been found to be an excellent tool for trend detection in different applications

the probability associated with S and the sample size n in order to statistically quantify the significance of the trend (Prashanth, 2005). Calculation of the variance of S , is given by using Equation (3) where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value) and t_p is the number of data points in the p th group. Computation of a normalized test statistic Z is shown in Equation (4).

(Prashanth, 2005) The Mann-Kendall non-parametric test was applied to the meteorological variables in the coastal area of Lagos state (Ikpe, 2015)

Standardized anomaly index (SAI) is a statistical tool used to depict the fluctuation exhibited by the hydro-meteorological parameters. SAI was first used by Karus (1997) to provide a synthesis of the average area behaviour of precipitation at a specified time. The index was found to be effective for rainfall variability in the Niger Basin area (Ojo, 1991). SAI was used to test for the trend and fluctuation of hydro-meteorological parameters in the study of climate change impact on water resources and adaptation strategies in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria (Ojoye, 2012). It

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anomaly (Valt et al., 2005). The equation adopted is presented in equation (5).

$$X_{TM} = \frac{1}{N} \sum_{i=1}^N (X_T - X_M) \sigma \quad (5)$$

Where: X_{TM} = variable departure for the next year, X_T = the year variable totals, X_M = the mean variable for the base period, σ = standard deviation for the base period, N = number of years when the data are available.

RESULTS AND DISCUSSION

Mann-Kendall: The Mann-Kendall analyses were carried out for the annual parameters and the outcome are presented in Tables 2 – 4 for mean, maximum and minimum respectively

Table 2: Mann-Kendall results for Mean Annual data at Victoria Island Marine Station

Variable	Auto correlation factors	Kendall S	Zs	Trend Nature	Trend Significance
Temperature	0.993	-2	0.0309	Negative	No
Rainfall	0.837	55	1.9668	Positive	Yes
Relative Humidity	0.719	101	3.0895	Positive	Yes
Wind Speed	0.787	74	2.2553	Positive	Yes
Sea level rise	0.653	130	3.9855	Positive	Yes

All the mean meteorological parameters such as rainfall, relative humidity, wind speed and sea level rise exhibited positive Kendall's (S) values which indicate that all the parameters have positive trend and can increase over time, however temperature showed negative Kendall's (S). Tidal rise, rainfall, relative humidity and wind speed has statistics Zs as 3.9855, 1.9668, 3.0895 and 2.2553 respectively which are more than 1.96 (test statistics for a

significant level of 5% i.e ($Z_{0.025} = 1.96$), this shows how the parameters have displayed positive statistical significance and this trend is likely to continue. Temperature has statistic Zs as 0.0309 which is less 1.96 hence there is no statistics significance. The auto correlation factor range of 0.653 – 0.993 for all the parameters showed a good fit for the analysis as presented in Table 2.

Table 3: Mann-Kendall results for Minimum Annual data at Victoria Island Marine Station

Variable	Auto correlation factors	Kendall S	Zs	Trend Nature	Trend Significance
Temperature	0.847	51	1.5448	Positive	No
Rainfall	0.888	37	1.1122	Positive	No
Relative Humidity	0.724	97	2.9659	Positive	Yes
Wind Speed	0.839	54	2.9659	Positive	No
Sea level rise	0.651	125	3.8310	Positive	Yes

Table 3 showed that all the maximum values of the parameters except temperature exhibited a positive trend as shown by Kendall's (S). The statistics Zs for sea level rise and relative humidity are 3.6456 and

2.3171 respectively showing that the trend is significant, while the positive trend exhibited by temperature, rainfall and wind speed is not significant

Table 4: Mann-Kendall results for Maximum Annual data at Victoria Island Marine Station

Variable	Auto correlation factors	Kendall S	Zs	Trend Nature	Trend Significance
Temperature	0.907	-2	0.8960	Negative	No
Rainfall	0.837	55	1.6683	Positive	No
Relative Humidity	0.775	76	2.3171	Positive	Yes
Wind Speed	0.870	43	1.2976	Positive	No
Sea level rise	0.674	119	3.6456	Positive	Yes

Table 4 showed that all the minimum values of the parameters exhibited a positive trend as shown by Kendall's (S). The statistics Zs for sea level rise and relative humidity are 3.8310 and 2.9659 respectively indicating that the trend is significant, while temperature, rainfall and wind speed have statistics (Zs) values less than 1.96 which implies no significance in their trend.

Standardized Anomaly Index (SAI): The air temperature, rainfall, relative humidity, wind speed and Sealevel rise at Victoria Island marine station were subjected to Standardized Anomaly Index (SAI) in accordance to equation 5. The (SAI) values obtained are plotted against the year for each station and presented in Figures 2-16, while the trend equations obtained are presented in Table 5.

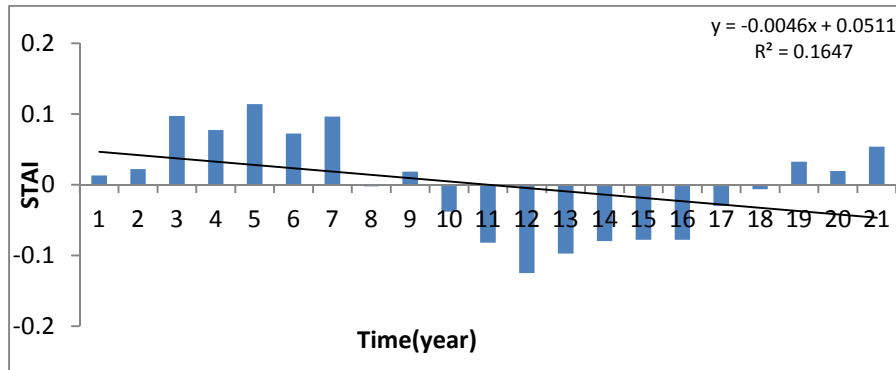


Fig 2: Mean Temperature Trend

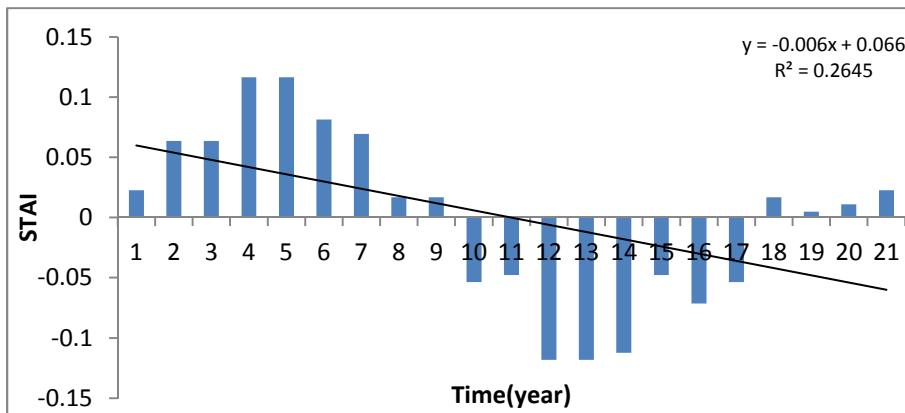


Fig 3: Maximum Temperature Trend

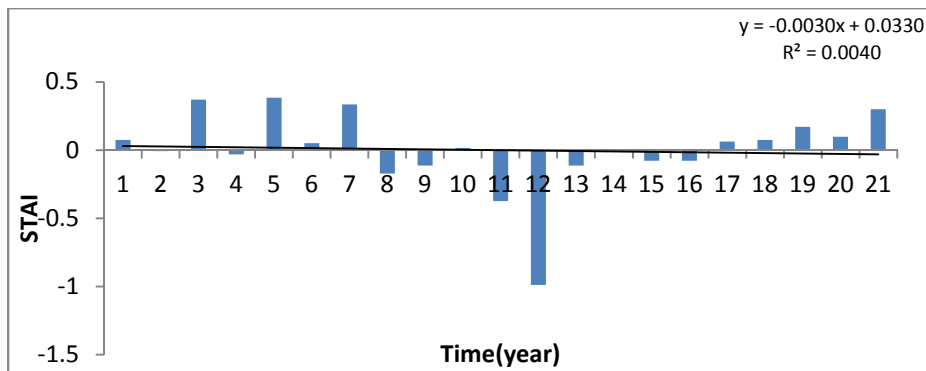


Fig 4: Minimum Temperature Trend

Figure 2-3 presents the trend for the mean, minimum and maximum for temperature respectively. The

parameter depicts negative trend with coefficient of determination (R^2) of 0.1647, 0.0042 and 0.2645

respectively. It can be observed that the slope of the trend equations are negative, this implies that temperature has tendency to decrease.

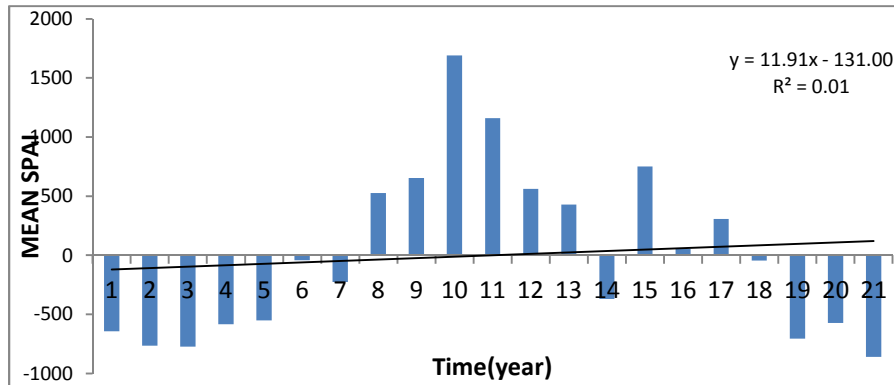


Fig5 Mean rainfalls Trend

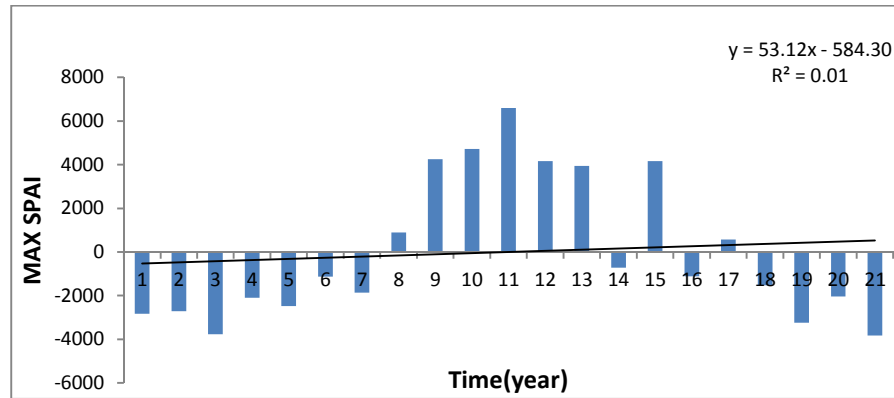


Fig6: Maximum rainfall Trend

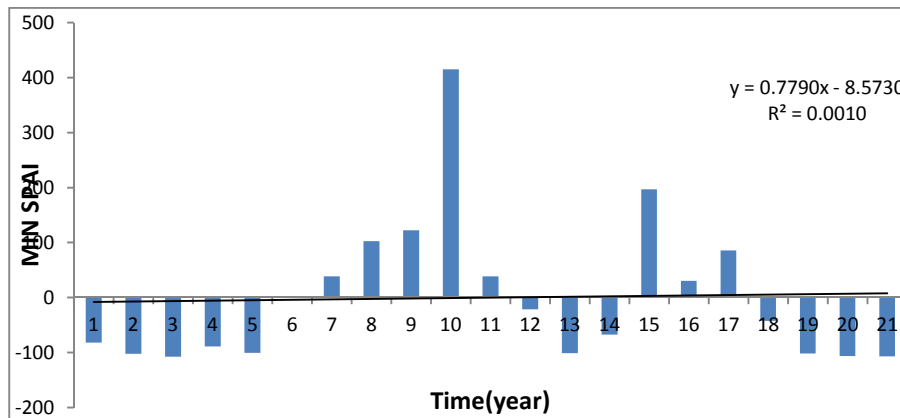


Fig 7 Minimum rainfall Trend

Figure 5 - 7 showed the mean, minimum and maximum rainfall trend respectively. The parameter depicts positive trend with coefficient of determination (R^2) of 0.0109, 0.0014 and 0.0102

respectively. It can be observed that the slope of the trend equations are positive, this implies that precipitation has tendency to increase.

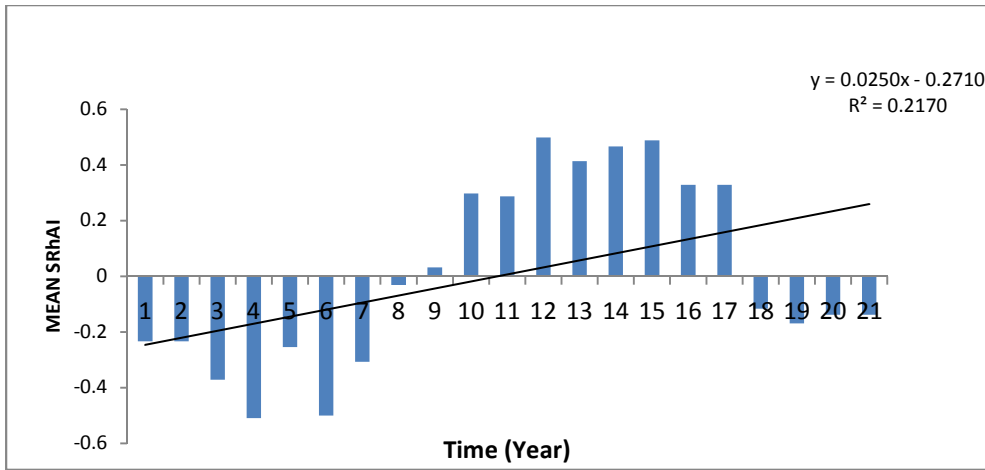


Fig8: Mean Relative humidity Trend

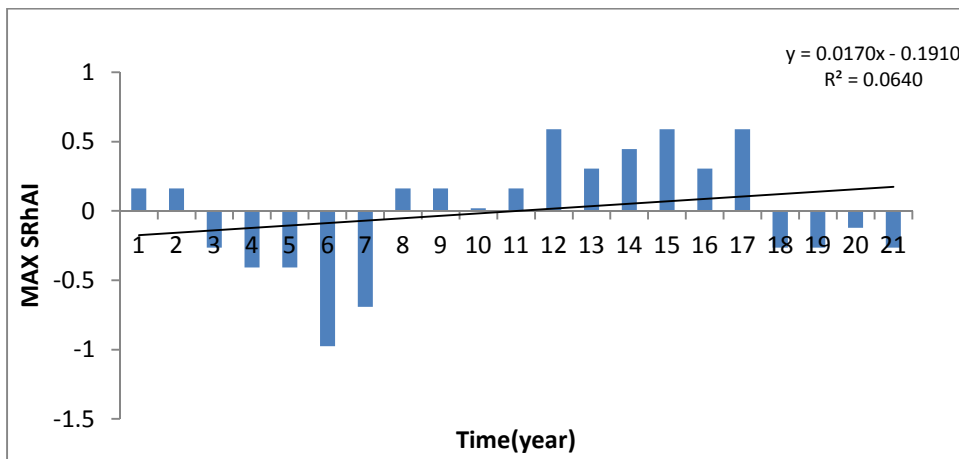


Fig 9: Maximum Relative humidity Trend

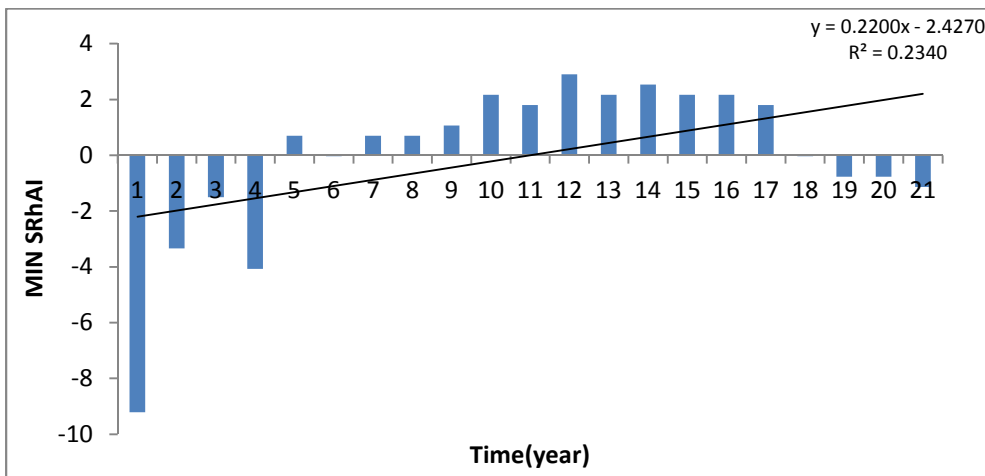


Fig10: Minimum Relative humidity Trend

Figure 8 – 10 presents the trend of mean, minimum and maximum relative humidity. The parameter indicated positive trend with the coefficient of determination (R^2) of 0.2177, 0.2944 and 0.0643

respectively. It can be observed that the slope of the trend equations are positive, this implies that relative humidity has tendency to increase

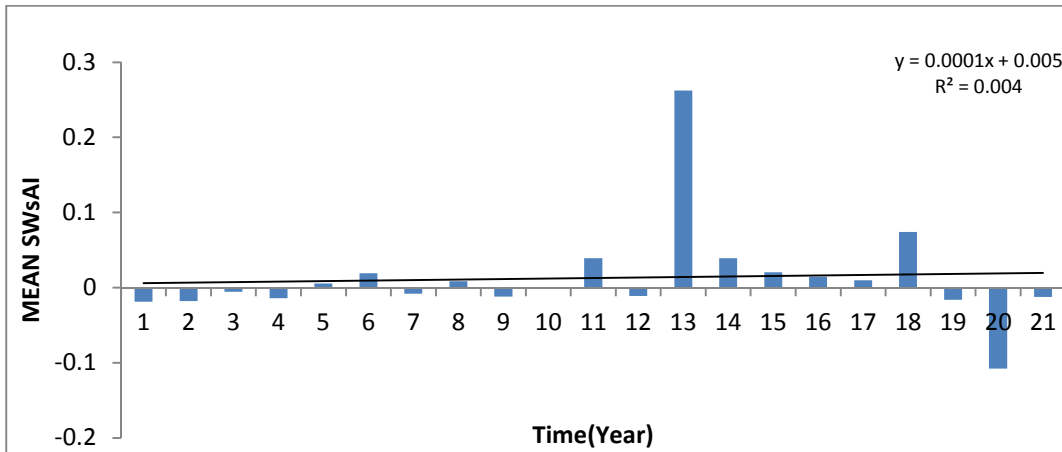


Fig11 Mean Wind speed Trend

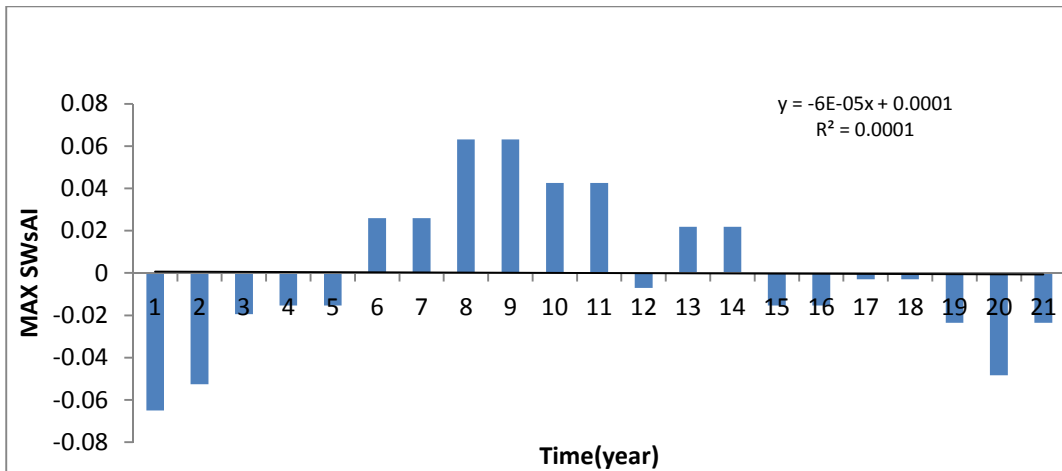


Fig12 Maximum Wind speed Trend

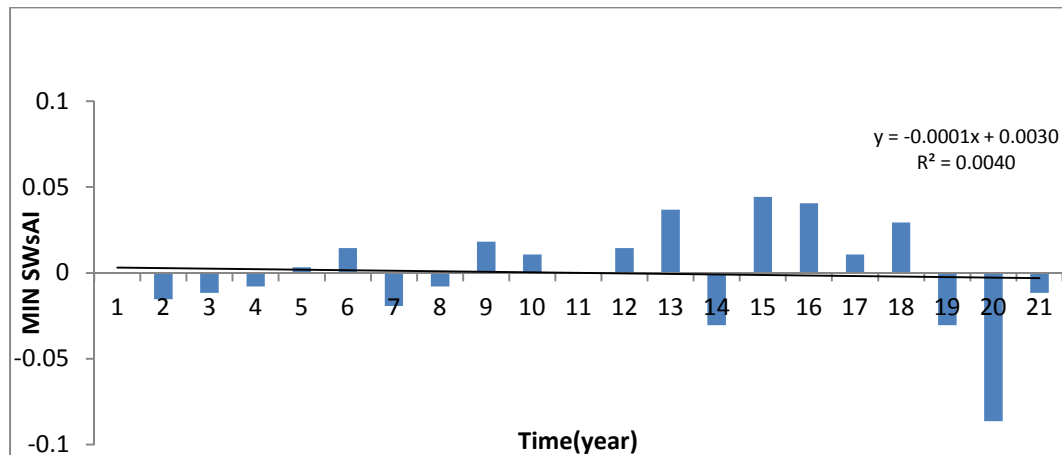


Fig 13 Minimum Wind speed Trend

Figure 11 – 13 presents the trend of the mean, maximum and minimum wind speeds respectively. The mean values for the wind speed shows positive trend, while minimum and maximum

values showed negative trend. The coefficient of determination (R^2) for the mean, minimum and maximum value is 0.0042, 0.0042 and 0.0001 respectively. It can be observed that the slope of the

trend equation for the mean wind speed is positive, while the slopes of the trend equations for the minimum and maximum wind speed are negative.

This implies that wind speed has tendency to increase but may not be noticed

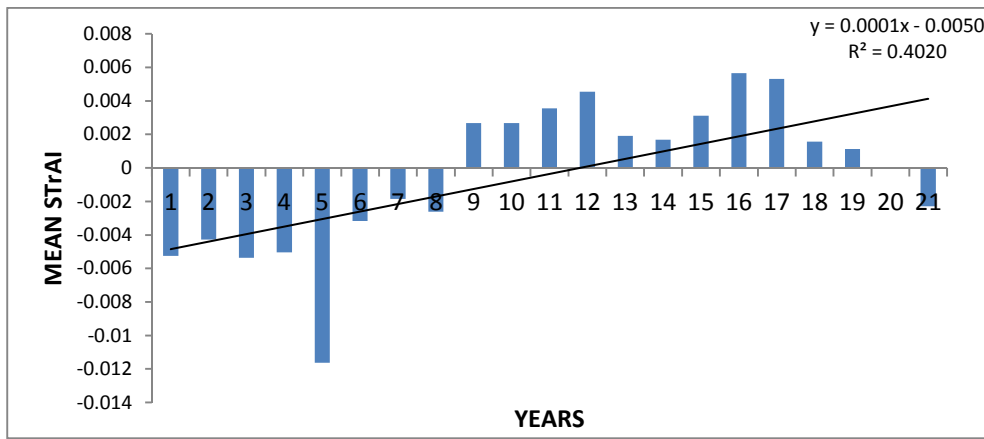


Fig 14: Mean Sea level Trend

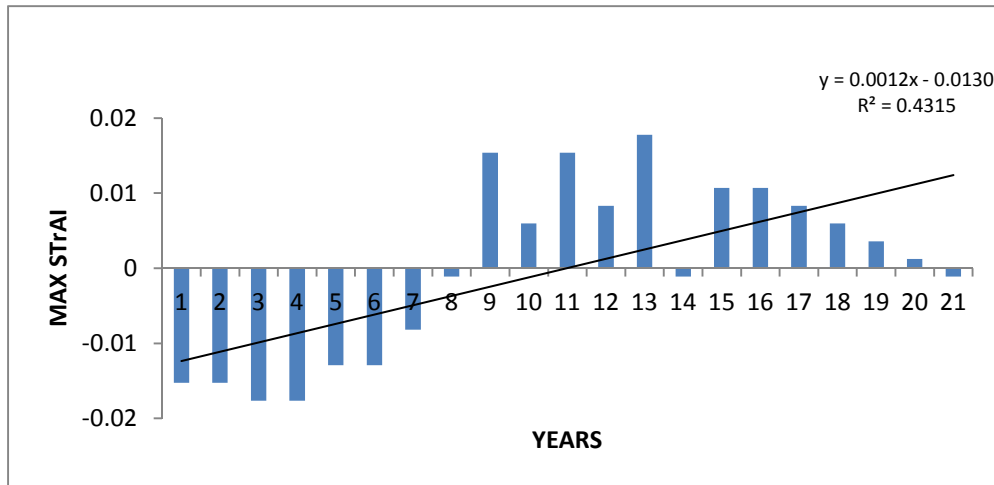


Fig 15 Maximum Sea level rise Trend

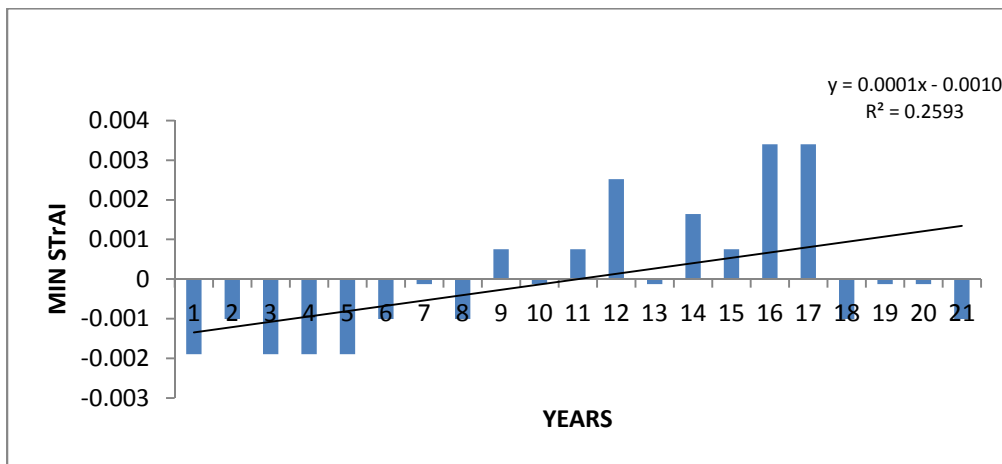


Fig 16 Minimum Sea level rise Trend



Figures 14 – 16 present the mean, minimum and maximum of sea level rise. The parameter depicted positive trend with the coefficient of determination (R^2) of 0.402, 0.2593 and 0.4315 respectively. It can be observed that the slope of the

trend equations are positive, this implies that sea level rise has tendency to increase. The trend equations and the coefficient of determination (R^2) obtained for temperature, rainfall, relative humidity; wind speed and sea level are presented in Table 5.

Table 5: Trend equations and coefficient of determination (R^2) for parameters

Parameters	Mean	Minimum	Maximum
Temperature (°C)	$Y = -0.004x + 0.051$ $R^2 = 0.164$	$Y = -0.003x + 0.033$ $R^2 = 0.004$	$Y = -0.006x + 0.066$ $R^2 = 0.264$
Rainfall (mm)	$Y = 11.91x - 131.00$ $R^2 = 0.010$	$Y = 0.779x - 8.573$ $R^2 = 0.001$	$Y = 53.12x - 584.3$ $R^2 = 0.010$
Relative Humidity (%)	$Y = 0.025x - 0.271$ $R^2 = 0.217$	$Y = 0.220x - 2.427$ $R^2 = 0.234$	$Y = 0.017x - 0.191$ $R^2 = 0.064$
Wind Speed (m/s)	$Y = 0.0001x - 0.005$ $R^2 = 0.004$	$Y = -0.0001x - 0.003$ $R^2 = 0.004$	$Y = -0.00006x - 0.0001$ $R^2 = 0.0001$
Sea level rise (m)	$Y = 0.0001x - 0.005$ $R^2 = 0.402$	$Y = 0.0001x - 0.001$ $R^2 = 0.2593$	$Y = 0.0012x - 0.013$ $R^2 = 0.4315$

Table 5 present the trend equations and the coefficient of determination (R^2) between the parameters and period. It can be observed that the coefficient of determination (R^2) for all the parameters are generally low, which indicated poor correlation between the parameters and time. However, the trend pattern revealed the nature of the parameters in relation with time, which is either increasing or decreasing.

Conclusion: It can be inferred from both Mann-Kendall trend test and standard anomaly index that there is tendency for increments in rainfall, relative humidity, windspeed and sea level rise, while reduction in temperature. This could be due to impact of climate change on the parameters thus there is need to monitor the variability of the hydro-meteorological variables in order to alleviate the incessant flooding problem of the coastline of Lagos state.

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