

MODELLING GLOBAL WARMING IMPACT ON THE RAINFALL OF SOME SELECTED CITIES IN THE NIGER DELTA OF NIGERIA

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ABSTRACT

The time series of meteorological data (rainfall and temperature) was analysed with the aim of detecting trends in the variables. The non parametric Man-Kendall test was used to detect monotonic trends, and the Sen's slope estimator, and Regression analysis were used to develop models for the variables. The study reveals that there is evidence of global warming in Owerri, and rainfall has significantly increased in Calabar over the years. Though the trends in rainfall of Owerri and Port-Harcourt were not significant, plots of the developed models reveal a positive trend in the rainfall of the stations. Based on the analysis of the time series (1983 – 2008), it was concluded that water supply is sustainable under the prevailing climate condition in the Niger delta.

Keywords: *Global warming, Man-Kendall test, Sen's slope estimator, Regression analysis.*

1.0 INTRODUCTION

Concerns about climate change have prompted calls for action at every level of government and across many sectors of economy and society. It is therefore pertinent to establish a suite of coordinated activities that will examine all issues associated with global climate change, including the science and technology challenges involved, and thus provide mitigating actions and strategies (The National academies, 2008). Global warming refers to an average increase in the Earth's temperature, which in turn causes changes in climate (EPA, 2009). The term "climate change" is often used interchangeably with "global warming." However, given the wide range of impacts beyond temperature variations, the former is generally the preferred in the scientific community because it helps convey that there are changes in addition to rising temperatures (Climate Institute, 2007). Climate change refers to the variation in the Earth's global climate or in regional climates over time. It describes changes

in the variability or average state of the atmosphere over time scales ranging from decades to millions of years. These changes can be caused by processes internal to the Earth, external forces (e.g. variations in sunlight intensity) or, more recently, human activities (wikipedia, 2009). In recent usage, especially in the context of environmental policy, the term "climate change" often refers only to changes in modern climate, including the rise in average surface temperature known as global warming. In some cases, the term is also used with a presumption of human causation (Climate Institute, 2007).

Global climate change is a sensitive subject which affects the environment, ecology, and quality of life on the earth. Environmentalists have been sounding warnings on rampant discharge of pollutants into the atmosphere, greenhouse effect, global warming and depletion of the ozone layer which are seriously threatening the life support system on the earth. Rich forests have been

mowed down in the pursuit of timber, farming, firewood etc. This has led to reduction in rainfall which has consequently encouraged desertification. The gradual drying up of Lake Chad and the creeping down of the Sahara Desert are danger signals (Caven, 1994). It has also been noted according to a new study by scientists from the University of California, Berkeley, and Harvard University— Not only has the average global temperature increased in the past 50 years, but the hottest day of the year has shifted nearly two days earlier (Science Daily, 2009).

Global warming enhances the water cycle by intensifying the cycle of water. It causes the earth atmosphere to be warmer, when the atmosphere is warmer, it evaporates more water and it can hold more vapour. More cloud will form and there will be more rain and snow especially in areas closer to water. In areas particularly away from water sources, more evaporation and transpiration could dry out soils and vegetation, resulting in fewer clouds and less precipitation. More rain affects other parts of the water cycle by causing more infiltration and runoff, also an increase in ground water and the amount of water in bodies of water that receive runoff. This change in water cycling and storage can cause flooding in this area or water may form new lakes and rivers on ground that was dry before. The environment thus become wetter and affects plants and humans and animals (ecosystem). Places further from water sources gets less precipitation, the ground gets drier due to evapotranspiration, once it dries out the atmosphere loses an important source of moisture and there are fewer clouds and less rain. Thus less infiltration and runoff, thus the area will probably get more droughts. Rivers and lakes become shallower and the amount of ground water decreases (EPA, 2009). Hence, it is absolutely necessary therefore, to note the imminent danger posed by global warming and depletion of fresh water resources.

The Niger Delta extends over about 70,000 km² and makes up 7.5% of Nigeria's land mass. Historically and cartographically, it consists of present day Bayelsa, Delta, and Rivers States. In the year 2000, however, it was extended to include Abia, Akwa-Ibom, Cross River, Edo, Imo and Ondo States in the region. Some 31 million people of more than 40 ethnic groups including the Efik, Ibibio, Annang, Oron, Ijaw, Itsekiri, Igbo, Urhobo, Yoruba, and Kalabari, are among the inhabitants in the Niger Delta (Wikipedia, 2010). The delta is an oil-rich region, and has been the centre of international controversy over devastating pollution, kleptocracy, and human rights violations. Figure 1 is a map of Nigeria showing Niger Delta Region. The region comprises of 1. Abia, 2. Akwa Ibom, 3. Bayelsa, 4. Cross River, 5. Delta, 6. Edo, 7. Imo, 8. Ondo, 9. Rivers as indicated.

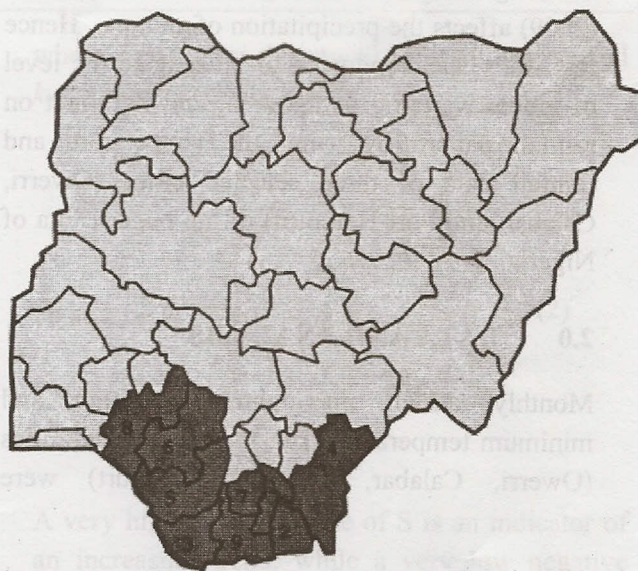


Figure 1 Map of Nigeria showing Niger Delta region

Coincidentally, Nigeria has become Africa's biggest producer of petroleum, including many oil wells in the Niger Delta. Some 2 million barrels a day are extracted in the Niger Delta. Since 1975, the region has accounted for more than 75% of Nigeria's export earnings. Much of the natural gas extracted in oil wells in the Delta is immediately burned, or flared, into the air at a rate of approximately 70 million m³ per day. This is

equivalent to 41% of African natural gas consumption, and forms the largest single source of greenhouse gas emissions on the planet (Wikipedia, 2010). Oil spills is also a key environmental issue in the Niger Delta of Nigeria. Oil spills in Nigeria occur due to a number of causes, including: corrosion of pipelines and tankers (accounting for 50% of all spills), sabotage (28%), and oil production operations (21%), with 1% of the spills being accounted for by inadequate or non-functional production equipment. Due to oil spill, the Niger Delta has witnessed the slow poisoning of surface water, destruction of vegetation and agricultural land, and contamination of wells, soils, and groundwater resources.

The flaring of gas in the Niger Delta has been reported to have increased the concentration of greenhouse gasses, possibly resulting in global warming. Global warming as noted by EPA (2009) affects the precipitation of an area. Hence this study was conducted to investigate the level of global warming in the area, and its effect on rainfall pattern by using the temperature and rainfall data of three selected cities (Owerri, Calabar, and Port-Harcourt) of the Niger Delta of Nigeria.

2.0 DATA AND ANALYSIS

Monthly rainfall, maximum temperature, and minimum temperature data for the selected cities (Owerri, Calabar, and Port-Harcourt) were

obtained from the Nigerian Meteorological Agency (NIMET), Oshodi Lagos, Nigeria. NIMET is the agency responsible for the measurement, control, and storage of the hydro-meteorological data of the areas in Nigeria. The nature of data collected are rainfall depth (mm), and maximum and minimum temperatures (°C) recorded for every month of the year. The rainfall data spanned between 1983 and 2008 (26 years) for all the stations. Temperature data spanned between 1983 to 2007 (25 years) for Owerri, and 1983 to 2008 (26 years) for Calabar and Port-Harcourt. For the analysis, the averages of the monthly data were estimated to give an average annual value. A summary of statistics for the meteorological variables is presented in Table 1.

Trend Analysis

The trend analysis was done in three phases: (i) the presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test, (ii) the slope of a linear trend is estimated with the nonparametric Sen's slope estimator, (iii) regression analysis of the time series were done to develop regression models for the climate parameters. Correlation coefficients of the meteorological variables and time were also computed to determine the strength of the linear relationship between the variable.

Table 1: Statistical summary of meteorological variables

Station	Variable	Statistics				
		Mean	Variance	Std. Deviation	Skew	Kurtosis
Owerri	Rainfall (mm)	201.22	644.42	25.39	-0.530	-0.049
	Minimum Temperature (°C)	23.42	0.30	0.55	-0.556	-0.115
	Maximum Temperature	32.19	0.20	0.45	0.299	-0.943

(°C)						
Calabar	Rainfall (mm)	241.65	971.47	31.17	0.798	0.122
	Minimum Temperature (°C)	23.09	0.31	0.55	-0.159	-0.309
	Maximum Temperature (°C)	30.79	0.17	0.42	-0.154	0.148
Port-Harcourt	Rainfall (mm)	187.39	514.25	22.68	-0.289	-0.033
	Minimum Temperature (°C)	22.66	0.12	0.35	0.253	-0.681
	Maximum Temperature (°C)	31.38	0.11	0.33	0.523	-0.737

Mann-Kendal Analysis

The non-parametric Mann-Kendall test, which is commonly used for hydrologic data analysis, can be used to detect trends that are monotonic but not necessarily linear. The null hypothesis in the Mann-Kendall test is that the data are independent and randomly ordered. The Mann-Kendall test does not require the assumption of normality, and only indicates the direction but not the magnitude of significant trends (McBean and Motiee, 2008). The Mann-Kendall test statistic S is calculated using the formula

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

where x_j and x_k are the annual values in years j and k , $j > k$, respectively, and

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

A very high positive value of S is an indicator of an increasing trend, while a very low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n , to statistically quantify the significance of the trend (Khambhammettu, 2005). The variance of S is computed as

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

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group. The values of S and $VAR(S)$ are used to compute the test statistic Z as follows

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

Z follows a normal distribution. The Z value is tested at 95% level of significance ($Z_{0.025}=1.96$). The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend (Khambhammettu, 2005).

Sen's Slope Estimator

Sen's slope estimator, which is a non parametric method was used to develop the linear models in this study. This methods offer many advantages that have made them useful in analyzing atmospheric chemistry data. Missing values are allowed and the data need not conform to any particular distribution. Besides, the Sen's method is not greatly affected by single data errors or outliers (Salmi et al, 2002). To estimate the true slope of an existing trend (as change per year) the Sen's nonparametric method is used. The Sen's method can be used in cases where the trend can be assumed to be linear i.e.

$$f(t) = Qt + B \quad (5)$$

where Q is the slope, B is a constant and t is time. In order to get the slope estimate Q in equation (5) the slopes of all data value pairs is first calculated using the equation

$$Q_i = \frac{x_j - x_k}{j - k} \quad (6)$$

where $j > k$. If there are n values x_j in the time series there will be as many as $N = n(n-1)/2$ slope estimates Q_i . The Sen's estimator of slope is the median of these N values of Q_i . Also to obtain an estimate of B in equation (5) the n values of differences $x_i - Qt_i$ are calculated. The median of these values gives an estimate of B (Salmi et al, 2002).

Regression Analysis

One of the most useful parametric models to detect the trend is the "Simple Linear Regression" model. The model for Y (e.g. precipitation) can be described by an equation of the form:

$$Y = aX + b \quad (7)$$

where, X = time (year), a = slope coefficients; and b = least square estimates of the intercept. The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is statistically significantly different from zero, the interpretation is that it is entirely reasonable to interpret there is a real change occurring over time, as inferred from the data. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive, and decreasing if the sign is negative. (McBean and Motiee, 2008). For this research, the Excel software was used to calculate the trend lines and to plot the figures.

Correlation coefficient

The correlation coefficient determines the strength of linear relationship between two variables. It always takes a value between -1 and $+1$, with 1 or -1 indicating a perfect correlation (all points would lie along a straight line, having a residual of zero). A correlation coefficient close to or equal to zero indicates no relationship between the variables. A positive correlation

coefficient indicates a positive (upward) relationship and a negative correlation coefficient indicates a negative (downward) relationship between the variables (Rahman, 2008). The correlation coefficients between temperature, rainfall, and time were calculated using Microsoft Excel software application.

3.0 RESULTS AND DISCUSSION

The The correlation coefficients between temperature, rainfall, and time for the stations are presented in Table 2, the result of the Mann-Kendal analysis is presented in Table 3, while the developed Sen model equations and Regression model equations are presented in Table 4.

Table 2: Correlation Coefficients between meteorological variables and time

Station	Variable	Correlation Coefficient
Owerri	Rainfall (mm)	0.200
	Minimum Temperature (°C)	0.401
	Maximum Temperature (°C)	0.544
Calabar	Rainfall (mm)	0.425
	Minimum Temperature (°C)	0.103
	Maximum Temperature (°C)	0.106
Port-Harcourt	Rainfall (mm)	0.174
	Minimum Temperature (°C)	0.241
	Maximum Temperature (°C)	0.392

Table 3: Summary of the Mann-Kendall Analysis

Station	Variable	S	Variance	Z	Trend Significance
Owerri	Rainfall (mm)	45	2058.3333	0.9698	Not Significant
	Minimum Temperature (°C)	118	1833.3333	2.7325	Significant
	Maximum Temperature (°C)	129	1832.3333	2.9903	Significant
Calabar	Rainfall (mm)	93	2058.3333	2.0278	Significant
	Minimum Temperature (°C)	55	2058.3333	1.1902	Not Significant
	Maximum Temperature (°C)	19	2056.3333	0.3969	Not Significant

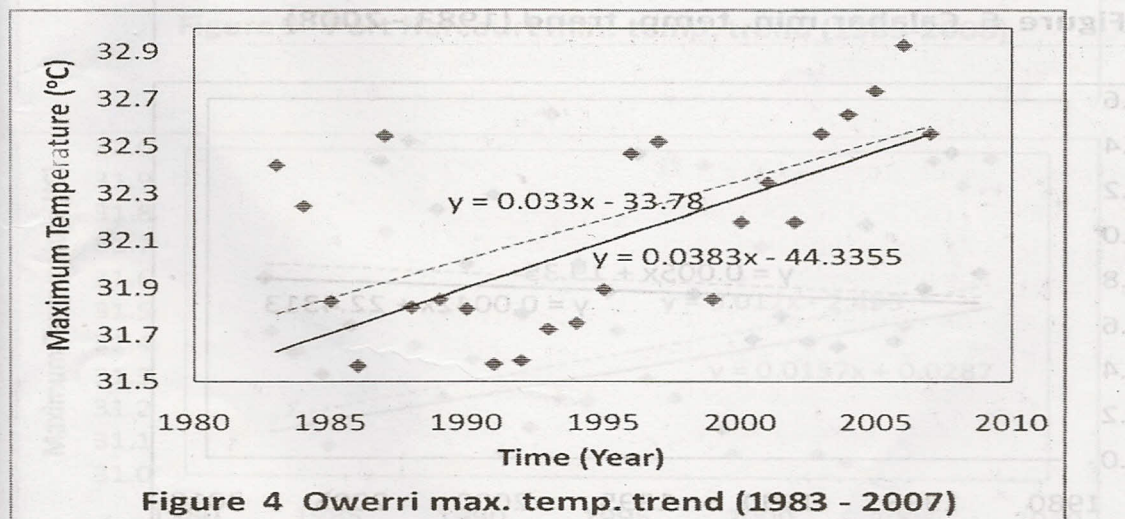
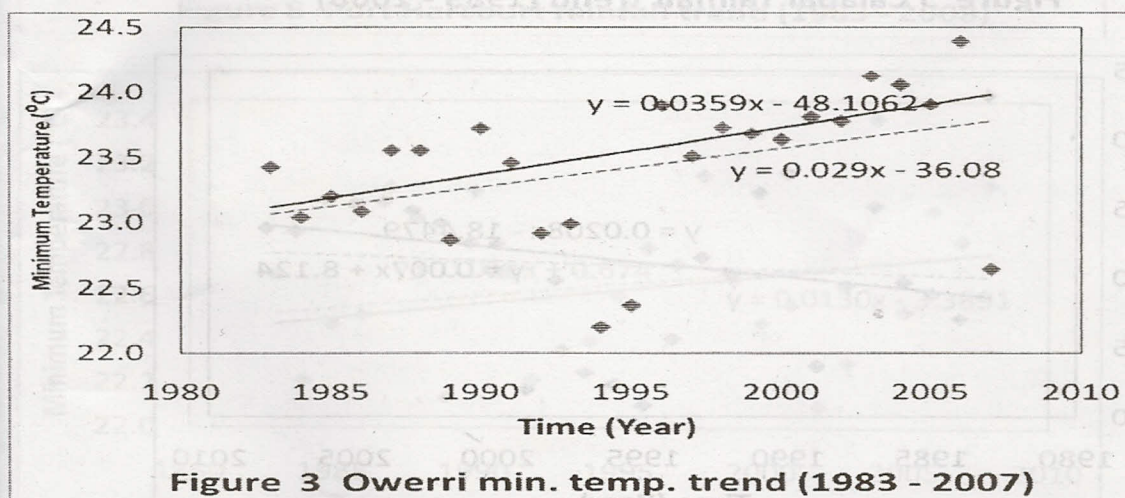
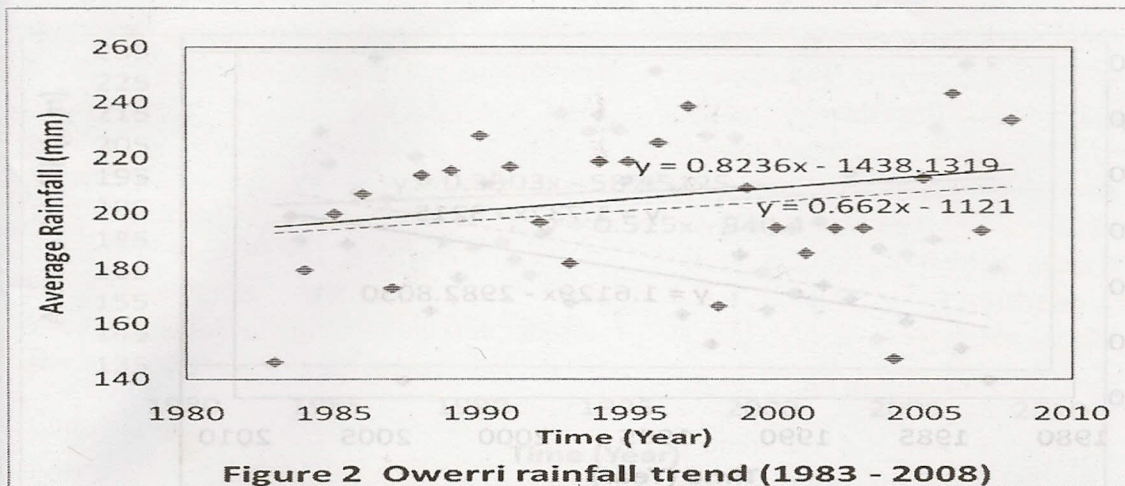
Port-Harcourt	Rainfall (mm)	23	2058.3333	0.4849	Not Significant
	Minimum Temperature (°C)	54	2057.3333	1.1685	Not Significant
	Maximum Temperature (°C)	59	2053.6667	1.2799	Not Significant

Table 4: Developed Sen and Regression Model Equations

Station	Variable	Sen Model Equation	Regression Model Equation
Owerri	Rainfall (mm)	$y = 0.8236x - 1438.1319$	$y = 0.662x - 1121$
	Minimum Temperature (°C)	$y = 0.0359x - 48.1062$	$y = 0.029x - 36.08$
	Maximum Temperature (°C)	$y = 0.0383x - 44.3355$	$y = 0.033x - 33.78$
Calabar	Rainfall (mm)	$y = 1.6129x - 2982.8030$	$y = 1.732x - 3215$
	Minimum Temperature (°C)	$y = 0.0208x - 18.4479$	$y = 0.007x + 8.124$
	Maximum Temperature (°C)	$y = 0.0042x + 22.4313$	$y = 0.005x + 19.35$
Port-Harcourt	Rainfall (mm)	$y = 0.3903x - 587.5125$	$y = 0.515x - 840.4$
	Minimum Temperature (°C)	$y = 0.0130x - 3.3891$	$y = 0.011x + 0.674$
	Maximum Temperature (°C)	$y = 0.0157x + 0.0287$	$y = 0.017x - 2.493$

x= time, and y represents the meteorological variable

The plots showing the time trend of the variable are presented in Figures 1 to 9.



The analysis reveals that the rainfall trend at Owerri is not significant. The Mann-Kendall Statistic $S = -45$, Sen slope estimate $Q = -0.8236$, and the regression slope coefficient $b = 0.662$ indicate a positive trend. However, a correlation coefficient of 0.2 reveals a weak

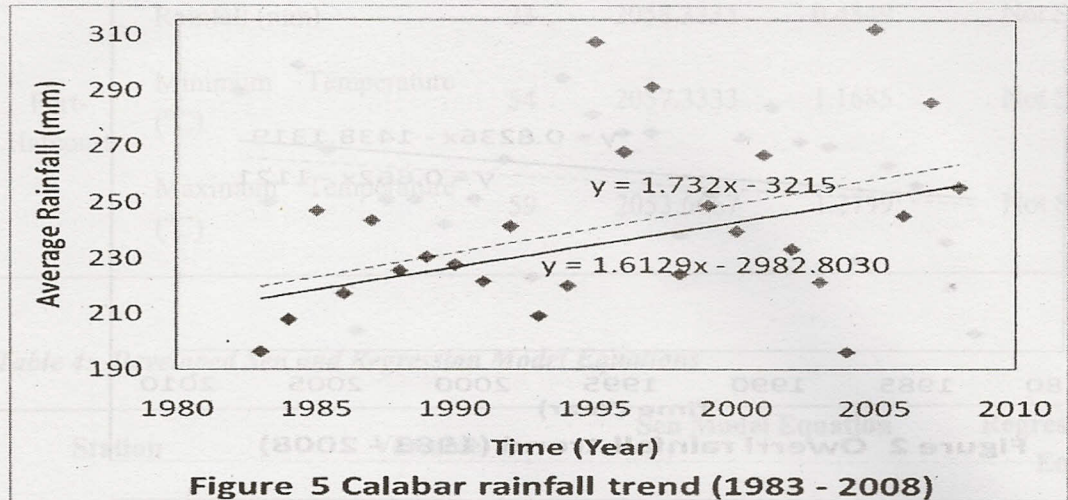


Figure 5 Calabar rainfall trend (1983 - 2008)

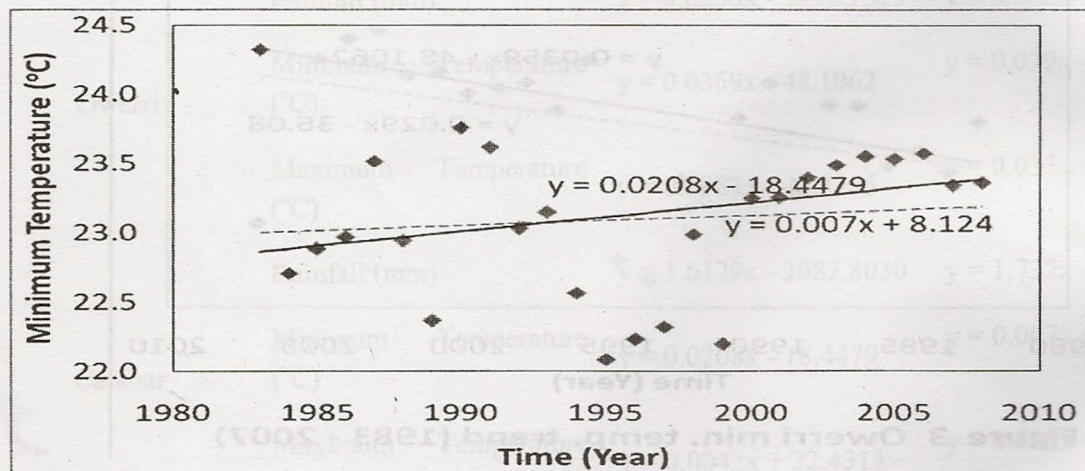


Figure 6 Calabar min. temp. trend (1983 - 2008)

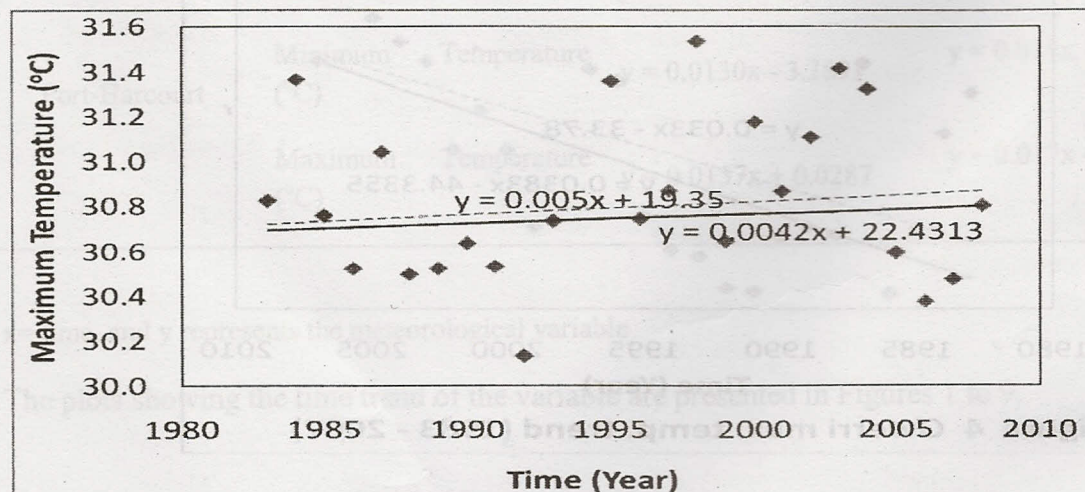


Figure 7 Calabar max. temp. trend (1983-2008)

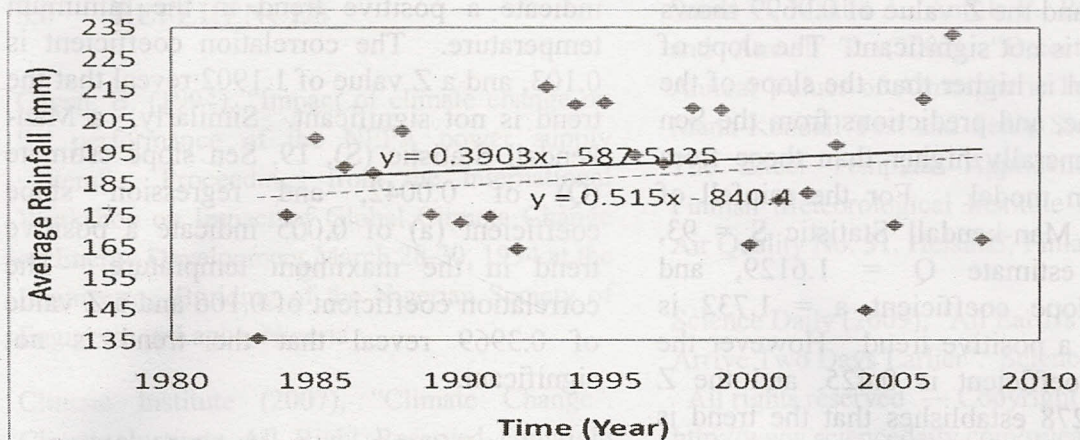


Figure 8 Port Harcourt rainfall trend (1983 - 2008)

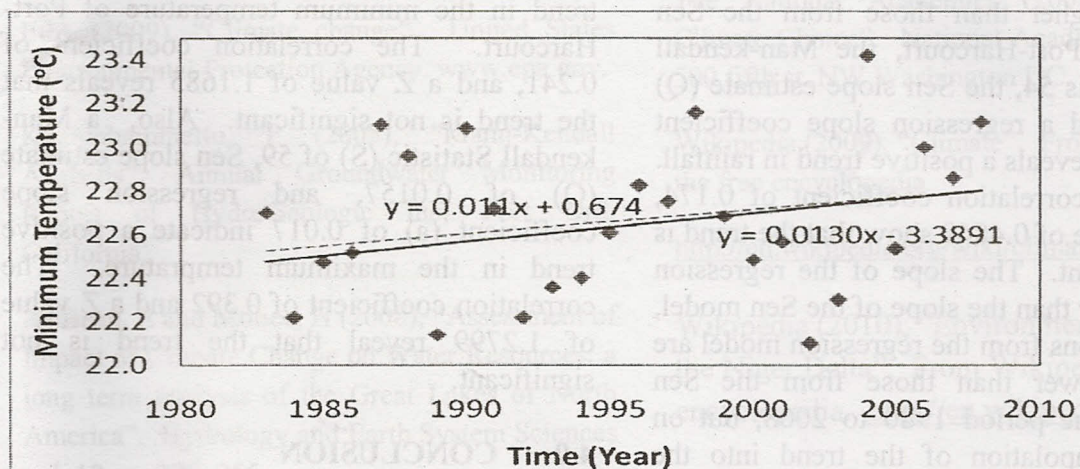


Figure 9 Port Harcourt min. temp. trend (1983-2008)

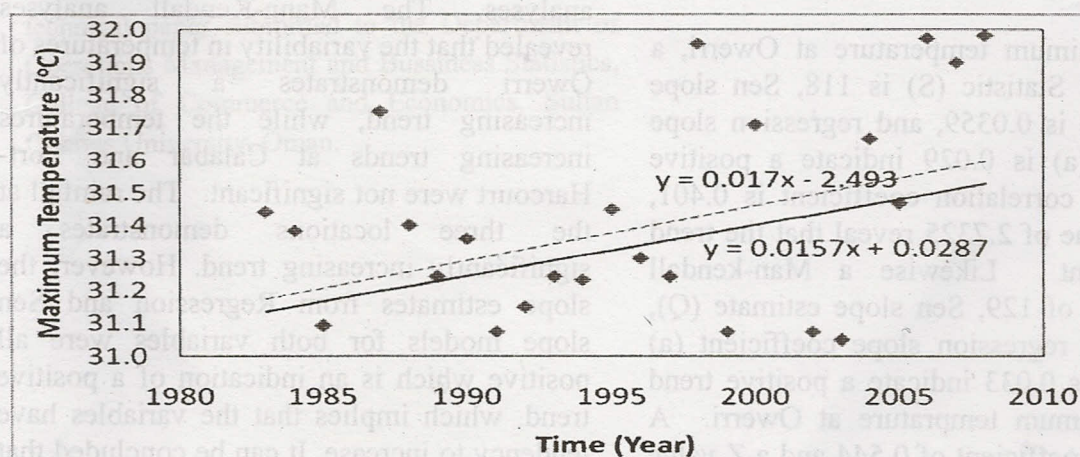


Figure 10 Port Harcourt max temp trend (1983-2008)

The analysis reveals that the rainfall trend at Owerri is not significant. The Man-kendall Statistic $S = 45$, Sen slope estimate $Q =$

0.8236 , and the regression slope coefficient $a = 0.662$ indicate a positive trend. However, a correlation coefficient of 0.2 reveals a weak

relationship, and the Z value of 0.9699 shows that the trend is not significant. The slope of the Sen model is higher than the slope of the regression line, and predictions from the Sen model are generally higher than those from the regression model. For the rainfall of Calabar, the Man-kendall Statistic $S = 93$, Sen slope estimate $Q = 1.6129$, and regression slope coefficient $a = 1.732$ is indicative of a positive trend. However the correlation coefficient is 0.425, and the Z value of 2.0278 establishes that the trend is not significant. The slope of the regression line is higher than the slope of the Sen model, and predictions from the regression model are generally higher than those from the Sen model. In Port-Harcourt, the Man-kendall Statistic (S) is 54, the Sen slope estimate (Q) is 0.3903, and a regression slope coefficient (a) is 0.515 reveals a positive trend in rainfall. However a correlation coefficient of 0.174, and a Z value of 0.4849 show that the trend is not significant. The slope of the regression line is higher than the slope of the Sen model, and predictions from the regression model are generally lower than those from the Sen model for the period 1980 to 2008, but on further extrapolation of the trend into the future, the predicted values from the regression model will be higher than those from the Sen model.

For the minimum temperature at Owerri, a Man-kendall Statistic (S) is 118, Sen slope estimate (Q) is 0.0359, and regression slope coefficient (a) is 0.029 indicate a positive trend. The correlation coefficient is 0.401, and a Z value of 2.7325 reveal that the trend is significant. Likewise a Man-kendall Statistic (S) of 129, Sen slope estimate (Q), 0.0383, and regression slope coefficient (a) which equals 0.033 indicate a positive trend in the maximum temperature at Owerri. A correlation coefficient of 0.544 and a Z value of 2.9903 indicate that the trend is significant. The slopes of the Sen models are higher than those of the Regression models respectively.

At Calabar, a Man-kendall Statistic (S), 55, Sen slope estimate (Q), 0.0208, and regression slope coefficient (a) which is 0.007

indicate a positive trend in the minimum temperature. The correlation coefficient is 0.103, and a Z value of 1.1902 reveal that the trend is not significant. Similarly, a Man-kendall Statistic (S), 19, Sen slope estimate (Q) of 0.0042, and regression slope coefficient (a) of 0.005 indicate a positive trend in the maximum temperature. The correlation coefficient of 0.106 and a Z value of 0.3969 reveal that the trend is not significant.

A Man-kendall Statistic (S) of 54, Sen slope estimate (Q) of 0.0130, and regression slope coefficient (a) of 0.011 indicate a positive trend in the minimum temperature of Port-Harcourt. The correlation coefficient of 0.241, and a Z value of 1.1685 reveals that the trend is not significant. Also, a Man-kendall Statistic (S) of 59, Sen slope estimate (Q) of 0.0157, and regression slope coefficient (a) of 0.017 indicate a positive trend in the maximum temperature. The correlation coefficient of 0.392 and a Z value of 1.2799 reveal that the trend is not significant.

4.0 CONCLUSION

The rainfall and temperature data of Owerri, Calabar and Port-Harcourt were subjected to Mann-Kendall, Regression and Sen slope analyses. The Mann-Kendall analyses revealed that the variability in temperatures of Owerri demonstrates a significantly increasing trend, while the temperatures increasing trends at Calabar and Port-Harcourt were not significant. The rainfall at the three locations demonstrates a significantly increasing trend. However, the slope estimates from Regression and Sen slope models for both variables were all positive which is an indication of a positive trend, which implies that the variables have tendency to increase. It can be concluded that there is positive impact of climate change on the rainfall of the selected cities, thus urban water supply is sustainable under the present climate condition of the Niger Delta.

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