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CONTENTS

Title of Paper	Page
Measurement of Mean Velocity Profile in a Turbulent Pipe Flow – A Numerical Approach <i>Odewole, G.A., M.A. Waheed and O.S. Olaoye</i>	1
Effect of Processing on Amylose, Resistant-Starch, Rapidly-Digestible-Starch, and Slowly-Digestible-Starch For <i>Gari</i> , A Processed Cassava Product. <i>Oyelade, O.J</i>	6
Improvement of A Simple Tension Infiltrometer for Determining Soil Hydraulic Properties <i>Ejiei C. J., K. Abdulkareem and O. O. Onatola</i>	14
Design and Implementation of SMS Based Wireless Appliance Control System <i>Abdul-Hameed T. A. and D.A. Folarin</i>	19
Cellular Damage and Storage Stability of <i>Lactobacillus Rhamnosus Gg</i> Dried In Disaccharide Matrices under Vacuum <i>Sunny-Roberts, E.O. and Knorr, D.</i>	25
Mechanochemistry: A Green Solution in Chemical Synthesis <i>Adeoye I.O., Onawumi O.O.E. and Onawumi A.S.</i>	33
Production of Bio-Diesel from <i>Jatropha Curcas</i> Seed Using <i>In-Situ</i> Technique: Effect of Catalyst Amount And Alcohol-Seed Ratio <i>Dairo O. U, Olayanju, T. M. A, and Amusan, O</i>	37
Analysis of Vibration Effect on Factory Foundation in a Flour Mill <i>Ohijeagbon I. O, Olusegun, H. D, Adekunle, A. S., Oladosu, O. A., and Bodunde, A.</i>	44
Triple Modular Redundancy Approach for Internet Connectivity <i>Adeosun O.O., E.R. Adagunodo and E.A. Olajubu</i>	52
Distribution of Radiofrequency Radiation around Base Stations in LAUTECH Environment <i>Akinloye M. K.</i>	57
Determination and Evaluation of Fuel Properties of Groundnut (<i>Arachis Hypogaea</i> , L.) Biofuel Blended With Diesel <i>Oniya O.O. and A.I. Bamgboye</i>	62
Power Factor Correction Using Static Capacitor: A Case Study of Nigerian 330kv Grid System <i>Adebayo I.G., Olaomi A.A. Akinkunmi, M. and Olayonwa, Paul</i>	69
Voltage Magnitude Improvement: A Case Study of Nigerian 330kv Transmission System <i>Olatunji D.O., O.G. Mojibola & J.O. Petinrin</i>	75
Analysis of Exhaust Gas Emissions and Performance Parameters on Non- Road Spark Ignition Engines <i>Aderibigbe A.A. , A. D Ogunsola and W. O Sanusi</i>	81
Performance Evaluation of a Three Bottom Standard Disc Plough At Varying Tilt and Disc Angles <i>Olaniran J.A. and Babatunde, O.O.</i>	88
Assessment of Water Consumption Pattern in Ilorin, Kwara State, Nigeria <i>Ayanshola A.M., Salami, A.W. and Sule, B.F.</i>	93

Optimal Capacitor Placement for Power Loss Reduction on Distribution Systems <i>Adejumobi I.A and Opeodu F.A</i>	101
Effects of Coverings on Radiation Exposure Rate in Some Indoor Environments <i>Akinloye M. K., Abodunrin O. P. and Ogungbade T. O.</i>	109
Effects of Exhaust Gas Recirculation on Performance and Exhaust Gas Emissions of Spark Ignition Engines <i>Aderibigbe A.A., A. D Ogunsola and W. O Sanusi</i>	113
Estimating Energy Requirements in Cottage Palm Oil Mill <i>Akinoso R. and Omolola, A.O.</i>	119
Pyrolysis of Palm Kernel Shells to Fuels and Chemicals Feedstocks <i>Lucas E.B. and O. E. Itabiyi</i>	124
Development of a Crop Residue Chopper <i>Jekayinfa S.O., T.B. Onifade and K.O. Olorode</i>	129
Statistical Evaluation of Impact of Climate Change on Hydro-Meteorological Variables at the Hydropower Reservoirs on River Niger in Nigeria <i>Salami A.W., Aremu A.S. and A.M. Ayanshola</i>	134
Design, Development and Testing of a Dried Yam Crusher-Grinder <i>Oriola, K.O. and Akande, F.B.</i>	142
Variation of Gaseous Air Pollutants Mixing Ratio with Meteorological Data in Ogere Transport Pool of Southwestern Nigeria <i>Jimoda L. A. , Lala M. A., Sonibare J. A., Adeniran J. A.</i>	147
Farm Machinery and Equipment Utilization in Some Selected Local Government Areas of Oyo State, Nigeria <i>Oniya, O. O., Akande, F. B., Ibrahim, S. O. and Sanusi, B. A.</i>	154
Effect of Swirl Chamber Length: Diameter Ratio on the Nozzle Discharge of an Agro-Forestry Swirl Nozzle <i>Taiwo A.</i>	159
Heuristic Approach to Production Scheduling for a Group Technology System <i>Enwerem G.C.</i>	165
An Appraisal of Road Condition Effect on Rural Transportation in Sekyere Central District of the Ashanti Region of Ghana <i>Taiwo A.</i>	171
Performance Evaluation of a Motor-Driven Cassava Chipping Machine <i>Adebayo, A.O. and Bamgboye, A.I.</i>	177
Effects of Processing Factors on the Motorized Kneading of Oil from Groundnut Kernels <i>Ola F. A., Babalola A. O. and O. O. Gbadebo</i>	182

STATISTICAL EVALUATION OF IMPACT OF CLIMATE CHANGE ON HYDRO-METEOROLOGICAL VARIABLES AT THE HYDROPOWER RESERVOIRS ON RIVER NIGER IN NIGERIA

*Salami, A.W., Aremu, A.S. and A.M. Ayanshola

Department of Civil Engineering, University of Ilorin, P.M.B 1515, Ilorin, Nigeria
*Corresponding author email: salami_wahab@unilorin.edu.ng

Abstract

The time series of hydro-meteorological data including temperature, relative humidity, rainfall, reservoir inflow, reservoir storage, and turbine release at Kainji and Jebba dams were analysed with the aim of detecting trends in the variables. The non parametric Mann-Kendall test was used to detect monotonic trends while the Sen's slope estimator and Regression analysis were used to develop models for the variables. The results showed that at Kainji, the rainfall, temperature, turbine releases and relative humidity have significant positive trend, while reservoir inflow and storage were observed to have insignificant negative trends. At Jebba, the temperature, reservoir inflow, turbine releases and storage have significant positive trends, while rainfall and humidity were observed to have insignificant negative trends. The positive trend in temperature at both stations is an evidence of increase in temperature in the vicinity of the reservoirs. It was also observed that the excess water released from the Kainji dam to sustain the operation of the Jebba dam has invariably affected storage at the Kainji dam. The variables with significant positive trend have tendency to increase, while those with insignificant negative trend have tendency to reduce slightly over time.

Keywords: Global warming, climate impact, hydro-meteorologic variables, Man-Kendall test, Sen's slope estimator, Regression analysis.

1.0 Introduction

Global climate change is a sensitive subject which affects the environment, ecology, and quality of life on the earth. EPA (2009) defined global warming as an average increase in the earth's temperature which in turn causes changes in climate. Over the last decade, scientists have revealed that the accumulation of carbon dioxide and other greenhouse gases is expected to lead to climate changes over the succeeding century (Mendelsohn, et al. 1994). It is speculated that as a result of global warming, more cloud will form and there will be more rain and snow especially in areas closer to water, whereas in areas particularly away from water sources, excessive evaporation would dry out soils and vegetation, resulting in fewer clouds and less precipitation. Thus, the area will probably get more droughts, rivers and lakes will become shallower and the amount of ground water decreased.

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, and firewood. 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). The danger is not only manifested in quantitative terms, but also in qualitative modification of surface or ground water. For example, in extreme meteorological events, dissolved organic matters, micro pollutants and pathogens are liable to increase in concentration or number as a consequence of temperature increase and heavy rainfalls in temperate countries (Delpa et al., 2009).

Global variations in climate have also brought about extreme events like flood and drought in quantitative terms, which have had drastic impacts on river basin development structures. Such structures include dams on which Nigeria has depended for most of its renewable energy generation (Ononiwu, 1994). The issues of climatic change, the global warming and the development of new infrastructure projects by neighbouring countries on the River Niger threaten the water level and adequate water flow into the Kainji and Jebba dams in Nigeria (Energy Digest, 2008). More so, the volume of water in a lake is determined by the contributions from its catchment

area and seasonal variations through distinctive rainy and dry seasons (Balarabe and Oladimeji, 1996).

The study of global warming impact on the rainfall of some selected Cities in the Niger Delta of Nigeria as reported by Salami et al (2011) revealed that there is positive impact of climate change on the rainfall of the selected Cities, and thus the urban water supply is sustainable under the present climate condition of the Niger Delta. Salami (2010) studied the climate impact on two hydro-meteorological of Jebba hydro power; the reservoir inflow has significant positive trends, while the evaporation has significant negative trends.

The changes in precipitation and water resources have put stakeholders on alert to understand the environmental changes and their impact on the hydrologic cycle (Hassan et al., 2010). Therefore, the extent to which these changes

have occurred in variables such as temperature, relative humidity, rainfall, reservoir inflow, and storage in dams needs to be studied. Hence, this study focuses on the impact of climate change on hydro-meteorological variables at the two major hydropower reservoirs in Nigeria. The objective is to determine the trends in the variables and link them with the performance of both dams.

2.0 Data and Analysis

Monthly minimum temperatures, relative humidity, rainfall, reservoir inflow, storage, and turbine release data for Kainji and Jebba dams were obtained from the respective dam stations. The spans of the obtained data are presented in Table 1. For the analysis, the average of the monthly data was computed to give an average annual value. A summary of statistics for the hydrological and meteorological variables is presented in Table 2.

Table 1 Span of obtained hydro-meteorological variables

Station	Variable	Period
Kainji	Minimum temperature	1972 - 2009
	Relative humidity	1980 - 2009
	Rainfall	2000 - 2009
	Reservoir inflow	1970 - 2003
	Storage	1970 - 2003
	Turbine release	1970 - 2003
Jebba	Minimum temperature	1982 - 2008
	Relative humidity	1982 - 2007
	Rainfall	1984 - 2009
	Reservoir inflow	1984 - 2008
	Storage	1984 - 2003
	Turbine release	1984 - 2003

Table 2: Statistics of hydro-meteorological variables at Kainji and Jebba hydropower dams

Station	Variable	Mean	Variance	Statistics Standard deviation	Skew	Kurtosis
Kainji	Minimum temperature (°C)	20.11	3.81	1.95	0.919	-0.242
	Relative humidity (%)	61.00	58.49	7.65	0.324	-1.014
	Rainfall (mm)	83.55	133.92	11.57	-0.644	-0.010
	Inflow (x10 ⁶ m ³)	2504.35	400603.38	632.93	0.438	-0.435
	Storage (x10 ⁶ m ³)	8058.58	521341.18	722.04	-0.172	-0.869
	Turbine release (x10 ⁶ m ³)	1881.96	175953.70	419.47	0.181	-0.306
Jebba	Minimum temperature (°C)	23.50	0.59	0.77	1.028	0.929
	Relative humidity (%)	72.09	13.73	3.71	0.414	-1.075
	Rainfall (mm)	90.82	222.23	14.91	1.520	3.037
	Inflow (x10 ⁶ m ³)	1055.75	75974.95	275.64	0.170	-1.079
	Storage (x10 ⁶ m ³)	3595.74	6369.61	79.81	0.132	0.154
	Turbine release (x10 ⁶ m ³)	2182.65	88622.83	297.70	-0.367	-0.876

Trend Analysis

The trend analysis was done in three phases. First the presence of a monotonic increasing or decreasing trend was detected using the nonparametric Mann-Kendall test. Next, the slope of a linear trend was estimated with the nonparametric Sen's slope estimator, after which regression analysis of the time series was carried out to develop regression models for the hydro-meteorological variables. Correlation coefficients of the meteorological variables with time were also computed to determine the strength of the linear relationship between the variables and time.

Mann-Kendall 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:

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

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

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

A high positive value of S is an indicator of an increasing trend, while a 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 $\text{VAR}(S)$ are used to compute the test statistic Z as follows:

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

The Z values were tested at the 95% ($Z_{0.025}=1.96$) and 99% ($Z_{0.001}=2.58$) level of significance. 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 estimator of slope, which is a non parametric method, was used to develop linear models in this study. This method offers many advantages that have made them useful in analyzing atmospheric 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 non parametric method is appropriate and the trend can be assumed to be linear such that:

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

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

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

where $k > j$. If there are n values of x_j in the time series, there will be as many as $N = n(n-1)/2$ slope estimates of Q_i . The Sen's estimator of slope is the median of these N values of Q_i .

To obtain an estimate of B in equation (5) the n values of differences $x_i - Q_i t_i$ are calculated. The median of these values gives an estimate of B (Salmi et.al, 2002). In this study, a program was written in Visual Basic to facilitate the computation of the Mann-Kendall statistics S , Sen's slope Q , and intercept B .

Regression Analysis

One of the most useful parametric models used to develop functional relationships between variables 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 significantly different from zero, the interpretation is that 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 Pearson product moment correlation coefficient measures the strength of linear relationship between two variables (Walpole, 1974; Adamu and Johnson, 1975). 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 the hydrological variables (minimum temperatures, rainfall, inflow, evaporation rates, relative humidity) and time were computed using Microsoft Excel software.

3.0 Results and Discussions

3.1 Results

The correlation coefficients between the climatic variables and time for the stations are presented in Table 3, the result of the Mann-Kendall analysis is presented in Table 4, while the developed Sen model equations and Regression model equations are presented in Table 5. The plots showing the time trend of the variable are presented in Figures 1 to 12.

Table 3: Correlation coefficients between meteorological variables and time

Station	Variable	Correlation Coefficient
Kainji	Minimum Temperature ($^{\circ}\text{C}$)	0.764
	Relative Humidity (%)	0.888
	Rainfall (mm)	0.501
	Reservoir Inflow (Mm^3)	-0.106
	Storage (Mm^3)	-0.338
	Turbine Release (Mm^3)	0.225
Jebba	Minimum Temperature ($^{\circ}\text{C}$)	0.687
	Relative Humidity (%)	-0.678
	Rainfall (mm)	-0.213
	Reservoir Inflow (Mm^3)	0.730
	Storage (Mm^3)	0.354
	Turbine Release (Mm^3)	0.884

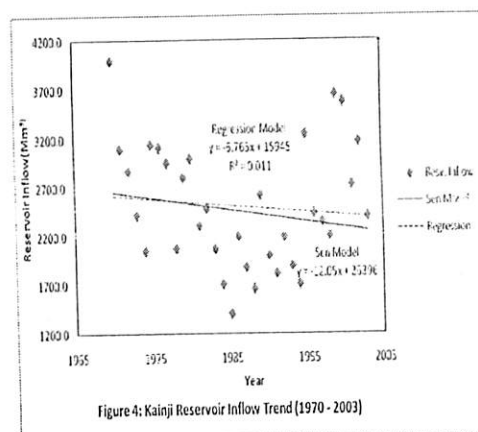
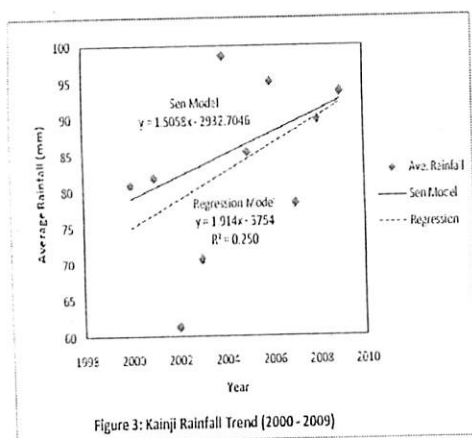
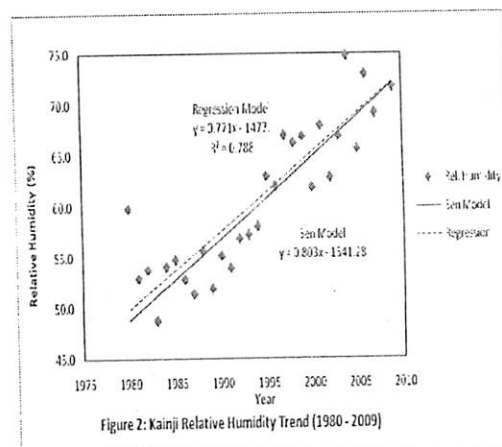
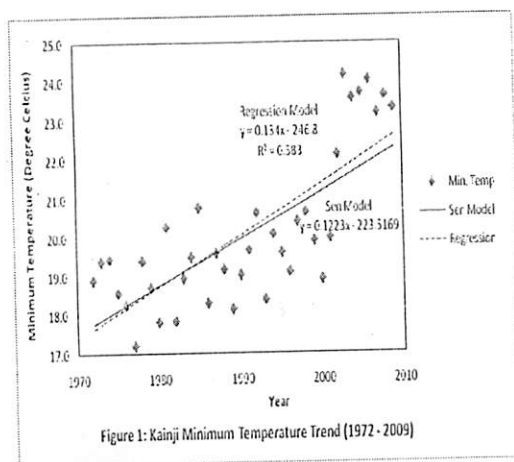
Table 4: Summary of the Mann-Kendall analysis

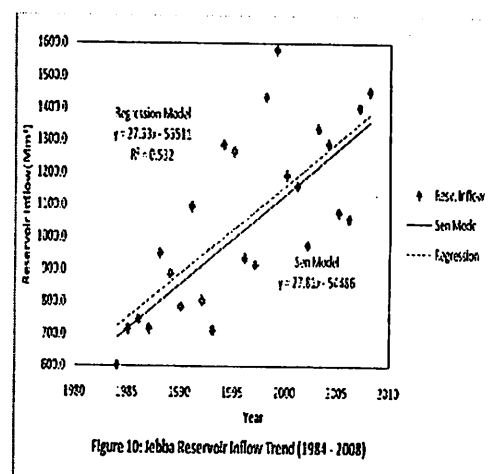
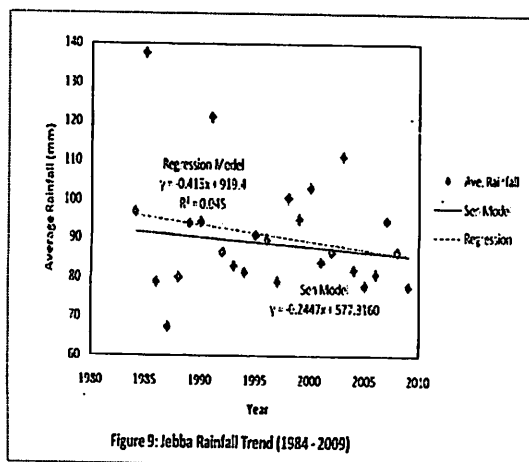
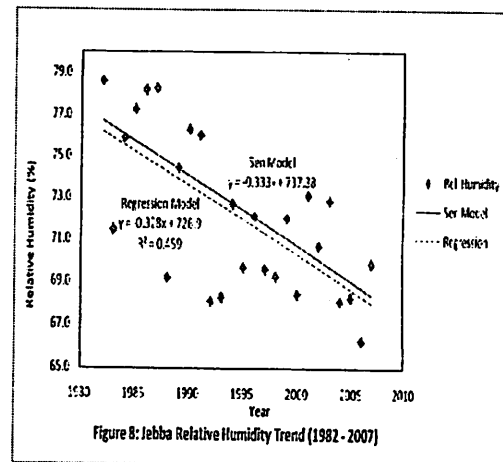
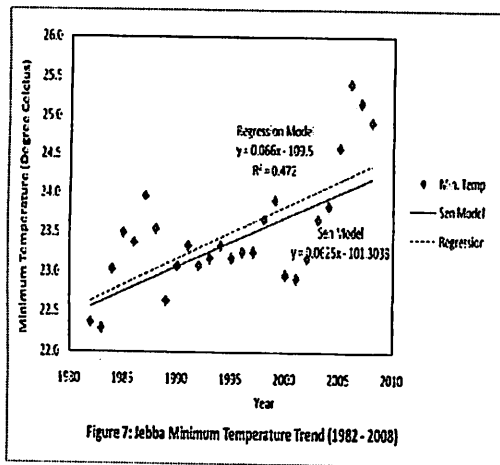
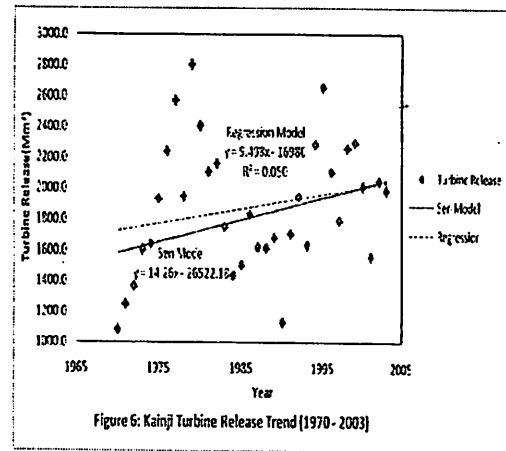
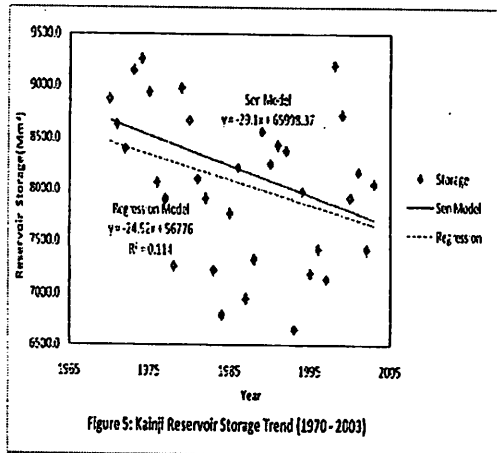
Station	Variable	S	Variance	Z	Trend Significance	
					95%	99%
Kainji	Minimum Temperature ($^{\circ}\text{C}$)	374	6326.00	4.69	Yes	Yes
	Relative Humidity (%)	309	3141.67	5.50	Yes	Yes
	Rainfall (mm)	15	125.00	1.25	No	No
	Reservoir Inflow (Mm^3)	-49	4550.33	-0.71	No	No
	Storage (Mm^3)	-133	4550.33	-1.96	Yes	No
	Turbine Release (Mm^3)	109	4550.33	1.60	No	No
Jebba	Minimum Temperature ($^{\circ}\text{C}$)	149	2294.33	3.09	Yes	Yes
	Relative Humidity (%)	-143	2056.33	-3.13	Yes	Yes
	Rainfall (mm)	-33	2058.33	-0.71	No	No
	Reservoir Inflow (Mm^3)	164	1833.33	3.81	Yes	Yes
	Storage (Mm^3)	42	950.00	1.33	No	No
	Turbine Release (Mm^3)	128	950.00	4.12	Yes	Yes

Table 5: Developed Sen and Regression model equations

Station	Variable	Sen Model Equation	Regression Model Equation
Kainji	Minimum Temperature ($^{\circ}\text{C}$)	$y = 0.1223x - 223.5169$	$y = 0.134x - 246.8$
	Relative Humidity (%)	$y = 0.803x - 1541.28$	$y = 0.771x - 1477$
	Rainfall (mm)	$y = 1.5058x - 2932.7046$	$y = 1.914x - 3754$
	Reservoir Inflow (Mm^3)	$y = 26396 - 12.05x$	$y = 15945 - 6.765x$
	Storage (Mm^3)	$y = 65998.37 - 29.1x$	$y = 56776 - 24.52x$
	Turbine Release (Mm^3)	$y = 14.26x - 26522.18$	$y = 9.498x - 16986$
Jebba	Minimum Temperature ($^{\circ}\text{C}$)	$y = 0.0625x - 101.3038$	$y = 0.066x - 109.5$
	Relative Humidity (%)	$y = 737.38 - 0.333x$	$y = 726.9 - 0.328x$
	Rainfall (mm)	$y = 577.3160 - 0.2447x$	$y = 919.4 - 0.415x$
	Reservoir Inflow (Mm^3)	$y = 27.81x - 54486$	$y = 27.33x - 53511$
	Storage (Mm^3)	$y = 4.575x - 5549.9$	$y = 4.781x - 59.36$
	Turbine Release (Mm^3)	$y = 45.44x - 88412.76$	$y = 44.47x - 86472$

x = time, and y represents the meteorological variable





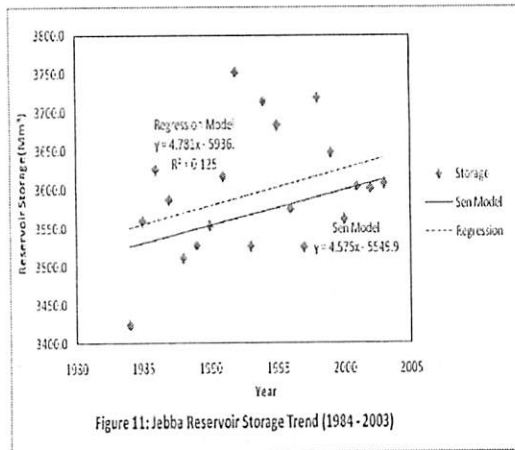


Figure 11: Jebba Reservoir Storage Trend (1984-2003)

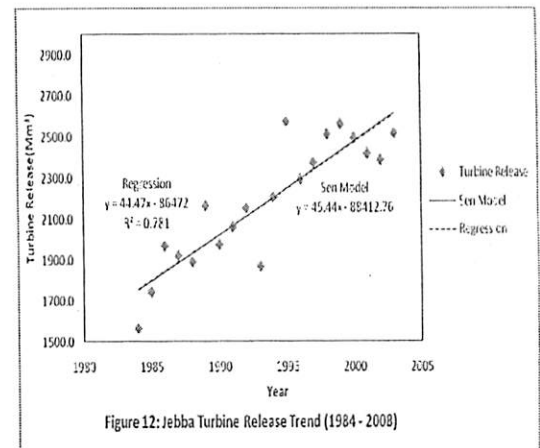


Figure 12: Jebba Turbine Release Trend (1984-2008)

3.2 Discussion of results

At Kainji, the analysis revealed a significant positive trend in temperatures over the 38 year period. The temperature trend is significant at the 95% and 99% level of significance thus indicating a very significant rise in temperature (Figure 1). The Mann-Kendall Statistic $S = 374$, Sen slope estimate $Q = 0.1223$, and the regression slope coefficient $a = 0.134$ indicate a positive trend. A correlation coefficient $r = 0.764$ also reveals a strong relationship, and the Z value of 4.6897 shows that the trend is highly significant. A Mann-Kendall Statistic $S = 309$ and positive values of Sen slope estimates and regression coefficient accompanied with a high Z value of 5.4950 also showed beyond reasonable doubt that relative humidity in the vicinity of the Kainji dam has been in a significant positive trend as depicted in Figure 2. The significant rise in relative humidity is an indication that the region is not drying up and thus the climate condition is likely to encourage adequate rainfall over the region. Rainfall has also been in an uptrend as presented in Figure 3, however, a Z value of 1.2522 indicates that the trend is not significant at the 95% and 99% level of significance. An analysis of the reservoir inflow at Kainji dam reveals a non-significant decrease in the trend at Kainji as depicted in Figure 4. The slight decrease in reservoir inflow to the dam may be attributed to the development of new infrastructures on the upper part of the Niger as noted by Energy Digest (2008); and less attributable to the impact of regional climate change as the study reveals a favourable climatic condition that favours increase precipitation in the vicinity of the Kainji dam.

In the vicinity of the Jebba dam, a significant positive trend in temperatures was also observed as indicated in Figure 7. The temperature trend was found to be significant at the 95% and 99% level of significance, indicating a significant rise in temperature. A Mann-Kendall Statistic $S = 149$, Sen slope estimate $Q = 0.0625$, and the regression slope coefficient of 0.066 indicate a positive trend. A correlation coefficient $r_s = 0.687$

also reveals a strong relationship, and the Z value of 3.0898 showed that the trend is highly significant. A Mann-Kendall Statistic $S = -143$ and negative values of Sen slope estimates and regression coefficient accompanied with a low Z value of -3.1314 showed beyond reasonable doubt that relative humidity in the vicinity of the Jebba dam has been significantly decreasing as presented in Figure 8. The significant drop in relative humidity is an indication that the region is drying up and thus the climate condition is likely to result in dry and harsh weather conditions, and insufficient rainfall in the region. As expected, rainfall has also been in a downtrend as depicted in Figure 9. However, a Z value of -0.7053 indicates that the trend is not significant at the 95% and 99% level of significance. An analysis of the reservoir inflow to the Jebba dam, however, revealed a significant increase in the inflow trend (Figure 10), which is inconsistent with the prevailing climate condition in the region. This prompted further analysis of hydrologic variable of the Kainji dam upstream of the Jebba dam. An analysis of the turbine release at the Kainji dam revealed an uptrend as indicated in Figure 6. However, a Z value of 1.6010 indicated that the trend was not significant at the 95% and 99% levels of significance. The non-significant uptrend in discharge from the Kainji dam may thus be viewed as the main factor producing the significant rise in the reservoir inflow to the Jebba dam as Kainji is a larger dam than the Jebba. Thus the Kainji dam has been the major water feed for the Jebba dam over the years.

The generous release from the Kainji dam has been propitious to the Jebba dam as storage at the Jebba dam has been in an uptrend over the years (Figure 11) thus favouring a significant increase in the turbine release for hydropower generation at the Jebba dam (Figure 12). However, this has an insidious effect on the operation of the Kainji dam as it has resulted in a significant drop in storage at the Kainji dam (Figure 5), indicated by a

Z value of 1.96 which is significant at the 95% level of significance (Table 3).

4.0 Conclusion

From the results of the analyses, temperatures in the vicinity of the Kainji and Jebba reservoirs have been in a significant uptrend over the years. Thus, it may be concluded that there is sufficient evidence of climate change the region. Increasing water release from the Kainji dam has favoured good operations of the Jebba reservoir due to increased in storage at the Jebba reservoir over the years. However, this has produced a significant drop in the storage which could affect the operation of the Kainji reservoir in the future, as the reservoir may be invariably drying up. Recommendation is hereby made to the operators of the dam to optimize the release of water from the Kainji reservoir into the Jebba reservoir so as to ensure optimal operation of both reservoirs and sustain power generation under the prevailing climate condition.

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