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Full Length Research Paper

The role of global warming in the reservoir storage drop at Kainji dam in Nigeria

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Statistical analysis of hydrometeorological data (temperature, relative humidity, rainfall, reservoir inflow, reservoir storage and turbine release) at Kainji dam was done with the aim of detecting trends. The non parametric Man-Kendall test was used to detect monotonic trends. The Sen's slope estimator and regression analysis were used to develop models for the variables. A Man-Kendall statistic S = 374 and a high Z value of 4.6897 reveals there is evidence of global warming in the areas around the dam. This has produced favourable climate conditions favouring increased rain in the areas surrounding the dam. Excess water has been released from the dam to sustain hydropower generation over the years. This has invariably affected storage at the dam. Recommendation was therefore made to the operators of the dam to optimize the release of water from Kainji dam to ensure ideal operation of the dam.

Key words: Global warming, Man-Kendall test, Sen's slope estimator, regression analysis.

INTRODUCTION

Global warming or climate variability is expected to alter the timing and magnitude in runoff and soil moisture. As a result, it has important implications for the existing hydrological balance and water resources as well as for future water resources planning and management. Quantitative estimation of the hydrological effects of climate change is therefore essential for understanding and solving potential water resource problems that may occur in the future (Guo and Ying, 1997). Global variations in climate have brought about extreme events like flood and drought which have had drastic impacts on river basin development structures. Such structures include dams on which Nigeria has depended for most of its renewable (green) energy generation (Ononiwu, 1994). For instance, Energy Digest (2008) states the twin issue of climatic change and developing new infra-structure projects by neighbouring countries on the River Niger have been identified as factors that are threatening to the water levels and adequate water flow into Kainji and Jebba dams in Nigeria. EPA (2009) defines global warming as an average increase in the earth's temperature which in turn causes changes in climate, and reported that global warming enhances the water cycle by intensifying the cycle of water. It speculates that because of global warming, more cloud will form and there will be more rain and snow especially in areas closer to water whereas in areas away from water sources, excessive evaporation would dry out soils and vegetation, resulting in fewer clouds and less rain. Thus the area will probably get more droughts, rivers and lakes will become shallower and ground water decreases. Thus, analysing long-term series data for predicting the influence of potential climate changes is an important application of statistics in recent hydrologic researches.

Global warming is no longer a speculation. The threat is real and has far reaching results. It is absolutely necessary therefore, to sensitize people of all nations about the imminent danger posed by global warming and depletion of fresh water resources and to establish a suite of coordinated activities that will examine the serious and sweeping issues associated with global climate change, including the science and technology challenges involved, and provide advice on actions and strategies nations can take to respond to it (National Academy of Science Washington DC, 2008). Therefore this study focuses on the specific impact of global warming as related to the drop in reservoir storage at Kainji hydropower dam in Nigeria. The objective of this

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Table 1. Statistical summary of hydrometeorological variables at Kainji hydropower dam.

Variable	Statistics				
	Mean	Variance	Standard deviation	Skew	Kurtosis
Minimum temperature (℃)	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 (Mm^3)	2504.35	400603.38	632.93	0.438	-0.435
Storage (Mm^3)	8058.58	521341.18	722.04	-0.172	-0.869
Turbine release (Mm^3)	1881.96	175953.70	419.47	0.181	-0.306

study therefore, is to develop functional relationships for the time series of temperature and rainfall for areas around the dam. This will help in determining whether global warming has resulted in conditions that are unfavourable to rainfall and inflow to the dam.

DATA AND ANALYSIS

Monthly minimum temperature, relative humidity, rainfall, reservoir inflow, turbine release and reservoir storage data for Kainji dam in Nigeria were obtained from the dam station. The minimum temperature data spanned between 1972 to 2009 (38 years), relative humidity data spanned between 1980 to 2009 (30 years) while the range of rainfall data was from 2000 to 2009 (10 years). Thirty-four (34) years (1970 to 2003) of reservoir inflow, reservoir storage and turbine discharge data were also obtained and used for the analysis. The arithmetic averages of the monthly data were computed to give an annual average value used in the analysis of the hydrometeorological variables. A summary of statistics for the meteorological variables is presented in Table 1.

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 were done to develop regression models.

Correlation coefficients of the meteorological variables and time were also computed to determine the strength of the linear relationship between the variables and time.

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 independent and randomly ordered data. The Mann-Kendall test does not require assuming 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 that follows:

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

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

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

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:

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

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:

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

Z follows a normal distribution. 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 it 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 that is:

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

Table 2. Correlation coefficients between meteorological variables and time at Kainji dam.

Variable	Correlation coefficient
Minimum temperature (℃)	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

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:

$$Q_i = \frac{x_j - x_k}{j - k} \tag{6}$$

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. 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). In this study a program was written in visual basic for applications to facilitate the computation of the Man-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:

$$Y = aX + b \tag{7}$$

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 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 and maximum temperatures, rainfall, inflow, evaporation rates and relative humidity) and time were computed using Microsoft excel software application.

RESULTS AND DISCUSSION

The correlation coefficients between the climatic variables 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. The plots showing the time trend of the variable are presented in Figures 1 to 6.

The analysis revealed a significant positive trend in tempratures over the 38 year period. The temperature trend is significant at the 95 and 99% level of significance thus indicating a significant rise in temperature (Figure 1). The Man-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 a = 0.764 also reveals a strong relationship and the Z value of 4.6897 shows that the trend is highly significant. A Man-Kendall statistic S = 309 and positive values of Sen slope estimates and regression coefficient accompanied by a high Z value of 5.4950 also showed beyond reasonable doubt that relative humidity around Kainji dam has been in a significant positive trend over the 30 year period analysed (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 for the 10 years of available data analysed (Figure 3). However, a Z value of 1.2522 indicates that the trend is not significant at the 95 and 99% levels of significance. An anaysis of the inflow at Kainji dam however revealed a non-significant decrease in the inflow trend at Kainji (Figure 4). From the analysis of the turbine release at Kainji dam, results revealed an uptrend in the variable over a 34 year period (Figure 5). However, a Z value of 1.6010 indicated the trend is not significant at the 95 and 99% levels of significance.The generous turbine release at Kainji hydropower dam has been propitious as it has helped maintain hydropower generation from the dam over the years. However, this has an insidious effect on the operation of the dam as it has resulted in a significant drop in the storage at the dam (Figure 6), indicated by a Z value of 1.96 which is significant at the 95% level of significance (Table 3). A review of a work by Salami et al. (2010) on the impact of climate change on water resources of River Niger at Lokoja, downstream of Kainji also revealed there is tendency for high increase in evaporation, temperature, sunshine hour while there is no much changes in rainfall. However, though not significant, the rainfall trend revealed a positive trend.

Table 3. Summary of the Mann-Kendall analysis at Kainji dam.

Variable	S	Variance	Z	Trend significance	
				95%	99%
Minimum temperature (℃)	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

Table 4. Developed Sen and regression model equations.

Variable	Sen model equation	Regression model equation
Minimum temperature (℃)	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

x= time and y represents the meteorological variable.

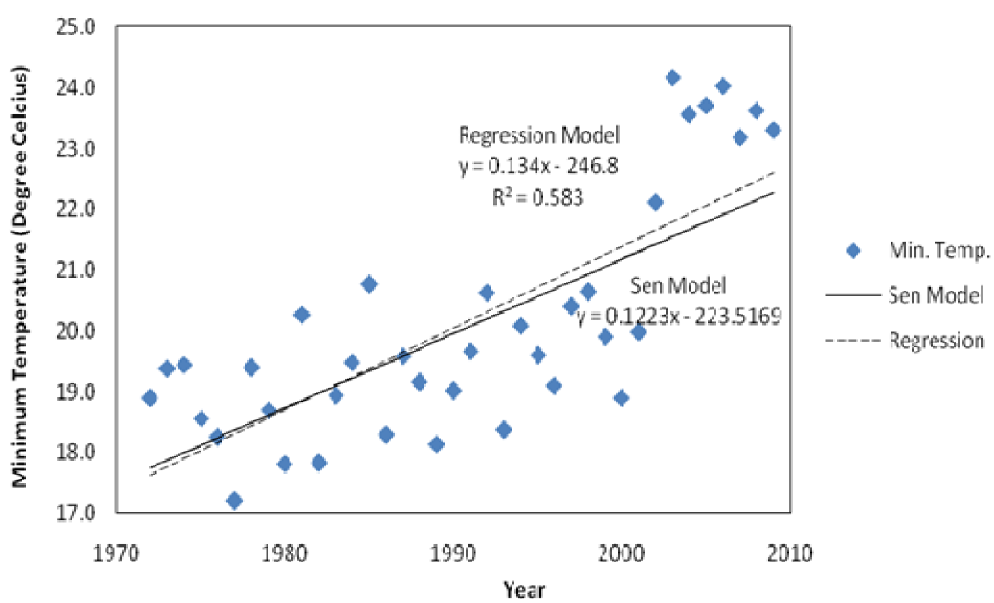

Figure 1. Kainji minimum temperature trend (1972 to 2009).

Conclusion

From the results of the analyses, temperatures in the vicinity of Kainji dam have been in a significant uptrend over the years. Thus it may be concluded there is enough evidence of global warming in the region. Global warming has produced favourable climate conditions around Kainji dam as revealed by the significant rise in relative humidity and an uptrend in the rainfall of the region. The slight decrease in inflow to the dam over the 34 year period may thus be attributed to the development of new infrastructures on the upper part of the Niger as noted by

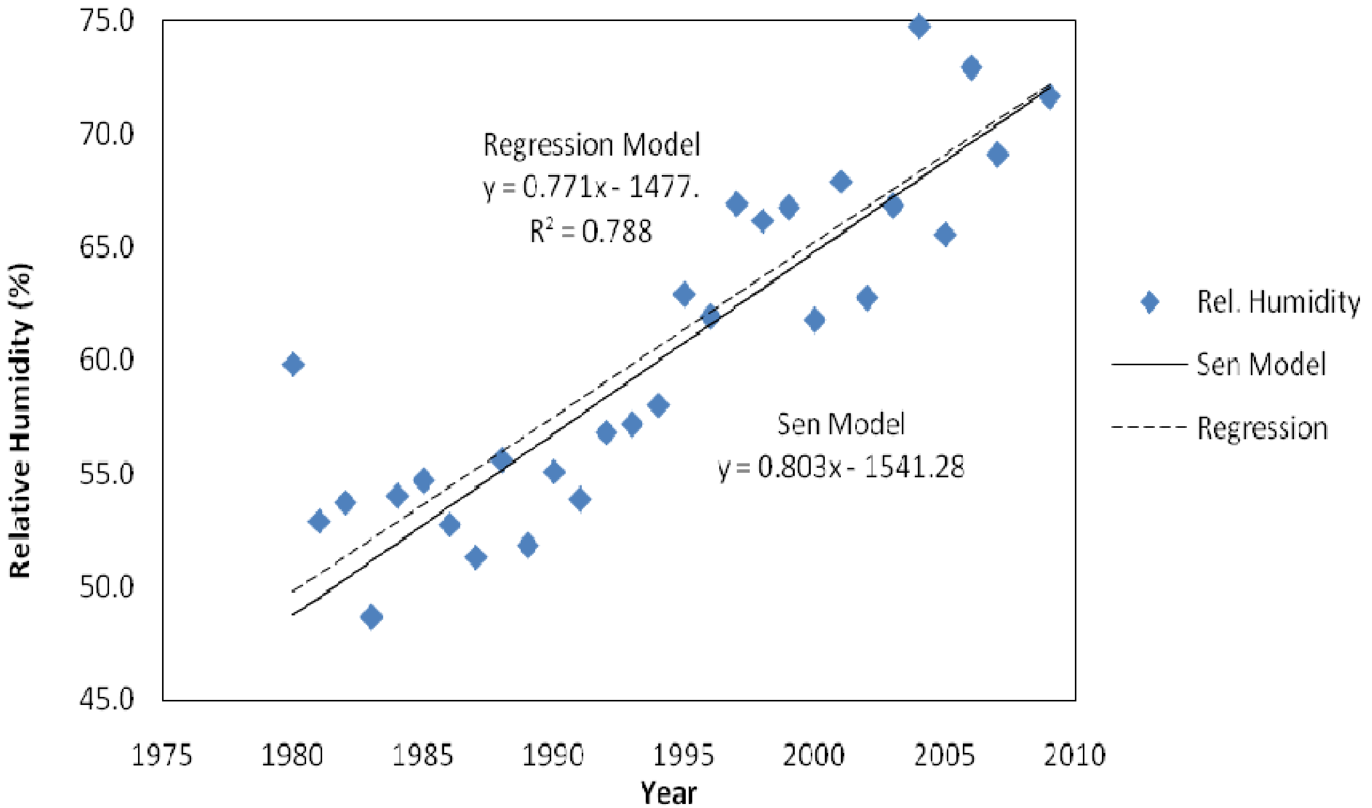

Figure 2. Kainji relative humidity trend (1980 to 2009).

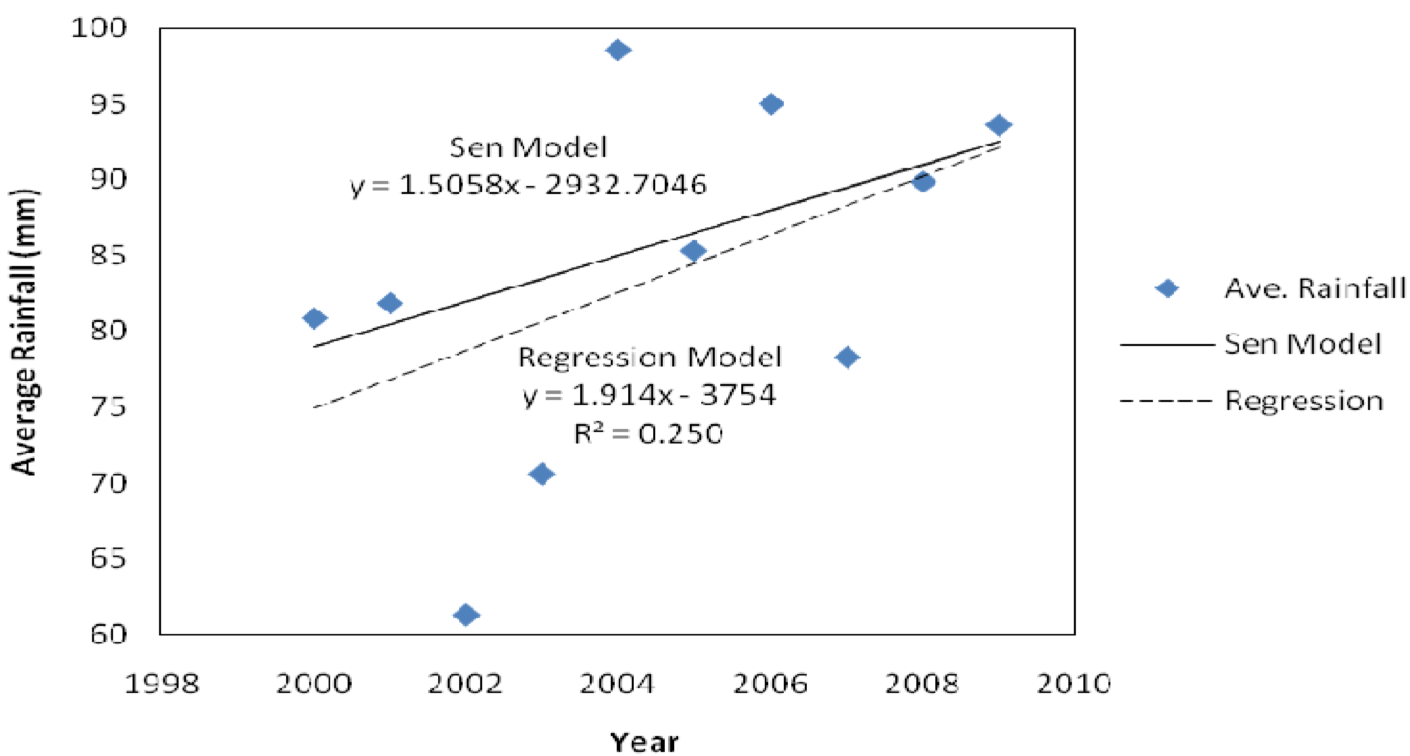

Figure 3. Kainji rainfall trend (2000 to 2009).

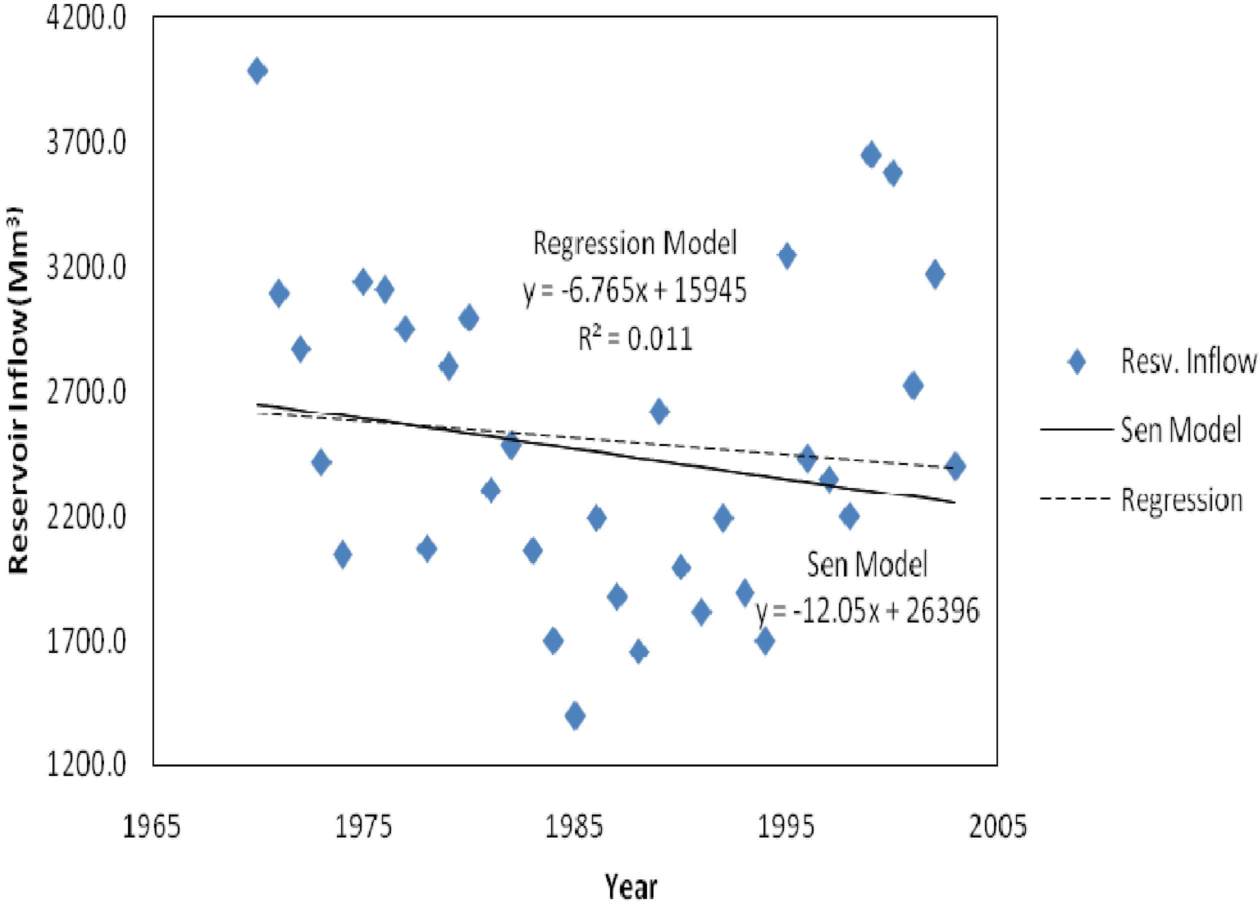

Figure 4. Kainji reservoir inflow trend (1970 to 2003).

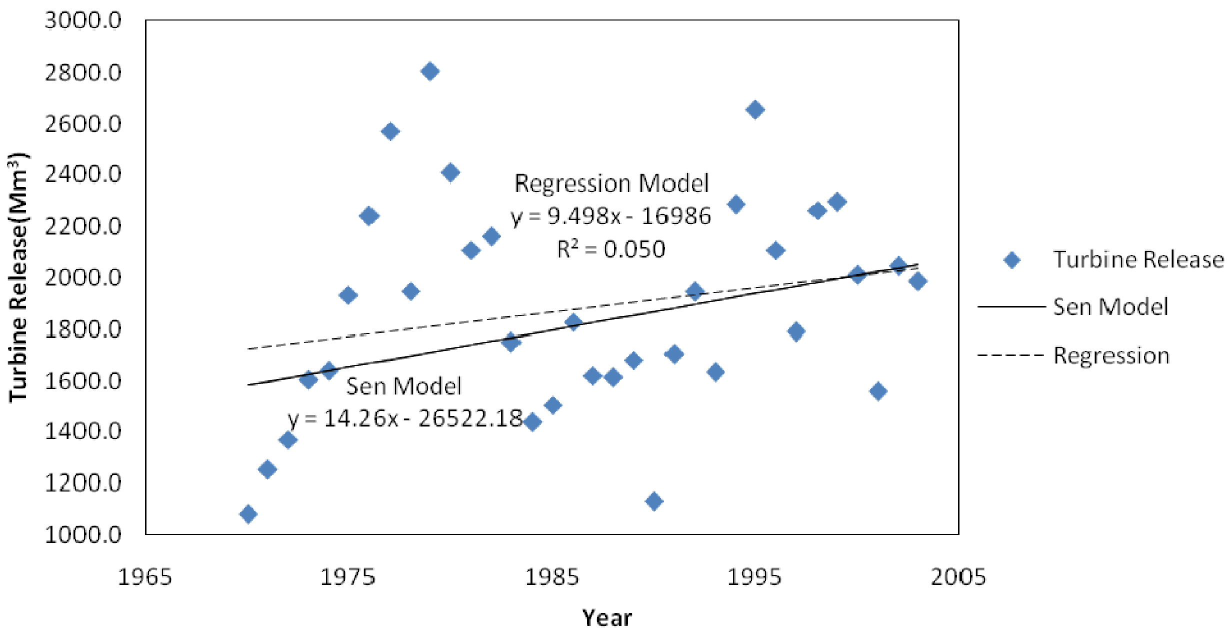

Figure 5. Kainji turbine release trend (1970 to 2003).

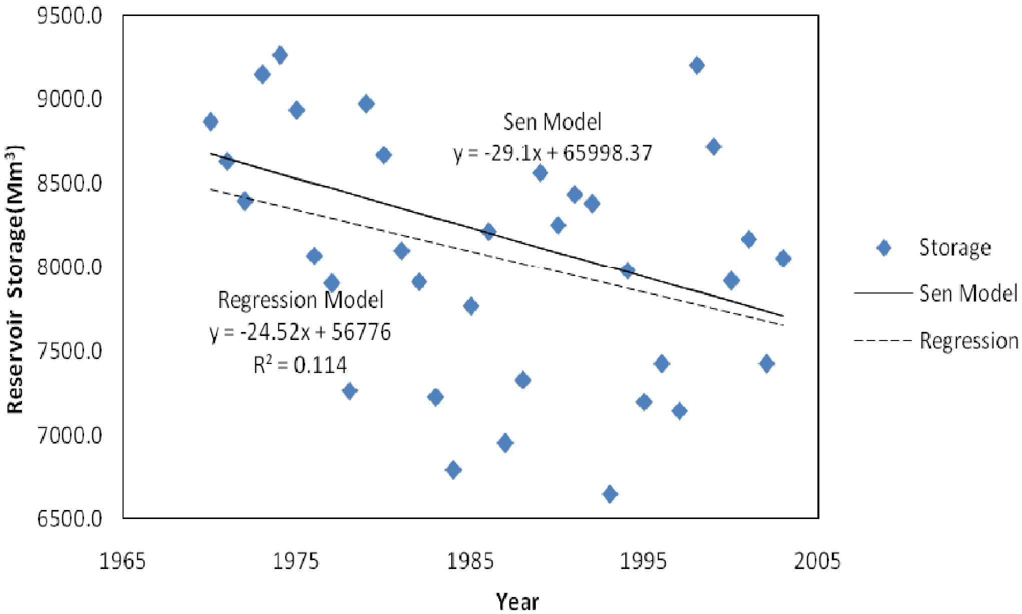

Figure 6. Kainji reservoir storage trend (1970 to 2003).

Energy Digest (2008); and less attributable to the impact of regional climate change as the study reveals a favourable climatic condition that favours increased precipitation in the areas around Kainji dam.The non-significant decrease in inflow to the dam and increase in turbine release from the dam have produced a significant drop in the storage which could affect the operation of the dam in the future, as the dam may be invariably drying up. Recommendation is hereby made to the operators of the dam to optimize the release of water from the dam so as to ensure optimal operation of the dam and sustain power generation under the prevailing climate condition.

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