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RAINFALL CLIMATOLOGY AND HYDRO ELECTRIC POWER GENERATION: A CASE STUDY OF KAINJI HYDRO ELECTRIC POWER STATION, NIGERIA.

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Abstract
The annual rainfall regime at Kainji, Niger State is considered in this study as the main input that determines hydro electric power generation in the station. With annual rainfall and hydropower generation data for 33 years (1970 – 2002) quite handy, a generation efficiency or $r = 0.50$ and $r^2 = 25\%$ singular contribution of the annual rainfall to power generation is established. The 33 year pattern was observed to be most variable without clear discernable patterns regarding both the annual rainfall and HEP generation. The analysis of respondents' feedback on the major constraints of the energy establishment identifies job dissatisfaction from the lack of motivation and outdated facilities as the main problem.

1 Introduction

Water availability is the most critical factor in hydroelectric power generation. It is the 'fuel' that drives the turbines in the dam. In terms of precipitation, it is not so much the amount but how it is available that matters. Water availability from annual rainfall is a function of the onset dates (O) and effective end (cessation dates C) of the rains. Both of these dates effectively control the hydrologic season usually referred to as the length of the rainy season (LRS). In the simplest form: LRS = (C – O). All three parameters are decisive in determining the type of spillway for a particular dam. The required discharge capacity of the spillway must be carefully determined from discharge records of the stream. There could however exist modification due to storage, which are also dependent on the LRS among other considerations. Average rainfall storage is critical since; in the case of failed dams for instance, a single over topping (yield exceeding maximum controllable flood) might cause disastrous failure.

Nigeria is located within the broad tropical climatic region of the world with two distinct seasons; the wet and the dry. Being in the radiative heat source region of the earth where convective currents of air are highest (Roger and Chorley, 1981; Adefolahu, 1981), the world's highest rainfall totals, intensity and duration are recorded in this climatic zone. However, fluctuations in time and space are a common attribute of all natural systems including the weather sub-system. This is known to be affecting human-related activities or ventures directly or indirectly such as hydro electric power generation for instance. In this region however, this variability is sufficiently observed to prompt a conclusion that there are indications of climate (rainfall) fluctuations in addition to seasonal changes.

Until the late 1970s, the National Electric Power Authority, through the Kainji power station, supplied most of the electrical energy requirements in the country. Of late however, electricity generation from the dam has been most variable and unreliable that one is confused as to the real causes of the failure. Could this be due to the global problem of climate change or the growth and development in the economy and hence greater demand for electricity, or is it due to mismanagement and equipment failures? Our focus in this study is climatic; the relationship between rainfall variability and hydro-electric power production. Accordingly the following research question guided the presence work.

(i) What is the baseline rainfall climatology and trend in the annual rainfall regime at Kainji?

(ii) What is the trend in the hydro-electric power generation over time at Kainji. ?

(iii) How do the annual rainfall fluctuations influence or relate with electricity generation at Kainji?

(iv) What are the main problems militating against effective and efficient electricity power generation at Kainji ?

2 Conceptual Framework

For this study however, fluctuations in wattage of electrical energy generated is believed to be due to shortages in the flow volume of the Niger. The decreasing rainfall trend with increasing temperatures globally and particularly at the Sahel Savanna region of West Africa largely accounts for the problem. In other words there are good reasons to expect a direct relationship between annual rainfall amount and hydro electric power generation at Kainji, given that other factors are in place. Locally however, the main dynamic controls of the weather and climate in West Africa are the Inter Tropical Discontinuity (ITD). This meteorological feature which lies west to east separates the main surface wind systems in the sub-region (Fig.1) This upward (North) and downward (South) moving climatic feature determines, to a large extend, the effective area of influence of the Hamarttan (Nov. – March) or the Rains (April – October) yearly in direct response to its latitudinal location.

In addition to the above explanation of annual rainfall and temperature changes in West Africa, activities of man through farming practices and over-grazing is particularly believed to be the main cause of desertification (Harmut, 2000). Desertification is a climate related environmental problem in the tropical Savana of Africa characterized by a gradual development of deserts like conditions in the erstwhile Savanna lands. This mainly man – induced ecological problem is caused by higher day time-temperatures and steadily decreasing annual rainfall amounts and duration. This more recent climate change concept while explaining change and variability in the global weather and climate also establishes the fact that man has contributed more to this global problem than nature.

3 Method of Study

3.1 Nature and Source of Data

Data used in the study were both primary and secondary. The primary data were from fifty questionnaires served both senior and junior staff of the establishment. The partly closed and open-ended questionnaire design strictly addressed the operational efficiency including the problems of the energy establishment. Thirty eight (38) junior and twelve (12) senior staff were selected for the interviewed and questionnaire administration using the systematic sampling design. Secondary data were obtained from meteorological station, the Power Generation Units and other official documents of the establishment. The measurement units are, however, kilowatts and millimeters for electricity generation of electric and rainfall respectively. Both data are in the ratio measurement scale (see Table 1).

Table 1: Annual Rainfall and Hydro-Electric Power Generation at Kainji

	POWER GENERATION (GW) (Y)	RAINFALL (MM) (X)
1970	162.1	832.6
1971	1780	902.5
1972	1602.3	830
1973	1433.5	786
1974	1484.6	798.5
1975	1461.8	660.2
1976	1618.4	857.1
1977	1519.7	808
1978	1714.7	858.7
1979	2571.6	818.9
1980	1785.8	904.9
1981	2342.8	916.9
1982	2414.7	973.7
1983	1929.4	760
1984	2359.9	817.1
1985	1859	665.1
1986	1285.8	734.6
1987	1500	704.4
1988	1857	793.2
1989	1642	449.6
1990	1543	870.7
1991	1714	783.1
1992	1143	707.7
1993	2204.1	1415.4
1994	1992	753.7
1995	2307.3	1015.2
1996	2401.3	1227.6
1997	1687.7	1098.1
1998	1906.6	823.3
1999	1805.5	1117.2
2000	2125.9	1349.8
2001	2477.3	1295
2002	1995.4	870.9
Total	61086.8	29020.8
Average	1851.1	879.4

Source: NEPA., Kainji, 2002

3.2 Data Analysis

Mathematical and statistical techniques were used for data treatment and analysis. The associated inferential statistics aided the researchers to arrive at objective conclusions regarding the stated major problems of study. Many methods are available for calculating trend (Gregory, 1969) the most common ones are the moving average techniques and the least squares regression techniques. A trend is the general pattern of fluctuation of data over time (Okoko, 2000). In this work a 3– yearly moving averages technique was used to treat 33 year data of the "noise" effect associated with time series data. Any 3 yearly 'noise' or random occurrence in the annual rainfall data are removed or removed leaving behind a more discernable temporal trend. The least square method is then used to estimate the relationship between rainfall and electricity freely.

Following Udofia (2001) and Spiegel (1988), the quantitative trend series analysis is modeled statistically as:

$$y = a + bx + e$$

Where;

y = estimated annual rainfall (dependent variable) in mm

x = time in years (Independent variable)

a = a constant or the y – intercept;

b = another constant or the coefficient of x;

e = error term or variables not being considered

4 Results and Discussion

4.1 Rainfall Climatology of Kainji

Baseline climatological analysis primarily involves the definition of certain statistical limits such as the average, deviations from established average values as well as the probability of occurrence of the series extremities among others. The 33 year (1970 –2002), annual rainfall data for Kainji provides minimum enabling condition for analysis and the fundamentals upon which other pertinent weather – related issues are based. Following this analysis therefore, the mean annual rainfall for Kainji town was determined to be 879.4mm for the period of study out of 29,020mm of total rainfall recorded for the period. The extreme values were found to be 1415.4mm and 449.6mm for 1991 and 1987 respectively; the annual rainfall range however was 965.8mm. The series standard deviation was established to be 230.1mm; the series coefficient of variability was equally established as 26.16mm. However, the likelihood of occurrence of the extremities for any one year using the z-score model were 13.41% and 88.10 percent for the corresponding upper extreme value of 1415.4mm and the lower value of 449.6mm respectively. The series trend following the application of the 3-yearly moving average treatment on the initial annual rainfall distribution produces a trend that fluctuates slightly above and below the average mark up to 1989 (Fig II). From 1990 to 2002, the trend is rising above the average. The explanation for the above scenario is difficult. It may be attributed to regular systemic attributes as the consequence of variability other than climatic change.

A quantitative model of the initial annual rainfall temporal pattern for theoretical and possible predictive purposes was developed as:

$$y = 711.8+0.098x+ e$$

The regression coefficient was however not significant at the 99% confidence level. The annual rainfall for the study area was not time dependent, the observed rising trend, particularly from 1990 though impressive is not significant.

For electric power generation at Kainji dam that is hypothesized to be rainfall dependent in this study, a grand total of 61087mw has been generated with 1979 having the highest output of electricity estimated at 2571mw. The least generated electricity at Kainji of 1143.1mw occurred in 1990; while the mean value for the 33-year distribution was 1851.1mw. The above extreme values show no direct relationship to their respective annual rainfall values. Almost half the study period enjoyed above-average power generation, while the remainder experienced below average power generations (see Figure IIb).

4.2 Rainfall Temporal Pattern and Hydroelectric Power Generation

The 33- year data on the annual rainfall and Electric Power Generation at Kainji were inductively analysed to determine the strength of the assumed dependent relationship. The inferential and analytical tools were the Correlation and Regression analyses. The Parametric Pearson's Product Moment Tecnnique is most appropriate where a ratio – measured dependent relationship is inferred between two or more variables.

The result of the correlation analysis between annual rainfall (x) and annual energy production (y) shows that r=0.05 is established (See Table 2). The strength of this relationship is highly significant at 0.01 probability level. Hydroelectric power generation bears a direct relationship with surface stream flow (which is a function of the annual rainfall). A measure of the percentage explanation of the variations in the dependent variable by the independent variable, the coefficient of determination (r^2), is just 25percent. This could be interpreted to mean that the operational efficiency of Hydroelectric power projects rely by about 25percent on the primary input element i.e adequate and uninterrupted stream flow. The remaining 75percent consist of management and other production factors to be discussed later.

Table 2: Model Estimation Parameters in relation to Hydropower Generation

Variable	Model estimation	F-ratio	R	R^2	T_{cal}	$T_{critical}$
Annual rainfall	$\hat{y} = 711.80 + 0.09x + e$	3.44	0.32	0.10	1.26	2.75
Power generation	$\hat{y} = 1635.2 + 12.7x + e$	10.33	0.50	0.25	3.21*	2.75

Note: Degree of freedom = 31. Source: Computed from Table 1

On the strength of the above highly significant r – value, it became imperative therefore that a theoretical management could be formulated. With the least square regression technique therefore, the simple linear function y = 1068.4 + 0.89x + e was developed and regression coefficient was significant at 99% confidence level ($t_c > t_t = 61.48 > 2.75$) with 31 degrees of freedom (Fig. III). The residual standard error was however determined to be 342 an under-estimation.

4.3 Problems of Power Generation at Kainji Dam.

The primary requirement for running an efficient and effective hydroelectric power project (rainfall) contributes only about one – quarter of the entire materials, financial and managerial requirements for such operation. However, interactions with both the senior and junior officer's cadre of the establishment at the Dam site revealed however that other production input requirements namely equipment, funding and managerial competence and staff motivation are mostly inadequate. Most of the staff, particularly the long – serving ones maintained that they have lost the initial zeal and enthusiasms due to the prevailing poor working conditions.

A summary of the main problems of the establishment base on an intensive study is presented in Table 3 as ranked

Table 3: Rankings of Operational Problems in Kainji

Issues / Problems.	Response	Percentage
Motivation	22	44
Materials	18	32
Corruption	6	12
Rainfall changes	5	10
Poor funding	1	2
Total	52	200

Source: Filed Survey Data, 2003

Forty-four percent (44%) of the workers interviewed complained of poor motivations and other conditions of service as the central problem of the establishment. Those who had put in more than 25years on the job particularly complained that the salaries they earned initially in the eighties meant much more than what they are receiving now. Special allowances and benefits such as staff shift, hazards and medical bills among others seemed to be gradually phased out yet the work demands of the establishment growing on a daily basis. Poor motivation breeds divided loyalty. The very poor and sorry state of equipment and tools at the complex ranked the second most pressing problem of the energy establishment. Lack of spares to replace the old and worn-out parts is seriously affecting the operational efficiency of the plant. The fabricating unit and workshops planned, as part of an entirely self-sustaining system has not function effectively as planned. Following this situation, the generating turbines can not be operated maximally for fear of a complete break down or system collapse.

The changing environmental conditions in the sub-regions, particularly the possibility of annual rainfall decline from the very catchment in the Guinean highlands down to Nigeria ranks the third amongst the problems. Six respondents or 12%, two of which are meteorological sub-unit staff gave an almost graphic account of annual temperature and rainfall situations of late in the sub-region. Annual rainfall is steadily decreasing in quantity and duration, temperature, on the other hand, is rather steadily with a higher likelihood for increase in direct response to the activities of man such as farming, bush burning and grazing etc. In the past few decades, the annual average temperature in the area has been steady at 28.1°c they maintained. Corruption at all levels was one the principal problems hindering the effective performance of the industrial establishment. The officials mismanaged subventions, grants and huge electricity tariffs through frivolous and inflated contracts cum outright embezzlement. Imprest to unit heads is hardly given as a result. Almost all, except one of those spoken to were of the opinion that the establishment could be self-sustaining if well managed as the respondent believed it was poorly funded by the government.

5 Discussion of Results

The study is essentially anchored on three main objectives namely; the determination of the rainfall climatology for Kainji, verification of the assumed relationship existing between variability in annual rainfall and hydro-electric power generation, and finally identifying the major problems of the Dam. Using the 33-year annual rainfall data, values for the annual total, mean, standard deviation, the coefficient of variability, the range and probability of critical occurrences and the trend were determined for rainfall. These values fell generally within the established limits for the tropical savanna climates; moderate rains, large deviations from the mean and, high ranges. With unusually high temperatures however, semi desert conditions are to be expected. The most intriguing findings yet have to do with the analysis of the temporal figures for the trend. The fact that the main input element, the annual rainfall at Kainji was below the average value mark for twenty years (1970 – 1990) raises much worries and concerns as to what should be the best option should this continue. The somewhat 'flashes', the seeming above average recordings after 1991, is deceptive as it was not statistically significant when tested. The global problem of climate change, the ecological problem of desertification and the increasing terrestrial daytime temperatures must not be forgotten as the likely causes of the observed. Besides, the possibility of the countries upstream e.g. Guinea, Burkina Faso, Mali being threatened with drought tampering with the river flow can equally lead to serious shortfalls in the flow volume of the Niger. However, a theoretical predictive model for planning and management purposes as well as for further research is developed as $y = 711.8 + 0.09x + e$; and the standard error is calculated to be 165mm. The relationship between annual rainfall and hydroelectric power generation is no more in doubt with the established significant relationship $r=0.50$ at 99percent confidence. The percentage contribution of annual rainfall variability to electricity generation at Kainji is just 25percent. If the desired efficiency in hydro electricity generation must be ensured then the other input requirements including adequate staff motivations, accountability etc etc must equally be given adequate attention. However, the relationship is mathematically modeled as:

$y = 1068.4 + 0.89x + e$ (with the standard error of 341.61mm).

Amongst the numerous problems of electricity generation at Kainji motivation ranks highest with well over 40percent of respondents indicating, while poor funding is ranked least with just 2percent. Poor state of materials and equipment of the power establishment is second to motivation. This is common with government establishments nationally. Rainfall decline, which motivated this research is ranked second to the last among the problems of the energy establishment.

6. Conclusion

Baseline climatology (including the annual trend), is determined for Kainji using 33 years annual rainfall data. The mean and standard deviation are determined as 879.4mm and 230.1mm respectively. The annual trend is variable and defined by the estimated equation y = 711.8 + 0.09x. The influence of annual rainfall on power generation at Kainji is positive and significant, but it contributes only about 25perccnt of requirements for power generation. Problems of the establishment are many but poor staff motivation ranked first while the poor state of the equipment's and machines was second. Rainfall changes is ranked second to the last. For Kainji hydro power station to be sustained, the other primary production inputs must be given due attention in the energy production process.

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