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Redundancies in Hydro Reservoir Elements and their Contributions to Electric Power Generation in the Jebba Hydrel Power Reservoir, Nigeria**Ifabiyi, Ifatokun Paul, Ph. D.**

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E-mail: tokunifabiyi@yahoo.com;tokunifabiyi@unilorin.edu.ng**Abstract**

Despite the over 100 years of electricity in Nigeria, power generation is still largely lagging behind its demand as all the hydro dams are still performing below installed capacities. The purpose of this paper is to expose the rates of redundancies in the contributions of reservoir elements to power generation in Jebba dam and to guide dam operators in designing reservoir rules. The data used in this study comprises of monthly power generated in mg/watts and monthly characteristics of 10 reservoir elements. These information were collected from 1990-1998. These data were obtained from the Hydrology Department of Power Holding Company of Nigeria, Jebba

Business Distinct; Jebba North, Nigeria. The data were interpreted with statistical averages, simple percentages, graphs, while factor-multiple regression and factor-stepwise regression were used as reduce-rank models to estimate rates of redundancies on monthly basis. Altogether, 24 mathematical operations were carried out; which is a breakdown of 2 factor regression modelling operations per month (one each for factor-multiple and factor-stepwise regression). The percentages of explanation of factor analysis equations range from 79.2% in April to 92.7% in December, with percentages of redundancies ranging from 7.70% in December to 20.8% in April. The percentages of explanation of multiple regression also vary from 13.4% in April to 98.5% in February, while its monthly percentages of explanations outside the multiple regression equations range between 1.50% in February to 86.6% in April. Also, the percentages of explanations of stepwise regression equation range between 0.00% in April to 95.7% in February and its rates of redundancies range from 4.30 % in February to 100% in April. The results show that high rates of redundancies were exhibited in the various associations. Meanwhile, redundancies were patterned after the reservoir hydrology. For example, high redundancies were experienced in the period of low inflows such as April and November, while low redundancies were exhibited in periods of high inflows such as January, September and October. The paper has exposed that high level of redundancies are exhibited on monthly basis. The knowledge of the redundancies are important to designs of reservoir rules. The study further recommends that attempt should be made to control reservoir evaporation.

Introduction

Redundancy and multicollinearity, are multivariate problems (and not bivariate problems) common in hydrological investigations. Researchers are sometimes confronted with the task of choosing amongst competing hydrologic indices to reduce computational efforts and variable redundancy, while still representing the major facets of the systems in question (Olden and Poff, 2003). Where

multicollinearity problem is not resolved, development of models will waste time and resources, and it may raise false alarm as models will be characterized by noise.

Redundancies or multicollinearity could be due to some of the followings: (i) the fact that some hydrological variables are computed from other variables within the same equation (ii) inclusion of the same or closely related variables twice in an equation, (iii) the inclusion of identical operations of a concept in an equation, (iv) sometimes, it may be because the variables are just highly correlated (for example, river basin variables are known to be highly correlated) and lastly (v) it could also be due to error on the side of the researcher. Indeed, where multicollinearity is not removed in sets of variables the standard error of estimate of such computation will be high and this might render any model questionable.

Various methods can be used to resolve multicollinearity problem. Some of these are: (i) avoidance of any flagrant errors on the part of the investigator, (ii) increasing the size of variables by the researcher, (iii) usage of information from previous researches, (iii) the use of joint hypothesis, (iv) dropping offending variables, (v) having knowledge of multicollinearity by the investigator and (vi) lastly by the use of factor analysis or any other method of data reduction. Different approaches have been used to resolve redundancies. For example, Roy, *et. al.* (1989) and Shen and Gao (2008) used ridge regression (RR) analysis to resolve multicollinearity problem. Olden and Poff (2003), Gallicchio and Chang, (2009) and Micheli (2010) have used Principal Component Analysis (PCA) in various studies in Europe and America to overcome multicollinearity in hydrological studies.

Electricity in Nigeria dated back to 1896 when it was first generated in Lagos 15 years after it was introduced to England. The Power Holding Company of Nigeria hydro stations supply about 80% of the total electric consumption in Nigeria from 3 large dams located in Shiroro, Jebba and Kainji. Unfortunately, after 100 years of power generation, the Nigeria power industry is still characterized by erratic

supply and inadequate coverage in terms of geographical spread, a record of low per capita consumption. For example, about 40% of the population is covered (Iwayemi, 2008). The poor performance of this sector has its toll on the economy of Nigeria, as the high cost of production has sent many industries packing, particularly in search of countries with least cost of production, while many local industries have folded up.

Dam operations play an important role in the quantity of power generation. This is because the performances of hydraulic turbines depend on the rules guiding water release. Where there is an inefficient reservoir rules water release will be affected, and this will consequently affect power generation. Meanwhile, even in the presence of adequate water, inefficient operation guidelines might reduce power generation. Efficient operation rules for a reservoir would be difficult to design without knowing the relative importance or the contribution of individual elements; especially on monthly basis. This is because reservoir hydrology may vary on monthly basis, particularly in the Niger basin where flow regime is characterized by at least 2 flood scenarios. Consequently, the contribution of the elements to power generation will likely vary along this pattern. Therefore, some elements will be dominant at certain period of the hydrological year, while, some may be of less importance at other times. Indeed, for efficiency in the power house, there is a need to understand these scenarios for efficient design of reservoir rule. This present study will examine the extent of redundancy existing in predicting power generation at the Jebba dam, Nigeria using reduce-rank models.

The Study Area

Jebba reservoir is located on latitude $9^{\circ} 35'$ and $9^{\circ} 50'N$ and longitude $4^{\circ} 30'$ and $5^{\circ} 00' E$. It located on river Niger, Nigeria (Fig. 1). It is a 540 mw dam. Jebba is underlain by Basement

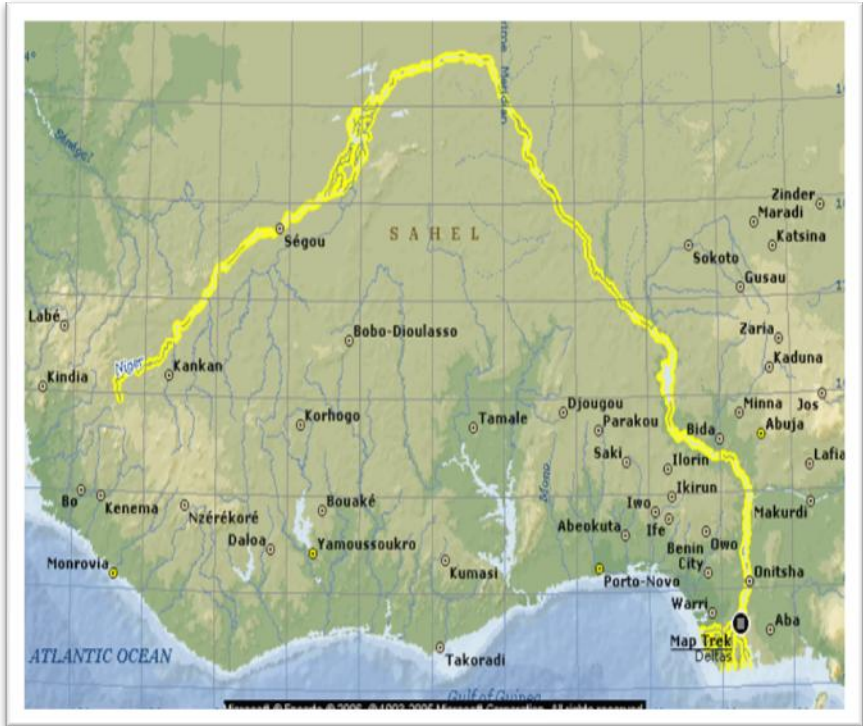


Fig. 1: The Niger Basin

(Adapted from Emoabino, I. U., Alayande, A. W. and O. A. Bamgboye (2007))

Complex rocks such as porphyritic granite, mica, quartzite, etc (Sagar, 1985; NEDECO, 1959; Imevbore, 1970). It has an estimated surface area of 303km^2 and a volume of $3.31 \times 10^9\text{m}^3$. The maximum depth is 105m and a mean depth of 11m (Ita, et al 1984)

According to NEDECO (1959) and NEDECO and Balfour Beatty (1961) 2 patterns are discernable in the seasonal hydrological regime of river Niger in Jebba. In the months of May to October rainfall in the northern parts of Nigeria south of Niamey produces flood that

quickly reaches Jebba area with a peak of 4,000-6,000 m³ s⁻¹ in September to October. This flood water is laden with silt and clay sediment and it is of high turbidity. Due to its colour, it is locally called 'white flood'. The second flood originates from the rivers headwater region from rivers of high annual rainfall in the Fouta Djallon highlands in Guinea and passes through sub-arid region and deltaic swamps in Timbuktu. In this area much of the water is lost to evaporation and infiltration. Little water is added before it reaches Kanji in November with a peak flow of 2000 m³ s⁻¹, the water is relatively clear, it is known as black flood (Oyebande, et al, 1990; Mbagwu, et al, 2000;; Olaosebikan, et. al., 2006).

These floods lead to high water levels which always give rise to water release at the dam sites and eventually have negative consequences on the study area. The flow regime of the River Niger below the Jebba dam is governed by the operations of the Kanji and Jebba Hydroelectric schemes and runoff from the catchments. The annual 'white floods' event which usually sets in July and peaks in September does not maintain the same frequency as almost every four years the flood sets in with greater velocity, this lead to the dam overflowing its banks. This has caused destruction to sugar cane plantation as a result of inundation of sugar cane field, irrigation pumps and submerging of farmlands occupied by various villagers. According to Lawal and Nagya (1999), Bolaji (1999), Olukanni and Salami (2008) and Sule, et. al. (2009) the havoc wreaked by the flooding of the lower Niger in 1998 and 1999 also has its effect on social services to the people of the area. For example, schools in about 32 and 52 villages were submerged in the flood of 1988 and 1999 in the downstream of Jebba respectively, while schooling for fleeing villagers remain disrupted and the hospitals were not spared by flood

Materials and methods

The data required in this study are mainly data on the monthly electricity generation in the power dam and information on the reservoir elements. These data were collected from the Hydrology Department of Power Holding Company, (Jebba Business District)

Jebba Hydropower Dam. A total of 10 hydro engineering/ reservoir elements were studied on monthly basis in this study. These are minimum inflow, storage balance, evaporation, average outflow, peak inflow, peak outflow, reservoir level, average inflow, minimum evaporation outflow and discharge. These parameters were sampled for 9 years (1990-1998).

The data collected were subjected to both descriptive and inferential analyses. The descriptive methods used in this study are: mean, frequency analysis and graphs. The inferential method used is the factor-regression model, which is combination of factor analysis and multiple regression and stepwise regression methods. The factor regression model (West, 2002; Carvalho, 2008) or hybrid factor model (Meng, 2011) is a special multivariate model with the following form.

$$y_n = Ax_n + Bz_n + c + e_n \dots \dots \dots (eq1)$$

Where,

y_n is the n -th $G \times 1$ (known) observation.

x_n is the n -th sample L_x (unknown) hidden factors.

A is the (unknown) loading matrix of the hidden factors.

z_n is the n -th sample L_z (known) design factors.

B is the (unknown) regression coefficients of the design factors.

c is a vector of (unknown) constant term or intercept.

e_n is a vector of (unknown) errors, often white Gaussian noise.

The factor regression model can be viewed as a combination of factor analysis model

$$(y_n = Ax_n + c + e_n \dots \dots (eq2)) \text{ and regression model}$$

$$(y_n = Bz_n + c + e_n \dots (eq3)).$$

Alternatively, the model can be viewed as a special kind of factor model, the hybrid factor model

$$\begin{aligned} \mathbf{y}_n &= \mathbf{A}\mathbf{x}_n + \mathbf{B}\mathbf{z}_n + \mathbf{c} + \mathbf{e}_n \\ &= [\mathbf{A} \quad \mathbf{B}] \begin{bmatrix} \mathbf{x}_n \\ \mathbf{z}_n \end{bmatrix} + \mathbf{c} + \mathbf{e}_n \\ &= \mathbf{D}\mathbf{f}_n + \mathbf{c} + \mathbf{e}_n \end{aligned} \quad \dots\dots\dots (\text{eq. 4})$$

where, $\mathbf{D} = [\mathbf{A} \quad \mathbf{B}]$ is the loading matrix of the hybrid factor model and $\mathbf{f}_n = \begin{bmatrix} \mathbf{x}_n \\ \mathbf{z}_n \end{bmatrix}$ are the factors, including the known factors and unknown factors.

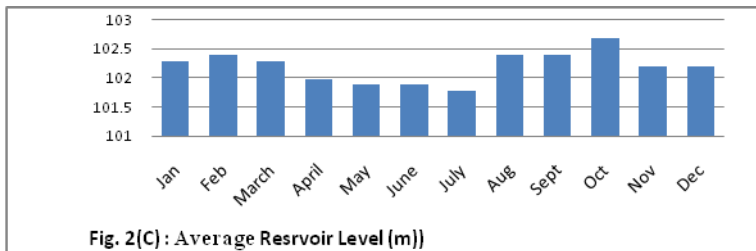
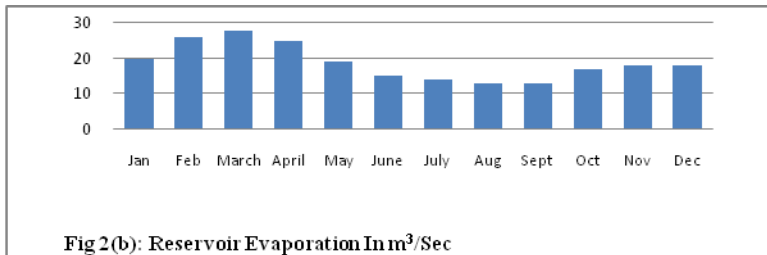
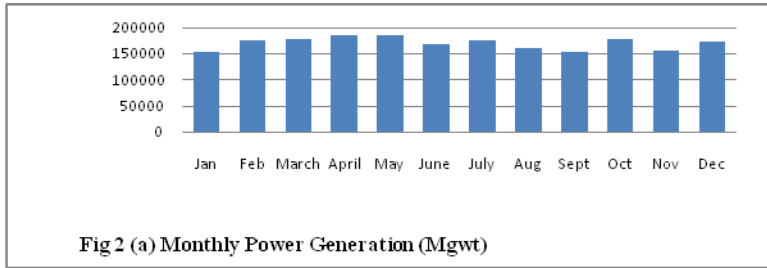
Factor analysis was used for data reduction purposes: To get a small set of variables preferably uncorrelated from a large set of variables most of which are correlated to each other in the data set. Multiple regression in form of factor -regression (where the orthogonal factor scores were used as input into the regression model) was used to study the relationships between reservoir elements and electricity generation. Stepwise regression analysis was used as a (reduce-rank model) to reduce and to model power generation in Jebba. Altogether, 24 mathematical operations were carried out; which is a breakdown of 2 factor regression modeling operations per month (one each for factor-multiple and factor-stepwise regression).

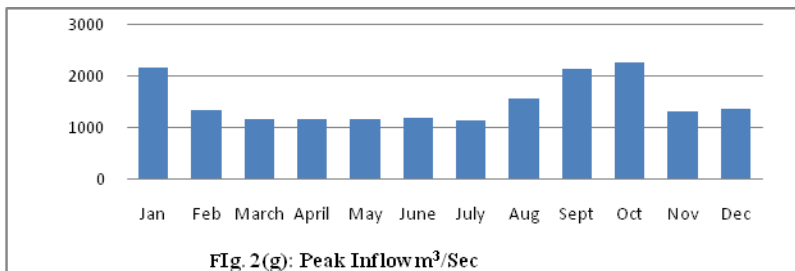
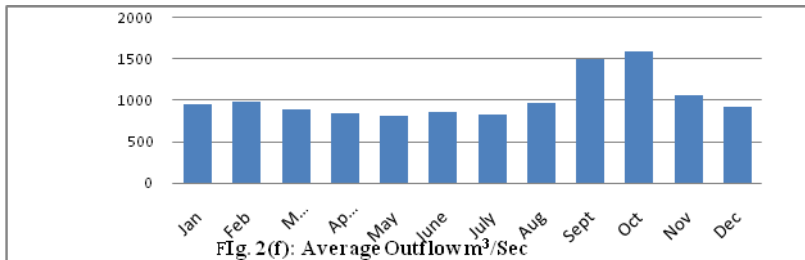
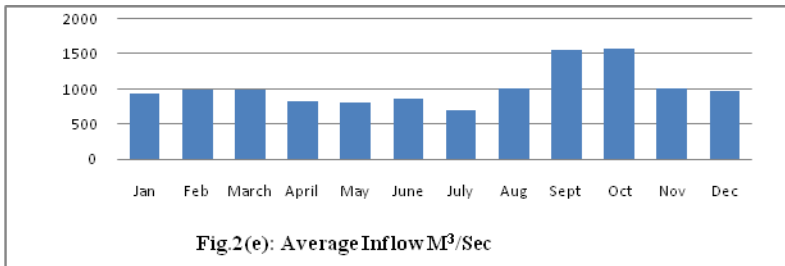
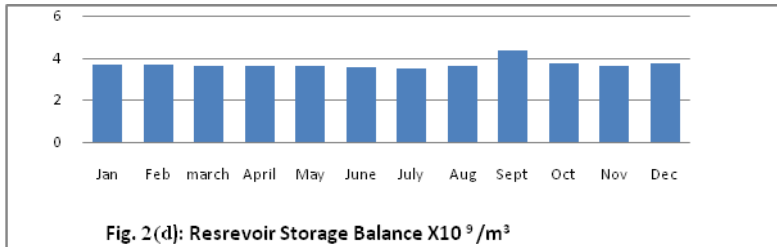
Results and Discussion

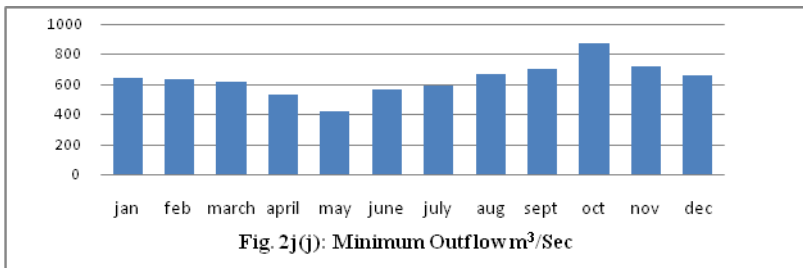
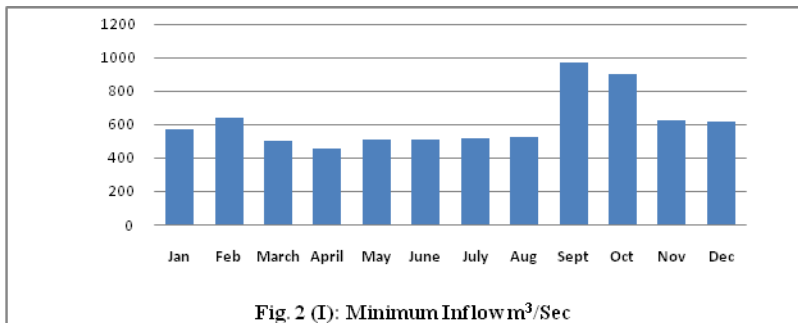
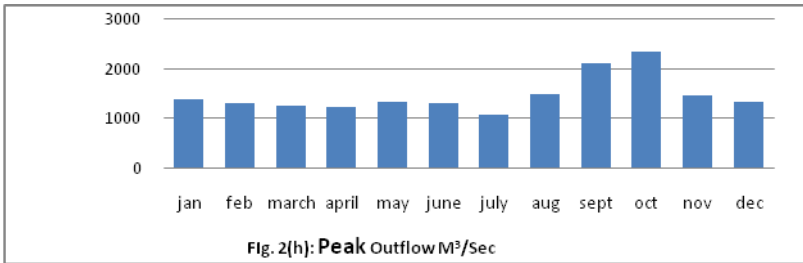
Monthly pattern of reservoir elements

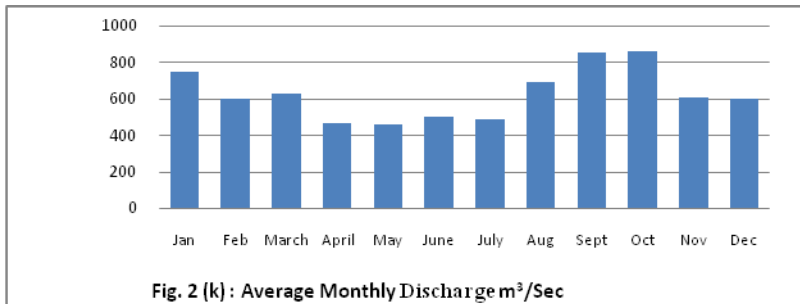
Figures 2 (a-k) clearly describe the pattern exhibited by individual reservoir elements between 1990 and 1991. The pattern exhibited by these elements trend along the double peak seasons (white and black flood) in the reservoir. For example, 10 different elements (namely: power generated, reservoir level, average inflow, average outflow,

peak inflow, peak outflow, minimum inflow, monthly discharge, storage balance and average discharge) have their peaks during the black flood season of September / October. In the same vein, almost all these elements have their least values in the off-peak periods of April to July. This further confirms that power generation and these elements are largely controlled by the hydrology of river Niger at Jebba.









Monthly of Redundancy

According to the results of factor analysis presented in Table 1; the 10 reservoir elements examined in this paper have various pattern of redundancies. For example, percentages of explanation of factor analysis range from 79.2% in April to 92.7% in December, with percentages of redundancies ranging from 7.70% in December to 20.8% in April (Table 1 and Fig 3(a, b, c.). The analysis of this is seen below

a) January

In the Month of January, only 3 parameters, namely: peak inflow, storage balance and lake evaporation were responsible for 90.6% of the variance in the equation. The other 7 elements contributed only 17.4% explanation. These other 7 variables were not significantly important to the equation in January.

b) February

In February, 4 hydro elements, namely: minimum inflow, storage balance, average outflow and peak inflow contributed 90.0% to the equation, while, 6 elements contributed 9.3% to the explanation. This implies that only 4 elements were relevant to the equation in February

c) March

The trend in March is similar to what obtains in the previous month. Minimum inflow, storage balance, average outflow and peak inflow

were responsible for 91.1% explanation in March. The remaining 6 element could only explain 8.9% of the variance in the equation.

d) April

In April, the percentage explanation was 79.2%, with peak outflow, storage balance, and average inflow as the contributory elements. The extent of redundancy in this month is 20.8%. However, 7 elements accounted for this.

e) May

The redundancy in the equation in May was 10.3%, this was contributed by 6 variables. The percentage explanation recorded by 4 factors (peak inflow, reservoir level, average outflow and evaporation) was 89.7%.

f) June

In June, the redundancy was almost similar to what obtains in May with 11.2%, 4 factors contributed 88.8% explanations in the equation. These factors are: minimum inflow, average outflow, discharge, and reservoir level.

g) July

Three elements were relevant to the explanation in July, these contributed 88.0% explanation to the variance in the equation. They are discharge, storage balance, and minimum outflow. Other 7 elements contributed 12.0% explanation to the variance in the equation.

Table 1: Model Summary of Reduce-Rank Model of Reservoir Elements and Power Generation in Jebba

Month	Reduction				Ranking						
	Factors Defining Variables				Regression						
	Reservoir Elements	Percentage Contribution (%)	Cumulative Contribution	(%) Redundancy	Stepwise regression				Multiple regression		
Reservoir Elements In The Equation					Individual Contribution	Cumulative Contribution	% Explanation Outside The Equation	% Explanation	% Explanation Outside The Equation	% Reduction	
January	Peak Inflow	49.6	82.6	17.4	Discharge	57.8	57.8	42.2	59.3	40.7	1.50
	Storage Balance	20.0									
	Evaporation	12.9									
February	Minimum Inflow	33.6	90.7	9.30	Peak Inflow	93.0	95.7	4.30	98.5	1.50	2.80
	Storage Balance	24.9									
	Average Outflow	21.7									
	Peak Inflow	10.3			Minimum Inflow	2.70					
March	Minimum Inflow	33.6	91.1	8.90	Storage	69.8	87.3	12.7	95.3	4.70	8.00
	Storage Balance	25.0									
	Average Outflow	21.7			Average Outflow	17.5					
	Peak Inflow	10.7									
April	Peak Outflow	37.4	79.2	20.8	Nil	0.00	0.00	100	13.4	86.6	13.4

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	Storage balance	26.4									
	Average Inflow	15.4									
May	Peak Inflow	27.5	89.7	10.3	Reservoir Level	95.0	95.0	5.00	97.6	2.40	2.60
	Reservoir Level	25.5									
	Evaporation	11.2									
	Average Outflow	25.4									
June	Minimum inflow	24.9	88.8	11.2	Reservoir Level	78.5	78.5	21.5	96.9	3.10	18.4
	Average Outflow	23.9									
	Discharge	16.2									
	Reservoir Level	23.7									
July	Discharge	37.4	88.0	12	Discharge	87.1	87.1	12.9	89.0	11.0	2.00
	storage balance	36.4									
	minimum outflow	14.2									
August	Average Outflow	37.4	88.0	12	Discharge	87.5	87.5	12.5	89.1	10.9	1.6
	Storage Balance	36.4									
	Discharge	14.2									
September	Minimum Inflow	33.0	87.4	12.6	Peak Inflow	72.2	72.2	27.8	79.7	20.3	7.50
	Average Outflow	30.8									
	Reservoir Level	23.6									
October	Peak Inflow	38.4	84.3	15.7	Peak Inflow	84.4	84.4	15.6	85.8	14.2	1.40
	Storage Balance	25.0									
	Average Inflow	20.9									
November	Average Inflow	27.9	80.9	19.1	Discharge	52.0	52.0	48.0	54.0	46.0	2.00

	Peak Inflow	27.4									
	Discharge	25.4									
December	Peak Outflow	26.0	92.3	7.70	Evaporation	55.5	55.5	44.5	91.0	9.00	35.5
	Minimum Outflow	18.2									
	Storage	17.4									
	Discharge	15.8									
	Evaporation	14.8									

Source: Authors computation 2012

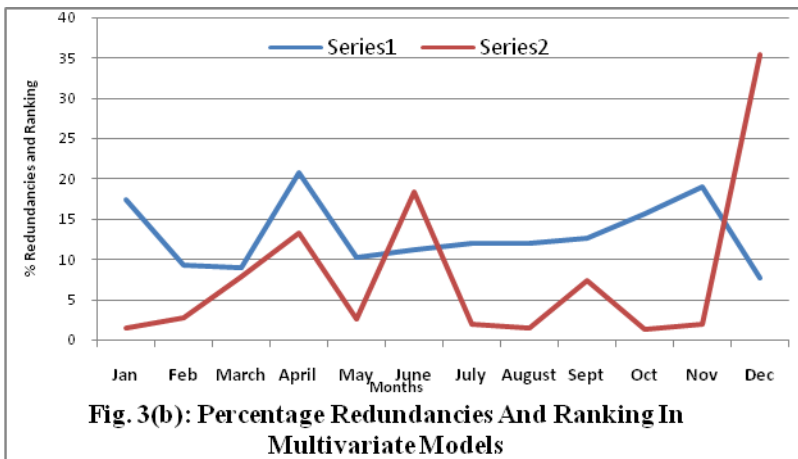
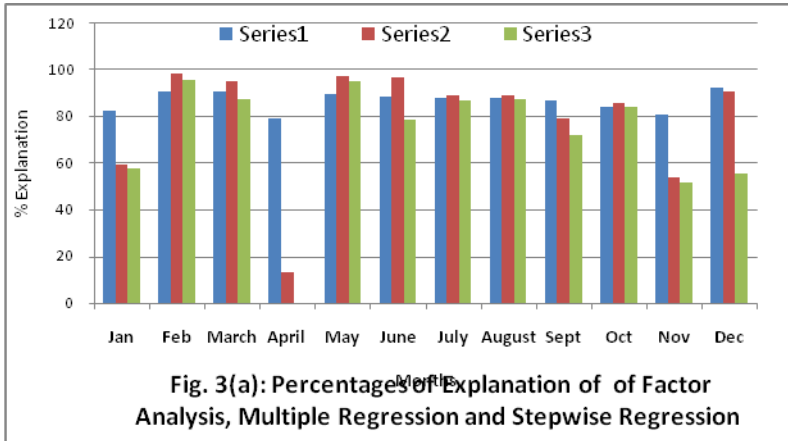


Fig.3(a)

Series1=Factor Analysis;

Series2=Multiple Regression

Series 3=Stepwise Regression Analysis

Fig3(b)

Series1=Factor Analysis;

Series 2= Stepwise Regression Model

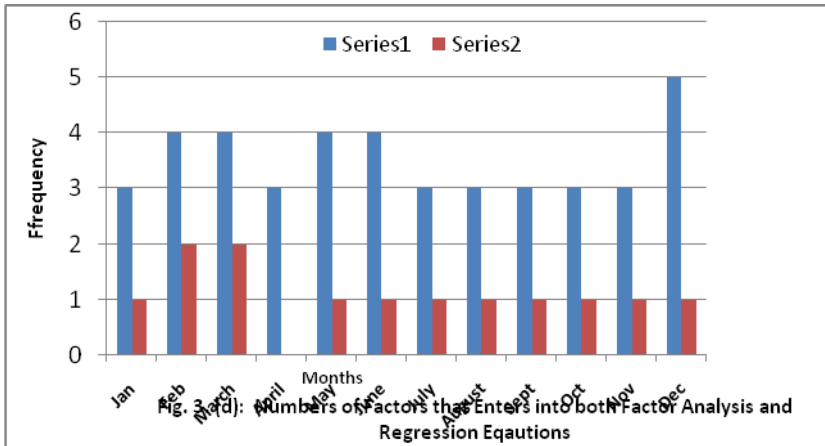
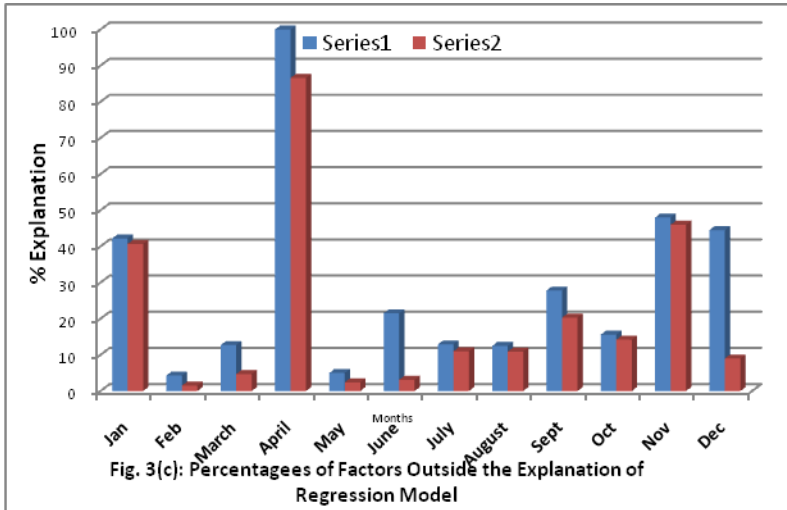


Fig. 3(c):

Series 1: Stepwise Regression

Series 2: Multiple Regression

Fig 3(d):

Series 1: Factor Analysis

Series 2: Stepwise Regression

h) August

The percentage redundancy in August was similar to what obtains in July (12.0%). However, the factors included in the explanation were different from what obtains in July. They are average outflow, storage balance and discharge; which together made a cumulative explanation of 88.0% explanation.

i) September

In September, 3 elements were also responsible for the explanation. These are minimum inflow, average outflows and reservoir level; they provided 87.4% explanation to the variance in the equation. The level of redundancy computed in September was 12.6% of which seven elements accounted for.

j) October

The total contributions of the 3 factors in October were 80.9% (peak inflow, storage balance and average inflow). The percentage redundancy was 15.7%, which was contributed by 7 variables.

k) November

In November, peak inflow, storage balance and average inflow contributed a total explanation of 84.3% to the variance. The level of redundancy was 19.1%.

l) December

The month of December has a contribution of 92.3% to the variance. The factors responsible for this are: peak outflow, minimum outflow, storage balance, discharge and evaporation.

Two patterns were discernable in the explanation of redundancies exhibited above. These are: high and low redundancies. High level redundancies were exhibited in January, April and November. Other months exhibited low redundancies in their explanations. This is patterned closely after the reservoir regime. For example April and

November are generally season of low inflow (Fig2e-k) hence; high redundancies were common during period of low inflow. In the same vein, low redundancies were noticed during periods of high reservoir inflow (Figs. 2(e-k)).

Percentage Ranking

The percentage prediction done by multiple regressions was later reduced by using stepwise regression to rank and reduced the factors to a few orthogonal ones. The percentages of explanation of multiple regression also vary from 13.4% in April to 98.5% in February, while its monthly percentages of explanations outside the multiple regression equations range between 1.50% in February to 86.6% in April. Also, the percentages of explanations of stepwise regression equation range between 0.00% in April to 95.7% in February and its rates of redundancies range from 4.30 % in February to 100% in April. That will be best predict power generation in the reservoir (Table 1, Fig 3a, b, c, d)). The results also showed different degree of redundancies.

a. January

The 3 factors which produced the factor analyses were able to produce 59.3% explanation. The stepwise regression analyses showed that only discharge explained 57.8%, while the stepwise multiple regression model, had an explanation of 57.8%. Peak inflow and lake evaporation accounted for 1.50% explanations in power generation in January.

b. February

Four factors (minimum inflow, storage balance, average outflow and peak inflow) explained 98.5% of the total variance in electricity generated in Jebba in February. The result of the stepwise regression shows that peak inflow and minimum inflow contributed 95.7% explanation to power generation. This implies that storage and

average outflow had a negligible contribution of 2.80% to power generation in February.

c. March

In March, minimum inflow, storage balance, average outflow and peak inflow predicted 95.3% of the electricity generated in Jebba; further analysis by stepwise regression show that 2 elements (storage balance and average outflow) predicted 87.3% of the 95.3% explanation. The other 2 elements only accounted for 8.0% explanation, suggesting that they are weak in their contribution to the explanation.

d. April

In April, the model predicted that 13.4 % of the electricity generated in Jebba is a result of peak outflow, storage balance and average inflow. All these factors equally entered the regression equation. This implies that 86% of the explanations for electricity generated are as result some other careful skills. The level of prediction was least in April; this is understandable in view of the low level of inflow in the reservoir. Fig. 2 (g-i) shows the month of April to have the least inflow.

e. May

The result presented in Table 1 suggests that in May, peak inflow, reservoir, evaporation and average outflow accounted for 97.6% of the power generated in Jebba dam. The result of stepwise regression shows that the elements have been reduced to only reservoir level which alone accounted for 95% of the energy generated. This implies that peak inflow, evaporation, and average outflow only accounted for 2.60% of the energy generated. May is also having low in flow. The higher the reservoir level the high the height of water and the more efficient the turbine production.

f. June

The result of the stepwise regression analysis in Table 1 shows that, reservoir level alone predicted 78.5% of the total explanation for the month of June. This shows that 9 other variables accounted for 21.5% of the variance. Again June is a period of low inflow in Jebba and the reservoir level is expected to play significant role in determining the energy produced.

g. July

About 89.1% of the electricity generated for July was due to discharge, storage balance and minimum outflow. The stepwise regression showed that only discharge accounts for 87.1% explanation. This implies that 3 reservoir elements accounted for only 5% variance in the explanation. The dominance of discharge is expected because July marks the beginning of the local flood water inflow in Jebba; it is also a time when storage is increasing.

h. August

In August, 89.1% of electricity is due to average outflow, storage balance and discharge. The percentage contribution of discharge was 87.5%. This shows that the other 2 factors contributed 1.4% explanation. The role of discharge is due to the incoming white flood, during which inflows are increasing and reservoir storage is increasing.

i. September

The 3 elements: peak inflow, average outflow, and reservoir level contributed 79.7% explanation to electricity generation. The stepwise regression on the other hand shows that 72.2% was contributed by minimum inflow. In September 7.5% of electricity generated was explained by 2 elements.

j. October

The percentage explanation in October shows the 3 reservoir element having an explanation of 85.8%, while, peak inflow alone predicted 84.4 % of the generated electricity. Hence, 2 elements predicted 1.6% of the electricity generated. The role of peak inflow in October is expected because October marks the highest inflow (Figs 2(c-k)); it is the most hydrologically active month in Jebba.

k. November

In November, average inflow, peak inflow and discharge predicted 54 % of the energy generated. Discharge alone predicted 52% of the energy generated. Hence, only 2% is explained by average inflow and peak inflow. This shows the level of reduction in the equation. The dominance of discharge is simply explained with the fact that in November the inflow is equally low and therefore discharge should be carefully managed in other to retain enough water in the reservoir. If too much water is discharged, then reservoir level will drop, storage will drop and power generation will be affected.

l. December

The 5 elements predicted 91.1% of the variance in the equation. The result of the stepwise regression shows that evaporation alone has a contribution of 55.5% in the variance, while the 4 other elements (peak outflow, minimum outflow, reservoir storage and discharge) contributed 35.5%. Fig 2(b) shows that November has a relatively high rate of lake evaporation. The month of October is cloudless, dry and generally hazy in Jebba and environ, therefore rates of potential evaporation will be high. Hence, this shows that some measure should be taken to reduce open water evaporation in November.

According to the above the percentages of explanation of factor analysis range from 79.2% in April to 92.7% in December, with percentages of redundancies ranging from 7.70% in December to 20.8% in April. The percentages of explanation of multiple regression

also vary from 13.4% in April to 98.5% in February, while its monthly percentages of explanations outside the multiple regression equations range between 1.50% in February to 86.6% in April. Also, the percentages of explanations of stepwise regression equation range between 0.00% in April to 95.7% in February and its rates of redundancies range from 4.30 % in February to 100% in April. This results shows that high levels of redundancies are exhibited in the association.

Two patterns are discernable in the pattern of explanation of redundancies exhibited by factor analysis. These are: high and low redundancies. High level redundancies were exhibited in January, April and November. Other months exhibited low redundancies in their explanations. This is patterned closely after the reservoir hydrological regime of low flow and high flow. For example, April and November are generally season of low inflow (Fig2e-k) hence; high redundancies were common during this period of low inflow. In the same vein, low redundancies were noticed during periods of high reservoir inflow (Figs2e-k).

The pattern exhibited by the percentages of explanations of both multiple and stepwise regression can be classified into 3 (see: Fig 3(b)) patterns. These are the high, moderate, and low patterns. As describe in Fig 3(b) November has the highest redundancy of 35%. April and June can be termed as moderate, while others have low redundancies. Figs 2 (a-k) shows that November and December have low peak flows. In April and June inflow is also low. In January, and October peak inflow is high. This therefore suggests that hydrological regime of Jebba reservoir dicatetes the contribution of the reservoir elements to power generation in Jebba. This study have therefore shown that reservoir elements are more active and contribute better to power generation in the months with high inflows compared to months with low inflows.

Implication for Reservoir Management

There is need to understand, the monthly contribution of the elements, as it will provide clues to efficient power generation. Such information will allow the computation of appropriate operation rules that will assist in driving reservoir operation for efficient energy generation.

The pattern exhibited by the power generation and reservoir elements closely trend after flow regime experienced in the Jebba reservoir. High rates of redundancies were common in the periods of low inflows such as April, June, November, etc. while, low rates of redundancies were recorded in the months of high peak inflows such as January, August, September and October. The results further show that in the hydrological moderate season (off-peak flow period and off-low flow period) more reservoir elements were more useful in determining power generation, as less redundancies were recorded. Certain variables were prominent at different time depending also on the reservoir flow regime. Discharge was prominent at the beginning and the end of flood seasons, suggesting that at these 2 times water inflow needed to be properly managed. Also, evaporation, lake level and reservoir balance became prominent in power generation during the low inflow seasons. Hence, it can be concluded that a strong relationship exist between reservoir elements and power generation in the Jebba reservoir. Inflow plays significant role in reservoir operations in Jebba. This position should be taken into consideration in designing reservoir rules for Jebba dam. Meanwhile, frantic efforts should be made to reduce evaporation particularly from the months of November to March in the reservoir. This will go a long way in ensuring that more water is available for generation.

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