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ASSESSMENT OF JEBBA HYDROPOWER DAM OPERATION FOR IMPROVED ENERGY PRODUCTION AND FLOOD MANAGEMENT

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ABSTRACT

One of the reservoir management options for flood moderation and energy production is the operation of Hydropower Dams to protect people and their socio-economic activities in flood plain areas. This study focuses on assessing Jebba Hydropower Dam Operation for improved energy production and flood management. Available Data for 27-year period (1984 - 2011) such as inflow, elevation, turbine release, generating head, energy generation, tailrace water level and plant coefficient was obtained from Jebba Dam Station. The present reservoir-operating rule was investigated using statistical analysis to model the operation of the multi-purpose reservoir. Statistical tests carried out in accordance with standard procedure include chi-square (χ^2), probability plot coefficient of correlation (r), and coefficient of determination (R^2). The results show that the optimal solution at operating performance of 50% reservoir inflow reliability has the total annual energy generation of 42105.63MWH with adequate water supply for downstream users and for irrigation throughout the year with annual optimal evaporation losses averaged at 58.16Mm^3. Average optimal energy generation obtained is 19% of the observed energy generation but with adequate water supply for downstream users and for irrigation throughout the year. It is, therefore, essential to develop a decision-making framework capable of handling the conflicting demands.

Keyword: Jebba hydropower dam, flood management, energy production, operating performance.

1. INTRODUCTION

The operation of Hydropower Dams (HDs) often impacts environmental and ecological balance. When inflows are low, energy output from HDs sources is limited and on the other hand when large water outflow occurs, it can cause flooding to adjoining lands downstream of the dam, where the flood plains are regions of economic, social and agricultural activities [1, 2]. The operations of the Jebba hydropower schemes and runoff from catchments govern the flow regime of the Jebba dam. Releases from Kanji HEP dam constitute the major inflow into Jebba HEP dam since it lies directly under it. This means that the more the release from upper reservoir, the faster the downstream reservoir fills up and the excess will be discharged thereby leading to flooding. The communities in the flood plains experience annual flooding when the authorities of dam station open the gates of the dams to let off water at the peak of the rains. The occurrence of flood has great effect on communities and farming activities downstream of Jebba dam [2]. In the same vein, the inability of the hydropower stations to operate at installed capacity could be attributed to the following reasons:

a) Hydrological factors such as: seasonal variation in flow to the reservoir; inter-annual variation in flow to the reservoir; conflict among competitive uses; and sediment trapped in the reservoir.
b) Non-hydrological factors such as: maintenance and spare parts problems; inadequate fund; human resources; and policy issues.

Globally, the most widely used form of renewable energy that accounts for 16 percent of world electricity consumption and 3,427 terawatt-hours of electricity production is hydroelectric energy. It is a flexible source of electricity since plants can be ramped up and down very quickly to adapt to changing energy demands. However, damming interrupts the flow of rivers and can harm local ecosystems. Building large dams and reservoirs often involves displacing people and wildlife and requires significant amounts of carbon-intensive cement [3]. Current studies on hydropower systems operations primarily focus on multiple uses of water in order to satisfy human needs and demands connected to economic and social activities. Brandao [4] expressed that water resources exploitation and control systems to satisfy human needs include power generation, urban and industrial water supply, irrigation, navigation, flood control and water pollution control.

Meeting the growing demands for electricity creates difficult decisions for many countries and the context of decision making is also changing, particularly in the light of climate change imperatives that encourage a move from emitting greenhouse gas. Despite these strengths, hydropower developments over the past-decades have been highly controversial due to accompanying social and environmental challenges [5]. Nigeria's per capital electricity consumption is said to be just 7% of

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Brazil's, and just 3% of South Africa's. Brazil has 100, 000 Mega Watts (MW) of grid-based generating capacity for a population of 201 million. South Africa has 40, 000 MW of grid-based generating capacity for a population of 59 million. In August 2010, the peak generating supplied by Nigeria's Power Holding Company (PHCN) was just 3, 804 MW for a population of 150 million, which is about 60% of her total potentials of 6, 380 MW of installed electric power generation capacity consisting of three hydropower plant and six thermal power plants [6]. The combined installed capacity of power stations in Nigeria is far below the country's electricity demand, resulting in epileptic supply of electricity. The situation is compounded by the failure of the existing power stations to operate at its installed capacity [7]. The potential for hydropower is usually assessed in terms of overall energy output, the maximum suitable installed power generation capacity and the typical variations in power production. Some factors such as fluctuations in demand, limitations in the power transfer grid, river discharge fluctuations and the feasibility of water storage and creating a head fall for energy production affect this potential [8].

In addition, the role reservoirs play in flood management is very important. Reservoirs store flood water and reduce flood risks by attenuating the flood peaks and intensity of flooding in the downstream reaches. The operations of reservoir for flood moderation play an important role in protecting people and their socio-economic activities in flood plain areas. In order to measure the hydrologic impacts of dams on the monthly level, Ritcher et al. [9] accounted for two characteristics; i.e. magnitude and duration of flows, while Lajoie *et al*. [10] considered the influence of watershed size and seasons. Additionally, some researchers took into account the root mean square error [11], coefficient of variation or coefficients of skewness [12], to evaluate the hydrological alteration by reservoirs. However, for proper operation of reservoirs during floods, managers are required to make precise and timely judgment on establishment/cancellation of flood control procedures, preparation of release/storage plans etc., based on available information. Although climate change may affect water resources and may lead to significant variations of the potential for hydropower at a country level, these variations are expected to cancel out roughly on the global scale, leaving the overall potential virtually unaffected [13, 14, 15]

Hydropower generations in Nigeria is estimated to be about 35.6% of the Nigeria's electricity sources with gas estimated at 39.8% and oil, 24.8% [16]. Because of the insufficiency of gas, hydropower has a larger advantage in that, once it is constructed, electricity can be produced at a constant rate. There is an urgent need to address the shortfall in the energy generation of Jebba Hydropower station through the development of operation scheme. Though, intense power sector reforms are currently being engineered nation-wide as revealed by studies, very little has been done to harness its abundant potentials. A range of factors limit hydropower potential which includes river discharge and its variation, landscape topography and environmental considerations, technical capacity, e.g., turbine design, limitations of the electrical transmission system, technical flaws and functionality of the energy market [8]. It was expressed by Worman et al. [17], that the annual discharge of rivers limits the overall energy from hydropower plants.

The determination of the amount of reservoir for a specified purpose such as flood control is based on hydrologic analyses that are governed by project formulation criteria. It is recognized that maintaining (in the case of new dams) or re-establishing (in the case of existing dams) the natural river condition by managed flow may not always be possible and may require a conflict management mechanism to adopt the approach. In addition, the available resources cannot meet the demands of all purposes in a given system, it is essential to objectively evaluate the system potential and the best form of operation. Therefore this study emanates from the need to assess Jebba Hydropower Dam operation for improved energy production and flood management in order to develop a decision-making framework capable of handling the conflicting demands.

2. METHODOLOGY

2.1 Description of study area

Jebba Hydroelectric Power Station is along River Niger, Nigeria, located between latitudes 9^o 10' N to 9^o 55' N and longitudes 4^o 30' E to 5^o 00' E at 76 m above sea level (about 100 kilometres downstream of Kainji dam). The station is one of the most cost-effective sources of electricity in Nigeria. It has maximum length of 100 kilometres (km), maximum depth of 32.5km, maximum width of 10 km and a mean depth of 3.3 m. The surface area is 350 km^2, maximum volume of 1000 x 10^6 m^3, operating head of 27.6 m and maximum flow per unit of 380 m^3/s. The dam, which has a generating capacity of 540 MW from six (6) turbines of 95 MW of power each, is enough to power over 364, 000 homes at operating head of 27.6 m. Each turbine is coupled to a generator of 119 MVA maximum continuous rating and 103.50 MVA base load rating. The dam was developed and constructed in 1979 and there has been no overhaul of the dam since inception. However, the station has been able to carry out routine minor and major repair works, and preventive maintenance which has kept the station performance well above average. Figure-1 show the location of Jebba Hydropower Dam on the Nigeria map and Table-1 represents the basic data on Jebba Hydropower System. Figure-2 shows the System Diagram of the Study Basin.

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Figure-1. Location of Jebba hydropower dam (JHD) on Nigeria map
(Source: Google Map, 2016).

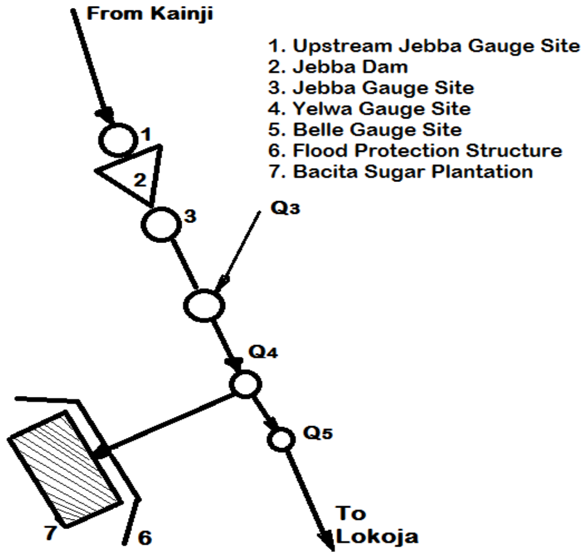

Figure-2. System diagram of the study basin.

Table-1. Basic data on the Jebba hydropower system.

First Year of Operation	1984
Installed Capacity (MW)	540
Design power plant factor	0.70
No. of generators	6
Reservoir flood storage capacity (Mm^3)	4,000
Reservoir flood level (m)	103.55
Water Surface Area (Km^2) at El. 103.0m	303.00
Maximum operating reservoir elevation (m.a.s.l)	103.00
Minimum operating reservoir elevation (m.a.s.l)	99.00
Maximum storage (Mm^3)(active storage capacity)	3,880
Minimum storage (Mm^3)(Dead storage capacity)	2,880

Source: Power Holding Company of Nigeria (PHCN) [18]

2.2 Variation in reservoir storage

According to the World Meteorological Organization [19], the daily change in reservoir storage (Δv) should reflect how the reservoir is operated. Operation planning for hydropower reservoirs is more focused on peak generation. Although the ability to shift from one unit to another increases the power network reliability [20]. In the case of a reservoir built for flood control, a consistent relationship between impoundment and change in flow variables can be expected [7, 21]. However, for a reservoir built for irrigation and hydroelectric generation, a noisy relationship should be expected because flood reduction normally would not be the main purpose [22]. From Figure- 3, it can be found that reservoir inflow has a tendency to increase the reservoir storage, because its contribution to Δv is positive. The amount of its contribution becomes larger and larger as time approaches the wet season and then becomes less and less as time approaches the dry season with the maximum value normally observed in June and minimum in February.

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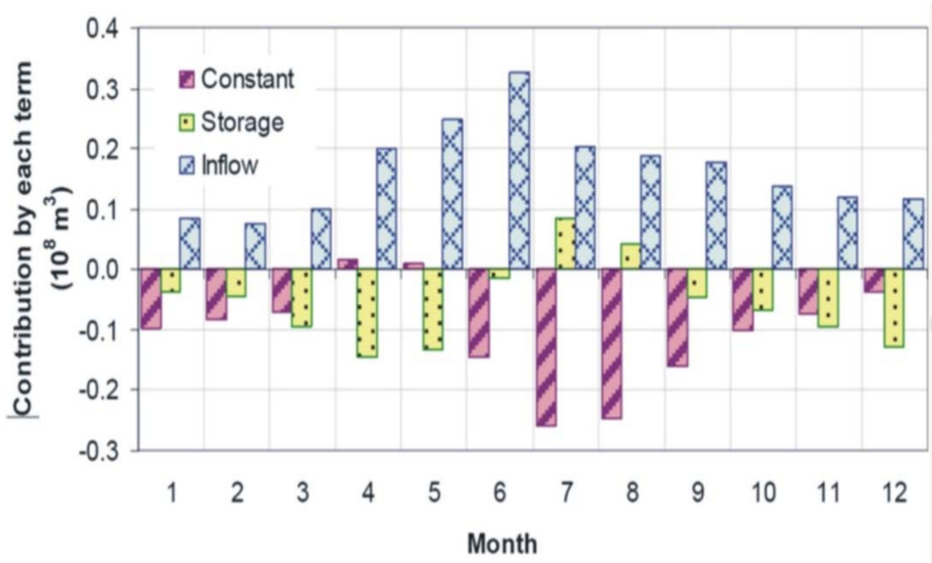

Figure-3. Contribution to the daily change of reservoir storage by each term
Source: world meteorological organization (2006).

It can also be deduced from Figure-3 that reservoir inflow increases the reservoir storage in July and August, and decreases the storage in the other months. This reflects the fact that reservoir operator is inclined to release water as the water level in the reservoir goes up in the pre-flooding season (April to June) so as to hold more possible flood water later, and store water in the post-flooding season (July and August) to maintain a relatively higher water level for the consideration of power generation. In dry season (September to March), the amount of inflow is small, so the reservoir operator has to release water to meet the demand for power generation and other purposes such as navigation, water supply, arresting seawater intrusion, etc. That is why, as shown in Figure-3, the amount of the contribution by the storage is negative (i.e. releasing water) in this period. The reservoir inflow in dry season, mainly caused by base flow from the upstream sub-basins, usually becomes less and less, with the minimum value observed at the end of the dry season (February to March). Then the absolute amount of the contribution by the reservoir storage becomes relatively larger and larger with the maximum value observed in April to compensate the less inflow for the sake of power generation and other demands from downstream. And in June, the influence of the reservoir storage on the reservoir operation reaches the minimum level when the influence of the inflow on the reservoir operation reaches the highest level [19].

2.3 Data collection and analysis

Tables 1 to 6 show average monthly statistical summaries for Hydropower data such as the average of reservoir inflow (I), storage (S), elevation (H), turbine release (Q), energy generation (E), and tail race water level (T) for period of 27 years (1984 – 2011) at the Jebba Hydropower station that were obtained. The data collected were subjected to statistical analysis which covered descriptive statistics to obtain statistical parameters such as mean, median, standard deviation, skewness coefficient variance, maximum and minimum values of the variables as shown in Tables-1-6. Statistical tests carried out in accordance with standard procedure include chi-square (χ^2), probability plot coefficient of correlation (r), and coefficient of determination (R^2).

2.4 Generating head as a function of reservoir storage

The elevation and storage data from the topographic map of Jebba reservoir impounding area along with the minimum operating reservoir elevation are presented in Table-2. The reservoir elevation can be plotted against the storage and the minimum operating reservoir elevation subtracted to obtain the relationship for generating head along with the coefficient of determination R^2.

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Table-2. Reservoir elevation-storage data and the minimum operating reservoir elevation.

Reservoir elevation, H_r **(m)**	Reservoir capacity S **(Mm^3)**	Minimum operating reservoir elevation, $H_{min2,t}$ **(m)**
100.00	3050	99.00
100.25	3110	99.00
100.50	3180	99.00
100.75	3240	99.00
101.00	3300	99.00
101.25	3380	99.00
101.50	3460	99.00
101.75	3530	99.00
102.00	3600	99.00
102.25	3670	99.00
102.50	3730	99.00
102.75	3810	99.00
103.00	3880	99.00

Source: Technical report on Jebba Hydropower Station (2012)

2.5 Estimation of reservoir inflow of various Probabilities of exceedence

The reservoir inflow was fitted into normal distribution based on the monthly mean and standard deviation of the historical data. The normal models obtained for the month of January to December are presented in equations (1) to (12) respectively, the predicted reservoir inflow of 50%, 75%, 90%, and 95% probabilities of exceedence and statistical parameters are presented in Table-3.

$$Q_{January} = 2816.34 + 999.71K \quad (1)$$

$$Q_{February} = 2494.06 + 819.14K \quad (2)$$

$$Q_{March} = 2534.55 + 857.25K \quad (3)$$

$$Q_{April} = 2476.57 + 752.28K \quad (4)$$

$$Q_{May} = 2348.31 + 748.76K \quad (5)$$

$$Q_{June} = 2167.84 + 615.30K \quad (6)$$

$$Q_{July} = 2074.62 + 787.14K \quad (7)$$

$$Q_{August} = 2784.15 + 1223.48K \quad (8)$$

$$Q_{September} = 4233.31 + 1950.59K \quad (9)$$

$$Q_{October} = 4404.78 + 2548.70K \quad (10)$$

$$Q_{November} = 2699.38 + 877.80K \quad (11)$$

$$Q_{December} = 2908.65 + 693.42K \quad (12)$$

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Table-3. Reservoir inflow of different reliabilities (probability of exceedence) and Statistical parameters.

Probability of exceedence **(Reliability of flow)**							
	P	**50%**	**75%**	**90%**	**95%**	**Mean**	**Standard Deviation**
Month	K	0	-0.675	-1.285	-1.645	(Mm^3)	(Mm^3)
Jan		2816.34	2136.54	1526.71	1171.82	2816.34	999.71
Feb		2494.06	1937.04	1437.37	1146.57	2494.06	819.14
Mar		2534.55	1951.62	1428.70	1124.38	2534.55	857.25
Apr		2476.57	1965.02	1506.13	1239.07	2476.57	752.28
May		2348.31	1839.15	1382.41	1116.60	2348.31	748.76
Jun		2167.84	1749.44	1374.10	1155.67	2167.84	615.30
Jul		2074.62	1539.36	1059.21	779.77	2074.62	787.14
Aug		2784.15	1952.18	1205.86	771.52	2784.15	1223.48
Sept		4233.31	2906.90	1717.04	1024.58	4233.31	1950.59
Oct		4404.78	2671.67	1116.96	212.17	4404.78	2548.70
Nov		2699.38	2102.48	1567.02	1255.41	2699.38	877.80
Dec		2908.65	2437.13	2014.14	1767.98	2908.65	693.42

2.6 Model fitting for hydropower variables

Model identification method to fit the model with the least square technique was adopted. In this case, the monthly average inflow, storage, elevation, turbine release, energy production and tailrace water level of Jebba Hydropower station for 27 years were used. The detailed model fitting charts are shown in Figures 4 to 9, respectively. The model fitting process was done by computing the trend and random components of the respective data with parameters α and β using the equation [20]:

Random Component (I_R): $I_R = I_o - T$ (13)

Estimated value: $I_E = 2I_o - T$ (14)

where: T, I_o, I_R and I_E are the trend, the observed data, random component of data and estimated value, respectively.

As shown in Table-4, the peak value of the reservoir inflow occurs during the month of October (4404.78 m^3/s), while the low flow occurred during the month of June. The monthly variation of the reservoir inflow is presented in Figure-4. This consequently influences the storage of the reservoir as shown in Table-5 with a storage value of (3689.46 m^3). The summary of statistics of reservoir elevation at Jebba dam is presented in Table-6. During the 27 years of operation (1984 - 2011), the peak average reservoir elevation was 102.35 m, while the lowest average reservoir elevation was 101.11 m in the month of July. The monthly variation of the reservoir elevation is presented in Figure-6. The monthly trends of the observed and measured reservoir inflows, storage, elevation of inflow, turbine release, energy and tailrace water level were determined as shown in Figures-4 to 9, respectively.

2.6.1 Statistical goodness of fit tests

The acceptability and reliability of the probability distribution was tested by using statistical goodness of fit tests. The statistical tests include chi-square (χ^2), the probability plot coefficient of correlation (r), and the coefficient of determination (R^2). The statistical tests were carried out in accordance with standard procedure [21, 23, 24, 25, 26].

2.6.1.1 Chi-square (χ^2) test

The predicted values of the parameters with established probability distribution models was compared with the observed values and the chi-square was used to determine how well the theoretical distribution fits the empirical distribution. This test was based on the sum of the squares of difference between the frequencies. The expression for the analysis of chi-square is

$$\chi^2 = \sum_{j=1}^{N} \frac{\left(o_j - e_j\right)^2}{e_j} \quad (15)$$

where: o = observed flow; e = predicted flow and N = total frequency

Murray and Larry [25] stated that if the computed value of chi-square is greater than some critical value (such as $\chi^2_{0.95}$ or $\chi^2_{0.99}$ which is the critical values at the 0.05 and 0.01 significance level respectively), it could be concluded that the observed frequencies differ

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significantly from the expected frequencies and it would be rejected, otherwise it would be accepted. Hence, if the χ^2 value calculated from equation (15) is less than critical value from statistical table, the model can be concluded to be strong or the fit of the data is good. Another way by which the conclusion can be made is that if the value of the ratio of calculated chi-square to the tabulated chi-square (χ^2_{cal} / χ^2_{tab}) is less than one, the probability distribution is strong. The distribution function that gives value very close to 1 is the best for the data [25].

2.6.1.2 Probability plot correlation coefficient (PPCC)

This is used to evaluate the linearity of the probability plot, so that if the sample is actively drawn from the hypothesized distribution the PPCC (r) is expected to be close to one. The quantity (r) called coefficient of correlation is given as:

$$r = \pm\sqrt{\frac{\sum\left(Q_{est} - Q_{mean}\right)^2}{\sum\left(Q_{obs} - Q_{mean}\right)^2}} \qquad (16)$$

Where:

Q_{est} = the value of inflow estimated with the probability function

Q_{mean} = the mean value of the observed inflow and

Q_{obs} = the value of the observed Inflow

2.6.1.3 Coefficient of determination (R^2)

This is a measure of the strength of relationship between the predictor and response variables. According to [27], the coefficient of determination in the regression theory is defined as:

$$R^2 = \frac{E_o - E}{E_o} \qquad (17)$$

Where:

$$E_o = \sum_{i=1}^{N}\left(Q_{i(obs)} - Q_{i(mean)}\right)^2 \qquad (18)$$

$$E = \sum_{i}^{N}\left(Q_{i(obs)} - Q_{i(est)}\right)^2 \qquad (19)$$

$Q_{i(est)}$ is the model output in the i^{th} time period, $Q_{i\,(obs)}$ is the observed data in the same period and $Q_{i(mean)}$ is the mean over the observed periods. The model is strong, if R^2 is very close to one.

2.6.1.4 Error of estimate

Two errors of estimate were taken into consideration for comparison of results in accordance to [28]. The first of them is the Root Mean Square Error (RMSE), which is given as:

$$RMSE = \sqrt{n^{-1}\sum_{i=1}^{n}\left\{Q_{obs}(i) - Q_{pred}(i)\right\}^2} \qquad (20)$$

The second is the Mean Absolute Error (MAE), which is defined as

$$MAE = n^{-1}\sum_{i=1}^{n}\left|Q_{obs}(i) - Q_{pred}(i)\right| \qquad (21)$$

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Table-4. Model fitting for reservoir inflow (Mm^3) at Jebba hydropower dam.

	Time **(month)**		Mean Observed Reservoir Inflow **(Mm^3)**		Reservoir Inflow (linear trend) **(Mm^3)**	Random Component	Mean Estimated Reservoir Inflow **(Mm^3)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+ (7)	(9)=(4)- (8)	(10)= [(4)-(8)]^2	(11)=[{(4)- (8)}/(8)]^2
Months	t	t^2	I_o	t * I_o	T= αt+β	I_R	I_E			
J	1	1	2816.34	2816.3394	2329.45	486.89	3303.23	486.89	237059.30	0.0217
F	2	4	2494.06	4988.117	2420.20	73.86	2567.92	73.86	5455.61	0.0008
M	3	9	2534.55	7603.6596	2510.94	23.61	2558.17	23.61	557.54	0.0001
A	4	16	2476.57	9906.2723	2601.69	-125.12	2351.45	125.12	15654.32	0.0028
M	5	25	2348.31	11741.556	2692.43	-344.12	2004.19	344.12	118417.58	0.0295
J	6	36	2167.84	13007.054	2783.17	-615.33	1552.51	615.33	378633.27	0.1571
J	7	49	2074.62	14522.309	2873.92	-799.30	1275.31	799.30	638885.25	0.3928
A	8	64	2784.15	22273.181	2964.66	-180.52	2603.63	180.52	32585.81	0.0048
S	9	81	4233.31	38099.75	3055.41	1177.90	5411.20	1177.90	1387443.93	0.0474
O	10	100	4404.78	44047.836	3146.15	1258.63	5663.42	1258.63	1584153.83	0.0494
N	11	121	2699.38	29693.188	3236.90	-537.52	2161.87	537.52	288922.95	0.0618
D	12	144	2908.65	34903.807	3327.64	-418.99	2489.66	418.99	175552.70	0.0283
Total	78	650	33942.556	233603.07				6041.78	4863322.10	0.80
Mean	6.50	54.17	2828.55	19466.92			2828.55			
α	90.74									
β	2238.71									
χ^2	0.80	Chi-Square								
R	0.98	Correlation Coefficient								
R^2	0.95	Coefficient of Determination								
RMSE	636.61	Root Mean Square Error								
MAE	503.48	Mean Square Error								

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Table-5. Model fitting for reservoir storage (Mm^3) at Jebba Hydropower dam.

	Time **(month)**		Mean Observed Reservoir Storage **(Mm^3)**		Reservoir Storage (linear trend) **(Mm^3)**	Random Component	Mean Estimated Reservoir Storage **(Mm^3)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+(7)	(9)=(4)-(8)	(10)=[(4)-(8)]^2	(11)=[{(4)-(8)}/(8)]^2
Months	t	t^2	S_o	t *S_o	T= αt+β	S_R	S_E			
J	1	1	3486.86	3486.8571	3471.62	15.24	3502.10	15.24	232.26	0.0000
F	2	4	3537.71	7075.4286	3479.49	58.22	3595.94	58.22	3389.82	0.0003
M	3	9	3523.36	10570.071	3487.37	35.99	3559.35	35.99	1295.27	0.0001
A	4	16	3482.14	13928.571	3495.24	-13.10	3469.04	13.10	171.60	0.0000
M	5	25	3467.43	17337.143	3503.12	-35.69	3431.74	35.69	1273.70	0.0001
J	6	36	3463.46	20780.786	3510.99	-47.53	3415.94	47.53	2258.95	0.0002
J	7	49	3385.64	23699.5	3518.87	-133.22	3252.42	133.22	17748.88	0.0017
A	8	64	3437.00	27496	3526.74	-89.74	3347.26	89.74	8053.79	0.0007
S	9	81	3633.43	32700.857	3534.62	98.81	3732.24	98.81	9763.51	0.0007
O	10	100	3689.46	36894.643	3542.49	146.97	3836.44	146.97	21600.50	0.0015
N	11	121	3551.11	39062.179	3550.37	0.74	3551.85	0.74	0.55	0.0000
D	12	144	3521.56	42258.667	3558.24	-36.69	3484.87	36.69	1346.00	0.0001
Total	78	650	42179.163	275290.7				711.95	67134.84	0.01
Mean	6.50	54.17	3514.93	22940.89			3514.93			
α	7.88									
β	3463.74									
χ^2	0.01	Chi-Square								
r	0.99	Correlation Coefficient								
R^2	0.97	Coefficient of Determination								
RMSE	74.80	Root Mean Square Error								
MAE	59.33	Mean Square Error								

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Table-6. Model fitting for reservoir elevation (m) at Jebba Hydropower dam.

	Time **(month)**		Mean Observed Reservoir Elevation **(m)**		Reservoir Elevation **(linear trend) (m)**	Random Component	Mean Estimated Reservoir Elevation **(m)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+(7)	(9)=(4)-(8)	(10)=[(4)-(8)]^2	(11)=[{(4)-(8)}/(8)]^2
Months	t	t^2	H_o	$t * H_o$	$T= \alpha t+\beta$	H_R	H_E			
J	1	1	101.81	101.80857	101.60	0.21	102.02	0.21	0.04	0.0000
F	2	4	101.74	203.48714	101.62	0.13	101.87	0.13	0.02	0.0000
M	3	9	101.77	305.29821	101.64	0.13	101.89	0.13	0.02	0.0000
A	4	16	101.65	406.59143	101.66	-0.01	101.64	0.01	0.00	0.0000
M	5	25	101.54	507.68393	101.68	-0.14	101.40	0.14	0.02	0.0000
J	6	36	101.41	608.45143	101.70	-0.29	101.12	0.29	0.08	0.0000
J	7	49	101.11	707.7975	101.72	-0.60	100.51	0.60	0.36	0.0000
A	8	64	101.42	811.36286	101.73	-0.31	101.11	0.31	0.10	0.0000
S	9	81	102.13	919.17643	101.75	0.38	102.51	0.38	0.14	0.0000
O	10	100	102.35	1023.5071	101.77	0.58	102.93	0.58	0.33	0.0000
N	11	121	101.82	1119.9768	101.79	0.02	101.84	0.02	0.00	0.0000
D	12	144	101.72	1220.6786	101.81	-0.09	101.63	0.09	0.01	0.0000
Total	78	650	1220.4664	7935.82				2.88	1.12	0.00
Mean	6.50	54.17	101.71	661.32			101.71			
α	0.02									
β	101.58									
χ^2	0.00		Chi-Square							
r	0.99		Correlation Coefficient							
R^2	0.99		Coefficient of Determination							
RMSE	0.31		Root Mean Square Error							
MAE	0.24		Mean Square Error							

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Table-7. Model fitting for turbine release (Mm^3) at Jebba Hydropower dam.

	Time **(month)**		Mean Observed Turbine Release **(Mm^3)**		Reservoir Inflow **(linear trend) (Mm^3)**	Random Component	Mean Estimated Turbine Release **(Mm^3)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+(7)	(9)=(4)-(8)	(10)=[(4)-(8)]^2	(11)=[{(4)-(8)}/(8)]^2
Months	t	t^2	Q_o	t *Q_o	T= αt+β	Q_R	Q_E			
J	1	1	2923.58	2923.5841	2481.73	441.86	3365.44	441.86	195236.22	0.0172
F	2	4	2604.83	5209.6613	2517.79	87.04	2691.87	87.04	7576.30	0.0010
M	3	9	2527.23	7581.6921	2553.85	-26.62	2500.61	26.62	708.52	0.0001
A	4	16	2529.42	10117.675	2589.91	-60.49	2468.93	60.49	3659.03	0.0006
M	5	25	2338.30	11691.517	2625.97	-287.67	2050.64	287.67	82751.34	0.0197
J	6	36	2212.31	13273.875	2662.03	-449.72	1762.60	449.72	202244.60	0.0651
J	7	49	2083.62	14585.359	2698.09	-614.47	1469.16	614.47	377568.40	0.1749
A	8	64	2772.19	22177.498	2734.15	38.04	2810.23	38.04	1446.94	0.0002
S	9	81	3199.80	28798.216	2770.21	429.59	3629.39	429.59	184550.32	0.0140
O	10	100	3558.63	35586.267	2806.27	752.36	4310.98	752.36	566042.76	0.0305
N	11	121	2673.61	29409.755	2842.33	-168.71	2504.90	168.71	28464.57	0.0045
D	12	144	2737.17	32846.051	2878.39	-141.22	2595.95	141.22	19942.41	0.0030
Total	78	650	32160.704	214201.15				3497.77	1670191.41	0.33
Mean	6.50	54.17	2680.06	17850.10			2580.06			
α	36.06									
β	2445.67									
χ^2	0.33		Chi-Square							
r	0.99		Correlation Coefficient							
R^2	0.98		Coefficient of Determination							
RMSE	373.07		Root Mean Square Error							
MAE	291.48		Mean Square Error							

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Table-8. Model fitting for energy generation (Mwh) at Jebba Hydropower dam.

	Time **(month)**		Mean Observed Energy **(Mwh)**		Energy Generation **(linear trend) (Mwh)**	Random Component	Mean Estimated Turbine Release **(Mwh)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+(7)	(9)=(4)-(8)	(10)=[(4)-(8)]^2	(11)=[{(4)-(8)}/(8)]^2
Months	t	t^2	E_o	t *E_o	T= αt+β	E_R	E_E			
J	1	1	201149.2	201149.15	174010.16	27138.99	228288.14	27138.99	736524518.76	0.0141
F	2	4	179092.5	358185.09	176190.17	2902.37	181994.92	2902.37	8423769.62	0.0003
M	3	9	183426.2	550278.71	178370.18	5056.05	188482.29	5056.05	25563669.61	0.0007
A	4	16	174818.9	699275.46	180550.19	-5731.33	169087.54	5731.33	32848123.82	0.0011
M	5	25	167722.0	838609.99	182730.20	-15008.20	152713.79	15008.20	225246175.57	0.0097
J	6	36	155854.9	935129.49	184910.21	-29055.30	126799.62	29055.30	844210272.03	0.0525
J	7	49	150044.0	1050308.2	187090.22	-37046.19	112997.85	37046.19	1372419848.59	0.1075
A	8	64	179755.6	1438044.7	189270.23	-9514.65	170240.94	9514.65	90528475.56	0.0031
S	9	81	223874.2	2014867.4	191450.24	32423.92	256298.07	32423.92	1051310430.10	0.0160
O	10	100	235006.1	2350061.4	193630.25	41375.89	276382.03	41375.89	1711964457.85	0.0224
N	11	121	191259.0	2103849.2	195810.26	-4551.24	186707.78	4551.24	20713787.77	0.0006
D	12	144	189999.9	2279999.3	197990.27	-7990.32	182009.62	7990.32	63845234.34	0.0019
Total	78	650	2232002.6	14819758				217794.44	6183598763.60	0.23
Mean	6.50	54.17	186000.22	1234979.85			186000.22			
α	2180.01									
β	171830.16									
χ^2	0.23		Chi-Square							
r	0.99		Correlation Coefficient							
R^2	0.98		Coefficient of Determination							
RMSE	22700.22		Root Mean Square Error							
MAE	18149.54		Mean Square Error							

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Table-9. Model fitting for tailrace water level (m) at Jebba Hydropower dam.

	Time **(month)**		Mean Observed Tailrace Water Level **(m)**		Tailrace Water level **(linear trend) (m)**	Random Component	Mean Estimated Tailrace water level **(m)**	Required for MAE	Required for RMSE	Required for Chi-square
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(4)-(6)	(8)=(4)+(7)	(9)=(4)-(8)	(10)=[(4)-(8)]^2	(11)=[{(4)-(8)}/(8)]^2
Months	t	t^2	T_o	t *T_o	T= αt+β	T_R	T_E			
J	1	1	73.92	73.920714	73.57	0.35	74.27	0.35	0.12	0.000022
F	2	4	73.77	147.54214	73.60	0.17	73.94	0.17	0.03	0.000005
M	3	9	73.67	221.01964	73.64	0.03	73.71	0.03	0.00	0.000000
A	4	16	73.58	294.32	73.67	-0.09	73.49	0.09	0.01	0.000002
M	5	25	73.43	367.12857	73.71	-0.28	73.14	0.28	0.08	0.000015
J	6	36	73.33	439.99071	73.74	-0.41	72.92	0.41	0.17	0.000032
J	7	49	73.22	512.5725	73.78	-0.55	72.67	0.55	0.31	0.000058
A	8	64	73.63	589.00286	73.81	-0.19	73.44	0.19	0.03	0.000006
S	9	81	74.37	669.3075	73.85	0.52	74.89	0.52	0.27	0.000048
O	10	100	74.58	745.75714	73.88	0.70	75.27	0.70	0.48	0.000085
N	11	121	73.84	812.185	73.92	-0.08	73.75	0.08	0.01	0.000001
D	12	144	73.79	885.45857	73.95	-0.16	73.63	0.16	0.03	0.000005
Total	78	650	885.11893	5758.2054				3.53	1.54	0.000280
Mean	6.50	54.17	73.76	479.85			73.76			
α	0.03									
β	73.54									
χ^2	0.00028		Chi-Square							
r	0.99		Correlation Coefficient							
R^2	0.98		Coefficient of Determination							
RMSE	0.36		Root Mean Square Error							
MAE	0.29		Mean Square Error							

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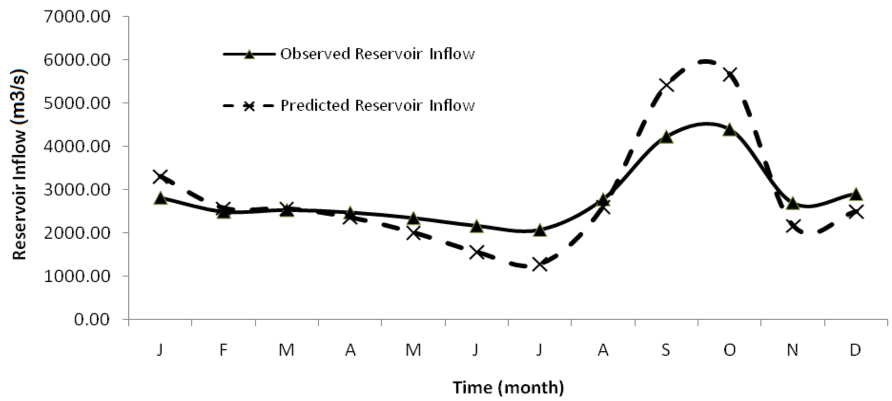

Figure-4. Model fitting for reservoir inflow of Jebba hydropower dam.

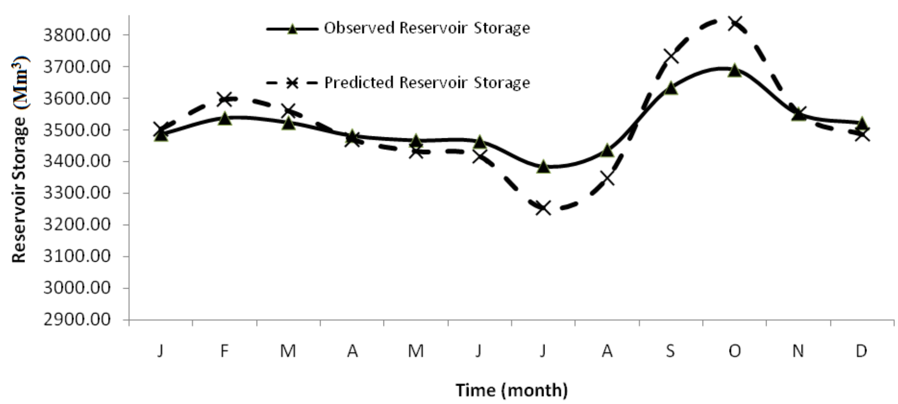

Figure-5. Model fitting for reservoir storage of Jebba hydropower dam.

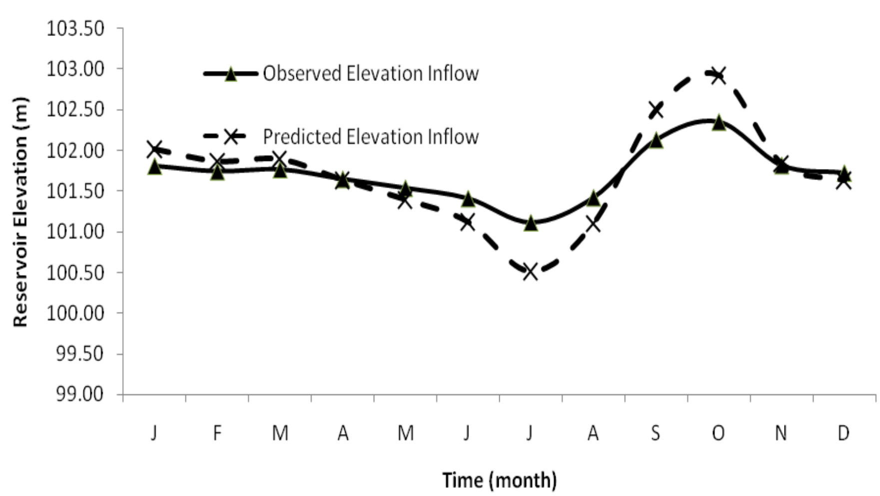

Figure-6. Model fitting for reservoir elevation of Jebba hydropower dam.

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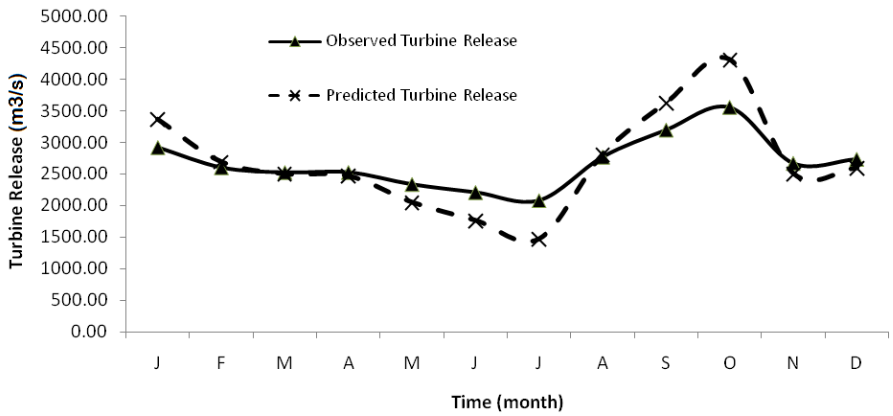

Figure-7. Model fitting for turbine release of Jebba hydropower dam.

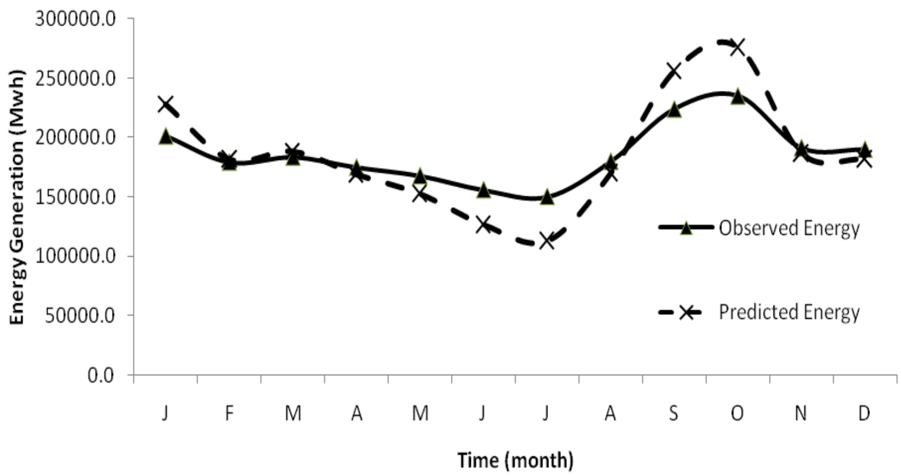

Figure-8. Model fitting for energy generation of Jebba hydropower dam.

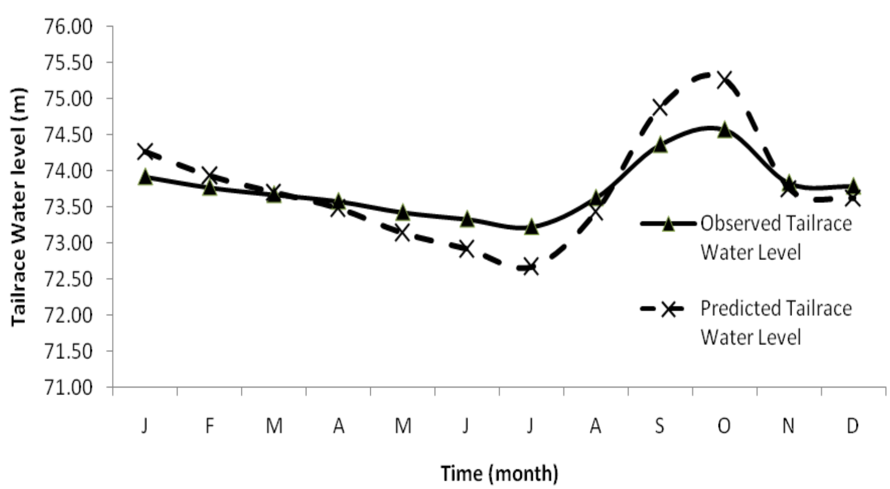

Figure-9. Model fitting for tailrace water level of Jebba hydropower dam.

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Table-10 shows the excess water release, evaporation loss and rainfall at Jebba Hydropower Dam. The mean and the maximum spillage is recorded in the month of October with attendant highest evaporation loss. From January to July, there is no spillage unlike August through to December.

Table-10. Excess water release, evaporation loss and rainfall at Jebba H.P dam.

Spillage at Jebba H.P dam **(1984 - 2006)**			Evaporation loss / Rainfall at Jebba H.P dam **(1984 - 2006)**			
Month	**Mean spillage** ($\overline{G}_{2,t}$)	**Max. spillage** ($\hat{G}_{2,t}$)	**Evaporation loss**		**Rainfall**	
	Mm^3	Mm^3	Mm	Mm^3	Mm	Mm^3
Jan	0.00	0.00	177.1	53.66	0.07	0.02
Feb	0.00	0.00	244.0	73.93	1.85	0.56
Mar	0.00	0.00	241.0	73.03	14.63	4.44
Apr	0.00	0.00	269.6	81.69	68.84	20.86
May	0.00	0.00	209.3	63.42	148.13	44.89
Jun	0.00	0.00	176.0	53.33	211.09	63.96
Jul	0.00	0.00	143.0	43.33	168.95	51.20
Aug	94.52	507.99	123.4	37.39	188.82	57.22
Sept	624.05	2230.93	139.2	42.18	221.62	67.15
Oct	792.73	2691.21	193.4	58.60	80.59	24.42
Nov	118.85	607.91	200.5	60.75	0.71	0.22
Dec	187.25	868.20	186.7	56.57	0.00	0.00

- Evaporation loss (Mm^3) = Evaporation depth × Lake surface area =303 km^2.
- Direct Rainfall inflow (Mm^3) = Rainfall depth × Lake surface area

3. RESULTS AND DISCUSSIONS

Tables 4 to 9 show average monthly statistical summaries for reservoir inflow, storage, elevation, turbine release, energy generated and tailrace water level, respectively, for periods of 1984 - 2011. The least square technique was adopted to fit the model which resulted into equations (13) and (14). The fitted models results computations and the resulting charts for the predicted data and the statistical goodness of fit tests (such as the chi-square, correlation coefficient, root mean square error, coefficient of determination and the mean square error), are shown in Tables 4 to 9 and Figures-4 to 9, respectively. As shown in Tables 4-9, the spread of the computed data are scattered and non-uniform throughout the year. The high spread of inflow, storage, energy generation and turbine release is a significant pointer that the hydrological process is not being uniform throughout the years. It is also clear that the four parameters (inflow, storage, energy generation and turbine release) are closely related. The pattern is similar with higher values in September-October and lower values in June-July. This seasonal routine is identified as an important factor influencing the functioning of the reservoir servicing the Hydropower dam. It was observed that the mean expectations on both the observed and estimated parameter values are the same for all parameters of inflow, storage, elevation, turbine release, energy generation and the tailrace water level.

For the reservoir inflow, there appears to be large errors of the RMSE and MAE but with reasonable results for the chi-square, correlation coefficient and coefficient of determination. The same was identified for reservoir storage, turbine release and energy generation. These also correspond to the fact that their parameters were scattered. The model fitting charts for all the parameters (Figures 4-9) show that, the predicted values begun slightly above the observed values and ends slightly below the observed values. In the probability of exceedence (reliability of flow) computed using normal distribution (Table-3), the values are in descending orders in the order of 50%, 75%, 90% and 95%. The optimal solution obtained at operation performance of 50% reservoir inflow reliability has the total annual energy generation of 42105.63MWH. The average optimal energy generation obtained is 19% of the observed energy generation but with adequate water supply for downstream users and for irrigation throughout the year.

4. CONCLUSIONS

The paper captures important issues that must be taken into account and the potential benefits that can be realized when appropriate measures are taken into consideration in the management of reservoir for

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hydropower and flood management purposes. Flood occurrence in the downstream regime is caused majorly by the sudden release of water from the hydropower dams located upstream of the study area. The determination of the amount of reservoir for a specified purpose such as flood control is based on hydrologic analyses that are governed by project formulation criteria. Previous literature has established that it is necessary to define specific rules that will help distribute the available water resources because most reservoir systems exhibit a competition among water uses. The guiding formulation principles in most free enterprise countries are generally that the project, with the specified amount of storage, must be economically justified (benefit/cost ratio must exceed one), the project should be formulated in practical extent to maximize net economic benefits, and the project should not result in significantly increased flood hazards for any flood event, especially one that would exceed the design capacity of the reservoir system. Projects with conservation storage should also provide a reasonable guarantee (probability) of dependable water supply from the reservoirs.

The study revealed that the sudden release of flood water at Jebba is not due to normal operation at the hydropower station, but due to sudden discharges at the reservoirs located upstream in order to create enough space for the incoming flood water. This automatically forces the release of water at Jebba and thus creating flood problem downstream. The flow regime of the River Niger downstream of Jebba dam is governed by the operations of the Kanji and Jebba hydroelectric power schemes and runoff from the catchments. Releases from Kainji HEP dam constitute the major inflow into Jebba HEP dam since it lies directly under it. This mean that the more the releases from upper reservoir the faster the downstream reservoir fill up and excess will be discharged thereby leading to flooding. In addition, the annual discharge of rivers limits the overall energy output from hydropower plants. However, discharge records are relatively short and subject to fluctuations over different periods that may persist for many years. It is important that water planners and managers consider a number of allocation alternatives by using system models. This will help to define the proper criteria and procedures to balance the allocation rules.

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