4

Assessment of Impact of Hydropower Dams Reservoir Outflow on the Downstream River Flood Regime – Nigeria's Experience

David O. Olukanni[1] and Adebayo W. Salami[2]

[1]Department of Civil Engineering, Covenant University, Ota, Ogun State,
[2]Department of Civil Engineering, University of Ilorin, Ilorin,
Nigeria

1. Introduction

Over more than five decades, the energy sector in Nigeria, particularly the rural energy sector, is characterized by lack of access, low purchasing power and over-dependence on traditional fuels for meeting basic energy needs. In an attempt by the government to solving this challenge, the hydropower scheme came on stream as the forerunner in 1968, 1986 and 1990 at Kainji, Jebba and Shiroro respectively. The objective was to improve access to reliable, secure, affordable, climate friendly and sustainable energy services and to boost investment in energy in Nigeria. However, this solution seems to be characterized with some challenges at the downstream sector of the hydropower dams. The communities in the flood plains experience annual flooding when the authorities of Power Holding Company of Nigeria (PHCN) open the gates of the dams to let off water at the peak of the rains. The floods have caused damages and untold hardships to lives and properties. The occurrence of flood has great effect on communities and farming activities downstream of Jebba and Shiroro dams.

Hydro Electric Power (HEP) is one of the few sources of energy that has assumed great significance since the beginning of the twentieth century. Electric power supply in Nigeria is government controlled and operated by the Power Holding Company of Nigeria (PHCN). PHCN has five thermal stations located at Afam, Delta, Egbin, Ijora and Sapele power stations and three hydropower plants located at Kainji, Jebba, and Shiroro hydropower power stations. They have installed capacities of 760 MW, 560 MW and 600 MW respectively and a total output of 1900 MW. The choice of hydro systems to generate peaking power carries a higher economic value of the water resource used and resulting in a substantial increase in the benefits realized. HEP project requires high initial investment cost, but are easy to run and generally have low maintenance cost compared to other sources of energy (Aribisala and Sule, 1998). One major reason that makes HEP attractive is that water, like wind and sun, is a renewable resource and is sustainable through the hydrologic cycle. This chapter presents an assessment of the impact of hydro electric power dams' reservoir outflow of Kainji, Jebba and Shiroro dam on the environment and the mitigation measures. Figure 1.1 displays the World Map showing the location of Nigeria while Figure 1.2 shows location of the three Hydro electric power dams with flood plain hatched.

1.1 Effect of reservoir outflow of dams

1.1.1 Effect of reservoir outflow of dams to the environment

The operation of HEP dams often leads to environmental and ecological problems. When inflows are low, energy output from HEP sources is limited. Water may not be released in adequate quantities from the reservoir, a situation that can affect ecological balance of the river below the HEP dam. On the other hand discharge from HEP dams can entail large water outflow which can cause flooding to adjoining lands downstream of the dam, where the flood plains are regions of economic, social and agricultural activities extensive damages will be incurred in the process. In Nigeria this is particularly so, as the riverbanks are used for farming and are inhabited by farming communities. The operation of hydropower dams in Nigeria has been based on conventional water release rule instead of using scientific analysis to determine the reservoir regulation policies (Sule, 2003). This has led to lack of proper water release plan.

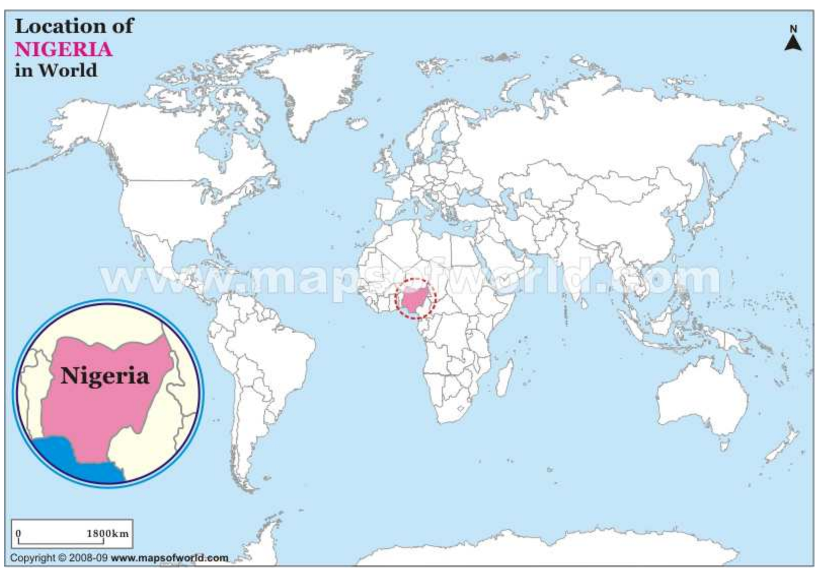


Fig. 1.1 Map of the world showing the location of Nigeria.

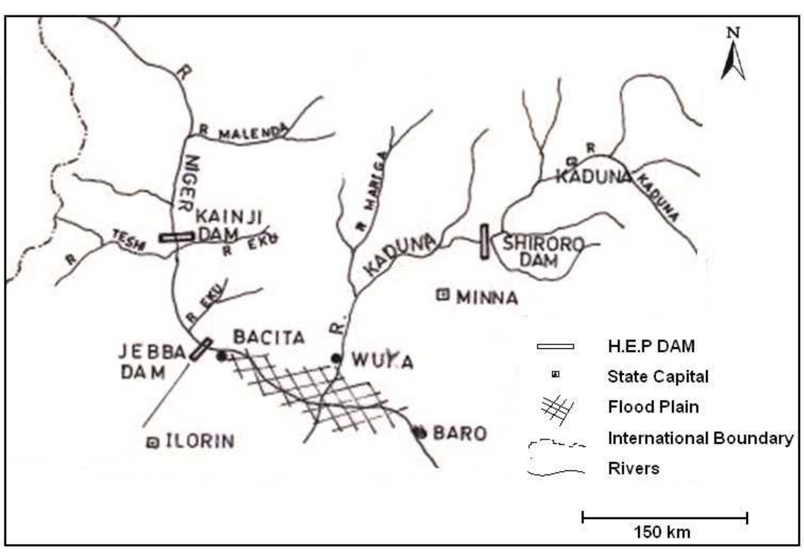


Fig. 1.2 Location of the three Hydro Electric Power Dams and flood plain hatched.

1.1.2 Effect of outflow of Kainji H.P dam on the downstream of Jebba H.P dam

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 constitutes the major inflow into Jebba HEP dam since it lies directly under it, this mean that the more the release from upper reservoir the faster the downstream reservoir fill up and excess will be discharged thereby leading to flooding. 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 has lead to the dam overflowing its banks. When the authority of PHCN opens the spillway gates of the dams to let out torrents of water, it creates flooding and other social impact on the downstream communities and projects. As reported by Lawal and Nagya (1999), the occurrence of flood at Mokwa and its environment in Niger State in 1997 and 1998 destroyed so many properties worth over five hundred million naira and submerged several houses, farmland and crops. The havoc caused by the flooding of the lower Niger in 1998 and 1999 also has its effect on social services to the people of the area (Bolaji, 1999). It has affected the sugar cane plantations, other farming activities and inundated the communities located within the flood plain of the river. In addition, the flooding experienced at the sugar cane plantation in Bacita, Niger State was due to excessive runoff from the catchment areas of the river when reservoirs of both Kainji and Jebba were filled. Over 2,260 ha of sugar cane farm were flooded and remained swamped for over six weeks (Sule, 2003). The flood damaged water conveyance structures, washed away the existing flood protection embankments, impaired roads and caused displacement of settlements and communities along River Niger. A total cost effect of $3.1 million was estimated during the 1994 flood damage to the sugar cane company which increase to $3.7 and $3.3 million in 1998 and 1999 respectively due to the re-occurrence of the same flood effect (Bolaji, 1999). The only alternative left to protect the dams from collapse as at that time was to discharge more water to the downstream areas.

1.1.3 Flood damage at downstream of Shiroro dam

Shiroro HEP dam was built on river Kaduna which forms one of the tributaries to River Niger. After the construction of the dam there were two serious floods in 1985 and 1988. Losses during these periods due to floods were in millions of naira and a large hectarage of arable land with crops submerged. The badly affected area was the Lavun local government area where properties worth millions of naira were destroyed. After 1985 and 1988 flooding, the reoccurrence is more frequent and the damages are higher. As reported by Lawal and Nagya (1999), properties worth over five million naira were destroyed due to the occurrence of flood at Mokwa, Rabba and its environs in 1997 and 1998.

1.2 Highlights on flood control measures

1.2.1 Non-structural measures

This represents an administrative measure of flood plain regulation and management. It involves flood forecasting and flood warning, based on observation of rainfall and river gauge reading in the upstream catchments areas. It is possible to forecast the magnitude and time of occurrence of flood at any downstream point in a river. With modern communication system like the telephone, radio, microwave, radar and artificial satellites, it is then possible to instantly transmit the data observed in the upstream of the catchments area to centrally located flood forecasting stations. The adoption of all flood mitigation measures except flood insurance creates economic benefits by reducing both the expected value of flood losses and the cost of risk taking, and the adoption of flood insurance creates economic benefits by reducing only the cost of risk taking.

1.2.2 Structural measures

The various structural measures prevent inundation of the flood plain in different ways. For example, reservoirs reduce peak flows; levees and flood walls confine the flow within pre-determined channels; improvements to channels reduce peak stages; the flood-ways help divert excess flow. Structural measures alter the stream-flow of rivers and channels resulting in reduction of frequency and severity of floods.

2. Analysis of reservoir inflow data and design of a structural control measure

The existing structural control measures at the stations have been impaired and there is need for redesign. The design of new structural measures would be based on the predicted flood level having 100 yrs return period. The reservoir inflow, turbine discharge and reservoir elevation data were collected from the hydrological unit of the three hydropower stations in Nigeria namely; the Kainji, Shiroro and Jebba hydropower stations. A total of 40 years (1970 – 2010), 27 years (1984 – 2010) and 20 years (1990 – 2010) of inflow data were collected from Kainji, Shiroro and Jebba hydropower stations respectively. The variations of the minimum and maximum reservoir inflow data are presented. The maximum reservoir inflow, turbine discharge and reservoir elevation data were fitted with the Gumbel probability distribution function in accordance to Olukanni and Salami (2008) and Olofintoye et al. (2009) for the prediction of flood of 100 year return period required for the design of flood control structures. This fits the peak and low values of the variables under consideration while the observed and predicted values were plotted. The relationships between the observed and predicted values of the peak and low reservoir inflow are presented. The peak reservoir inflow data were selected for the three hydropower stations and ranked according to Weilbull plotting position. The corresponding return period are determined and plotted against the maximum reservoir inflow data in order to fit the best probability distribution for the prediction of future occurrence of the flood.

3. Hydrological assessment

3.1 Statistical analysis

This section involves the statistical, time series, flow duration curve and probability distribution analyses of the hydrological variables collected at the three hydropower stations. The statistical analysis carried out covered descriptive statistics (i.e. the estimation of the mean, standard deviation, skewness coefficient, minimum and maximum values of the variables). The statistics of the reservoir inflow, turbine discharge and reservoir elevation for Kainji, Jebba and Shiroro are presented in Table 3.1, 3.2 and 3.3 respectively.

3.2 Time series analysis

A time series is plotted for maximum and minimum values to depict the variations of the hydrological variables such as reservoir inflow, turbine discharge and reservoir level. The monthly and annual trends of the maximum and minimum variables were determined.

3.2.1 Kainji hydropower dam

3.2.1.1 Reservoir inflow

The summary of statistics of reservoir inflow at Kainji dam is presented in Table 3.1a. During the 40 years of operation (1970 – 2010), the peak reservoir inflow was 3065.0 m^3/s, while the lowest reservoir inflow was 9.4 m^3/s. The peak value occurs during the month of September in 2000, while the low flow occurred during the month of June 1972. The monthly and annual variation of the reservoir inflow is presented in Figures 3.1a and 3.1b respectively.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1319.52	1119.23	506.87	202.26	91.48	130.65	344.23	1020.23	1749.11	1227.54	1350.90	1400.37
S.D	457.68	599.56	457.88	266.50	85.76	107.94	159.72	373.99	584.28	803.42	349.24	386.40
Skew	-0.26	0.22	2.00	3.20	2.39	1.77	1.27	1.34	0.51	-0.25	-1.31	-1.13
Max	2157.00	2340.00	2251.00	1405.00	455.00	522.00	866.00	2267.00	3065.00	2617.00	1801.00	1962.00
Min	468.64	280.55	81.55	13.00	13.46	9.40	97.00	455.00	807.03	29.12	510.74	527.77

Source: Kainji Hydroelectric Power Station (2010)

Table 3.1 a) Statistics of the reservoir inflow at Kainji Hydropower dam (m^3/s) (1970-2010).

where:
Mean= Average value; S.D=Standard deviation; Skew=Skewness coefficient;
Max= Maximum; Min=Minimum

The trend in Figure 3.1b is that reservoir inflow reached a peak in 2000 and has been reducing slightly since then. This may be due to control releases from the upstream reservoir from neighboring country like Niger Republic. Figure 3.1a indicated two peak seasons, occurring in the months of February and September. The first peak inflow is due to black flood resulting from excess releases from upstream reservoirs from neighboring countries which get to Nigeria during dry season, while the second peak flow is due to white flood resulting from excess rainfall within River Niger catchment within Nigeria.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	784.16	813.77	747.86	793.90	720.41	666.18	632.00	709.35	746.30	752.98	740.50	766.69
S.D	232.94	269.72	234.07	232.14	195.55	171.33	197.99	257.17	259.44	252.30	208.79	232.56
Skew	0.14	0.45	0.34	0.18	0.30	-0.10	0.00	0.45	0.69	0.52	-0.10	0.53
Max	1234.43	1431.96	1203.41	1345.23	1176.13	1026.62	1060.00	1445.34	1396.60	1289.02	1248.93	1401.94
Min	377.06	405.22	404.27	416.17	404.79	337.31	206.42	203.32	300.60	380.23	198.27	382.77

Source: Kainji Hydroelectric Power Station (2010)

Table 3.1 b) Statistics of the turbine discharge at Kainji Hydropower dam (m^3/s) (1970-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	140.88	140.85	139.94	138.27	136.37	134.52	133.79	134.50	137.39	139.00	140.00	140.57
S.D	0.94	1.00	1.41	1.79	1.95	2.12	1.63	1.43	1.92	1.87	1.47	1.12
Skew	-1.28	-1.17	-0.66	-0.39	-0.11	0.04	-0.26	0.49	0.25	-0.93	-1.00	-1.11
Max	141.89	141.89	141.90	141.10	139.58	138.27	136.89	137.80	141.23	141.61	141.70	141.72
Min	138.49	137.96	136.30	134.22	132.95	130.28	130.33	131.76	133.96	134.16	136.49	137.82

Source: Kainji Hydroelectric Power Station (2010)

Table 3.1 c) Statistics of the reservoir elevation at Kainji Hydropower dam (m) (1970-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1064.00	988.20	903.00	913.80	823.52	834.60	757.72	1055.44	1637.00	1642.20	1002.16	1065.76
S.D	320.32	340.85	304.11	276.06	241.37	259.96	288.46	453.32	705.46	942.13	338.30	265.55
Skew	0.15	0.09	0.06	0.30	0.19	0.02	1.17	0.92	0.79	1.08	0.55	0.11
Max	1575.00	1637.00	1422.00	1566.00	1282.00	1332.00	1567.00	2379.00	3182.00	3636.00	1688.00	1565.00
Min	518.00	378.00	417.00	436.00	428.00	359.00	378.00	445.00	750.00	666.00	516.00	610.00

Source: Jebba Hydroelectric Power Station (2010)

Table 3.2 a) Statistics of the reservoir inflow at Jebba Hydropower (m^3/s) (1984-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1092.40	1019.65	930.00	922.54	860.04	824.15	767.27	997.15	1319.23	1314.31	1037.65	1014.57
S.D	308.34	351.84	305.81	312.02	237.47	250.00	288.14	407.05	391.22	433.39	336.48	278.64
Skew	0.02	-0.04	0.08	0.04	0.32	0.03	0.90	0.34	0.05	0.30	0.21	0.22
Max	1575.00	1643.00	1466.00	1672.00	1383.00	1340.00	1556.00	1927.00	2079.00	2143.00	1655.00	1606.00
Min	585.00	376.00	425.00	232.00	451.00	362.00	328.00	366.00	633.00	685.00	479.00	514.00

Source: Jebba Hydroelectric Power Station (2010)

Table 3.2 b) Statistics of the turbine discharge at Jebba Hydropower (m^3/s) (1984-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	102.20	102.13	102.11	101.90	101.95	101.87	101.53	101.71	102.16	102.40	102.14	102.08
S.D	0.45	0.52	0.52	0.65	0.62	0.65	0.57	0.56	0.48	0.55	0.73	0.52
Skew	0.13	-0.93	-0.18	0.01	-0.99	-0.76	0.32	0.25	-0.25	-1.33	-1.04	-0.14
Max	102.87	102.87	102.98	102.98	102.90	102.91	102.65	102.74	103.02	103.05	103.00	102.78
Min	101.52	100.65	100.86	100.60	100.19	100.27	100.76	100.61	101.21	100.82	100.27	101.16

Source: Jebba Hydroelectric Power Station (2010)

Table 3.2 c) Statistics of the reservoir elevation at Jebba Hydropower (m) (1984-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	43.05	53.04	45.87	29.19	76.67	190.45	434.09	924.50	1043.24	476.63	94.32	68.05
S.D	14.68	79.24	70.00	17.46	46.95	58.77	164.65	187.98	243.34	196.12	35.48	77.04
Skew	-0.11	4.30	4.13	1.67	2.47	0.26	-0.32	1.44	1.12	0.80	0.63	4.11
CV	0.34	1.49	1.53	0.60	0.61	0.31	0.38	0.20	0.23	0.41	0.38	1.13
Max	73.40	385.66	336.02	78.94	245.78	318.79	684.18	1431.29	1752.51	878.17	178.24	387.10
Min	18.97	12.52	10.84	9.87	21.95	97.72	56.49	680.48	627.08	239.51	46.49	26.36

Source: Shiroro Hydroelectric Power Station (2010)

Table 3.3 a) Statistics of the reservoir inflow at Shiroro Hydropower dam (m^3/s) (1990-2010).

3.2.1.2 Turbine discharge

The summary of statistics of turbine discharge at Kainji dam is presented in Table 3.1b. During the 40 years of operation (1970 – 2010), the peak turbine discharge was 1445.34 m^3/s, while the lowest turbine discharge was 198.27 m^3/s. The peak value occurs during the month of August in 1979, while the low turbine discharge occurred during the month of November 2000. The monthly and annual variation of the reservoir inflow is presented in Figures 3.2a and 3.2b respectively. The trend in Figure 3.2b indicated highest discharge value in 1979 and has been decreasing steadily until 1990. The discharge starts to increase again until 1994 after which it start decreasing. The trend exhibited by releases from Kainji has direct influence on reservoir

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	236.99	260.65	255.32	238.34	213.58	231.07	338.20	359.43	339.27	345.93	245.03	225.88
S.D	81.36	71.07	72.44	85.20	79.13	84.18	84.69	140.14	149.38	119.09	121.24	86.59
Skew	0.11	-0.55	-0.30	0.68	0.12	2.41	0.33	1.30	-0.04	-0.26	-0.04	0.04
CV	0.34	0.27	0.28	0.36	0.37	0.36	0.25	0.39	0.44	0.34	0.49	0.38
Max	416.63	390.13	381.98	444.95	407.48	525.85	494.03	792.45	604.63	575.27	504.75	435.86
Min	75.60	99.21	118.17	87.31	35.84	141.63	172.84	127.50	94.33	86.36	22.15	20.80

Source: Shiroro Hydroelectric Power Station (2010)

Table 3.3 b) Statistics of the turbine discharge at Shiroro Hydropower dam (m^3/s) (1990-2010).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	375.85	373.18	369.98	366.19	362.92	361.28	361.65	410.97	377.23	381.05	380.17	378.07
S.D	2.67	3.00	3.29	3.32	3.03	2.64	2.56	19.32	2.27	1.73	1.79	2.13
Skew	-0.40	0.25	0.65	1.22	1.22	0.20	0.05	-2.08	-0.52	-2.13	-1.68	-1.05
CV	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.00	0.00	0.01
Max	379.99	378.94	377.52	375.29	371.87	366.36	367.80	423.80	380.75	382.20	381.97	381.00
Min	370.43	367.97	365.77	362.28	358.25	355.33	355.44	364.39	372.53	375.56	374.87	372.91

Source: Shiroro Hydroelectric Power Station (2010)

Table 3.3 c) Statistics of the reservoir elevation at Shiroro Hydropower dam (m) (1990-2010).

inflow at Jebba dam. When the releases from Kainji is high, the reservoir inflow at Jebba dam also high, while low releases from Kainji implies low reservoir inflow at Jebba dam. The operation of Kainji dam dictate operation pattern in Jebba dam, excess releases at Kainji will force the reservoir manager at Jebba dam to release so as to accommodate releases from Kainji and thereby causing flooding at the downstream area.

3.2.1.3 Reservoir elevation

The summary of statistics of reservoir elevation at Kainji dam is presented in Table 3.1c. During the 40 years of operation (1970 – 2010), the peak reservoir elevation was 141.90 m, while the lowest reservoir elevation was 130.28 m. The peak value occurs during the month of March in 1973, while the low reservoir elevation occurred during the month of June-July in 2007. The monthly and annual variation of the reservoir inflow is presented in Figures 3.3a and 3.3b respectively. The trend in Figure 3.3b is that the maximum reservoir elevation has remained relative constant since 1970, but lowered in 1978, 1984, 2004, and 2007. The minimum elevation was raised to 136.37 m in 1974 and subsequently lowered to 130.28 m in 2007. This is to allow for more water to be stored in the dam when water is released from the upstream reservoir in the neighboring country or as a result of black flooding. The trend in Figure 3.3a indicated lowest values during the months of June-July and highest value in the month of March.

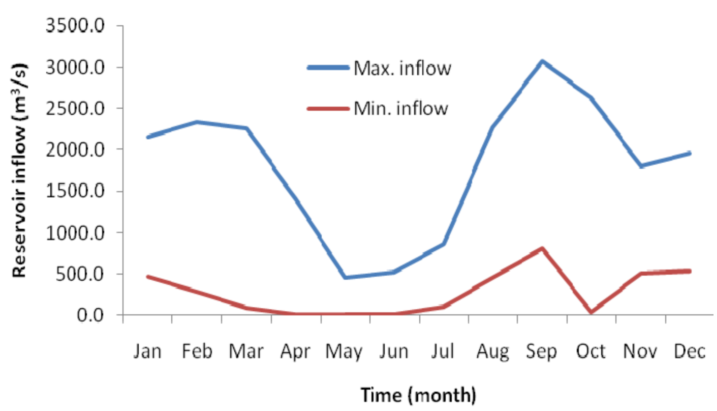


Fig. 3.1 a) Montly variation maximum and minimum reservoir inflow at Kainji HEP dam (1970 - 2009).

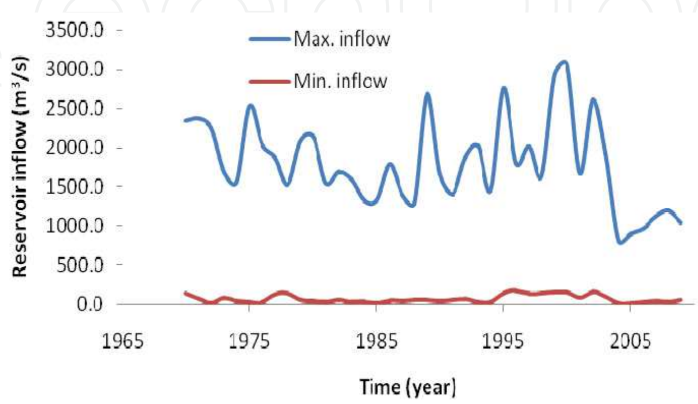


Fig. 3.1 b) Annual variation of maximum and minimum reservoir infloe at Kanji HEP dem (1970 - 2009).

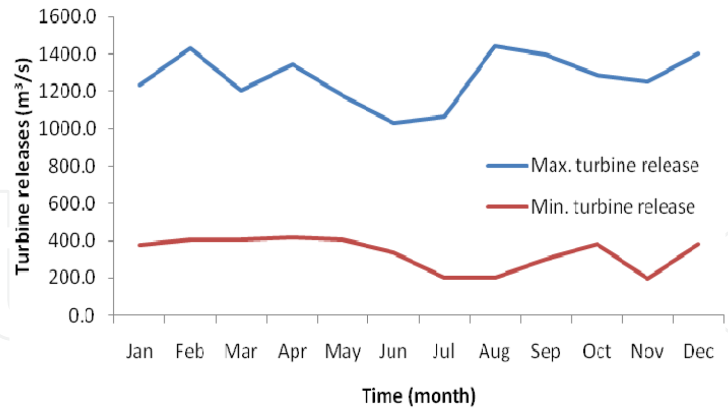


Fig. 3.2 a) Monthly variation of maximum and minimum turbine releses at Kanji HEP dem (1970 - 2009).

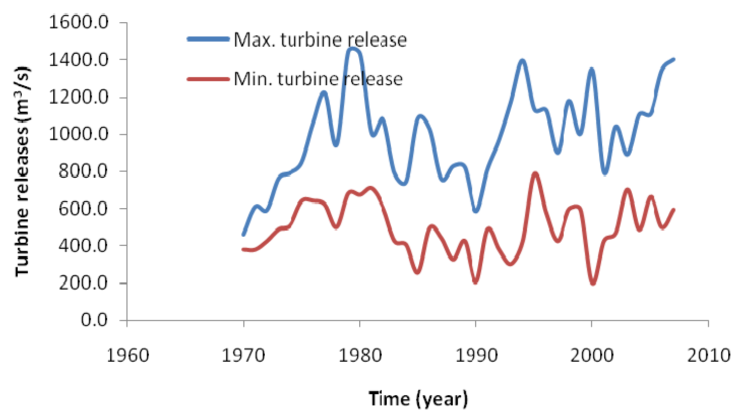


Fig. 3.2 b) Annual variation of maximum and minimum turbine releses at Kanji HEP dam (1970 - 2009).

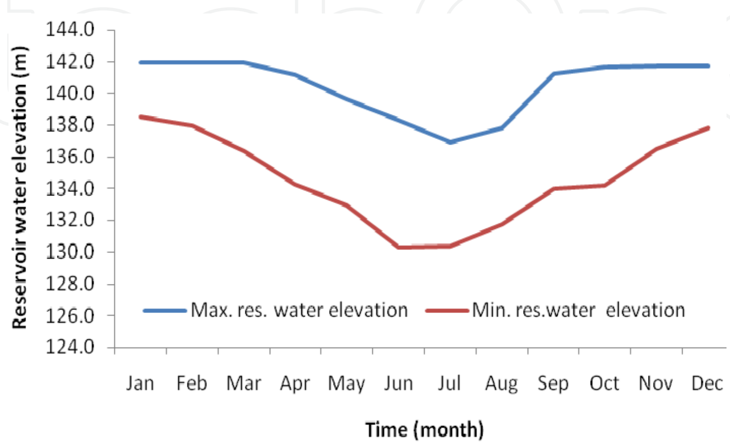


Fig. 3.3 a) Monthly variation of maximum and minimum reservoir water elevation at Kanji HEP dam (1970 -2009).

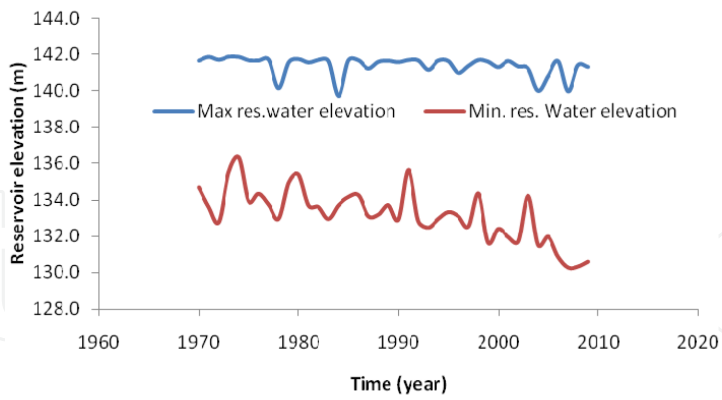


Fig. 3.3 b) Annual variation of maximum and minimum reservoir water elevation at Kanji HEP dam (1970 - 2009).

3.3.1 Jebba hydropower dam

3.3.1.1 Reservoir inflow

The summary of statistics of reservoir inflow at Jebba dam is presented in Table 3.2a. During the 27 years of operation (1984 – 2010), the peak reservoir inflow was 3636.0 m^3/s, while the lowest reservoir inflow was 378.0 m^3/s. The peak value occurs during the month of October in 1998, while the low flow occurred during the month of February 1984. The monthly and annual variation of the reservoir inflow is presented in Figures 3.4a and 3.4b respectively. Reservoir inflow reached a peak in 1998 and has been reducing slightly since then. This is not unconnected with the discharge from Kainji which has also reduced since 1997 but started increasing since 1995.

3.3.1.2 Turbine discharge

The summary of statistics of turbine discharge at Jebba dam is presented in Table 3.2b. During the 27 years of operation (1984 – 2010), the peak turbine discharge was 2143.0 m^3/s, while the lowest reservoir inflow was 232.0 m^3/s. The peak value occurs during the month of October in 2008, while the low flow occurred during the month of April in 1987. The monthly and annual variation of the turbine discharge is presented in Figures 3.5a and 3.5b respectively. The trend in Figure 3.5b is that discharge has been increasing steadily since 1990. Even the lowest release in 2010 was as high as the highest release at the early stages of the dam operation. This means higher likelihood of flooding in recent years compared to pre-1990.

3.3.1.3 Reservoir elevation

The summary of statistics of reservoir elevation at Jebba dam is presented in Table 3.2c. During the 27 years of operation (1984 – 2010), the peak reservoir elevation was 103.05 m, while the lowest reservoir elevation was 100.19 m^3/s. The peak value occurs during the month of October in 1994, while the lowest value occurred during the month of May in 1985. The monthly and annual variation of the reservoir elevation is presented in Figures 3.6a and 3.6b respectively.

3.3.2 Shiroro hydropower dam

3.3.2.1 Reservoir inflow

The summary of statistics of reservoir inflow at Shiroro dam is presented in Table 3.3a. During the 20 years of operation (1990 – 2010), the peak reservoir inflow was 1752.51 m^3/s, while the lowest reservoir inflow was 9.87 m^3/s. The peak value occurs during the month of September in 2003, while the low flow occurred during the month of April 2008. The monthly and annual variation of the reservoir inflow is presented in Figures 3.7a and 3.7b respectively. The trend in Figure 3.7b is that the reservoir inflow reached a peak in 2003 and has been reducing until 2005 when it starts to increase. The first peak value was experienced in 1992 and start decreasing until 2002. The highest peak in 2003 might be due to high rainfall within the catchment of River Kaduna, which is the main source to the Shiroro reservoir. The trends in Figure 3.7a indicate peak inflow during September and low inflow during April.

3.3.2.2 Turbine discharge

The summary of statistics of turbine discharge at Shiroro dam is presented in Table 3.3b. During the 20 years of operation (1990 – 2010), the peak turbine discharge was 792.45 m^3/s, while the lowest turbine discharge was 20.80 m^3/s. The peak value occurs during the month of August in 2004, while the low turbine discharge occurred during the month of December in 2002. The monthly and annual variation of the turbine discharge is presented in Figures 3.8a and 3.8b respectively. The trend in Figure 3.8 is that discharge has been increasing steadily since 1990 until 1998 when it start to decrease. From 2000 it starts to increase again until it get to a peak in 2004 and start to decrease. The fluctuation in the pattern of releases might be connected to reservoir flow pattern. The highest value experienced in some years might lead to flooding at the downstream reaches of the reservoir. The trend in Figure 3.8a indicated that the occurrence of the peak discharge is in the month of August. Hence flooding may be experienced in August annually.

3.3.2.3 Reservoir elevation

The summary of statistics of reservoir elevation at Shiroro dam is presented in Table 3.3c. During the 20 years of operation (1990 – 2010), the peak reservoir elevation was 423.80 m, while the lowest reservoir elevation was 355.44 m. The peak value occurs during the month of August in 1991, while the low reservoir elevation occurred during the month of July in 2009. The monthly and annual variation of the reservoir elevation is presented in Figures 3.9a and 3.9b respectively.

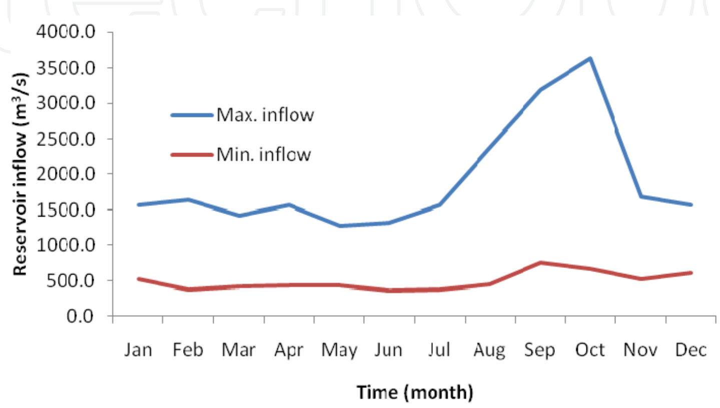


Fig. 3.4 a) Monthly maximum and minimum reservoir inflow at Jabba HEP dam (1984 - 2008).

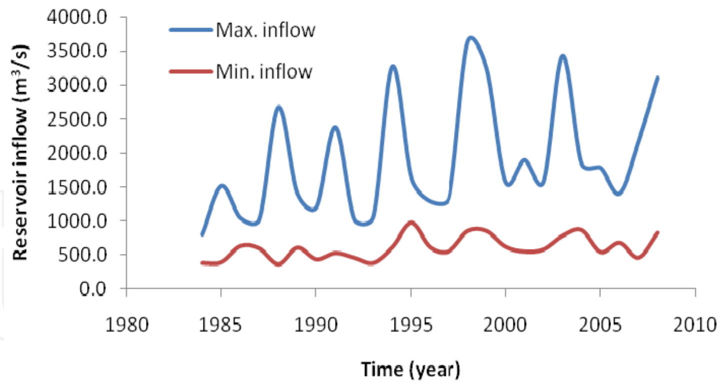


Fig. 3.4 b) Annual variation of maximum and minimum reservoir inflow at Jabba HEP dam (1984 - 2009).

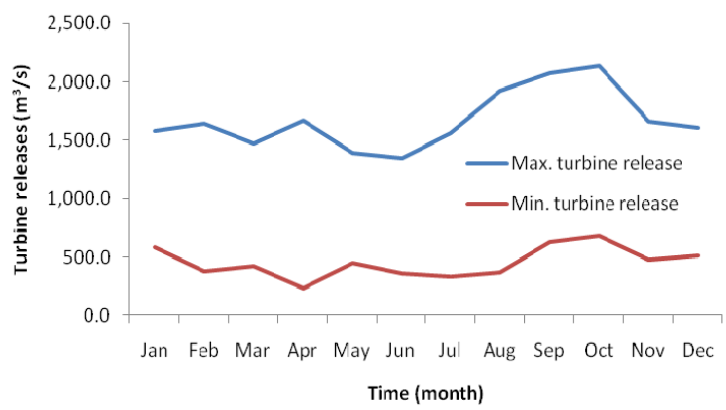


Fig. 3.5 a) Monthly variation of maximum and minimum turbine releases at Jabba HEP dam (1984 - 2010).

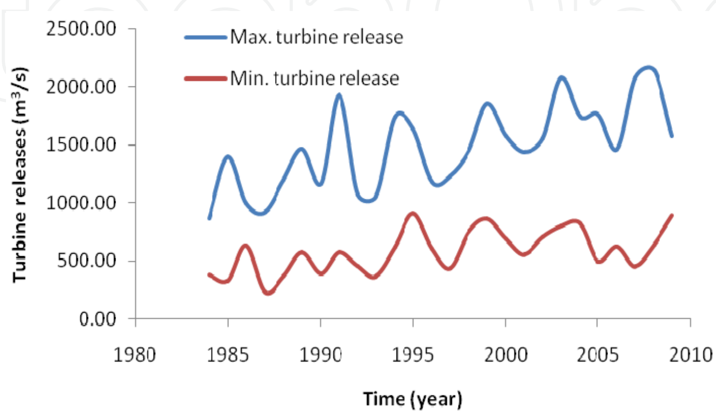


Fig. 3.5 b) Annual variation of maximum and minimum turbine releases at Jabba HEP dam (1984 - 2010).

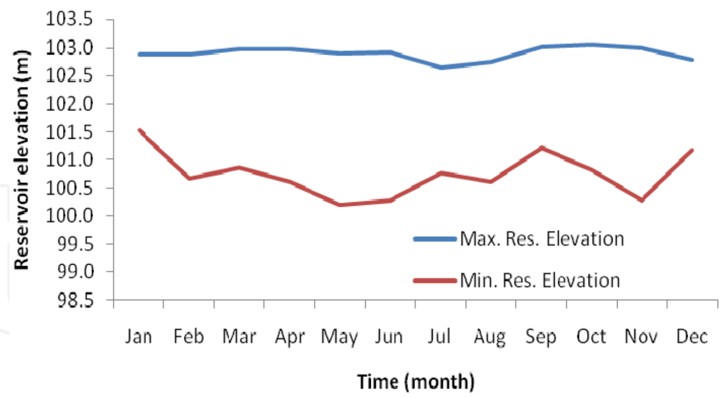


Fig. 3.6 a) Monthly variation of maximum and minimum reservoir elevation at Jabba HEP dam (1984 - 2003).

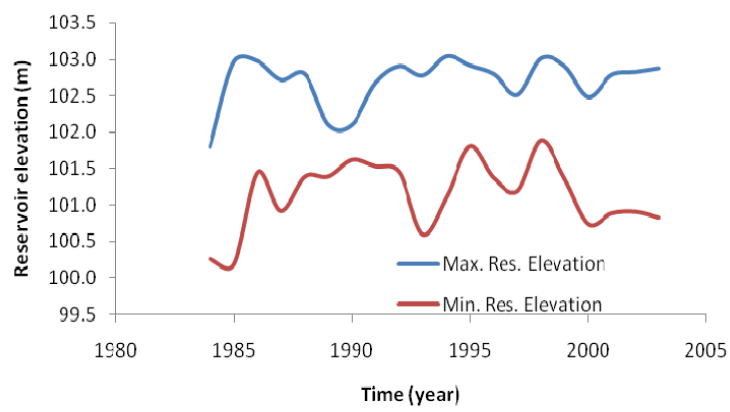


Fig. 3.6 b) Annual variation of maximum and minimum reservoir elevation at Jabba HEP dam (1984 - 2003).

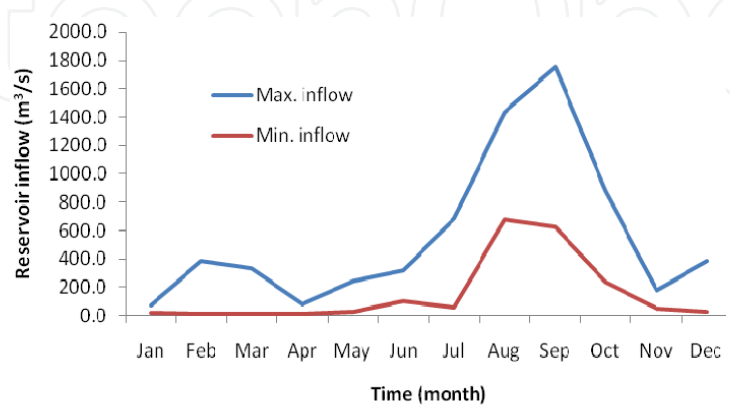


Fig. 3.7 a) Monhly variation maximum and minimum reservoir inflow at Shiroro HEP dam (1990 - 2009).

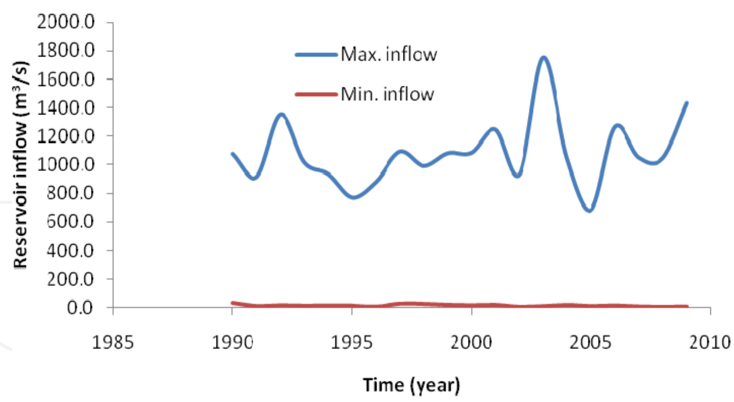


Fig. 3.7 b) Annual variation of maximum and minimum reservoir inflow at Shororo HEP dam (1990 - 2009).

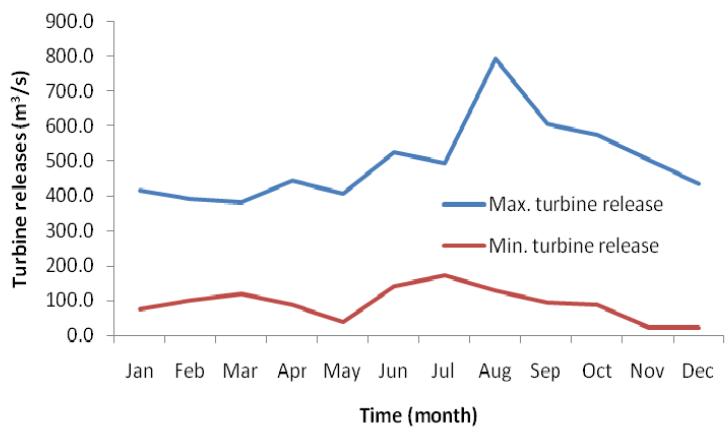


Fig. 3.8 a) Monthly variation of maximum and minimum turbine releases at Shiroro HEP dam (1990 - 2009).

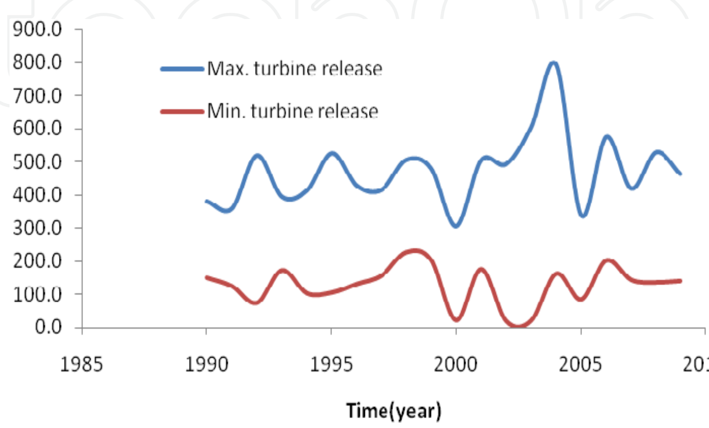


Fig. 3.8 b) Annual variation of maximum and minimum turbine releases at Shororo HEP dam (1990 - 2009).

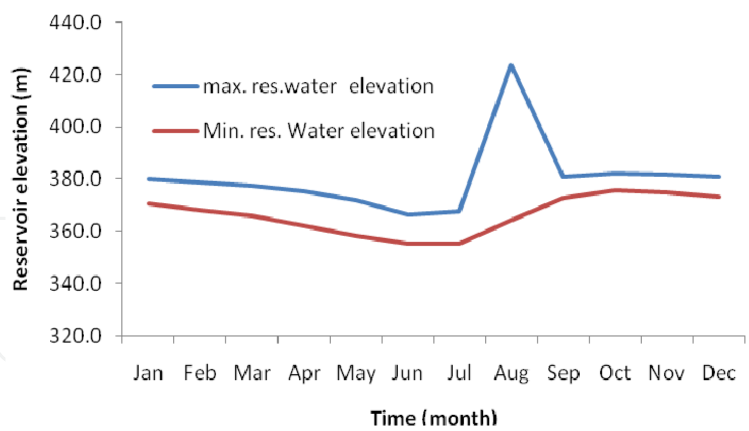


Fig. 3.9 a) Monthly variation of maximum and minimum reservoir elevation at Shiroro HEP dam (1990 - 2009).

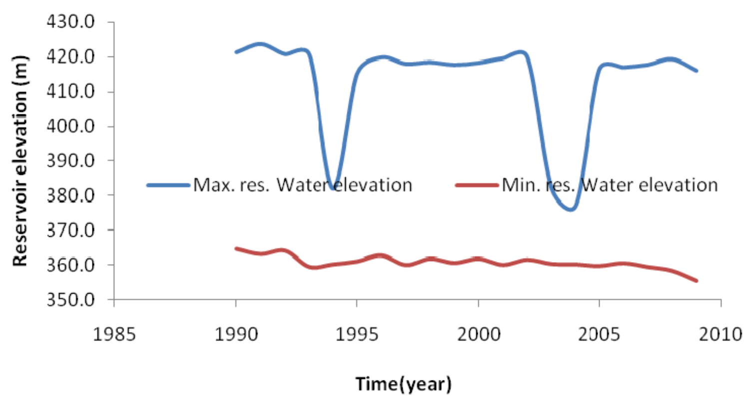


Fig. 3.9 b) Annual variation of maximum and minimum reservoir elevation at Shiroro HEP dam (1990 - 2009).

The trend in Figure 3.9b is that the maximum reservoir elevation has remained relatively constant since 1990, but lowered in 1994, 2003, and 2004. This might be connected to low reservoir inflow has indicated in Figure 3.7b. The minimum elevation was raised to 364.57 in 1990, and was subsequently lowered to 355.33 m in 2009. This might be as a result of over drawn of water for energy generation and to allow for more water to be stored in the dam in case of high flow from River Kaduna and its major tributaries contributing flow to the reservoir.

3.4 Flow duration curve (FDC)

The flow duration analysis was carried out in accordance to the method established by Oregon State University in 2002 to 2005, (http://water.oregonstate.edu/streamflow/). The method involves establishment of relationship between discharge and percent of time that the indicated discharge is equaled or exceeded (exceedence probability). The FDC can be used to determine dependable flow of various reliabilities such as 50%, 60%, 75%, 90%, 95% and 99% of the power output that can be guaranteed at various levels of reliability while ensuring that flooding is either eliminated or reduced. The flow duration curve analysis was carried out for reservoir inflow and turbine discharge at the three hydropower dams. The dependable reservoir inflow and turbine discharge at 50% exceedence probability was obtained as 700 m^3/s and 760 m^3/s for Kainji, 1000 m^3/s for Jebba and 160 m^3/s and 300 m^3/s for Shiroro respectively. The dependable reservoir inflow and turbine discharges of reliabilities such as 50%, 60%, 75%, 90%, 95% and 99% from Figure 3.10a – 3.12b and the estimated power output that correspond to various reliabilities are presented in Table 3.4a.

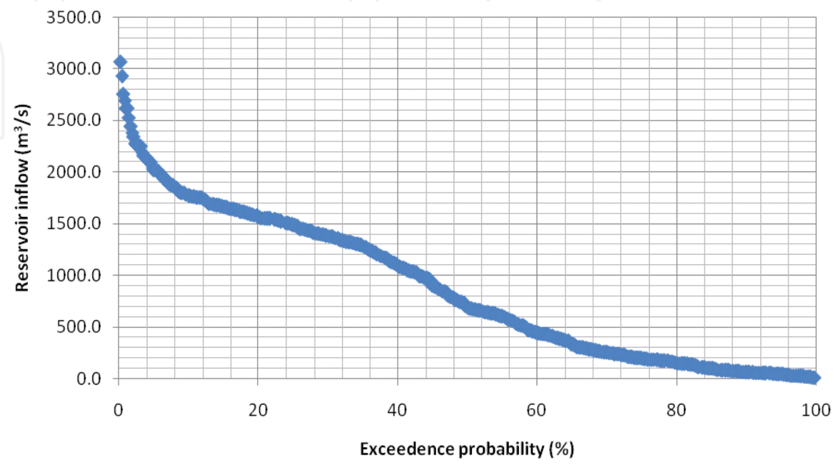


Fig. 3.10 a) Flow duration curve for resrevoir inflow at Kainji H.P dam (1970-2010).

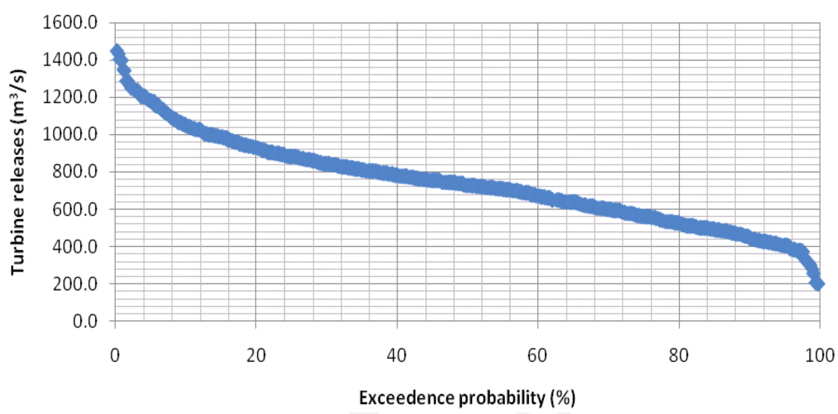


Fig. 3.10 b) Flow duration curve for turbine release at Kainji H.P dam (1970-2009).

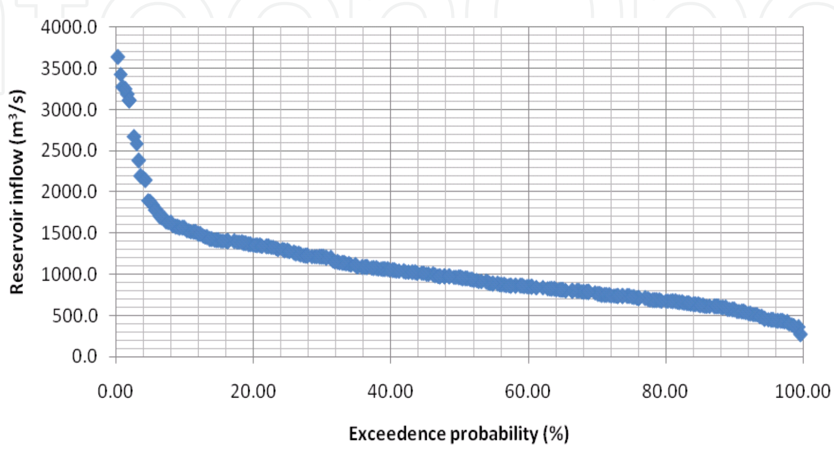


Fig. 3.11 a) Flow duration curve for reservoir inflow at Jabba H.P dam (1984-2010).

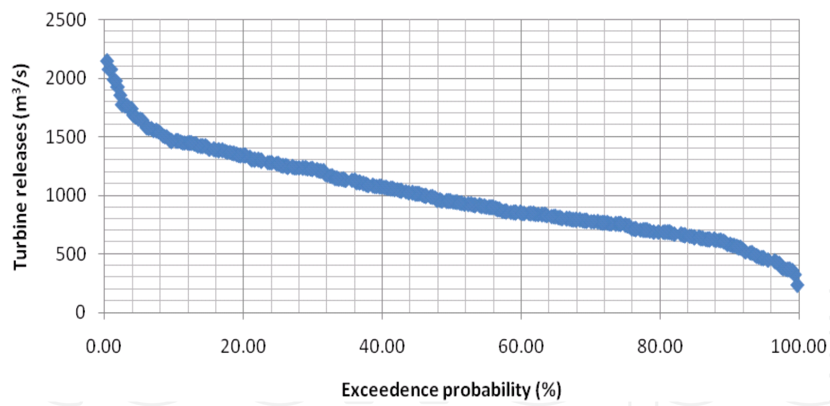


Fig. 3.11 b) Flow duration curve for turbine releases at Jabba H.P dam (1984–2009).

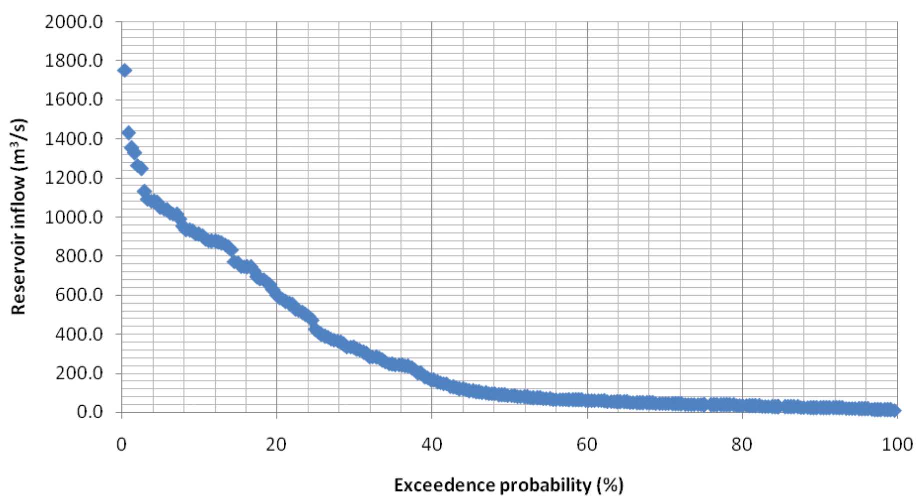


Fig. 3.12 a) Flow duration curve for reservoir inflow at Shiroro H.P dam (1990-2010).

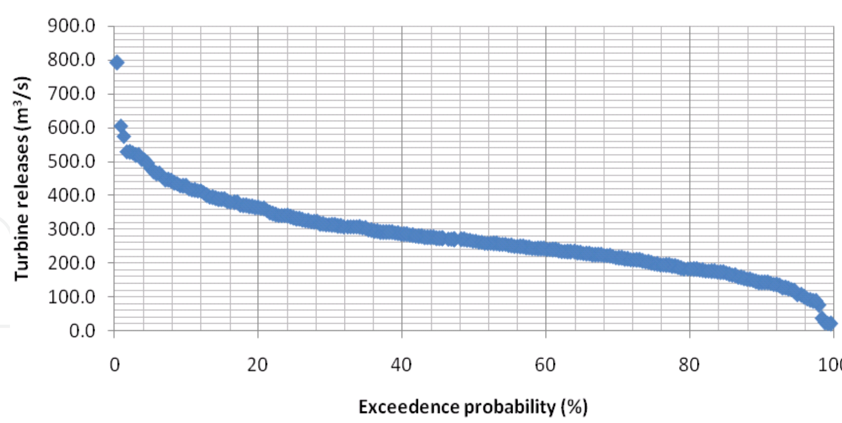


Fig. 3.12 b) Flow duration curve for turbine releases at Shiroro H.P dam (1990-2009).

Table 3.4 shows discharges of various reliabilities and the power output that can be guaranteed at Kainji, Jebba and Shiroro hydropower dams. For example 920 m^3/s can be drawn in 75% of the time and can drive one unit of turbine to generate about 200 MW of power every day. Also 540 m^3/s can be drawn in 90% of the time and can drive one unit of turbine to generate about 120 MW of power every day, while 500 m^3/s can be drawn in 95% of the time and can drive one unit of turbine to generate about 100 MW of power every day.

This implies that the more the amount of energy to be generated the more the quantity of water to be discharged. Care must be taken to avoid downstream flooding.

Kainji Dam Optimum head used H = 42.2m	Level of reliabilities (%)	50	60	75	90	95	99
	Turbine discharge (m^3/s)	760	720	600	480	440	200
	Energy output (MW)	252	239	199	159	146	66
Jebba Dam Optimum head used H = 29.3m	Level of reliabilities (%)	50	60	75	90	95	99
	Turbine discharge (m^3/s)	1000	960	920	540	500	200
	Energy output (MW)	230	221	212	124	115	46
Shiroro Dam Optimum head used H = 97m	Level of reliabilities (%)	50	60	75	90	95	99
	Turbine discharge (m^3/s)	300	280	220	160	120	10
	Energy output (MW)	228	213	168	122	92	8

Table 3.4 Turbine discharge and corresponding power output for the three Stations.

Table 3.4 show discharges of various reliabilities and the power output that can be guaranteed at three hydropower dams. For example 600 m^3/s can be drawn from Kainji in 75% of the time and can drive one unit of turbine to generate about 190 MW of power every day. Also, 480 m^3/s can be drawn in 90% of the time and can drive one unit of turbine to generate about 150 MW of power every day, while 440 m^3/s can be drawn in 95% of the time and can drive one unit of turbine to generate about 140 MW of power every day. This implies that the more the amount of energy to be generated the more the quantity of water to be discharged. Care must be taken to avoid downstream flooding.

3.5 Probability distribution analysis

The Gumbel extreme value type 1 (EV1) probability distribution function was used in fitting the low and high reservoir inflow and turbine discharge at the hydropower dams in order to predict values for various return periods. The probability functions of the form presented in equation (1) was obtained for high and low values of the variables for flood and low flow prediction respectively (Raghunath, 2008).

$$\begin{aligned} Q_T &= \bar{Q} + \sigma(0.78y_T - 0.45) \\ y_T &= -\ln(-\ln(1-p)) \end{aligned} \tag{1}$$

$$\begin{aligned} Q_T &= \bar{Q} + \sigma(0.78y_T - 0.45) \\ y_T &= -\ln(-\ln(p)) \end{aligned} \tag{2}$$

where :

Q_T = inflow value having T return period ; $\bar{Q} = Mean \quad value$
σ= Standard deviation; y_T = Reduced Variate; P = Probability

3.5.1 Reservoir inflows and turbine discharges fitted with Gumbel probability function

In order to show how best the Gumbel probability distribution function fits the peak and low values of the variables under consideration, the observed and predicted values were

plotted. The peak and low values of reservoir inflow and turbine discharge at Kainji, Jebba and Shiroro HEP dams were fitted with Gumbel probability distribution and the following functions were obtained as presented in Table 3.5. The result in Table 3.5 shows that the statistical goodness of fit tests such as probability plot coefficient of correlation (r) and coefficient of determination (R^2) were very high for the entire variable; hence the Gumbel probability distribution function can be adequately used to predict both peak and low values of the variables. Based on this fact, values of the variables for different return periods are predicted and presented in Table 3 .6.

3.5.2 Estimation of return period

The analysis of the historical data revealed that the lowest and the peak reservoir inflow rates are 9.40m^3/s and 3065.0m^3/s for Kainji, 378.0 m^3/s and 3636.0 m^3/s for Jebba, and 9.87 m^3/s and 1752.51 m^3/s respectively, while the lowest and the peak turbine discharges are 198.27 m^3/s and 1445.34 m^3/s for Kainji, 232.0 m^3/s and 2143.0 m^3/s for Jebba, and 20.80 m^3/s and 792.45 m^3/s for Shiroro respectively. However, the return periods of these parameters were determined based on the Gumbel probability distribution function developed for each variable. The results are presented in Table 3.6.

Table 3.6 implies that peak reservoir inflow will occur every 33 years while low inflow will be expected every 13 years and the peak turbine discharge (flooding) may occur on the average of every 19 years while the lowest turbine discharge will be rear for Kainji Dam. The peak reservoir inflow will occur every 25 years for Jebba Dam while low inflow will be expected every 20 years. The peak turbine discharge (flooding) may occur on the average of every 18 years while the lowest turbine discharge will also be rear. This also indicates that the peak reservoir inflow will occur at interval of 65 years for Shiroro Dam while low inflow will be expected every 25 year. The peak turbine discharge (flooding) may occur on the average of every 78 years while the lowest turbine discharge will be rear.

4. Result and discussion

The chapter involves collection of data and information concerning the reservoir inflow, turbine discharge and reservoir elevation data from the hydrological unit of the three hydropower stations in Nigeria. The relationships between the observed and predicted values of the peak and low reservoir inflows and turbine discharges are presented in Figures 3.15a and 3.18b. The result in Table 3.5 shows that the statistical goodness of fit tests such as probability plot coefficient of correlation (r) and coefficient of determination (R^2) were very high for the entire variable; hence the Gumbel probability distribution function can be adequately used to predict both peak and low values of the variables. Based on this fact, values of the variables for different return periods were predicted and presented in Table 3.6.

Hydropower dams	Hydrological data		Developed equations	r	R
Kainji Station	Reservoir inflow	Peak	$Q_T = 1798.8 + 562.18(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.99	0.98
		Low	$Q_T = 67.9 + 49.72(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.96	0.92
	Turbine Discharge	Peak	$Q_T = 990.3 + 252.88(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.98	0.95
		Low	$Q_T = 494.7 + 142.82(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.97	0.94
Jebba Station	Reservoir inflow	Peak	$Q_T = 1893.00 + 859.89(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.98	0.95
		Low	$Q_T = 604.40 + 172.99(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.98	0.95
	Turbine Discharge	Peak	$Q_T = 1480.40 + 374.56(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.98	0.95
		Low	$Q_T = 570.40 + 180.10(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.98	0.95
Shiroro Station	Reservoir inflow	Peak	$Q_T = 1080.70 + 240.70(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.98	0.96
		Low	$Q_T = 20.30 + 7.71(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.99	0.98
	Turbine Discharge	Peak	$Q_T = 473.10 + 108.59(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(1-p))$	0.97	0.94
		Low	$Q_T = 129.10 + 60.09(0.78y_T - 0.45)$ $y_T = -\ln(-\ln(p))$	0.95	0.90

Table 3.5 Summary of the developed equation for the prediction of the hydrological variables.

Reservoir inflow (m^3/s)						Turbine discharge (m^3/s)					
Peak			Low			Peak			Low		
Kainji	Jebba	Shiroro	Kainji	Jebba	Shiroro	Kainji	Jebba	Shiroro	Kainji	Jebba	Shiroro
3065	3636	1753	9	378	10	1445	2143	80	198	232	21
33	25	65	13	20	25	19	18	78	3093	520	288

Table 3.6 Return periods of peak and lowest variables for the three Hydropower Dams respectively.

Statistical analysis carried out on the reservoir inflow data showed that inflow to Kainji Dam is related to the control release from upstream reservoir in the Niger Republic and this implies that the flow hydrology at Kainji is mostly controlled by the upstream reservoir in another region. The same observation can be extended to Jebba reservoir in that the inflow depends on the control releases at Kainji. The reservoir inflow data revealed that spillway releases occur at Kainji throughout the year (monthly), while spillage occurs at Jebba reservoir between the months of August through to December. Peak discharges occur during the month of October at the two reservoirs and is indicated as the month of high flood level downstream of the reservoirs. Analysis of water management options for different level of reliabilities for turbine discharge and energy output performed using probabilistic reservoir inflow of 50%, 60%, 75%, 90%, 95% and 99% reliabilities for the various scenarios were presented in Table 3.5. Values of energy generation were estimated for each value of turbine discharge selected. The developed equations in Table 3.5 relating hydrological variables for energy generation can be used to predict flood limits for any desired amount of energy.

5. Conclusion

The main cause of flood in the downstream regime was identified to be the sudden release of water from the hydropower dams located upstream of the study area. The study revealed that the sudden release of flood water is not due to normal operation at the hydropower stations in Nigeria, but is due to sudden discharges at the reservoirs located in the Niger Republic and the Republic of Mali. This leads to excess releases at Kainji 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 model results revealed that the problem at the Bacita sugar plantation is due to the location of their water abstraction level and the persistence flood problem at the downstream areas is because the flood wall could no longer serve the intended purpose. The flood wall was put in place before the construction of the dams.

5.1 Recommendations

Water management at the three reservoirs needs improvement so that the energy generation output can be improved on and the management of PHCN at Kainji, Jebba and Shiroro should provide information to communities and local authorities on the release of water especially during the months of August to October. It is recommended that joint release policy be established between Nigeria, Niger Republic and Mali in order to alleviate persistence flood problem in the country since the analysis of the reservoir inflow at Kainji revealed that it is a control release from upstream reservoirs in another region. It also recommended that a study should be carried out to assess the state of facilities at the hydroelectric power stations and identify the components that are malfunctioning in order to recommend required improvement.

6. References

Aribisala, J. O. & Sule, B. F. (1998). Seasonal operation of a Reservoir Hydropower system, Technical Transactions, Nigerian Society of Engineers, NSE, Vol. 33 No 2: 1-14

Bolaji, T. (1999). Sacked by the Almighty River Niger, Newspaper Publication, the Guardian on Sunday, October 23, pp 4 -5

Jebba hydro-electric Power Station (2010). Hydrology, Meteorology and Reservoir operational data. Hydrology section. Jebba, Niger State, Nigeria

Kainji hydro-electric Power Station (2010). Hydrology, Meteorology and Reservoir operational data. Hydrology section. Kainji, Niger State, Nigeria

Lawal, A. F. & Nagya, M. T. (1999). Socio-Economic effects of flood disaster on farmers in Mokwa Local Government Area, Niger State, Nigeria, A paper presented at the 33rd Annual Conference of Agricultural Society of Nigeria held at National Cereal Research Institute, Badeggi, Niger State, Nigeria. Pp 1 – 10

Olofintoye, O. O.; Sule, B. F. & Salami, A. W. (2009). Best-fit Probability Distribution model for peak daily rainfall of selected Cities in Nigeria. New York Science Journal, 2(3), ISSN 1554-020, (http://www.sciencepub.net/newyork) (sciencepub@gmail.com)

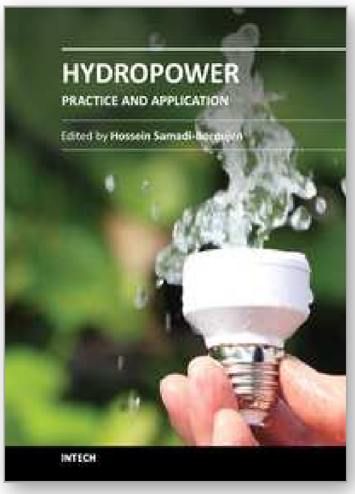
Olukanni, D. O. & Salami, A. W. (2008). Fitting probability distribution functions to reservoir inflow at hydropower dams in Nigeria. Journal of Environmental Hydrology, Vol. 16 Paper 35, pp. 1-7, 2607 Hopeton Drive San Antonio, TX 78230, USA

Oregon State University (2002). Flow Duration Curve (FDC). Accessed 25th, April, 2011, Available from (http://water.oregonstate.edu/stream)

Raghunath, H.M (2008). Hydrology: Principles, Analysis, Design. New Age International Limited, Publishers, New Delhi, Revised Second Edition. www.newagepublishers.com

Shiroro hydro-electric Power Station (2010). Hydrology, Meteorology and Reservoir operational data. Hydrology section. Shiroro, Niger State, Nigeria

Sule, B. F (2003). Water Security: Now and the future, 65th Inaugural lecture, University of Ilorin, Ilorin, Nigeria. 70 pp, Civil Engineering Department, University of Ilorin, Nigeria



Hydropower - Practice and Application
Edited by Dr. Hossein Samadi-Boroujeni

ISBN 978-953-51-0164-2
Hard cover, 320 pages
Publisher InTech
Published online 09, March, 2012
Published in print edition March, 2012

Hydroelectric energy is the most widely used form of renewable energy, accounting for 16 percent of global electricity consumption. This book is primarily based on theoretical and applied results obtained by the authors during a long time of practice devoted to problems in the design and operation of a significant number of hydroelectric power plants in different countries. It was preferred to edit this book with the intention that it may partly serve as a supplementary textbook for students on hydropower plants. The subjects being mentioned comprise all the main components of a hydro power plant, from the upstream end, with the basin for water intake, to the downstream end of the water flow outlet.