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EVALUATION OF SUSTAINABLE HYDROPOWER POTENTIAL OF UNILORIN AND ASA DAMS IN ILORIN, KWARA STATE, NIGERIA

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ABSTRACT

This paper presents the evaluation of sustainable hydropower potential of Unilorin and Asa dams in north central Nigeria. The domestic and institutional water demands, evaporation losses over reservoir surface area and rate of reservoir sedimentation were determined which constituted the primary obligatory function of the dams. The river flow at the dams were estimated and extended based on Markov model. The peak and low flows were obtained as 20.00 m^3/s and 0.01 m^3/s for Unilorin dam, while 148.00 m^3/s and 0.05 m^3/s were obtained for Asa dam. The storage required at each dam to satisfy the primary obligatory function was estimated using sequent peak analysis, while the 50% sustainable flow for power generation was determined using flow duration analysis methods. Based on the available 50% sustainable flow of 2.55 m^3/s and 8.00m^3/s respectively for Unilorin and Asa dam, the corresponding hydropower potential of 0.18 MW and 1.53 MW were obtained.

Keywords: Unilorin Dam, Asa Dam, Water Demands, Flow Duration Curve, Hydropower Potentials

INTRODUCTION

Power is a very important infrastructure in the overall sustainable development of a nation; therefore there is an ever increasing need for more power generation in all countries of the world. In true global perspective of power demand, most countries of the world are formulating methods and devices to explore the various possibilities of energy generation. Energy and water has been identified to play critical roles in sustainable development. Hydropower is a renewable source of energy, which gives off no pollution gases, hence a clean source of generating electricity (Gurbuz, 2006). From the criterion of mass generation, thermal, hydro and nuclear are most prominent. Other sources like solar currently have limited contribution. Among the disadvantages of hydropower projects is that it is capital intensive and have long gestation periods (Aribisala and Sule, 1998). However, where there are existing storage facilities like Unilorin Dam, both cost and gestation period is reduced. Akoshile and Olaoye (2010) stated that there is enormous exploitable hydropower potential on the African continent but despite this, Africa has one of the lowest hydro-utilization rates. Currently less than 7% of the potential has been harnessed. Small hydropower can adequately contribute to meet the electricity needs of the African countries. Availability of seasonal and permanent rivers and streams provide excellent opportunities for hydropower development in the continent. The harnessed small hydropower in Nigeria is only about 33.0 MW. As Bosona and Gebresenbet (2010) said, one way of improving water management is increasing the efficiency of utilization of dam reservoirs. Melka Wakana Hydropower plant in Ethiopia was modeled and powersim simulation software was used to simulate its operation. The recorded mean monthly data of reservoir inflow, evaporation rate, energy production, turbine release, reservoir elevation was considered as time series input data. The results of the simulation analyses indicated that yearly energy production was increased by 5.67% while evaporation loss was reduced by 38.33%, but the power plant still produces below its design capacity by 12.21%. Salami and Sule (2011) in their study to retrofit hydropower generation to a multipurpose reservoir discovered that 3MW hydropower plant can be incorporated and other functions would be satisfied. In a more recent study (Salami and Sule, 2012) on the optimal water management modeling of Kainji and Jebba hydropower system on River Niger in Nigeria has shown that an optimal energy of 5995.60 GWH can be generated, which is about 41% higher than the average energy generation of 4261.12 GWH obtained from the historical records at the power plants. The Rivers Niger and Benue with several tributaries constitute the Nigerian river system which offers some potential renewable source of energy for economically viable large hydropower development. The major rivers also include Kaduna, Sokoto, Hadejia, Yobe, Gongola, Ogun, Osun, Imo, Cross River, etc (Sule, 2003).

Nigeria is blessed with a number of rivers and streams which are either seasonal or perennial. The estimated long term power demand of Nigeria was put at 25GW for the year 2010 to sustain industrial growth (Okpanefe and Owolabi, 2001). The Power Holding Company of Nigeria (PHCN) has an installed capacity of 6GW, but actual available output is less than 2.5GW. Of this, thermal plants provide 61%, while hydropower generation is about 31% (Olivia, 2008). The overall potential of hydropower generation of Nigeria is in excess of 11GW (Zarma, 2006). This means that less than 20% of the hydropower potential of the country has been realized. This study is aimed to evaluate the hydropower potential of Unilorin and Asa Dams in the North Central region in Nigeria in order to develop mini hydro scheme at these locations to boost energy need of the dwellers.

MATERIALS AND METHODS

Site Description

The Unilorin Dam, commissioned in 2007 primarily for water supply, is located on the Oyun River. The catchment of River Oyun is located between Latitude 8^0 38' and 9^0 50' North and between Longitudes 8^0 03 and 8^0 15'East (Figure 1). River Oyun originates at an elevation of 490m amsl, close to Ila–Orangun and flows in an approximately North – west direction for about 80km before joining River Asa, which eventually discharges into Niger River. The Dam is a zoned earthfill embankment with an ogee-shaped concrete spillway. The intake for water supply and the low lift pumping station are located on the wing wall.

The Asa Dam, commissioned in 1978 primarily for water supply, is located on the Asa River at a point which is 5 km south of Ilorin city centre (Figure 1). Even though development and the expansion of the town have reduced this to less than a kilometer, the reservoir created by the dam is away from town. The Dam is a composite earth embankment with a central spillway followed to the right by a mass concrete non overflow gravity section. The intake for water supply and the low lift pumping station are located on the wing wall. The Dam parameters are shown in the Table 1.

Water Resources of the Dams

The knowledge of water resources of dams is required to decide the hydropower potential of its reservoir since the power is directly proportional to the flow and head. To fairly select the most appropriate hydraulic equipment and estimate the Dam's potential, the water resources analysis must take the following into consideration: (a) The water to meet the primary responsibility of the Dam; (b) The evaporation losses over the reservoir area; (c) The reservoir sediments which may have reduced the storage capacity; (d) The direct rainfall on the reservoir and; (e) The inflow into the reservoir.

Table 1: Relevant details of the Unilorin and Asa Dams

S/No	Item	Details	
		Unilorin Dam	Asa Dam
A	RESERVOIR		
1.	Catchment area (km^2)	573	950
2.	Average Annual Yield (Catchment Runoff), (x 10^6 m^3)	50	855
3.	Live storage (x 10^6 m^3)	1.54	34.7
4.	Dead storage (x 10^6 m^3)	0.26	3.60
5	Surface area @ elevation 294 m amsl (Km^2)	0.696	7.32
6	Reservoir capacity @ elevation 294 m amsl (10^6 m^3)	1.80	43
B	DAM EMBANKMENT		
1.	Type	Zoned earth fill embankment	Composite earth fill embankment
2.	Crest length (m)	178	402
3.	Top width (m)	5	6
4.	Maximum height of embankment (m)	10.30	27
5.	Maximum height of earth core	8.90 m	
6.	Upstream slope	1:3	1:3
7.	Downstream slope	1:2	1:2.5
C	SPILLWAY		
1.	Type	Ogee-shaped concrete	Ogee-shaped concrete
2.	Crest length (m)	50	65
3.	Maximum height (m)	7.70	11
4.	Freeboard height (m)	2.50	2.50

Source: CIWAT (2007) Technical Report on Unilorin dam and KSWB (1973) Planning report.

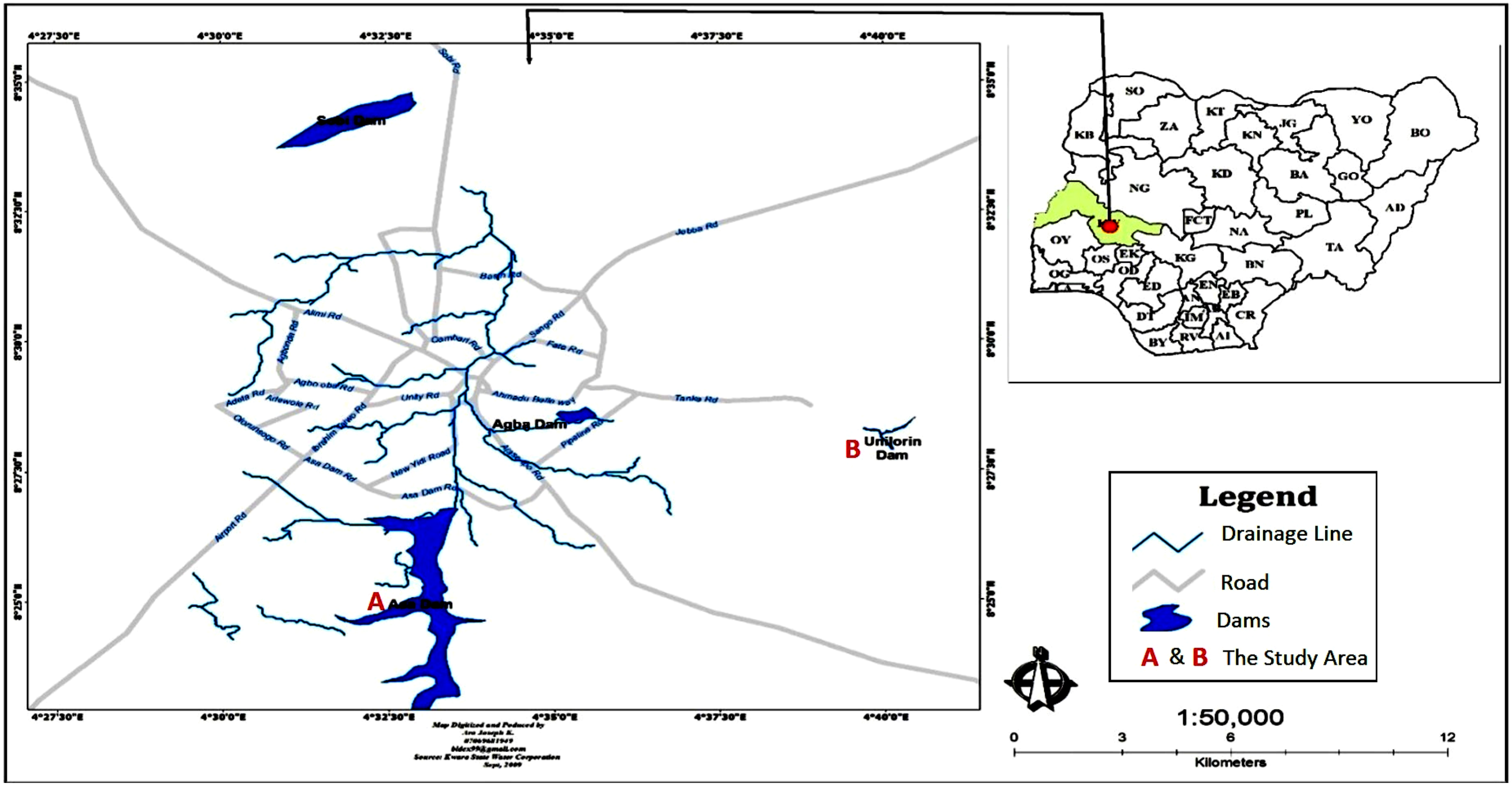

Figure 1: Map of Ilorin showing the location of the lake dams. Inset: map of Nigeria showing the states [Adopted from: Ogunkunle, *et al*, 2016]

Water Supply

It is necessary to determine the amount of water needed to fulfill the primary mandate of the Dam which is water supply. It is assumed that the population making use of Unilorin dam is 30,000 people including academic activities. The per capital consumption recommended by the World Bank for urban areas is 120 l/d. This puts the total demand for 30,000 people at 3600 m^3/day (≈0.05 m^3/s), while for the Asa dam with demand for about 1.2 million people was estimated as 144,000 m^3/d (≈ 2.0 m^3/s) based on Eq.(1)

$$D = \text{Population x Per Capital Consumption} \quad (1)$$

Evaporation Losses from reservoir

Considerable quantity of stored water in a reservoir is lost due to evaporation, seepage and leakage. Of these, the most active is evaporation. The main factors which determine its rate include net radiation, water availability, wind velocity, atmospheric temperature and "reflexibility" of land surface (Michael, 1985 and Fetter, 2007). Free water evaporation is measured by using shallow pans, called Class A pans. However, evaporation pan data cannot be directly applied to free water surfaces like reservoirs because of physical and climatological factors (Subramanya, 2002) thus the pan evaporation of Ilorin, obtained from the metrological Station at Ilorin airport has to be adjusted by multiplying it with the pan coefficient of 0.8. The reservoir evaporation is taken as a product of monthly evaporation and reservoir surface area at ¾ maximum capacities. From the data presented in Table1 and the topographical data used to establish the Elevation-Surface area-Capacity curve, the reservoir surface area corresponds to about 0.56 km^2 and 5.49 km^2 for Unilorin and Asa dam respectively. These values were used in the computation of the monthly evaporation losses, the mean monthly losses for Unilorin and Asa dam were obtained as 180 m^3 and 1500 m^3 respectively.

Reservoir Sediment

The storage capacity of the Dams is expected to reduce with time based on the accumulation of sediments. However, a quick check was done using the Flemings equation and the Brune Curves for reservoir trap efficiency (Linsley, 1992). The sediment yield range of solids concentration is usually given for many rivers and streams in this region to be between 1.0 g/l to 2.0 g/l and higher values for areas further north. The same regional sediment rating curve that is sediment S per unit discharge is as in Eq. (2).

$$S = e^{(-0.0124R+11.81)} + 1.0 g/l \quad (2)$$

where

R = annual rainfall in mm for the project area (1200 mm) and S was obtained as 1.0464 g/l.

The total annual sediment inflow was obtained by multiplying the sedimentation rate with the catchment runoff given in Table 1 to obtain the annual sediment inflow as 52.88 x 10^6 kg. Taking the value of consolidated sediment as 1500 kg/m^3, the sediment volume per year was obtained as 0.0353 x 10^6 m^3 and 1.20 x 10^6 m^3 for Unilorin and Asa dams respectively.

Reservoir Inflow

Monthly inflow data of Oyun River at Oyun Dam Offa was available from 1972 to 1981 (Salami and Ajenifuja, 2009). In modeling the monthly reservoir inflow, the Thomas – Fierring model based on a first order Markov model was adopted and the synthetic flow series were calculated using observed historical monthly stream flow sequences (Salami, 2007), the model developed was used to extend the flow up to the year 2011. CIWAT (2007) revealed that the catchment area of oyun river at Oyun dam Offa and Unilorin dam is 106 km^2 and 573 km^2 respectively (Nurudeen, 1987). Based on the catchment area and the extended flows for Oyun River at Oyun dam Offa, the river flows at Unilorin dam were estimated using equation (3). The hydrograph of Oyun river flow at Unilorin dam is presented in Fig 2, while the summary of the monthly flow statistics is presented in Table 2. The method was based on the fact that the characteristics of the watershed of rivers in humid regions are generally homogeneous and the spatial distribution of monthly or seasonal rainfall does not significantly vary from one part of the river basin to another. In these situations, estimated flows Q_t^s at any site s can be based on the watershed areas A^s above those sites, and the stream flow $Q_t^{s'}$ and watershed area $A^{s'}$ above the nearest or most representative gage site s'. The equation is given as in Eq. (3). (Loucks et, al. 1981).

$$Q_t^s = Q_t^{s'}\left(\frac{A^s}{A^{s'}}\right) \quad (3)$$

Where:

Q_t^s = stream flow at ungauged site downstream (m^3/s); $Q_t^{s'}$ = stream flow at gauged site upstream (m^3/s); A^s = watershed area contributing to gage site s (km^2) and; $A^{s'}$ = watershed area contributing to gage site s' (Km^2)

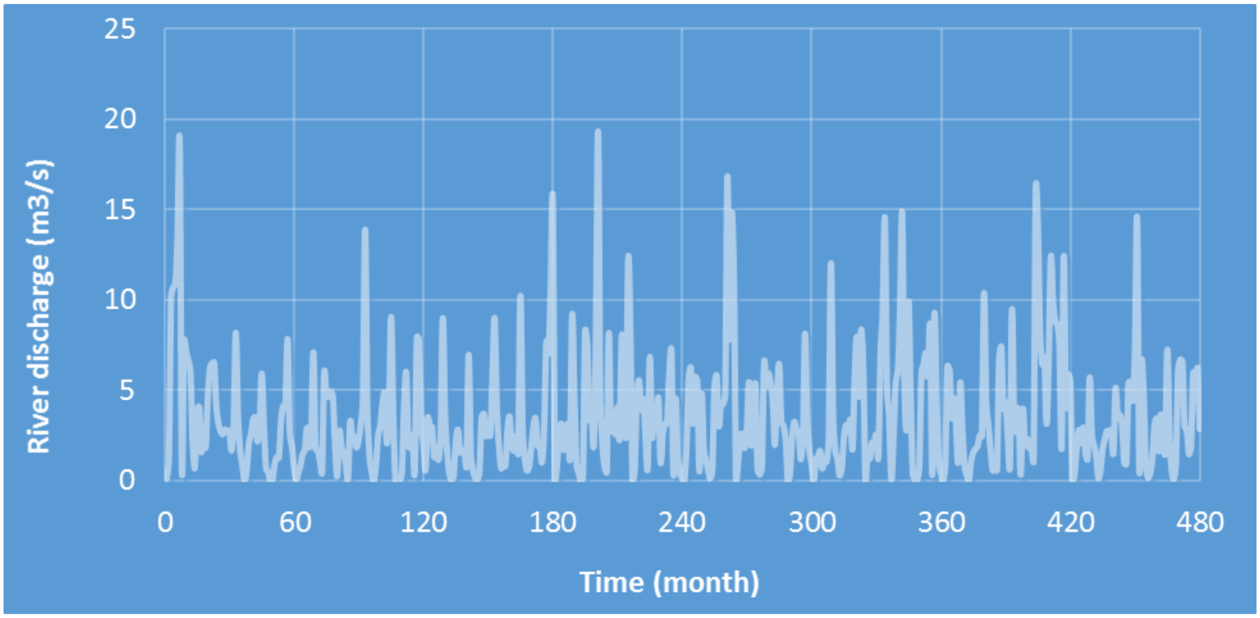

Figure 2: Variation of Oyun River flow at Unilorin Dam

Table 2 Statistics of monthly flow (x10^6 m^3) for Oyun River at Unilorin dam (1972-2011)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.48	4.46	10.39	11.04	8.76	10.58	9.50	8.62	21.46	11.45	8.48	6.58
Median	0.33	2.22	7.88	8.93	7.27	8.32	6.30	6.59	20.25	9.99	4.46	2.43
S.D	2.68	5.06	6.74	5.80	6.04	7.36	9.57	8.61	8.81	6.50	8.94	8.96
C.V	1.81	1.14	0.65	0.53	0.69	0.70	1.01	0.99	0.41	0.57	1.05	1.36
Min	0.02	0.11	2.34	3.41	1.85	3.32	2.75	0.68	7.12	3.50	0.17	0.02
Max	12.3	19.79	33.21	27.79	29.42	38.57	49.97	43.42	50.12	38.91	38.46	41.64
Skew	2.72	1.77	1.52	1.08	1.99	2.53	2.88	2.14	1.35	2.17	1.76	2.26

C.V = Coefficient of Variation, $U_{x,i}$=Mean of natural logarithms of the monthly flows; SD = Standard deviation and; $S_{x,i}$= Standard deviation of natural logarithms of the monthly flows

Similarly, the monthly inflow data at Asa Dam site was available from 1966 to 1985. The data were also extended to year 2011 based on Thomas – Fierring as above. The hydrograph of Asa River flow at Asa dam is presented in Fig. 3, while the summary of the monthly flow statistics of the predicted flow is presented in Table 3.

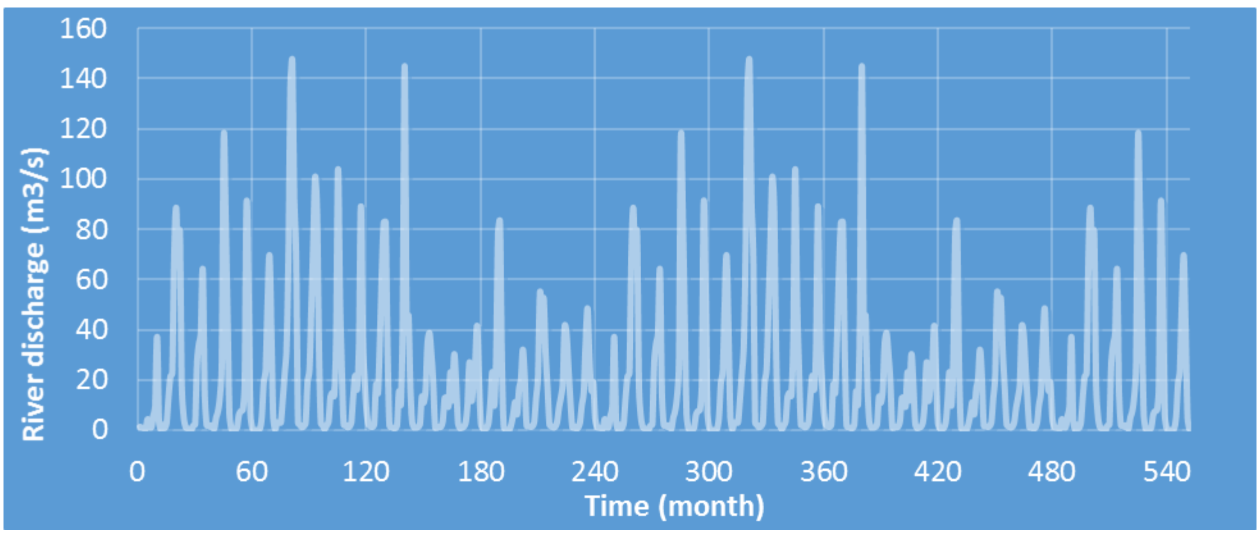

Figure 3: Variation of Asa River flow at Asa Dam

Available Flow for Power Generation and Hydropower Potential

It is not economically feasible to harness the entire runoff of a river during flood as this will require a huge storage. In this case, the storage is defined and fixed and the firm yield for power generation is dependent on overflow and some other quantity available from the reservoir without infringing on the water supply requirement.

Table 3 Statistics of monthly flow ($x10^6$ m^3) for Asa River at Asa dam (1966-2011)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.51	1.11	1.32	3.50	11.38	15.56	28.95	52.90	67.52	52.89	22.05	2.79
Median	1.58	1.07	1.28	2.90	11.48	14.90	22.05	43.93	69.60	50.35	20.12	2.64
S.D	0.71	0.61	0.84	3.07	6.13	9.20	20.73	35.04	39.82	23.75	14.19	1.79
C.V	0.47	0.55	0.64	0.88	0.54	0.59	0.716	0.66	0.59	0.45	0.65	0.64
Min	0.10	0.07	0.05	0.05	0.20	0.34	0.94	5.74	5.69	2.82	0.38	0.15
Max	2.96	3.09	3.32	13.19	22.33	33.42	76.87	147.5	147.2	101.2	69.43	7.46
Skew	-0.3	0.89	0.55	1.39	-0.04	0.26	0.73	1.10	0.17	-0.01	0.81	0.66

C.V = Coefficient of Variation, $U_{x,i}$=Mean of natural logarithms of the monthly flows

S.D = Standard deviation, $S_{x,i}$= Standard deviation of natural logarithms of the monthly flows

Sequent – Peak Analysis

The Sequent – Peak method computes the cumulative sum of the inflows minus the reservoir releases over the time interval chosen for analysis. The analysis assumes that the time interval includes the critical period which is the time period over which the flows have reached a minimum causing the greater drawdown of the reservoir. The other assumption is that the total release over time interval of analysis does not exceed the total reservoir inflow (Mays and Tung, 1992). In this case, the Sequent – Peak method is implemented using Eq. (4).

$S_t = W_t - I_t - R_t + E_t + S_{t-1}$, if positive. (4)

$S_t = o$, otherwise.

Where:

S_t = Storage at time t; W_t = Water Supply demand; I_t = Inflow; R_t = Direct Rainfall on Rainfall; E_t = Evaporation from reservoir and; S_{t-1}, = Previous Storage

The maximum value of S_t is the required active reservoir storage capacity for the flow sequence and the considered releases. The storage required at Unilorin dam to meet the specified obligations was determined using the Sequent – Peak method as $S_t = 0.4 \times 10^6$ m^3 leaving a balance of 1.37×10^6 m^3 for other uses. Similarly for the Asa dam, the storage for the specified obligation was estimated as $S_t = 9.67 \times 10^6$ m^3 leaving a balance of 26.54×10^6 m^3.

Flow duration curve for River flow at Unilorin and Asa dams

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 flow duration curve obtained is presented in Fig. 4 and 5 for Unilorin and Asa dams respectively from which the 50% sustainable flow of $2.60m^3/s$ and 10.00 m^3/s was obtained respectively. However, the available flow from the 50% sustainable flow for power generation was obtained by subtracting the water supply requirements, (section 2.2.1) which gives 2.55 m^3/s and 8.00 m^3/s respectively for Unilorin and Asa dams.

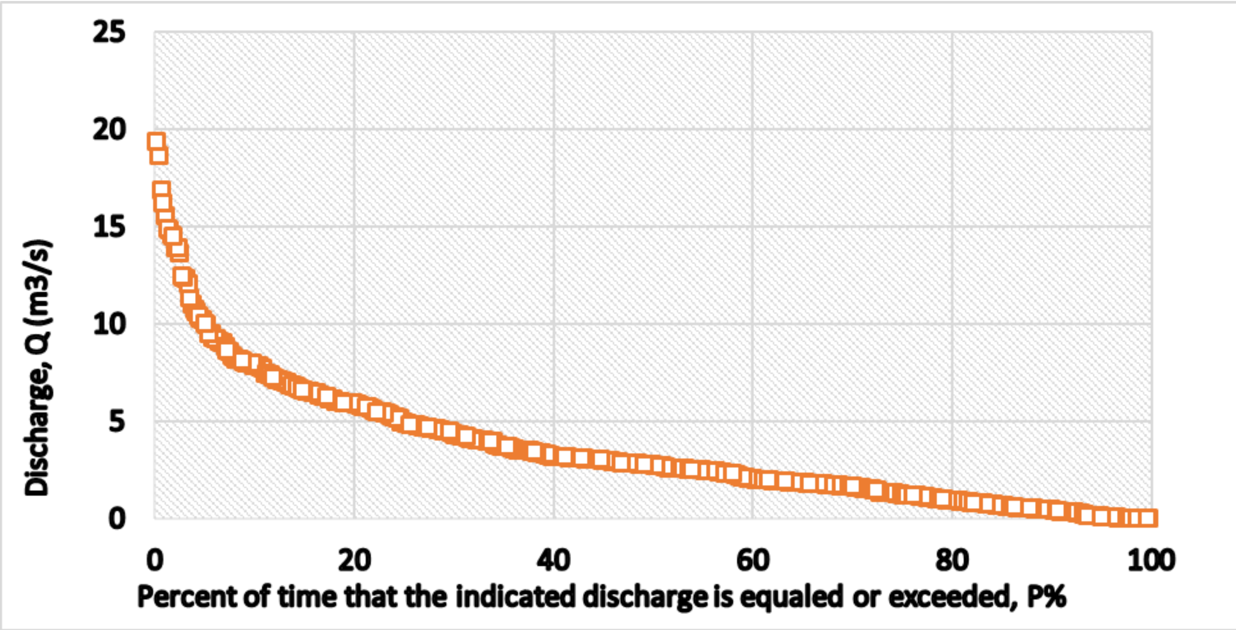

Figure 4: Flow Duration Curve for Oyun River at Unilorin Dam

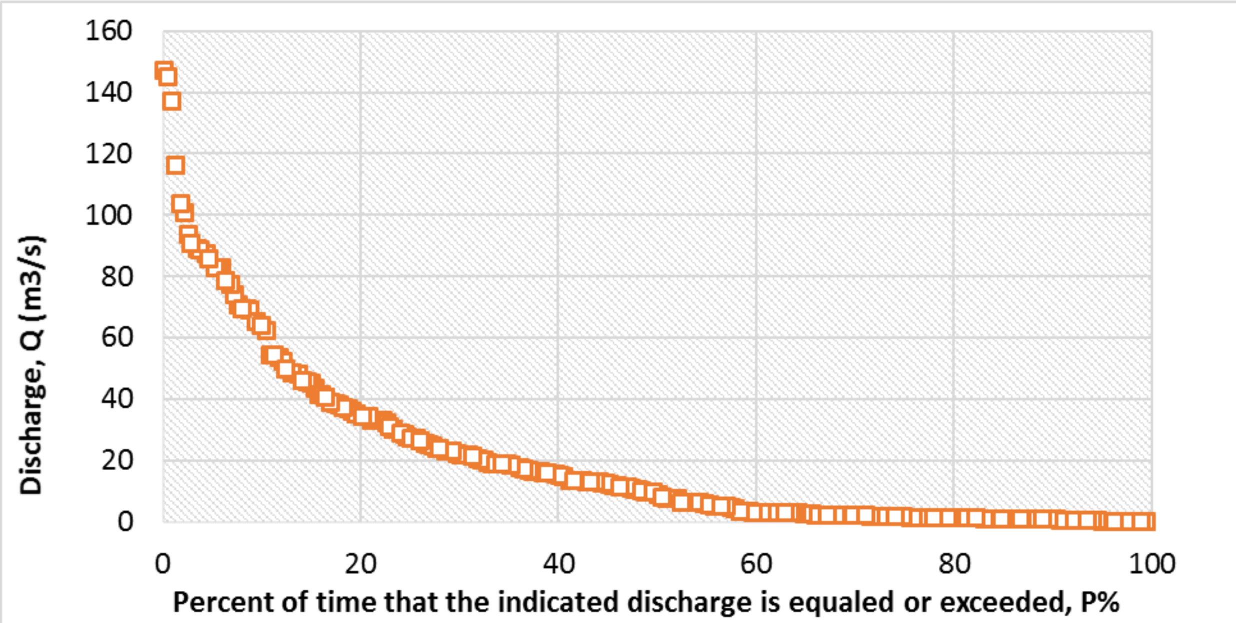

Figure 5: Flow Duration Curve for ASa River at Asa Dam

Hydropower Potential of the Dams

The hydropower potential of the dam was estimated from the equation 5:

$$P = 9.81 \times Q \times H \times E_t \times E_g \quad (5)$$

Unilorin Dam

where P = Power (KW); H = Net Head = 10 m; E_t = Turbine efficiency = 80%

E_g = Generator Efficiency = 90% and Water supply requirement = 0.05 m^3/s for Unilorin community as estimated in section 2.2.1

Asa Dam

where P = Power (KW); H = Net Head = 27 m; E_t = Turbine efficiency = 80%

E_g = Generator Efficiency = 90% and Water supply requirement = 2.0 m^3/s for Ilorin community as estimated in section 2.2.1

The estimation of the energy potential is presented in Table 4.

Table 4: Estimated energy potential for 50% sustainable flows for the dams

River dams	50% sustainable Flow (m^3/s)	Available flow (m^3/s) for power	Net head (m)	Turbine efficiency (%)	Generator efficiency (%)	Power (MW)
Unilorin	2.60	2.55	10	80	90	0.18
Asa	10.00	8.00	27	80	90	1.53

RESULTS AND DISCUSSION

The details of the dams were presented in Table 1. The Table indicated that the live and dead storage is 1.54 x 10^6 m^3 and 0.26 x 10^6 m^3 respectively for Unilorin dam with the net head of 10 m. similarly for the Asa dam the the live and dead storage is 34.7 x 10^6 m^3 and 3.60 x 10^6 m^3 with net head of 27 m. The analysis carried out on water resources of the dams revealed that the Unilorin dam can sustain its main purpose of supplying the University with its water requirement of 3600 m^3/day and also take care of 6.0 m^3/day losses due to evaporation as estimated. The statistics of the available flow is presented in Table 2. Similarly for Asa dam the analysis revealed that the dam can surport the water supply requirement of 144,000 m^3/d for the Ilorin communities as well as take care of 50m^3/d losses due to evaporation. The statistics of the available flow is presented in Table 3. The flow analysis also revealed adequate reservoir inflow that can recharge the reservoirs of both dams.

However, the variability of the estimated river flow at Unilorin and Asa dams is presented in Figure 1 and 2 respectively. The analysis also revealed a peak and low flow of about 20 m^3/s and 0.01 m^3/s respectively for Unilorin dam, and 148 m^3/s and 0.05 m^3/s for Asa dam.

From the sequent peak analysis, about 1.37 x 10^6 m^3 storage will be available for additional uses with storage required by sediment estimated to be about 0.04 x 10^6 m^3 and that required for water supply as 0.40 x 10^6 m^3 for Unilorin dam. Similarly for the Asa dam, about 26.54 x 10^6 m^3 storage will be available for additional uses with storage required by sediment estimated to be about 1.2 x 10^6 m^3 and that for water supply estimated as 9.67 x 10^6 m^3.

The flow duration analysis also showed a 50% sustainable flow of 2.60 m^3/s and 10.00 m^3/s for Unilorin and Asa dam respectively. The available flow for power generation was estimated as 2.55 m^3/s and 8.00 m^3/s respectively. The hydropower potential estimated for the dams were presented in Table 4 estimated as 0.18 MW and 1.53 MW for Unilorin and Asa dam respectively.

CONCLUSIONS

The River flows at Unilorin and Asa dams were modeled and extended to 2011 based on Markov model. The sequent peak analysis was adopted to estimate the storage required by each dam to serve the primary function and to determine excess for other purposes such as hydropower in accordance to Locks. The flow duration curve was established in accordance to the procedure developed by Oregon State University and the 50% sustainable flow were obtained as 2.60 m^3/s and 10.00 m^3/s for Unilorin and Asa dam respectively. While the actual flow available for power was estimated by subtracting the water supply requirements and the hydropower potential estimated as 0.18 MW and 1.53 MW for Unilorin and Asa dam respectively.

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