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Interpolation of Rainfall-River Orle Discharge for Developing 1.032 MW of Hydropower in Estako-West, Nigeria

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*Annual rainfall is of great importance to every nation and provides useful data on agricultural, hydrology and hydraulics designs. The research study presents the evaluation of the hydropower potential of river Orle using the analytical potential interpolation of hydrological elements (Rainfall, river discharges e.t.c) with emphasis of developing 1.032 MW power plant-reservoirs. Hydropower is a renewable energy source based on the natural water cycle and most mature, reliable and cost-effective renewable power generation technology. Gumbel's Probability Distribution method, U.S Soil Conservation technique and empirical formulation were used to estimate maximum flood design, rainfall distribution and intensity and peak river flow. The hydrological data provided by Benin-Owena River Basin stationed in Auchi Polytechnic were applied for the analysis. The outputs revealed that annual average rainfall of 98.1 mm or more in 75-year; 130.1 mm or more in 50-year out of 100 years. The exceedence probability for a rainfall of 158.1mm is 0.25 with observed rainfall greater than normal. At discharge (10.77 * 10^{-2} m^3/s), the proposed Orle hydropower scheme generated 1.032MW during the peak of wet and 76.6 KW was evaluated during the drying season at (0.80 * $10^{-2}m^3/s$). The study draws a conclusion that for runoff river scheme at 41.7% flow, the total hydropower potential of 0.676 MW was evaluated.*

***Keywords**: renewable energy, discharge, rainfall, reservoirs, hydro-power, Runoff*

1. Introduction.

Water resources are the most important natural resources because they are not only renewable natural resources but also abundantly available in Nigeria[1]. A favorable topographic condition because of high variation of elevation (from less than 110m to 9008 m) makes Nigeria one of the richest countries in terms of hydro power potential and is the major source of electricity in the country [2]. It is environmental friendly without significant emission of CO_2 and associated greenhouse gases. The growing population and industrial sector require reliable energy supply, which can only be fulfilled by hydropower in the country like Nigeria. With the strong hydro potential capacity of Nigeria, 5% of this capacity has not been put into use and this largely responsible for erratic power supply in Nigeria [3].

The mere fact is that the water from river Orle in Auchi-Nigeria has been used as a source of energy suggests that there may be potential for the use of the streams for electricity generation with hydropower plants [4]. The development of energy from small, mini and micro hydropower projects are being encouraged and supported worldwide because of its relative advantage of being a safe and clean renewable source of energy that can be developed and managed by local communities [567,8]. Although SHP is still experiencing slow growth in its development in Nigeria, yet recent reviews have shown that Nigeria is blessed with huge hydropower potentials [9], [10], [11], [12]. The growing concern over environmental degradation caused by fossil fuel based systems, opposition to large hydropower projects on grounds of displacement of land and population, environmental problems with nuclear fuel based systems and the ever-rising shortage of power highlights the need for tapping alternate energy sources for power generation [13].

To locate sites suitable for hydroelectric power generation, preliminary studies and sufficient knowledge of the topography, the stream network and its flow regime are required. This kind of data is only insufficiently available for the study of river orle hydropower potential. However, an innovative method using globally available satellite data, local rainfall data and terrestrial support data allow a rough assessment of the Orle's hydropower potential [3]. The main objective of this research is to evaluate the hydropower potential of the Orle River based on the available hydro-meteorological data such as river discharge (flow), rainfall, runoff and the depth cross-section.

2. Materials and Methods

2.1. The study area

The Orle reservoir is located in Estako-west in Edo state, Nigeria. It lies within the sub basin of the Niger River system in Middle-belt Nigeria. It is on grid reference 223000N, 1825000E [3]. The tentative length of Orle River is 100 km. Comparing to other rivers, the Orle valley is steep and confined in narrow gorges except at the Oyimo to Awara reach where it swells to approximately 600 m width, and rest of the valley is good for cultivation. The prominent villages surrounding the reservoir are Auchi, Agbede, Aviele, Irrua and Awara. Fig 1.1 and 1.2 show the orientation of proposed weir and topographical survey of hydropower of Orle dam.

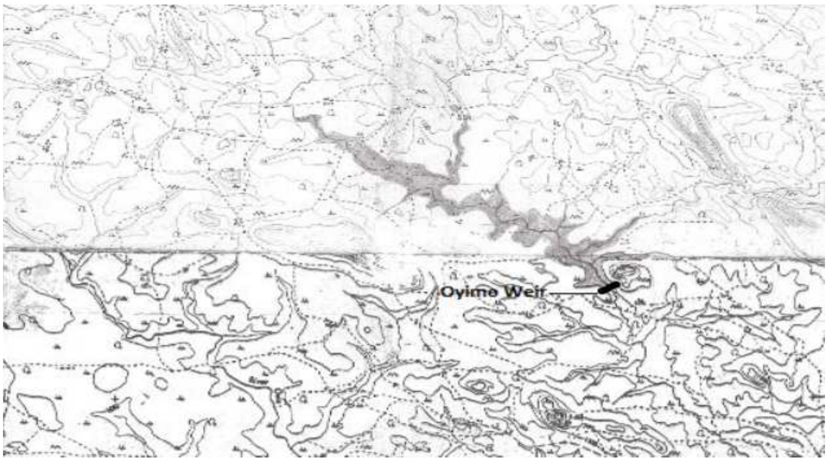

Figure 1.1. Orientation of the proposed weir of Orle dam[14]

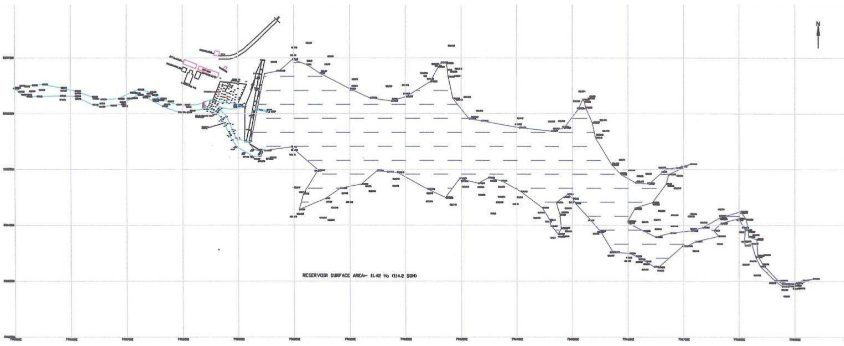

Figure 1.2.Topographical survey of Hydropower of Orle dam [14]

2.2. Hydro-meteorological analysis

The research study used the hydro-meteorological data provided by Owena-Benin Basin stationed at the Department of Civil Engineering, Auchi Polytechnic, Auchi. Daily rainfall data of 2004 to 2013 were used for the model, but the relative humidity, wind speed and air temperature were not applied. The gauge weight for each sub-basin was evaluated as follows:

$$W_i = \frac{A_i}{A} \tag{1.1}$$

Where, I = index for gauge stations, Wi = gauge weight, Ai = intersection thiessen polygon area A = Total area of sub-basin under consideration [15].

Runoff and discharges from the basin were generated from the observed rainfall data in order to allow adequate evaluation of flow pattern through the month and season of the year as follows [14]

$$R_f = CA(cm) * R_d * Coeff \quad (1.2)$$

Where; R_f is generated runoff, CA is the catchment area, R_d is the rainfall depth. The reservoir volume was evaluated as follows [14]:

$$Q = \frac{A * D}{3} \quad (1.3)$$

Where:
Q = Volume of reservoir (m3)
A = Surface area at full supply level (m^2)
D = Maximum depth (m)

The reservoir capacity was computed using the Simpson rule equation using Equation as follows [16]:

$$V = \frac{1}{2}[h_2 - h_1][A_2 - A_1]$$

V is the average volume between two elevation contour intervals, h_1 and h_2 are the respective contour level / height of each reservoir at point 1 and 2, A_1 and A_2 are the area covered by respective contour lines. The reservoir capacity is the cumulative volume computed over the whole contour lines across the entire reservoir.

2.3. Rainfall- Runoff Modelling

Geo HMS coupled with HEC was applied for simulating rainfall-runoff because it provides more realistic and accurate flow compared to the generated output of empirical, formula or regression equation or lumped model, a semi distributed deterministic model produced a more realistic picture of the flow and lumped models, For hydropower design and other during in normal conditions are very necessary [15]. Such quantities are determined by statistical analysis of long term hydrological data collected at a project site on regular basis. Rainfall-runoff model is used for generating long term daily discharges for catchment of sparsly gauged river [15]. The theoretical power potential is calculated as follows:

$$P = 9.81\eta Q \quad (1.4)$$

Where, η = overall efficiency, Q = design discharge

For determining the power potential, the following are the design consideration:

a. The net head is considered as 90 % of the gross head which is common practice for power potential assessment for desk study level.
b. The efficiency considered for turbines, generators and transmission are 90%, 95% and 98% which yields to the overall efficiency of 84%.

c. The downstream release of 10 % is considered for environmental consideration. The 10% seasonal outage is considered for both dry and wet period. [15].

Rainfall frequency analysis was carried out using Weibul's approach to predict dependable rainfall for any given probability level [17].

$$T_r = \frac{N+1}{M} \tag{1.5}$$

Where Tr = Return period
n= number of times
M=observation

Exceedence probability (P) is computed as follows:

$$P = \frac{1}{T_r} \tag{1.6}$$

3. Results and discussion

Climate is the primary features that contribute to the hydrology of a region and is largely dependent on the geographical position on the earth's surface. Climatic factors of importance are rainfall, its duration, its intensity and aerial distribution. Other parameters are temperature, sunlight, relative humidity and evaporation [15]. The climate of the project site was divided into dry season (Nov-Feb) and the wet season (March-October) each year [15]. Observed rainfall data is shown in Table 1.1. The generated from runoff from the observed rainfall from the catchment area is shown in Table 1.2 using 10-year rainfall dataset. The following assumptions were applied in the computations: Rainfall is evenly distributed over the catchment basin; and catchment basin runoff coefficient was taken to be 85% based on the hydro-meteorological characteristics of the basin. The output of monthly simulated discharge (Discharge required for each month of the year for power generation and water supply) exceedence reservoir release and rainfall frequency are shown in Table 1.3, 1.4 and 1.5 respectively. Reservoir capacity was computed using the Simpson rule computational equation. Rainfall exceedence probabilities (P) 75%, 50% and 25% corresponded to annual average rainfall depth of are read as 98.4 mm, 130.2 mm and 158.1 as indicated in Fig 1.1 respectively. Therefore, the rainfall depth obtained at (p) 75% and 50% dependable rainfall depth to produce energetic river flows and discharges. However, annual average rainfall depth of 98.4 mm can occur in 75 out of 100-year, while 130.2 mm annual average rainfall is expected to be experienced for more than 50 out of 100 years. The exceedence probability of obtaining annual average rainfall is 25% indicating that rainfall of this magnitude can only be expected in one-quarter of a century.

Table1.1. Observed rainfall data (2004-2013)

Month / Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual rainfall (mm)	Average rainfall (mm)
2004	0.0	11.9	50.1	88.1	95.4	168.5	200.5	175.2	237.2	111.7	5.5	0.0	1144.1	95.3
2005	0.0	18.5	37.6	138.3	161.5	260.4	298.1	250.6	314.6	190.2	10.2	4.4	1684.9	140.3
2006	0.0	34.0	170.5	189.1	225.5	272	310.1	230.8	295	135.5	7.2	2.4	1882.8	156.8
2007	0.0	5.9	101.1	185.2	185.5	280.3	285.2	220.1	315.3	160.2	14.1	0.0	1752.9	146.1
2008	0.0	61.4	87.4	244.6	249.7	198.4	357.2	267.9	243.9	173.3	43.0	5.2	1932.0	161.0
2009	26.7	24.6	84.8	148.2	258.6	240.4	81.9	132.6	148.5	185.3	98.1	30.3	1460.0	121.0
2010	5.0	33.9	96.9	95.8	133.6	152.6	241.6	118.5	213.5	79.3	22.0	5.8	1198.5	100.0
2011	0.0	0.0	78.2	85.4	143.3	164.2	278.0	174.5	250.4	22.0	0.0	0.0	1196.0	100.0
2012	0.0	0.0	25.0	115.3	175.3	124.6	208.4	99.3	194.4	90.4	0.0	0.0	1032.7	86.0
2013	0.0	0.0	87.2	94.4	170.2	329.2	502.5	212.4	453.3	213.2	0.0	0.0	2062.4	171.8

Source: Auchi Polytechnic meteorological station

Table1.2. Direct runoff and discharge using average rainfall depth (2004-2013).

Month	10-yr Month Average Rainfall (mm)	10-yr Month Average Rainfall (m)	Catchment area (m^2) $*10^6$	Volume of runoff (m^3) $*10^6$	Adjusted volume of runoff with CF(0.85)$*10^6$	Discharge m^3/s
Jan	3.17	0.0032	1.236	0.003955	0.00336	0.0012
Feb	19.0	0.0190	1.236	0.023484	0.01996	0.0075
March	81.8	0.0818	1.236	0.101104	0.08593	0.0321
April	138.4	0.1384	1.236	0.171011	0.14540	0.0544
May	179.8	0.1798	1.236	0.222222	0.18889	0.0706
June	219.1	0.2191	1.236	0.270807	0.23018	0.0860
July	276.4	0.2764	1.236	0.341630	0.29038	0.1086
August	188.2	0.1882	1.236	0.232615	0.19772	0.0739
Sept	266.6	0.2666	1.236	0.329517	0.28008	0.1047
Oct	136.1	0.1361	1.236	0.168219	0.14298	0.0534
Nov	20.0	0.0200	1.236	0.024720	0.02101	0.0080
Dec	4.8	0.0048	1.236	0.005932	0.00504	0.0018

Source: Simulated output, 2016

Table 1.3. Simulated discharge for Orle reservoir

Month	Volume *10^5 m^3	Average discharge (m^3/s)
January	0.1	0.0037
February	0.1	0.0040
March	0.1	0.0037
April	0.1	0.0038
May	1.0	0.0373
June	1.0	0.0386
July	1.0	0.0373
August	1.0	0.0373
September	1.0	0.0386
October	1.0	0.0373
November	0.1	0.0037
December	0.1	0.0037

Source: Simulated output, 2016

Table 1.4. Annual Exceedences for rainfall frequency analysis

Average annual rainfall(mm)	Annual rainfall in descending order	Ranking (M)	Return period: $T_r = \frac{N+1}{M}$	Exceedence probability: $P = \frac{1}{T_r}$	(%) Probability Exceedence
95.3	171.8	1	11.0	0.09	9.0
140.3	161.0	2	5.5	0.18	18.0
156.8	156.8	3	3.7	0.27	27.1
146.1	146.1	4	2.8	0.36	36.2
161.0	140.3	5	2.2	0.45	45.1
121.0	121.0	6	1.8	0.54	54.1
100.0	100.0	7	1.6	0.64	64.2
100.0	100.0	7	1.6	0.64	64.2
86.0	95.3	8	1.2	0.82	82.0
171.8	86.0	9	1.1	0.91	91.0

Source: Simulated output, 2016

Table 1.5. Average monthly discharges exceedences and potential power at exceedence

Discharge Q(10^{-2} m^3)	Descending order Q(10^{-2} m^3/s)	Ranking	P.Exceedence (%)	Potential Power at Exceedence (KW)
1.2	10.77	1	8.33	1,032.0
7.5	10.41	2	16.67	997.6
32.1	8.60	3	25.00	824.1
54.4	7.39	4	33.33	708.1
70.6	7.06	5	41.67	676.6
86.0	5.44	6	50.00	521.3

108.6	5.34	7	58.33	511.8
73.9	3.21	8	66.67	307.6
104.7	0.80	9	75.00	76.6
53.4	0.75	10	83.33	71.8
8.0	0.18	11	91.67	12.9
1.8	0.12	12	100.00	8.6

Source: Simulated output, 2016

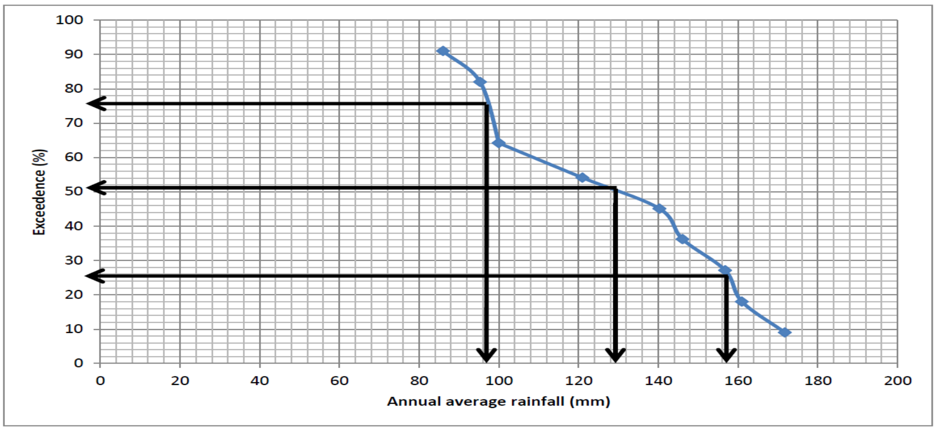

Figure 1.1. Rainfall frequency-exceedence curve

The actual demand for power based on the capacity of dam can be achieved if there is sufficient water in the reservoir. The simulation output in Table 1.3 indicates that total volume of 1.0 x $10^5 m^3$ could be supplied during the months of May to October every year to meet purposes of power generation and municipal water demand without reservoir being depleted to dead storage. However, water supply for both power generation and municipal water would be low during the dry season (Nov-April) with average reservoir volume and river discharge of 0.1*105 m^3 and 0.00373 m^3/s due to excessive evapotranspiration but municipal water demand could still be adequately met with difficulty in generating up to 25% of power required as shown in Table 1.3. The situation is quite different during the wet-rainy season (mostly May-October), the reservoir capacity and river discharge were simulated at $1.0*10^5 m^3$ and 0.0373 m^3/s respectively. During period, there is enough water satisfy both power and municipal hydro-requirement.

At river discharge (10.77 * 10^{-2} m^3/s), the proposed Orle hydropower scheme can generate 1.032MW during the peak of wet and 76.6 KW could be produced during the drying season at (0.80 * $10^{-2} m^3/s$) discharge as shown in Table 1.4 as against total maximum electrical power demand for all the communities around the Orle reservoir was estimated as 572.56kW by the PHCN. Fig 1.3 shows the strong relationship between potential power generated (KW) and river discharge with R^2

=1.00. The strong power potential estimated from the Orle river shows that the proposed small hydropower of 1.032 MW is feasible. With this magnitude of power supply, this will create formidable economic life of the dwellers in Auchi, Aviele, Jattu and Fugai thus reduces poverty. However, precision agriculture could easily be carried out because of availability of water for irrigation and other agricultural practices.

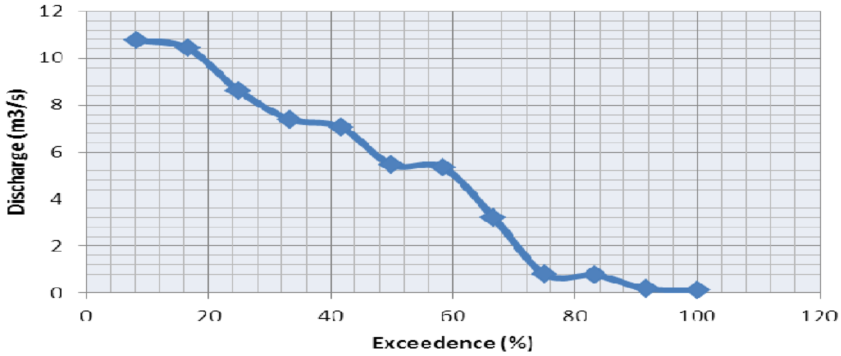

Figure 1.2. Flow duration curve at Orle river

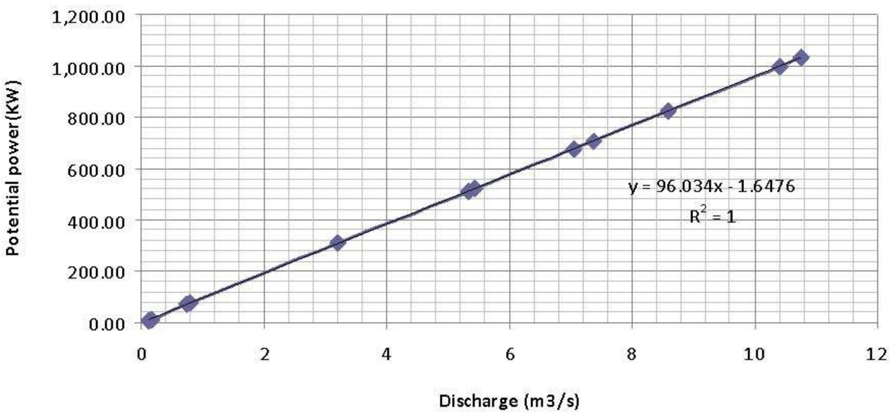

Figure 1.3. Potential power rating and river discharge

4. Conclusion

This study delineated the hydropower potential of Orle basin for run of river scheme using a distributed rainfall-runoff model for a gauged basin that could interpolate the flow hydrograph at any ungauged site within catchment. Generated output of hydrological iteration shows strong potential of developing Small Hydropower (SHP) at Orle due to optimal hydropower potential of 1.032 MW evaluated which can be utilized for power generation to meeting the maximum energy requirement of 572.56kW and diesel and petroleum energy mix 10.4 KW of the surrounding communities. The study draws a conclusion that for runoff river scheme at 41.7% flow, the total hydropower potential of 0.676 MW was evaluated, which is more than the total energy required (Hydropower and fossil fuel). The realization of utilizing this renewable energy source to bring about the desired sustainable developments, lower high dependence on fossil fuel to generate energy, deforestation will be gradually reduced because less attention will be given to firewood for cooking. In addition, this development will create job opportunity and discourage rural-urban migration and holistically improve welfare status of the dwellers and makes the environment friendly since no significant CO_2 emission and associated greenhouse gases (GHGs) have been reportedly linked to hydropower generation.

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