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Evaluation of the Hydropower Potential of Otamiri River for Electric Power Generation

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Abstract: This research presents the estimation of the hydropower potential of River Otamiri through the hydrological analysis of the elements of climate as it affects its catchment area (section passing through the Federal University of Technology Owerri). The study involves the estimation of maximum design floods for the watershed using the Gumbels Probability Distribution Method for various return periods (T_r) with the development of unit hydrograph, storm hydrograph, runoff hydrograph and flood duration curve for the catchment area of the river. In addition watershed parameters like peak flow (Q_p), lag time (T_l), time of concentration (T_c) and rainfall intensity (I_c) were determined using the soil conservation service method and other empirical formulas. In order to determine the available flow for power generation, the stage/head of the river was estimated from records provided by the River Basin Development Authority (R.B.D.A) and flow duration analyses were carried out. The analysis revealed that for time flows of 50, 75 and 100% the following energy values were obtained 34.5 MW, 11.3 MW and 1.5 MW, respectively.

Keywords: Hydropower, hydropower potential, river Otamiri

INTRODUCTION

Hydropower is referred to as water power or hydraulic power; it is the energy that comes from the force of moving water or water in motion (Sharma and Sharma, 2003). The fall and movement of water is a part of a natural continuous cycle called the “WATER CYCLE" or "HYDROLOGIC CYCLE". Gravity drives the water thereby moving it from high ground to low ground. The force of moving water can be extremely powerful, this force is what is used to generate energy for hydro-electric schemes or projects. In other words, hydropower is the motive energy or mobile energy contained in water which can be converted into electricity through hydropower plants (Deschande, 1986). According to Kucsre *et al*. (2011), hydropower is a clean, renewable and reliable energy source that serves national environmental and energy policy objectives .It is one of the most important renewable sources for production of electric power due to several obvious reasons. It is renewable in nature, unlike wind, supply variability within shorter time period is less and most importantly Green House Gas (GHG) emission is least. It is derived from the falling water, either from rivers and streams flowing downhill along the river course due to force of gravity. The energy associated with this flowing water is known as kinetic energy that is released through the friction of flowing water with the rocks and the sediment in the river beds (Kucsre *et al*., 2011). Harnessing the kinetic energy from the flowing water for driving turbine generates hydropower. Hydropower functions by converting the energy of moving water or flowing water into electricity, the volume of water flow and height (head) from the power plant to the water surface created by dams determine the quantity of electricity generated (Khang, 2006). Hydropower is dependent on the head or level of water and the volume of flow of water to generate electricity (Bhattacharya, 1988). 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 (Inamdar *et al*., 2006). Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations. It is a proven, mature, predictable and typically price competitive technology. Hydropower has among the best conversion efficiencies of all known energy sources (about 90% efficiency, water to wire). It requires relatively high initial investment, but has a long lifespan with very low operation and maintenance costs (Eickemeser *et al*., 2001). The main objective of this research is to evaluate the hydropower potential of the Otamiri River based on the basic information of the river discharge (flow), rainfall and the depth cross-section.

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HYDROPOWER POTENTIAL

According to World Energy Council (2004), "hydropower potential of a river is the theoretical possibility, capability, potential or tendency for power to be generated from that river", it is regarded as the inherent ability of a river to generate electricity if favored with the required factors. It should also be noted that this theoretical capability is dependent on calculations of topography and amount of runoff extracted and allowed to fall down to the lowest level of the sea level. According to Eurelectric (1997), the gross hydropower potential is defined as the annual energy that is potentially available if all natural runoff at all locations were to be dammed and harnessed down to sea level (or to the border line of a country) without any energy losses. The gross capability of a river to generate electricity depends on the topography and amount of precipitation over the catchment of the river. The share of this highly theoretical potential which has been or could be developed undercurrent technology, regardless of economic and other restrictions form the technical hydropower potential (Bernhard *et al*., 2010). From this, the economic hydropower potential is the portion, which can or has been developed at costs competitive with other energy sources. Finally, the exploitable hydropower potential takes into account environmental or other special restrictions. For comparison of magnitudes, Eurelectric (1997) estimates the world's gross hydropower potential at 51 000 TWh/a, the economic hydropower potential at 13 100 TWh/a and the exploitable hydropower potential at 10 500 TWh/a. An assessment of hydropower potential can be made from actual energy potentials calculated from digital maps of slope and runoff. Coefficients of variation and low flow indices proved good potential measures of flow variability and risk. This method allowed rapid identification of micro and macro hydropower potential. The hydropower potential obtained from analysis or research carried out on a river can give an assurance of actual power that can be obtained from that river.

MATERIALS AND METHODS

Climate and vegetation of study area: The Otamiri river is one of the major rivers in Imo state, Nigeria, the river runs south from Egbu past Owerri and through Nekede, Ihiagwa, Eziobodo, Olokwu Umuisi, Mgirichi and Umuagwo to Ozuzu in Etche in Rivers state from where it meets or flows to the Atlantic Ocean. The length of the river from its source to its confluence at Emeabiam with Oramiriukwa river is 30 km. The watershed covers about 10,000 km^2 with annual rainfall of about 2250-2750 mm. The watershed is mostly covered by depleted rain forest, having thick underbrushes, creeping vines and deep green vegetation which is as a result of heavy decay of plant droppings and foliage. The mean temperature of about 25 degrees centigrade and relative humidity of about 75-85% is experienced within the region throughout the year. The study area is in the rainforest belt region having peak rainfall during the months of June, July and September and low rains in December and January (Ibe and Uzoukwu, 2001).

Organic nature and type of soil: The otamiri watershed is dominated by sandy soil with little percentages of clay, loam and silt. The area is acidic with pH of between 4.67-5.6 for upper and lower layers and 5.0-5.6 at the crest and valley bottom and lower at midslope (Njoku *et al*., 2011). The watershed also in addition has low organic carbon ranging between 0.676-3.764 meq/100 g for upper soil layer, 5.34-4.27 meq/100 g for lower soil layer and lower at the midslope, low nitrogen concentration range of 0.008-0.068% and 0.018-0.048% for upper and lower soil layers (Njoku *et al*., 2011). The general slope of the Otamiri watershed is 0.016 (Simmers, 1988). The soil type belongs to ferralic. The soil profile is remarkably uniform throughout the area, deeply weathered and intensely leached (Ibe and Uzoukwu, 2001).

Geology and position: The study area is located within southeastern Nigeria sedimentary basin. The study area consists of Owerri metropolis and environs. It is bounded by latitudes 5°15″-5° 35″N and longitude 6°55″-7°15″E. The study area is within the subequatorial region which is characterized by two major seasons namely, the rainy season and the dry season (Iloeje, 1972). It is under laid by the sedimentary sequence of the Benin formation (Miocene-Recent) and the underlying Ogwashi-Asaba formation (Oligocene). The Benin formation is made up of friable sands with minor intercalations of clay. The sand units are mostly coarse-grained. The formation starts as a thin edge at its contact with Ogwashi-Asaba formation in the north of the area and thickens southwards (seawards). The average thickness of the formation at the study area is 800 m. The terrain of the study area is characterized by two types of land forms; highly undulating ridges and nearly flat topography. Various structural units (point bars, channel fills, natural levees, back swamp deposits and oxbow fills) are identifiable within the formation indicating the variability of the shallow water depositional medium. The flat southern part is under laid by thick unconsolidated sand with the minor lenses and stringers. Borehole lithologic logs reveal that the undulating hills and ridges are underlain by a succession of thick unconsolidated sandstones and relatively thin clay units belonging to the Benin formation. The ridges trend in the north-south direction and have an average elevation of about 122 m (Uma,

1984). In between those ridges are valleys of the Otamiri River, Oramiriukwa River and their tributaries.

Hydrogeology: The study area is drained by two rivers, namely the Otamiri and Nworie. The Otamiri River has maximum average flow of 10.7 m^3/s in the rainy season (September-October) and a minimum average flow of about 3.4 m^3/s in the dry season (November-February). The total annual discharge of the Otamiri is about 1.7×10^8 m^3 and 22% of this (3.74×10^7 m^3) comes from direct runoff from rainwater and constitutes the safe yield of the river (Egboka and Uma, 1985). The depth to groundwater varies from 15 m-35 m in parts of the Owerri urban area. The aquifers have reasonable thickness and are extensive (Ibe and Uzoukwu, 2001).

METHODOLOGY

Data collection and literature: In determining the available hydropower potential of the study area (Otamiri river), historic climatic and hydrological data on the river have to be assembled and collated so as to determine the availability of water and its distribution throughout the year and from year to year (Lindsley *et al*., 1992). In order to obtain the potentials of the study area for hydropower generation the flow characteristics and pattern of the stream or river have to be calculated or obtained from the hydrological yearbook of River Basin Authorities or Meteorological Service Centers with stations located along the study area (Arora, 2004).

RESULTS AND DISCUSSION

Results of Table 1 shows:

Column (2) Total Precipitation (T.P)
T.P = summation of rainfall values in each month from 1995-2010
Column (3) Average Precipitation (A.P)
A.P = total precipitation of each month/number of years
A.P = TP/n; Where n = number of years
Column (4) Total Rainfall days (T.R.D)
T.R.D = summation of rainfall days in each month
Column (5) Average Rainfall Days (A.R.D)
A.R.D = total rainfall days in each month between 1995-2010
Number of that month with the period
Column (6) Rainfall Intensity (R.I)
R.I = TR/ARD
But critical Rainfall Intensity (I_c)
$I_c = P/T_r\,(T_r + 1/T_c)$
where, T_r = Storm Period/Rainfall Days (ARD)
T_c = Time of Concentration of the storm.
But $T_c = 0.0195\,[L^{0.77}/S^{0.385}] = 0.0195\,[30\times 1000^{0.77}/0.016^{0.385}]$
$= 0.0195\times13765.66 = 268.43$ min = 4.47 h.

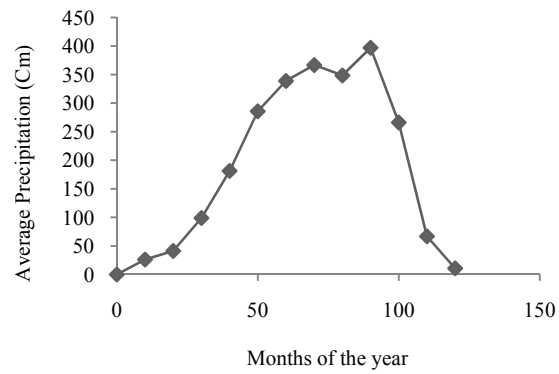

Fig. 1: Rainfall hydrograph of the catchment area

The Fig. 1 shows hydrograph is the relationship between average precipitation and months of the year. The Fig. 1 depicts the rise and fall/decline of precipitation with respect to the periods/months of the year in response to the seasons (rainy and dry) of the year.

Determination of watershed parameters:
- Lag time $T_l = 0.6\,T_c$
But T_c from 4.1 above = 4.47 h, substituting in the above relationship we have;
$T_l = 0.6\times4.47 = 2.68$ h.
-T_r is the same as the average rainfall days for each of the months.
-Area of the catchment in consideration is 100 km^2
-Slope, S = 0.016

Results of Table 2 shows:

Column 2, T_r = duration of rainfall (average rainfall days) converted to hours
Column 3, Peak Time, $T_p = T_r/2+T_l$
Where T_l = lag time = 2.68 h
Column 4, Discharge, Q (m^3/s)
$Q = 2.78\,C\,I_c\,A$
where, C = characteristic discharge coefficient of watershed, 0.50
I_c = critical rainfall intensity for each month.
A = Area of Watershed, 100 km^2

- The highest discharge value = 10112.25 m^3/s
- The lowest discharge value = 284.95 m^3/s
- The average discharge value = 5166.94 m^3/s

The Fig. 2, hydrograph represents the relationship of discharge with time, the graph portrays the trend of discharge (m^3/s) its rise, decline and fall with respect to the periods in the year.

Development of parameters for flow duration curve: For the determination of the flow duration curve the Table 3 shows the various values used to obtain the graphical relationship.

Table 1: Values for total precipitation, average precipitation, rainfall days and rainfall intensity

Month	Total precipitation (cm)	Average precipitation (cm)	Rainfall days	Rainfall days (average)	Rainfall intensity (cm/hr)
January	418.30	26.14	22	1	4.97
February	657.00	41.06	38	2	7.66
March	1583.10	98.94	97	6	18.21
April	2902.00	181.38	195	12	33.33
May	4573.70	285.86	237	15	52.40
June	5422.80	338.93	251	16	62.15
July	5869.30	366.83	333	21	67.21
August	5576.14	348.51	340	21	63.88
September	6352.50	397.03	341	21	72.75
October	4258.50	266.14	288	18	48.76
November	1068.40	66.78	75	5	12.32
December	172.20	10.76	15	1	2.05

Table 2: Values for storm hydrograph

Month	T_r (hrs)	T_p (hrs)	Discharge (m^3/s)
January	24	14.68	690.83
February	48	26.68	1064.74
March	144	74.68	2531.19
April	288	146.68	4632.87
May	360	182.68	7336.00
June	384	194.68	8638.85
July	504	254.68	9342.19
August	504	254.68	8879.32
September	504	254.68	10112.25
October	432	218.68	6777.64
November	120	62.68	1712.48
December	24	14.68	284.95

Table 3: Values for percentage time of flow

Month	Discharge (m^3/s)	Number of days of rainfall (m)	% of time
September	10112.25	21	8.3
July	9342.19	21	16.7
August	8879.32	21	25.0
June	8638.55	16	33.3
May	7336.00	15	41.7
October	6777.64	18	50.0
April	4632.87	12	58.3
March	2531.19	6	66.7
November	1712.48	5	75.0
February	1064.74	2	83.3
January	690.83	1	91.7

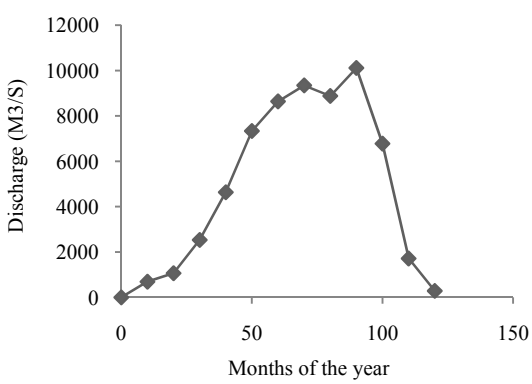

Fig. 2: Discharge hydrograph of the catchment area

Column 2, discharge
Column 3, number of rainfall days, m

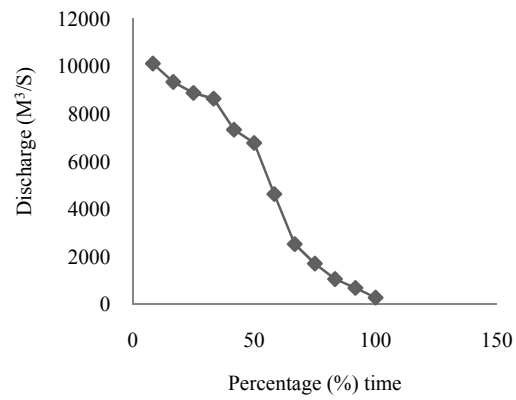

Fig. 3: Flow duration curve of Otamiri River

Column 4, % time of rainfall, $P = m/n \times 100$

where,
m = Number of times a particular event has been equaled or exceeded
N = Number of days of event/total number of events

The flow duration curve in Fig. 3 is a regressive curve, the discharge decreases with percentage time because within the year the degree of flow is subject to the seasons in the year which are the rainy and dry season. The flow is dependent on the availability of water in the percentage time of the year.

Determination of maximum annual observed flood for recurrent intervals: The determination of the maximum annual flood in the study area was done to predict the flood pattern and the increase observed as regards the discharge (Q). Within the return periods (Tr). The Table 4 shows the various values used in the estimation of the flood:

$\sum Q = 62000.26$
$N = 16$ years, $x = \sum Q/12 = 0.52 \times 10^4$, $\delta = (\sum(X - x)^2/n - 1)^{1/2}$
where, n = 16; substituting values we have the following;
$= (15.45/16 - 1)^{0.5} = 0.321 \times 10^4$

Table 4: Values for estimation of design flood for return periods, using gumbels distribution method (Arora, 2004)

Month	Q (m^3/s)	Rank (m)	T_r = n+1/m	(X -x)	$(X - x)^2$
September	10112.25	1	17.00	0.49×10^4	2.40×10^7
July	9342.99	2	8.50	0.41	1.70
August	8879.32	3	5.67	0.37	1.37
June	8638.00	4	4.25	0.34	1.16
May	7336.00	5	3.40	0.21	0.44
October	6777.64	6	2.83	0.16	0.26
April	4632.87	7	2.43	-0.06	0.03
March	2531.19	8	2.13	-0.27	0.73
November	1712.48	9	1.89	-0.35	1.23
February	1064.74	10	1.70	-0.41	1.70
January	690.83	11	1.55	-0.45	2.03
December	284.95	12	1.42	-0.49	2.40

Table 5: Values of stage of Otamiri River from 1978-1987 and 1997

Month	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1999
January	0.27	0.34	0.46	0.65	0.67	0.91	0.91	0.93	1.00	0.96	0.53
February	0.26	0.40	0.40	0.63	0.61	0.86	0.91	0.90	0.98	0.94	0.51
March	0.36	0.35	0.42	0.60	0.63	0.78	0.94	0.91	1.12	0.97	-
April	-	0.43	0.11	0.36	0.59	0.63	0.77	0.89	0.92	0.98	0.39
May	-	0.44	0.13	0.36	0.72	0.74	0.79	0.86	0.99	1.00	0.39
June	0.18	0.47	0.21	0.43	0.62	0.83	0.82	0.90	0.98	1.00	0.40
July	0.23	0.44	0.34	0.45	0.66	0.83	0.90	0.93	0.95	0.99	0.43
August	0.24	0.52	0.36	0.58	0.63	0.80	0.94	0.98	0.94	1.04	0.45
September	0.47	0.65	0.50	0.72	0.63	0.91	0.88	1.05	1.02	1.15	0.71
October	0.60	0.83	0.54	0.74	0.72	1.00	0.96	1.02	1.03	1.01	0.88
November	0.63	0.63	0.56	0.65	0.72	0.90	0.96	0.94	1.01	1.02	0.63
December	0.53	0.59	0.49	0.62	0.74	0.91	0.85	0.93	1.01	0.99	0.53
Average	0.31	0.52	0.38	0.57	0.66	0.84	0.81	0.94	1.00	1.00	0.53

Since n = 16, from appendix we interpolate between values of 15 and 20 to obtain Y_n and δ_n; for Y_n;
20 = 0.5236; 16 = Y_n; 15 = 0.5128
(20-16)/16-15 = (0.5236-0.5128)/Y_n-0.5128
4 = 0.0108/Y_n-0.5128
Y_n = 2.062/4 = 0.5155
For the value of δ_n; 20 = 1.0628
16 = δ_n; 15 = 1.0206
(20-16)/ 16-15 = (1.0628-1.0206)/δ_n - 1.0206
$4\delta_n$ = 0.0422+4.0824
δ_n = 4.1246/4 = 1.0312

Therefore the values Y_n = 0.5155 and δ_n = 1.0312, for n = 16 years

Determination of a and Q_f; a = δ_n/δ = 1.0312/0.321 = 3.212

Q_f = Q – (Y_n/δ_n) δ = 0.52 – (0.5155/1.0312)0.321 = 0.52 -0.16 = 0.36

Determination of the reduced variate Y_T for the desired return period

Y_T = -loge [+loge [T_r/T_r - 1]]

For a return period of 20 years. i.e., T_r = 20 years, we have;

Y_T = -loge [+loge [20/20-1]] = 2.98

For T_r = 25 years

Y_T = -loge [+loge [25/25 -1] = 3.19

For T_r = 30 years

Y_T = -log [+loge [30/30 -1]] = 3.38

Estimation of the magnitude of the maximum annual flood:

$Q = Q_f + Y_T/a$

For the various return periods of 20, 25 and 30 years, respectively we have;

Q_{20} = 0.36+2.98/3.212 = 1.288
= $1.288\times10^4 m^3/s$
Q_{25} = 0.36+3.19/3.212 = 1.353
= $1.353\times10^4 m^3/s$
Q_{30} = 0.36+3.38/3.212 = 1.412
= $1.412\times10^4 m^3/s$

The maximum annual flood for the return periods are as follows:

T_r 0f 20 years, Q_{20} =1.288×10^4 m^3/s
T_r of 25 years, Q_{25} =1.353×10^4 m^3/s
T_r of 30 years, Q_{30} = $1.412\times10^4 m^3/s$

Determination of the stage of Otamiri: The stage of the study area which is Otamiri River is simply the mean head or elevation of the river at different months of the year there are shown in Table 5.

N/B expunged table is found in the appendix

From the above table the average stage during the above period is given by:

A = ∑AV/n = 7.56/11 = 0.69 m

Table 6: Hydropower potential of river at various flows

Time of flow (%)	Available flow (m^3/s)	Net head (m)	Turbine efficiency (%)	Generator efficiency (%)	Power (KW)
50	6700.00	0.69	80	95	3.45×10^4
75	2200.00	0.69	80	95	1.13×10^4
100	284.95	0.69	80	95	0.15×10^4

N/B; the stage of otamiri above as stated is calculated based on the available data provided from Anambra Imo River Basin Development Authority, within the above period of time (Table 5).

Assessment of hydropower potential (H.P):

Average monthly discharge:
= 1/12(cumulative of all discharge)
= (690.83+1064.74+2531.19+4632.87+7336+8638.55 +9342.19+8879.32+10112.25+6777.64+1712.48+ 284.95)×1/12
= 4447.04 m^3/s

According to Sule *et al*. (2011), the hydropower potential, H.P of the river is given by:

$$P = g\ Q\ H\ E_t\ E_g$$

where,
g = Acceleration due to gravity (9.81 m^2/s)
Q = Available flow
E_t = Efficiency of the turbine
E_g = Efficiency of the generator
H = Head or stage of the river

But on converting the power from KW to MW we have the following (Table 6):

Power, P at 50% time of flow = 34.5 MW
Power, P at 75% time of flow = 11.3 MW
Power, P at 100% time of flow = 1.5 MW

CONCLUSION

Based on statistical analysis and data/hydrological information gathered with regards to the study area (Otamiri River) and its catchment area, the overall Available Hydropower Potential (AHP) at various percentages of flow reliability are as follows; for 50% of time of flow AHP is 35.4 MW, for 75% of time of flow AHP is 11.3 MW and for 100% time of flow AHP is 1.5 MW. The hydropower system or plant to be used in the catchment area is a runoff river system, this is because there is very low elevation or head to generate a high amount of energy required to drive the turbine. The required power can only be obtained when there is a direct impact of the force or impact of river flow on the blades of the turbine. The greatest indicator of development of an economy and independence in a nation's gross domestic product is measured by the quality and quantity of power it generate to meet the requirements of manufacturing, production, distribution and consumption of its populates.

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