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Small Hydro Power Viability Assessment of Elemi River in Ekiti State of Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OOF designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author TO managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

A stable, reliable and uninterrupted power supply is one of the basic requirement for economic, social and industrial growth of any nation. Electricity generation capacity in Nigeria is grossly insufficient for the growing demand and there is a need to incorporate small hydropower (SHP) schemes which can be installed in some of the available rivers and streams that are scattered around the country to complement the energy shortage and deficiency. This paper investigated the viability of Elemi river, Ado-Ekiti, Nigeria for a small hydropower scheme as a possible source of off-grid electricity generation to solve the incessant power outages in the three major higher institutions within its catchment. The power demand of the three higher institutions was estimated using questionnaires. The hydrological data for the study area for 11 years spanning 2005 to 2015 were collected and analyzed to determine the flow duration curve (FDC). The mean average velocity of the stream was calculated as 1.21m/s, with average annual flow discharge of 45.9 m^3/s, and an average minimal flow of 9.1 m^3/s. The average mean estimated hydro power potential obtainable using a diversion scheme is 2.21MW. It was discovered that the yield capacity of Elemi river for

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power generation with a diversion scheme could not provide the power requirement for any of the 3 higher institutions within its course due to its relatively flat terrain with the maximum derivable head of 8 m. A recommendation for the construction of a dam for an impounded scheme with a minimum gross head of 20 m, which adequately serve the needs, of at least one of the Institutions is made.

Keywords: Sustainable energy; small hydropower; gross head; obtainable power; mean discharge; flow duration curve.

1. INTRODUCTION

Renewable energy is a resource that can be re-generated through natural process within a relatively short time. Nigeria has renewable energy resources in excess of 1.5 times that of fossil energy resources [1], in energy terms. The low level of electricity access in Nigeria, particularly in the rural areas, and many of its tertiary institutions, can be increased through the use of renewable energy resources for sustainable development [1,2]. Some of the major challenges facing the development of renewable energy in Nigeria are high capital cost, intermittency of reserve availability, inadequate fiscal and economic incentives, low level of public awareness in subscribing to financing and the development of the scheme, inadequate indigenous capacity in design and construction and lack of capacity for the local manufacturing of alternative energy system components resulting into limited supply at higher cost [2,3]. Renewable energy is now globally accepted as a suitable source for sustainable development especially in the rural areas [1,3,4]. It is pollution free, clean and eco-friendly energy source that comes from an inexhaustible resource like solar, wind, small hydro and biomass [4].

Nigeria electricity generation capacity as at year 2015 ranges between 4,500MW to 6,500MW, which was far short of the required energy demand in the range of 10,000MW [5,6] to support a progressive economic growth and development. In Nigeria, the electricity generation utility, now unbundled from government finance to a private Holding Company [5,7], has been unable to cope with the electricity demand that is growing at an average of 7% annually [5,7], with about 65% of the rural populace lack of access to the available conventional power [7]. Since lack of access to electricity and rural poverty are closely correlated, the low level of electricity generation in Nigeria has not only posed great threat to the living standards of about 65% rural population but also to the rapid socio - economic development of these sets of people [3,4,6]. However, in many towns and villages, there are several streams, small rivers and water-falls that can be harnessed to generate the required energy for the communities and the surrounding educational institutions (be it primary, secondary or tertiary) by exploring small hydro schemes.

Hydropower schemes are classified according to their power output. The generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro [3,6]. Small hydro can be further subdivided into mini hydro, (those with less than 1,000 kW), and micro hydro which has a capacity of less than 100 kW [7,8,9]. Micro hydro is usually the application of hydroelectric power scheme for smaller communities, single families or small enterprise, while small hydro power scheme can serve small towns and big enterprises. Small hydro plants may be connected to conventional electrical distribution networks as a source of low-cost renewable energy or alternatively, built in isolated areas that would be uneconomical to serve from a network, or in areas where there is no national electrical distribution network [5,7,9]. Since small hydro projects usually have minimal reservoirs and civil construction work, they are seen as having a relatively low environmental impact compared to large hydro [6,8]. The low environmental impact depends strongly on the balance between stream flow and power production. One tool that helps evaluate this issue is the Flow Duration Curve (FDC) [5,10]. The FDC is a Pareto curve of a stream's daily flow rate versus frequency. Reductions of diversion of streams help the river's ecosystem, but reduce the hydro system's Return on Investment (ROI). The hydro system designer and site developer usually strike a balance to maintain both the health of the stream and the economics [5,8,10]. The hydropower potentials of small rivers and swift flowing streams in Nigeria has been estimated to be about 736MW of electrical energy [10,11]. This is a large quantum of energy, if fully tapped, to propel changes and development [4,7], and being exploited in this work.

Basically, hydropower takes advantage of the kinetic energy of falling water guided through channel of penstocks to drive a turbine. The spinning turbine rotates a generator's electro-magnet (rotor) located inside a cylinder (stator) containing windings of electric wires to generate electricity.

Hydropower is the most efficient and reliable of all renewable energy sources [7]. The simplicity of the process – direct conversion of mechanical energy into electricity – explains the very high efficiency of hydropower plants which research has shown to be between 85% to 95% [11]. As underlining factor, the system requires a sizeable flow of water and a considerable elevation gradient, called the "effective hydraulic head" to obtain an operational scheme, without having to build elaborate and expensive structures.

Flow rate is the quantity of water available in a stream or river and may vary widely over the course of a day, week, month and year. Mathematically, stream flow or discharge is the rate at which a volume of water passes through a cross section of a stream per unit time, and with a measuring unit of m^3/s [12]. Given a sufficient flow rate, small-hydro power helps to provide clean energy with small environmental impact than the bigger facilities. This paper investigates the viability of Elemi river, Ado-Ekiti, Nigeria for a small hydro scheme as a possible source of off-Grid electricity generation to solve the problem of incessant power outages in the three major higher institution within its catchment

2. RESEARCH METHODOLOGY

2.1 Description of the Study Area

River Elemi is a main tributary Ogbese. The domain of the study area covers a land area of 850 km^2. The catchment elevation ranges from 550msl near the source at Igede-Ekiti (7°46'00.67"N; 5°16'00.50"E) to 356msl at the gauge station Erinfun (7°36'56.04"N; 5°17'51.54"E) [13]. The river is of the second order type (that is, the main channel has one tributary link at any considered section along its course) with the tributaries at the upper and the lower courses. The channel length of the upper course from the source at Igede to the first gauge station at Ago Aduloju is approximately 29 km with an average gradient of 0.0025. Elemi river at the lower end course is easily accessible through Emirin, Erifun and Igbodogi villages in Ado Ekiti, Ekiti State of Nigeria. The river course is as shown in Fig. 1. The mean monthly rainfall varies between 45 mm and 225 mm. The temperature is reasonably uniform at 30°C throughout the year. The average relative humidity during the wet season is 95% and 45% in the dry season. It has an undulating relief, ranging from 10 km to 25 km upstream, varying in height with some isolated mountains rising up to 350 m.

The region of study is characterized by wide flood plains with a lot of alluvia deposit on top of the basement rock formation [9,14]. The terrain is relatively flat and surrounded by a chain of mountain range. In some sections, the mountains rise almost steeply from 100 to 250 meters at Iworoko and at Ado-Ekiti. The main rivers running through the project site are river Omosuo at Iworoko north end of the Ekiti State University campus and Elemi in Ado-Ekiti. The 3 higher Institutions to be served with the output of the study have a combined average population of 70,000 people [15], all stuffed with high energy consuming equipments in Engineering and Medicine.

2.2 Materials and Methods

The river tributaries include river Esure down Southwest of the Ekiti State University and river Ofin at Ago Igbira, about 5km south of the Ekiti State University, Ado Ekiti campus. Available hydrological data between 2005 and 2015 from the Federal Ministry of Water resources, and Irrigation and the Nigeria Meteorological Agency were used to compute the stream flow. Daily rainfall data were obtained from the Nigeria Meteorological Agency [16], while the social and environmental impact data were obtained at Ilokun village through administration of questionnaire and interview.

2.2.1 <u>Data acquisition</u>

The following procedures were used to prepare data collected from 2005 to 2015 for daily flow analysis:

a). Missing daily discharge data were filled using the daily seasonal mean values. These were obtained from the daily discharge time-series by getting the average for a particular day in a particular month in all the years available.

b). Average rainfall over the catchment was obtained by using the Arithmetic method, where

Fig. 1. Study area location

Fig. 2. River Elemi in the dry season at Ilokun in January 2016

the average for a particular day in a month was obtained by averaging values for that day in the time series from all stations in the catchment [15].

c). The mean annual flow is calculated from the data (2005 to 2015) of flows of as follows;

The mean monthly flows

$$= \frac{\sum(\text{Mean Daily Flow for each day})}{\text{Number of days in a month}} \quad (1)$$

Mean annual for each year (MAF)

$$= \frac{\sum(\text{Mean Daily Flow for each year})}{12} \quad (2)$$

Mean annual for all years

$$= \frac{\sum(\text{Mean Daily Flow for each year})}{11} \quad (3)$$

The corresponding catchment discharge q_i based on the rainfall data was obtained by equation 4 [17]:

$$q_i = \frac{Q_i A_i}{86400} \ (\text{m}^3\text{s}^{-1}) \quad (4)$$

Where Q_i is the catchment runoff and A_i is the catchment area.

The surface runoff yield, Q (mm) which is the net catchment response to rainfall in excess of the field capacity is represented by the equation 5 [18]

$$Q = \frac{(R-0.2S)^2}{(R+0.8S)} \quad (5)$$

and $Q = 0$ given that $R \leq 0.2S$ where Q is the predicted surface runoff depth (mm), R is the daily rainfall depth (mm), and S is the potential maximum soil water retention capacity which depends on the seasons, land use and soil condition.

The parameter S, is the initial abstraction (infiltration, interception, soil moisture retention) related to the curve number, *CN* which ranges from 0 to 100 depending on hydrologic forcing factors of the catchment given by equation 6,

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (6)$$

The constant, 25.4, in the equation 6 is a conversion scale of inches to mm which returns the value of S in mm.

Table 1 shows the mean annual flow from which Table 2 dataset was computed. The computation involved re-arranging the annual flow in a descending order followed by a range of class intervals to construct the flow duration curve. The plotting position is calculated using Weibull plotting relationship [11,12].

A flow duration curve was used to assess the expected availability of flow over time and the determination of power and energy to decide on the design flow and the selection of the turbine [19]. The flow duration curve is specified by twenty -one values Q_0, Q_1, Q_2, Q_3,........ Q_{20}, representing the flow in 5% increment. If a system is independent, the design flow should be available 95% of time or more [15]. The percentage probability, Pp, of any flow magnitude Q being equaled or exceeded is given as (7);

$$Pp = Di/(\sum Mi+1) \times 100 \quad (7)$$

where Di = order number of the discharge or class interval and ∑Mi = total number of data points in the list.

Stemming from equation 4, the average river velocity was calculated for the different sections of the river at different times and season of the year is shown in Table 3. The 1st measurement was taken in the month of April, the 2nd in the month of June, 3rd in the month of July and the 4th in the month of September. From Table 3, the mean average velocity was calculated as, 1.21 m/s and the mean discharge over an average cross sectional area (mean depth of 1.58m and an average width of 13.64 m) was obtained as

$$1.21 \times 1.58 \times 13.64 = 26.1 \text{ m}^3/\text{s}$$

2.2.2 Estimating the hydropower potentials of the Elemi River

The power available from the turbine was calculated using the power equations (8)

$$P(W) = \eta \rho g Q H_n \quad (8)$$

where P is power (Watts), η is the overall efficiency of the turbine -generator in %, ρ is the density of water (1000 kg/m^3), g is the acceleration due to gravity (9.8 m/s), Q is the water discharge expected to pass through the turbine (m^3/s), H_n is the net head (m).

The actual head seen by a turbine, termed the net head, was slightly less than the gross head H_g due to losses incurred when transferring the water into and away from the turbine via water conveyance structures. The net head was calculated using (9)

$$H_n = H_g - \{ \zeta_h (H_g) + h_w\} \quad (9)$$

where,

H_n = net head (m)
H_g = gross head (m)
ζ_h = conduit head percentage loss (typically 3% - 8%)
h_w = maximum tail water level (m)

Let Q_i represent the flow values constituting the primary flow duration curve; then, a minimum non-usable flow must bypass the small hydro plant in order to meet environmental regulations and irrigation requirements downstream and to account for the leakage that may occur at the point of diversion [11,12]. This minimum flow, also known as the residual flow (Q_r), was subtracted from all values of primary flow. Hence, the residual flow effectively shifted the primary FDC downwards thereby reducing the volume of flow available to the turbine and creating a secondary FDC consisting of the flows available for power generation (Q_j). The available flow values were thus calculated using (10) [8,9].

$$Q_j = Q_i - Q_r \quad (10)$$

i, j = {0,1,2,3,….,n}
n = number of equally spaced intervals on the FDC

where,

Q_i= flow values of the primary FDC (m^3/s)
Q_j= flow values of the secondary FDC (m^3/s)
Q_r = residual flow (m^3/s)

"i" and "j" are subscripts indicating the exceedance probability of a flow value on the primary FDC and secondary FDC respectively.

Table 1. The mean annual flow in m³/s for a period of year 2005 -2015

Month/ Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
2005	11.6	07.4	15.6	23.8	45.5	57.9	65.1	72.6	77.9	65.7	60.9	40.2	45.4
2006	07.1	02.6	11.7	18.9	41.6	58.3	68.9	77.1	82.3	70.2	58.9	36.4	44.5
2007	16.8	11.1	16.3	24.6	48.2	59.7	70.4	81.3	87.1	71.2	55.7	34.6	48.1
2008	21.2	15.4	21.5	30.7	49.4	63.9	75.6	82.9	89.9	67.7	59.2	39.2	51.4
2009	12.1	08.3	12.7	18.6	39.6	48.7	59.4	69.6	74.5	60.5	52.3	28.9	40.4
2010	19.5	10.7	16.1	23.3	49.9	59.4	67.4	79.1	84.7	71.6	63.1	43.6	49.0
2011	16.2	09.9	17.4	25.3	52.5	58.1	64.1	75.6	84.5	66.3	60.7	39.4	47.5
2012	10.1	07.2	12.4	20.8	42.9	60.1	67.7	79.3	88.3	73.3	62.9	37.2	46.9
2013	09.3	04.4	10.6	18.7	35.9	48.6	68.1	76.3	82.5	70.7	60.4	39.6	43.8
2014	16.1	11.4	20.3	22.8	37.5	46.3	62.0	69.4	76.9	64.7	56.9	37.7	43.5
2015	13.4	11.6	18.8	19.1	39.2	51.1	63.6	74.8	79.2	65.1	57.7	36.1	44.1
Monthly mean for the period	13.9	09.1	15.8	22.8	43.8	55.6	66.6	76.2	82.5	67.9	58.9	37.5	45.9

Table 2. Daily mean discharge records

Daily Mean Discharge m³/s	Number of days in each year the flow enters the class interval											M_i	D_i	P_p
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015			
129.9 -120.0	0.0	0.0	01	01	0.0	0.0	0.0	01	0.0	02	0.0	05	05	0.1
119.9 -110.0	0.0	02	02	0.0	0.0	01	0.0	01	0.0	02	01	09	14	0.3
109.9 -100.0	03	01	02	01	02	03	01	02	01	03	02	21	35	0.8
99.9 - 90.0	01	01	01	02	06	02	01	06	03	02	04	29	64	1.6
89.9 - 80.0	03	08	04	05	04	03	05	08	10	06	07	63	127	3.2
79.9 - 70.0	10	08	12	17	14	10	09	12	16	11	08	127	254	6.3
69.9 - 60.0	16	10	09	14	18	13	22	28	19	14	23	186	440	10.9
59.9 - 50.0	54	65	47	67	63	72	61	59	64	68	76	696	1136	28.3
49.9 - 40.0	58	47	51	46	66	61	63	51	56	72	62	633	1769	44.0
39.9 - 20.0	118	126	138	145	106	92	128	129	109	97	102	1290	3059	76.1
19.9 - 0.0	102	96	98	68	86	108	75	69	87	88	80	957	4017	99.9
Total Number of Days	365	365	365	366	365	365	365	366	365	365	365	4017		

Table 3. River Elemi average velocity at different depths

Depth (m)	1st Measurement (m/s)	2nd Measurement (m/s)	3rd Measurement (m/s)	4th Measurement (m/s)
1.28	1.17	1.28	1.21	1.44
1.33	1.15	1.24	1.19	1.42
1.49	1.14	1.23	1.19	1.37
1.56	1.10	1.22	1.15	1.28
1.64	1.09	1.20	1.13	1.32
1.67	1.09	1.18	1.12	1.26
2.11	1.04	1.16	1.11	1.31
Average	1.127	1.212	1.157	1.329

2.2.3 The power duration curve

When the power equation (8) was expanded to accommodate the distinct efficiencies and losses of the small hydro system and Q_k taken as the plant's rated flow; $P_{k(j)}$ is the power output of the small hydro plant due to available flows (Q_j) relative to the plant's rated flow (Q_k), and $P_{k\,(j)}$ was evaluated using (11) [10].

$$P_{k\,(j)} = \rho\, g\, Q_j\{H_g - (H_h + H_w)\}\eta_{t\,k\,(j)}\, \eta_g\, (1 - \zeta_t)(1 - \zeta_p) \quad (11)$$

j, k = {0,1,2,3,….,n}
n = number of equally spaced intervals on the FDC
$Q_j = \min(Q_j, Q_k)$

"j" and "k" are subscripts indicating the excedance probability of a flow value on the secondary FDC

when $Q_j = Q_k$; $P_{k\,(j)}$ is plant's rated output (P_k).

where;

η_t = turbine relative efficiency
η_g= generator efficiency (typical 93 - 98%)
ζ_t = transformer losses (typical 1 - 3%)
ζ_p= parasitic electricity losses (typical 1 - 4%)
ρ = density of water (1,000 kg/m^3)
g = acceleration due to gravity (9.8 m/s^2)
Q_j = available flows for power generation (m^3/s)
Q_k = plant's rated flow (m^3/s)
H_g = gross head (m)
H_h= hydraulic head losses (adjusted over the range of available flows)

$$H_h = H_g\zeta_h \{Q^2_j / Q^2_k\} \quad (12)$$

where

ζ_h = conduit head percentage loss (typical 3 - 8%)

H_w= tail water head losses (adjusted over the range of available flows) and is defined only for (Q_J> Q_K)

$$H_w = h_w \{(Q_j - Q_k)^2 / (Q_{max} - Q_k)^2\} \quad (13)$$

where,

h_w = maximum tail water river (m)
Q_{max} = maximum water river flow from the primary FDC (m^3/s)

The power outputs obtained from (8) were used to establish power duration curve (PDC) for the proposed small hydro plant.

The minimum potential power, $P_{min,}$ is the plant's rated output when the minimum annual flow rate is taken as the plant's rated flow. The average potential power, P_{ave}, is the plant's rated output when the average annual flow rate is taken as the plant's rated flow.

2.2.4 Annual optimum operation period determination

The plant's annual optimum operation period is an estimation of the number of days in a year that the small hydro plant can deliver rated output. The annual optimum operation period was calculated using (14).

$$T_o = P_r(Q_k) \times t_d \quad (14)$$

where,

T_o = optimum operation period (number of days)
t_d= approximate number of days in a year (365 days)
$Pr(Q_k)$ = excedance probability of the plant's rated flow (%)

2.2.5 Annual maximum reduction in rated output

The annual maximum reduction in the plant's rated output gives an indication of the quantity of power required to complement the small hydro plant during periods of reduced flows. The maximum reduction in the plant's rated output was calculated from the PDC using (15);

$$P_r = P_k - P_f \quad (15)$$

where,

P_r = annual maximum reduction in rated output (kW)
P_f = plant's firm output (kW)

The small hydro plant's firm output (P_f) is the power output that a small hydro plant can reliably provide throughout the year and is calculated from (11) when j = 100 i:e $Q_j = Q_{100}$.

2.2.6 The annual energy production

The annual energy produced by the small hydro plant was calculated by approximating the area of the region under the PDC. To achieve this trapezoidal integration was employed. In order to numerically implement the trapezoidal rule, a domain discretized into "n" equally spaced intervals such that "n" represents the percentage exceedance intervals on the power duration curve with "n + 1" flow values was considered. The approximation of the integral is given in (16) [11,16];

$$\int_a^b f(x)dx = \frac{h}{2}\sum_{z=0}^{n} \{f(x_Z) + f(x_{Z+1})\} \quad (16)$$

Equation (13) was modified to calculate the small hydro plant's annual energy production using (17);

$$E = \frac{h}{2}\sum_{j=0}^{n} \{P_{k(j)} + P_{k(j+1)}\} t_y A \quad (17)$$

where,

E = the annual energy produced by the plant (kWh)
$P_{k(j)}$ = the power outputs from (11) (kW)
A = plant's annual availability (typically 85 - 98%)
t_y = approximated number of hours in a year (8760 hrs)
h = percentage spacing of the intervals on the PDC (1%)

3. RESULTS

From Table 1, the average minimum monthly flow is 9.1 m^3/s for Elemi river, which occurs in the month of February in each of the sampled years between 2005 and 2015. The maximum monthly flow of 82.5 m^3/s at the peak of the rainy season in September is exacerbated by good network of storm-water channels directed to the river course. The mean monthly annual flow for the period is 45.9 m^3/s. The minimum mean annual flow for the sampled years is 40.4m^3/s, while the maximum is 51.4 m^3/s, and the mean annual flow for all the sampled years is 45.9 m^3/s.

The daily mean discharge records of Table 2, was used for plotting the flow duration curve. From the flow duration curve between year 2005 and 2015, it was established that the minimum flow of water is 4.1 m^3/s, with a discharge at 20% Percentage time, $Q_{20\%}$ = 58.2 m^3/s; the discharge at 80% Percentage time, $Q_{80\%}$ = 28.6 m^3/s and the discharge at 95% Percentage time, $Q_{95\%}$ = 12.4 m^3/s.

The amount of power that can be generated from a small hydro-electric power plant is dependent on the net head of the river, discharge and overall efficiency of the system. Since the stream basin is fairly straight with wide flood plains and a lot of alluvial deposit on top of the basement rock formation in the entire study area, it was discovered that the maximum height derivable from the study area is about 8m.

Using the Average Discharge Values in Table 1 and an effective stream height of 8 m, the hydropower potentials of Elemi river without constructing a dam on its course were calculated.

From the measured data obtained on Elemi River, the average annual maximum, minimum and mean discharge from Table 1 data were used to calculate expected obtainable power as:

Average Annual maximum discharge = 82.5 m^3/s

Average Annual Minimum Discharge= 9.1 m^3/s

Annual Mean Discharge = 45.9 m^3/s

Gross head = 8m

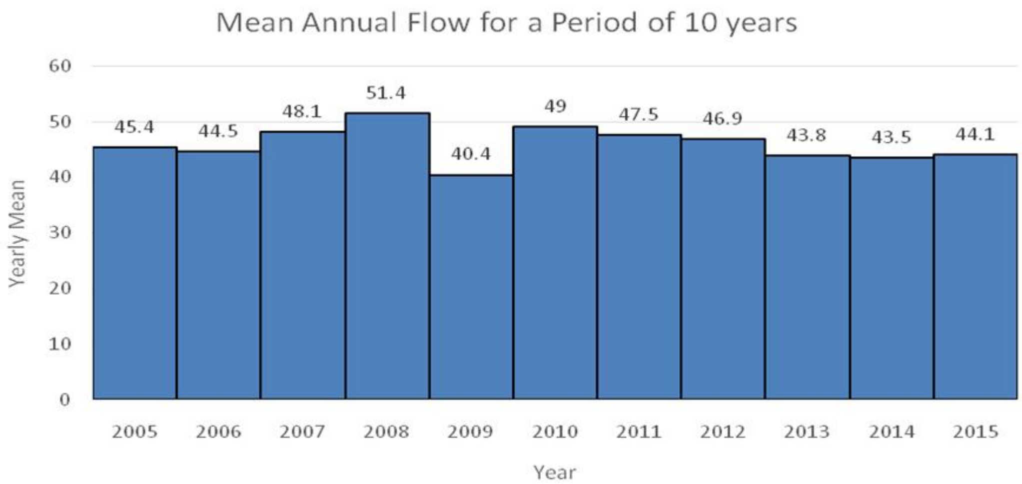

Fig. 3. Mean annual flow chart for Elemi river between 2005 and 2015

The maximum tail water level (h_w) was taken as 1.00 m with a residual flow Q_r as 2.05 m^3/s. The residual flow was taken as 50% of the minimum flow (i.e.(4.1)/2 = 2.05 m^3/s). The system efficiencies were taken as (from their typical values for research purposes);

Generator efficiency η_g= 95%

Turbine efficiency η_t= 85%

Transformer efficiency ζ_t= 1%

Conduit Head % losses ζ_p= 4%

Plant availability (A) = 95%

The minimum potential power or the obtainable power at minimum discharge P_{min} was calculated from the minimum annual flow of Table 1 and the FDC chart. The annual minimum discharge from Table 1, and the FDC chart of Fig. 4 is Annual minimum discharge = Q_{min} = 9.1 m^3/s

The Residual flow = 2.05 m^3/s

Equation 10 was used to find the flow values of the second FDC as Q_j = 9.1 -2.05 = 7.05 m/s

The application of equation 9, 11, 12 and 13 with $Q_j = Q_k$ was used to obtain the net head H_n as

H_n = 8 - {(0.04 x 8) + 1} = 6.68 m

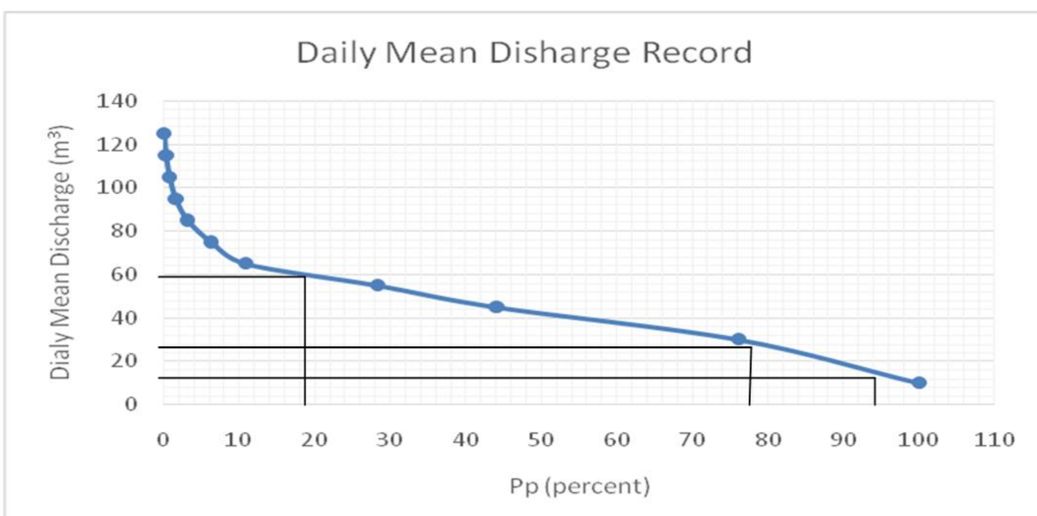

Fig. 4. Flow duration Curve for Elemi river for a sampled period between 2005 and 2015

From equation 11 and 12, it was noted that the overall efficiency of the turbine generator is

$\eta = \eta_{t\,k\,(j)}\,\eta_g\,(1 - \zeta_t)(1 - \zeta_p) = 0.7674$

With the use of equations 8 and 11, the obtainable power or minimum potential power from the river was calculated as;

$P_{min} = 1000 \times 9.81 \times 7.05 \times 6.68 \times 0.7674$
$= 354.53kW.$

At minimum potential P_{min}, the annual optimum operation period for the plant was determined with the use of equation 14 as

$T_o = 1 \times 365$ days = 365 days

Thus, at minimum potential P_{min}, the plant is expected to operate successfully through the year round, and the annual maximum reduction in rated output at P_{min} with the use of equation 15 is

$P_r = P_k\text{-}P_f = 0.$

The annual energy production was calculated with the use of equation 14 in which case, $P_{k\,(j)} \approx (P_{k\,(j+1)}$

and

$E = 354.54 \times 0.95 \times 8760$
$= 2.95MWHr$

With the use of equations 11 and 12, the maximum obtainable power or maximum potential power from the river was calculated as;

$P_{max} = 1000 \times 9.81 \times (82.5 - 2.05) \times 6.68 \times 0.7674$
$= 4.05MW.$

At maximum potential P_{max}, the annual optimum operation period for the plant was determined with the use of equation 14 as

$T_o = 0.01 \times 365$ days = 3.65 days

Thus, at maximum potential P_{max}, the plant is expected to operate successfully for about 4 days in a total of 365 days of the year, and the annual maximum reduction in rated output at P_{min} with the use of equation 15 is

$P_r = P_k\text{-}P_f = 4.05 - 0.354 = 0.$

The annual energy production was calculated with the use of equation 17, in which case, $P_{k\,(j)} \approx (P_{k\,(j+1)}$

And E = 354.54 x 0.95 x 8760 = 2950481.88 = 2.95 MWHr

With the use of equations 8 and 11, the mean obtainable power or mean potential power from the river was calculated as;

$P_{mean} = 1000 \times 9.81 \times (45.9 - 2.05) \times 6.68 \times 0.7674$
$= 2.21MW.$

At maximum potential P_{mean}, the annual optimum operation period for the plant was determined with the use of equation 14 as

$T_o = 0.5 \times 365$ days = 182.5 =183 days

Thus, at maximum potential P_{max}, the plant is expected to operate successfully for about 183 days in a total of 365 days of the year, and the annual maximum reduction in rated output at P_{min} with the use of equation 15 is

$P_r = P_k\text{-}P_f = 4.05 - 2.21 = 0.$

The annual energy production was calculated with the use of equation 17 in which case, $P_{k\,(j)} \approx (P_{k\,(j+1)}$

And E = 354.54 x 0.95 x 8760 = 2950481.88 = 2.95MWHr

With the Average Mean (Nominal Flow) Discharge = 45.9m^3/sec.

The Total Yearly Run-Off volume of the river at this discharge value is 45.9m^3/sec $\times$ 60 sec $\times$ 60 min $\times$ 24hrs $\times$ 365 days = 1.45 $\times$ $10^9 m^3$

Average Total Yearly Run-Off Volume of the river = 1.45 $\times$ $10^9 m^3$

The non availability of a good height limits the maximum obtainable power to 4.05MW, at the peak of the river's discharge. The mean obtainable power is 2.21MW for an average of 183 days, and thus makes it unsuitable for large power consumers like the Ekiti State University, Ado Ekiti with a population of over 32,000 and estimated load demand of 5.6MW, as well as Afe Babalola University, Ado Ekiti with a population of over 18,000 and estimated load demand of 6.8MW. Also the mean obtainable power is unsuitable to power the Federal Polytechnic, Ado Ekiti with a population of over 25,000 and estimated load demand of 4.7MW average (derived from response to questionnaires) which is along the course of the river without embarking on a dam construction. However, for small factories, of less than 2.0MW need which may be sited along Elemi river course, the diversion scheme will serve their purpose.

In order to harness the potentials of the stream all year round for better power output, a dam with a minimum head of 20 m is recommended along with the course of the river. This will give an estimated output as detailed below;

The average mean potential power or the obtainable power at mean discharge P_{mean} was calculated from the mean annual flow of Table 1 and the FDC chart. The annual mean discharge from Table 1, and the FDC chart of Figure 4 is Annual mean discharge = Q_{mean} = 45.9

The Residual flow = 2.05

Equation 10 was used to find the flow values of the second FDC as Q_j = 45.9 -2.05 = 43.85

The application of equation 8, 9, 11 and 12 with $Q_j = Q_k$ was used to obtain the net head H_n as

$H_n = 20 - \{(0.04 \times 20) + 1\} = 18.2$ m

From equation 5 and 8, it was noted that the overall efficiency of the turbine generator is

$$\eta = \eta_{t\,k\,(j)}\, \eta_g\, (1 - \zeta_t)(1 - \zeta_p) = 0.7674$$

thus the overall efficiency = 0.7674

With the use of equations 8 and 11, the obtainable power or mean potential power from the river is calculated as;

$$P_{min} = 1000 \times 9.81 \times 43.85 \times 18.2 \times 0.7674 = 6.0\text{MW}.$$

With an estimated average of 6MW obtainable power in an average of 183 days, the Elemi river with a dam construction can serve any one of the 3 institutions along its course conveniently.

4. ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT ON RIVER ELEMI

The environmental impact assessment for the citing of Elemi river hydropower plant to serve the need of either of the 3 institutions along its course was conducted on social and environmental impacts. The social and environmental assessment shows no negative impact. On the positive impacts, the SHP will contribute to the economic growth of the area, and reduce poverty by removing energy constraints to enterprises that can offer employment opportunities to the poor, as well as clean energy at affordable prices than the use of firewood, kerosene and diesel, with overall improved environment with less pollution. The impact on water flow and fish migration and other natural habitats is minimum, and the construction poses no threat to the natural vegetation.

5. CONCLUSION

The Elemi river small hydro power viability assessment was conducted with available hydrological data for 11 years spanning 2005 to 2015. The result obtained showed that the head of the river course is 8 m. With average minimum and the maximum discharge of $9.1 m^3/s$ and $82.5 m^3/s$, average hydropower obtainable is 2.21MW with an optimum operating period of 183 days per annum. The annual energy production obtainable for the total average yearly run-off of $1.45 \times 109 m^3$ is 2.95MWHr.

It was discovered that the yield capacity of Elemi River for power generation with a diversion scheme could not provide the power requirement for any of the 3 higher institutions within its course due to its relative flat terrain. A recommendation for the construction of a dam for an impounded scheme with a minimum gross head of 20 m, will adequately serve the needs, of at least one of the Institutions is proposed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sambo SA. Renewable energy policy and regulation in Nigeria. Paper Presented at the International Renewable Energy Conference, 7th -9th October; 2003.
2. Aliyu VO, Elegba SB. Prospects for small hydro power development for rural appliances in Nigeria. Nigeria Journal of Renewable Energy; 1990.
3. Kela R, Usman KM, Tjjani A. Potentials of small hydro power in Nigeria: The current status and investment opportunities. International Journal of Scientific & Engineering Research. 2012;3(5):134-142.
4. Onyemaechi AB, Charles I. Small hydropower projects for rural electrification

in Nigeria's developer's perspective. International Journal of Innovative Technology and Exploring Engineering (IJITEEE). 2013;3(5).
5. Fagbohun OO. Studies on small hydro-power potentials of Itapaji dam in Ekiti State, Nigeria. International Journal of Engineering Inventions (IJEI). India. 2015;5(1):28-36.
6. Okpanefe PE, Owolabi S. Small hydropower in Nigeria. Ministry of Power & Steel, Nigeria. TCDC Training Workshop on SHP; 2002.
7. Fagbohun OO, Adebanji BA. Integrated renewable energy sources for decentralized systems in developing countries. Journal of Electrical and Electronic Engineering (JEEE), India. 2014;9(5) ver.1:26-35. Aned-ddl 12.1676/iosr-jeee-E09512635;
DOI: 10.9790/1676-09512635
8. Adebanji B, Adepoju GA, Fagbohun OO. Development of a hybrid simulation and optimization model for rural electrification. Journal of Scientific Research & Reports. 2015;15(6):1-13.
9. Adepoju GA, Adebanji B. Feasibility study and optimal design of small hydropower-photovoltaic diesel generator hybrid power system for Itapaji-Ekiti, Nigeria. Journal of Scientific Research and Reports. 2016;11(2):1-10.
10. Omotoso T, Aribisala JO. Small hydropower development: Prospect of River Elemi in meeting electricity demands of University of Ado Ekiti. Proceedings of the First National Engineering Conference of the Faculty of Engineering, University of Ado Ekiti, Nigeria. 2008;152-155.
11. Ramakumar R. Role of renewable energy in the development and electrification of remote and rural areas. IEEE Power Engineering Society General Meeting, Denver, CO. 2014;2(10):2103-2105.
DOI: 10.1109/PES.2004.1373253
12. Adejumobi IA, Adebisi OI. Exploring small hydropower potentials for domestic and information communication technology infrastructural application in rural communities in Nigeria. Proceeding of the 12th Biennial International Conference of Botswana Institution of Engineers, Gaborone, Botswana. 2011;19-26.
13. Omotoso T. Water quality profiling of rivers in a data-poor area. PhD Thesis Submitted to the University of Manchester. 2016;68.
14. Mohibullah MA, Mohd R, MohdIqbal AH. Basic design aspect of micro hydro power plan and its potential development in Malaysia. National Power and Energy Conference (PECON) Proceedings, Kuala Lumpur, Malaysia; 2004.
15. Akinbami JFK. Renewable energy resources and technologies in Nigeria: Present situation, future prospects and policy framework. Mitigation and Adaptation Strategies for Global Change, Kluwer Academic Publishers, Netherlands. 2001;6(2):155-188.
16. Balla P. Development of community electrification in Kenya: A case of small scale-hydro for rural energy. Master's Thesis, Lund University, Sweden; 2003.
17. Soil Conservation Service. Urban hydrology for small watersheds. TR-55, USDA Washington DC.
Available:https://www.hec.usace.army.mil/publications/TechnicalPapers/TP-77
18. Huang M, Gallichand J, Wang Z, Goulet M. A modification to the soil conservation service curve number. Hydrol. Process. 2006;20(5):579-589. Willey Inter Science.
Available:https://www.interscience.wiley.com
DOI: 10.1002/hyp.5925
19. Ghale BB. Private micro hydro power and associated investments in Nepal. The Barpak Village Case. Cited in Ashoka Organization; 2004.
Available:www.ashoka.org

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