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Evaluation of the Small Hydropower Potential of River Ethiope Using the RETScreen Software

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Abstract:In this study, the River Ethiope was critically studied as a source of renewable energy for small hydropower development. The aim was to carry out detailed evaluation of the river's hydropower generation potential using RETScreen software.Data on daily flow that was used for flow duration curve was obtained from the Benin Owena River Basin Authority's hydrological year book for a period of six years (1989 – 1994). Also in this study, meteorological data on rainfall, temperature, wind evaporation and humidity were obtained from the Meteorological Weather Station at the Geography Department, Delta State University, Abraka. These data were used to observe the seasonal variations and how this variation affects the flow rate.RETScreen clean energy analysis software was used for the evaluation of the energy output from the River Ethiope. Four alternative project formulations were evaluated using the RETScreen software. The results of the four alternative project formulations using the RETScreen Software are as follows: Case 1(for a flow rate of Q = 9.6 m^3/s, with a head of 5, 10, 15 and 20 m, the output power P are: 357, 753,1142 and 1,526 kW respectively), Case 2 (for a flow rate of Q = 10.8 m^3/s, with a head of 5,10, 15 and 20 m, the output power P are: 402, 848,1,286, 1,719 kW respectively), Case 3 (for a flow rate of Q = 13.8 m^3/s, with a head of 5, 10, 15 and 20 m, the output power P are: 516, 1,086, 1,646, 2,200 kW respectively), Case 4 (for a flow rate of Q = 31.73 m^3/s, with a head of 5, 10, 15 and 20 m, the output power P are: 1,195, 2,509, 3,800 and 5,079 kW respectively). The results of the evaluations showed that the River Ethiope is capable of generating 1.20 MW on a design flow of 31.73 m^3/s and a head of 5 m. While on a design flow of 31.73 m^3/s and a head of 15 m, 3.8 MW of electricity could be generated if properly harnessed. It can therefore be concluded that the River Ethiope when fully utilised could generate electric power capable of satisfying part of the power need of the surrounding communities.

Key Words: Hydropower; Small hydropower; RETScreen software; Flow rate; Head.

1.0 Introduction

The River Ethiope of Delta State, Nigeria (Figure 1) is a valuable water resource that can sustain irrigation, recreation, power generation and vast array of ecosystem types.

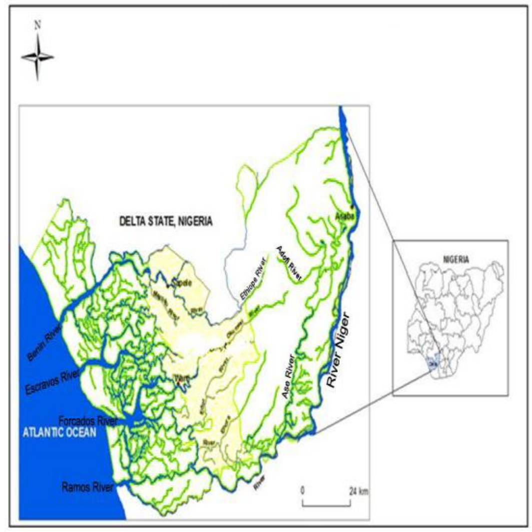

Figure 1. Location of River Ethiope in relation to drainage distribution in Delta State.

The head waters of the River Ethiope are situated at the outskirts of the Umuaja community located north-east of Obiaruku the Ukwani Local Government Headquarters. From Umuaja where the seeps form several springs coalesce (Figure2), the river flows south and southwest-wards toward the Delta State University town of Abraka at which point it swings west and northwest with tortuous meanders toward Sapele where it is joined at Amukpe by the Jamieson River to form the main trunk of the Benin River as shown in Figure 3.

Figure 2. River Ethiope at the source at Umuaja.

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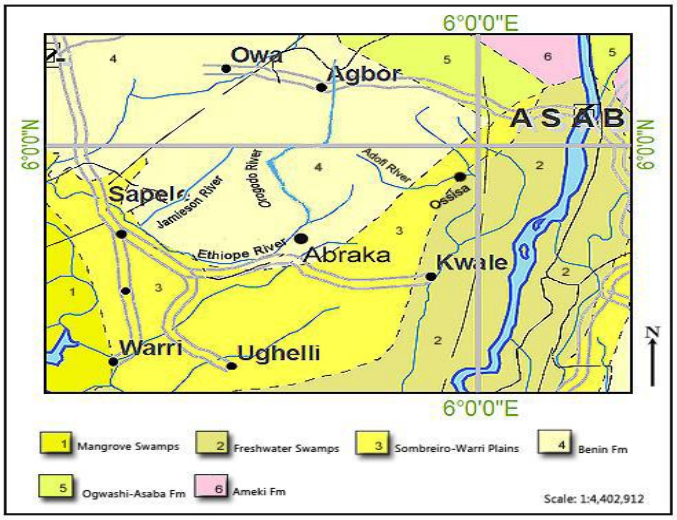


Figure 3. Geological Map of part of Western Niger Delta Showing the location of River Ethiope [1].

At the source, River Ethiope is very narrow, (see Figure2), but 70 kilometres later at Sapele, it is more than 100 metres in width and is deep enough to accommodate ocean going vessels. The total length of the river from the source at Umuaja to where it drains into the sea is 119 km.The River Ethiope has two tributaries: the Orogodo River and the Jamieson River. The OrogodoRiver flows into the River Ethiope only in the wet rainy season. In the dry season, it retreats northwards into a swamp just north of Ugo. No tributaries join the River on its south bank from the Warri deltaic plain[1].Near the source of River Ethiope, are a lake of about 83.1meters wide and a length of over 100 meters, with water in it all year round. This natural lake is located at Umutu, it narrows down to only about 5 m wide at which location a collapsed bridge was earlier constructed (see Figure 4). This natural lake has never been exploited for hydro power, and indeed River Ethiope, apart from small fishing activities, swimming, washing of clothes, sand mining and water source for human use is yet to be fully harnessed [2]. The potentials of the lake are herein being exploited and investigated for its productive use.

Figure 4. The Lake at Umutu

This research focuses on the evaluation of the river's potential for small hydropower development using RETScreen software. The four alternative project formulations using the RETScreen software as presented in this study will give decision makers various options that they may consider in their choices of harnessing the power generation potential of River Ethiope.

2.0Sources of Data

2.1 Meteorological Data

Meteorological data are especially important on hydrologic research because the climate and the weather of an area exert a profound influence on most hydrologic processes. Meteorological data that have significant bearing on hydropower development are those of rainfall, temperature, wind, humidity and evaporation. These data are all observed for a period of six years (2008-2013) at the Geography Department of Delta State University Weather Station, Abraka. The mean monthly distributions of rainfall, temperature, relative humidity, evaporation and wind-speed/direction for the six year period (2008-2013) are presented in Table 1.

Table1. Mean Monthly Distribution of Rainfall, Temperature, Humidity, Evaporation and Wind Speed/Direction at Abraka (2008-2013)

Months	Rainfall, mm	Temperature ^0C	Humidity %	Evaporation mm	Wind m/s
January	36.38	30.75	80.50	125	34.18/NE
February	58.13	30.93	84.57	100	55.27/NE
March	183.5	30.58	82.95	105	37.70/SW
April	212.4	30.58	88.87	83	50.75/SW
May	314.1	29.20	88.98	60	43.77/SE
June	443.5	29.90	87.67	68	32.47/SE
July	347.9	29.47	92.57	67	39.58/SE
August	278.0	29.15	93.60	86	33.18/SE
September	344.1	29.85	92.58	72	37.90/SE
October	218.1	30.05	90.53	54	32.37/SE
November	145.7	31.42	86.43	121	38.18/NW
December	26.67	31.33	82.83	123	33.03/NE

2.2 Hydrological Data

Measurement of stream flow from a hydrological stream gauging network are the main and best source of the surface water flow data [3].In Nigeria, stream flow measurement are carried out by Government through the River Basin Development Authority(RBDAs), who established gauging stations on rivers within their areas of operations.

The Benin Owena River Basin Development Authority (BORDA) in 1980 installed one staff and automatic recorder unit at its gauging station on River Ethiope on a bridge at Abraka as shown in Figure 5. Although the gauge was installed in 1980 and data gathering commenced almost immediately, raw data processing, storage and dissemination was a problem at BORBDA [4], and it was not until ten years later in 1990 that BORBDA initiated the publication of Hydrological Year books. Unfortunately, ten years of data had been lost by this time. Furthermore, publication had continued till 2004 but without data for the gauging station on the River Ethiope. As a result, only data for the six year period between 1989 and 1994 are available and were used in this study for monthly flow data. The monthly flow data of the River Ethiope are given in Table 2.

Table 2 Monthly Flow Data 1989 – 1994 (m^3/s)

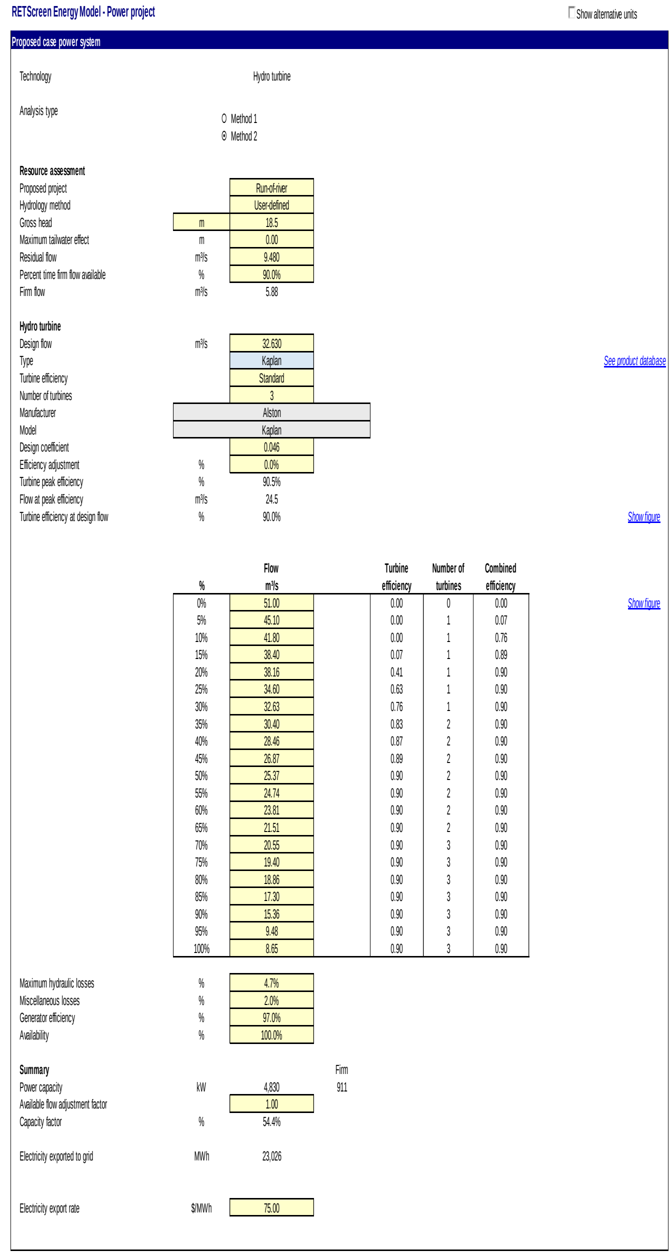
Year	Jan.	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1989				10.62	9.48	8.65	15.36	21.51	23.51	26.17	25.37	27.6
1990	20.81	18.95	15.48	10.52	8.94	15.49	14.47	25.97	30.47	40.83	34.63	30.9
1991	26.8	24.4	24.4	25.0	19.4	17.3	20.2	32.4	41.8	46.5	45.1	38.2
1992	33.1	28.5	24.8	21.2	20.1	19.5	24.5	33.7	37.2	39.5	38.2	34.6
1993	30.4	26.87	22.85	18.85	18.86	19.13	24.74	32.63	40.55	42.32	38.4	33.46
1994	29.68	27.48	21.50	20.55	18.73	17.49	23.81	28.16	38.16	51	49.6	42.5
Avg	28.16	22.5	21.81	17.81	15.92	16.26	20.51	29.11	35.28	40.9	38.55	34.54

2.3 Evaluation of the Project Formulations Using RETScreen Software

The hydrological data on monthly flow of the River Ethiope as presented in Table 2 were evaluated using RETScreen software.RETScreen runs on Microsoft Excel platform and uses empirical equations to calculate the energy output and cost of the projects. Figure 5 shows the general layout of the program and it has; 'Start, Energy Model, Cost Analysis, Emission Analysis, Financial Analysis, Risk Analysis and Tools sheets. In this study, only Energy Model was used to evaluate probable energy output from the River Ethiope.

Figure 5 General Layout of the Program

The data entered into the energy model sheet was used to calculate the energy output of the project. The energy sheet prepared for the River Ethiope is shown in Figure 6.



%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	51.00	0.00	0	0.00
5%	45.10	0.00	1	0.07
10%	41.80	0.00	1	0.76
15%	38.40	0.07	1	0.89
20%	38.16	0.41	1	0.90
25%	34.60	0.63	1	0.90
30%	32.63	0.76	1	0.90
35%	30.40	0.83	2	0.90
40%	28.46	0.87	2	0.90
45%	26.87	0.89	2	0.90
50%	25.37	0.90	2	0.90
55%	24.74	0.90	2	0.90
60%	23.81	0.90	2	0.90
65%	21.51	0.90	2	0.90
70%	20.55	0.90	3	0.90
75%	19.40	0.90	3	0.90
80%	18.86	0.90	3	0.90
85%	17.30	0.90	3	0.90
90%	15.36	0.90	3	0.90
95%	9.48	0.90	3	0.90
100%	8.65	0.90	3	0.90

Figure 6 The Energy Sheet

The project type, assumed gross head , residual flow, percent time firm flow available, design flow, turbine type and numbers, maximum hydraulic losses, generator efficiency and electricity export rate are as indicated in the Figure 6. Since the flow duration curve can be calculated from the data in Table 2, user defined hydrology method was used. Standard was selected for the Turbine efficiency and built in efficiency in Turbine database of RETScreen were used. Design coefficient is a dimensionless factor used to adjust the turbine efficiency by taking into account varying manufacturing techniques [5]. In this study, software default value was used. Miscellaneous losses include parasitic electricity losses and transformer losses. Since a value of 2% is identified as appropriate for most hydro-plants in RETScreenManual [5], 2% was used in this study for

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miscellaneous losses. 96% availability is suggested by RETScreen Manual if the plant will have 15 days downtime in a year. 100% availability is selected since the project in this study has multiple turbines and failure of all three turbines at the same time is not possible. Therefore, even in the low flow seasons the projects will continue to generate electricity.

2.4 Four Alternative Project Formulations Using RETScreen Software

In this study, four alternative power output was developed using different flows and heads to run the software and the output is presented in Table 3.

Table 3 Outputs of RETScreen Software through Successive Runs with Variable Design Flow and Head Values

Cases	Input Gross Head (m)	Output Power Capacity (kW)
Case 1 $Q = 9.6\ m^3/s$	5	357
	10	753
	15	1,142
	20	1,526
Case 2 $Q = 10.8\ m^3/s$	5	402
	10	848
	15	1,286
	20	1,719
Case 3 $Q = 13.8\ m^3/s$	5	516
	10	1,086
	15	1,646
	20	2,200
Case 4 $Q = 31.73\ m^3/s$	5	1,195
	10	2,509
	15	3,800
	20	5,079

Design flow and head are the fundamental parameters that affect both energy and power capacity and the cost of a small hydropower project. When design flow decreases, both power capacity and initial cost values decrease [6]. As can be seen from Table 3, with a design flow of $31.73m^3/s$ and a minimum head of 5 meters, the system can generate approximately 1.20 MW of electricity which can solve part of the power need of the host community.

3.0 Results and Discussion

As noted in Table 1, the rainfall starts in February/March and terminates in November. The annual mean rainfall for six years (2008 – 2013) monitored at Abraka is approximately 2578.38 mm and mean monthly rainfall for the period is 214.87 mm. The mean monthly distribution of rainfall for the period is shown in Table 1and from this Table, minimum rainfall occurs in December with an average of 26.67 mm and maximum rainfall occurs in June with an average of 413.5 mm. No flood events have been recorded in the upper and middle courses of the River Ethiope. This is as a result of a wide, gently sloping flood plain, unconsolidated nature, high porosity and permeability of the sediments, which allows for rapid in-filtration and downward movement of water [7].

The stream flow data available for the six years of data as presented in Table 2 was used to plot the flow Duration Curve (FDC) and the power duration curve (PDC) as represented in Figure 7. The shape of the flow duration curve describes the suitability of the site for small hydropower production. A very steep curve shows abrupt change in amount of discharge for a relatively short period of time – signalling that the site is prone to floods (unsuitable)[8]. A flat flow duration curve is preferable as it indicates that the total annual flow will be more evenly spread over the year, giving a useful flow for longer periods and less severe floods [9]. The shape of the slope in the flow duration curve as represented in Figure 7 shows that the River Ethiope is suitable for small hydropower development.

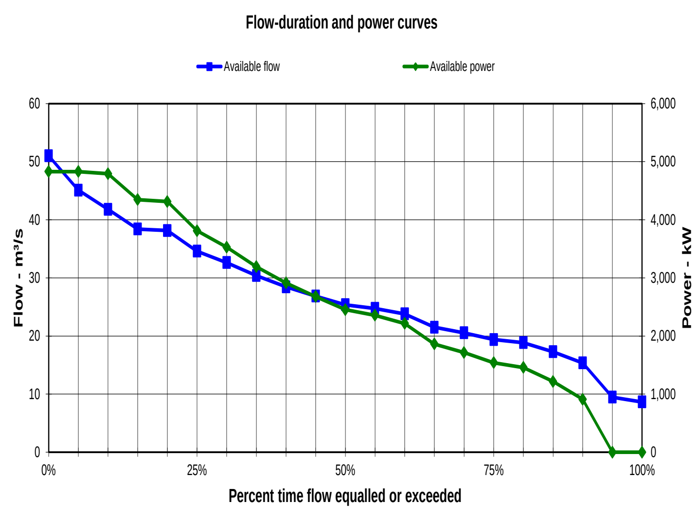

Figure 7 Flow and Power Duration Curves for River Ethiope.

From Figure 7, the flow rate at 60% exceedence is 23.81 m^3/s. This means that this flow is equaled or exceeded for 60% of the time and so basically the flow is at this flow or at a higher flow for 60% of the time. The Power at this 60% exceedence is 2.2 MW. The flow rate at 20% exceedence is 38.16 m^3/s. This is a higher flow rate, so the flow is only at or greater than this flow rate for a smaller proportion of the year and the Power at this 20% exceedence is 4.3 MW. At 100% exceedence, the flow is 8.85 m^3/s which is the lowest flow rate recorded, so by definition, the flow in the river is at this flow rate or more for 100% of the time and as can be seen, the Power output is practically zero.

Flow rates between Q_0 and Q_{10} are considered high flow rates and Q_0 to Q_1would be extreme flood events. It is important that hydropower systems are designed to cope with such extreme flows. Flows from Q_{10} to Q_{70} would be the medium range of flows and hydropower systems are designed to operate efficiently right across these flow rates. Flow rates from Q_{70} to Q_{100} are the low flows where hydropower systems will just be operating but at a low power output and as flow moves further to the right on the FDC, hydro systems will begin to shut down due to low flows. As can be seen in Figure 7, as flow rates moves from Q_{95} toward Q_{100}, the system moves into the low-flow draught flow.

4.0 Conclusion

Developing small hydropower projects requires time and money as well as engineering experience. In order to assist engineers in conducting feasibility analysis of hydropower projects, many computer tools have been developed. RETScreen International Clean Energy Analysis Software is a decision support tool which could be applied internationally. RETScreen is a useful software which can be used worldwide to evaluate the energy production and savings, life-cycle, costs, emission reductions, financial viability and risk for various types of energy technologies (RETS) such as small hydropower. RETScreen – small Hydro Software is capable of making optimizations to maximize the delivered energy and minimize the initial cost of SHP project within a short duration of time, without detailed study. For reservoir and run- off river type of projects, a pre- feasibility report can be prepared in a small period of time compared to the traditional feasibility studies. Moreover, the report can be revised every time by changing some variables and thus different alternatives can be compared easily without extensive calculation which is really helpful for the designers. In this study, the data collected were entered into the RETScreen software and the outputs are analyzed in details. Additional alternative, which take into account the effects of variable discharge and head were carried out. The results of this study show that RETScreen software can be used in Nigeria's small hydropower projects and that River Ethiope when fully utilized is capable of generating electric power that could satisfy part of the power need of the surrounding communities.

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