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Harnessing the Small Hydropower Potential of River Iyi-Ukwu in Oshimili North Local Government Area of Delta State, Nigeria as a Renewable Energy Source

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Abstract: *This study examines the small hydropower potential of River Iyi-Ukwu in Oshimili North Local Government Area of Delta State, Nigeria as a renewable energy source. The discharge (m^3/s) of River Iyi-Ukwu was well investigated using the Velocity - Area method while using segment method to obtain the depth of the river with which the river profile was drawn. The head from source to destination of the river was approximated from a topographic map of Onitsha in Anambra State, Nigeria. The results show that theoretical power of about 1.83 MW of electricity is realizable from the river on a discharge of 2.887 m^3/s and a head of 76.2 m. This amount of power can go a long way in solving part of the energy crisis in Nigeria especially at the rural areas.*

Keywords: *Renewable Energy, Small Hydropower, Discharge, Topographic Map, River Profile, Head.*

1. Introduction

Energy is vital for all living things on earth [1] since all human activities depend on one form of energy or another. The process of generating electric energy using fossil fuel produces heat which increases the entropy of the earth. It is estimated that global energy related carbon-dioxide emissions (CO_2) will increase by some 50 per cent between 2004 and 2030, unless major policy reforms and technologies are introduced to transform the way energy is produced and consumed [2]. For efficient operation therefore, it is increasingly important to conserve energy and to reduce the effect of green house [3]. The search for renewable energy sources and their technology development is of paramount importance to have a balance and buoyant environment for better quality of life. Energy supply from renewable sources is therefore an essential part of every country's strategy, especially when there is a serious threat of environment degradation and challenge for maintaining sustainability of fossil fuels the major source for power plant [4].

Nigeria is reasonably endowed with renewable energy resources such as large rivers and some natural falls. The Niger and Benue Rivers with several tributaries constitute the Nigerian river system which offers some potential renewable source of energy for economically viable large hydropower development [5]. In addition, several scores of small rivers and streams also exist within the present split of the country into eleven River Basin Authorities, some of which maintain minimum discharge all the year round [5]. Harnessing these potentials through Small Hydropower (SHP) development will go an extra mile toward a drastic reduction of electric energy crisis in the country [6]. This study is motivated by the availability of small hydropower potential for electricity generation in the rural settlements of Delta State, Nigeria, which has suffered neglect due to the inept approach employed successive governments in addressing the lingering issue of economic under-development occasioned by little or no electric power for developmental purposes. This study therefore focuses attention on the small hydropower potential of River Iyi-Ukwu in a rural community of Illah in Delta State. The River is located at N 06^{0}38'23.0'' 44 m above sea level. Figure 1 shows cut-out section showing River Iyi-Ukwu and some other rivers in Delta State.

Figure1. *Cut out section showing River Iyi-ukwu and some other rivers in Delta State*

These other rivers are: River Utor, River Uburubu, River Kwan-Kwo and River Epacho. These rivers will be investigated for their small hydropower potentials and the possibility of harnessing them for water supply and irrigation in the State.

2. MATERIALS AND METHODS

2.1. Data Collection

The data required for this study are hydrological data which were obtained for a period of four (4) consecutive months. The data include stream-flow, depth and width measurements across the river to ascertain the cross sectional area. The materials involved in the measurement of stream-flow or discharge are measuring tape, two stop watch, twine (rope) of about 100 m, meter rule, pegs, cutlasses, colored float and for the measurement of head, contour map and Google earth soft-ware.

2.2. Measuring Stream-Flow

Normally in Nigeria, stream-flow measurement are carried out by Government through the established River Basin Development Authorities (RBDA), who established gauging stations on rivers within their areas of operations [7]. River Iyi-Ukwu is under the catchment area of the Benin Owena River Basin Development Authority (BORBDA). So far since the inception of this River Basin Development Authority, no gauging station has been established on this river. However, for un-gauged station like River Iyi-Ukwu, there are several methods for measuring stream-flow but in this study, only the Velocity-Area method was used.

2.3. Velocity-Area Method

Velocity-Area method of measuring discharge or stream-flow involves the determination of the cross-sectional area of the river and the mean velocity [8]. The river cross-section is determined from the river profile obtained by segment method. In this method, a twine was tied across the width of the river and at 20 cm intervals, the depth of the river was measured using the meter rule as can be seen in Figure 2. The measurands were plotted on computer software (Microsoft Excel) and the cross sectional area was determined from the plot.

Figure2. *Measuring River Depth*

Figure3. *Marking out a portion of river*

In determining the discharge of the river, the cross-section where width and depth was fairly consistent was chosen. Twine (rope) was used to mark out a rectangular area of 8 m x 6.8 m as shown in Figure 3 for velocity measurement. The float method was used to measure the velocity of the river. In this method, the speed of the mid-stream surface water was measured by timing a floating object over a known distance, d. The floating object should be heavy enough to be partially submerged. The floating object was placed at a point in the stream where the velocity is required. The time, t it takes to cover the marked distance, d was recorded. The result of the average flow velocity was obtained by dividing the distance, d by the time, t it took the float to cover the specified distance as can be seen in Figure 4.

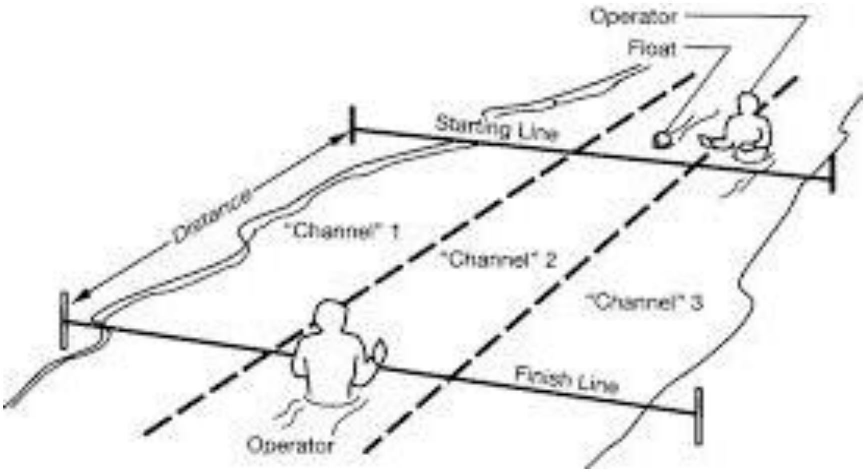

Figure4. *Measuring stream Velocity using Float Method*

The surface velocity, Vs of the water is given by equation 1.

$$V_s = \frac{d}{t} \qquad (1)$$

Where Vs is surface velocity (m/s), d is distance covered by float (m), t is time it took float to cover distance (s).

The flow rate or discharge Q, in each section equals the mean velocity, V multiplied by the cross-sectional area, A [9].

That is

$$Q = VxA \qquad (2)$$

2.4. Head Measurement

Head is how far the water drops. It is the distance from the highest level of damned water to the point where it goes through the power producing turbine. The head is one of the most important on-site survey parameters. It helps to determine the potential power, the type of turbine to be used and the necessary civil engineering construction. There are several methods that can be employed in the measurement of available head. Some of these methods are more suitable on low-head sites, but are too tedious and in-accurate on high heads [10]. The gross head is not strictly a constant but varies with the river flow. As the river fills up, the tail water level is often faster than the head-water level, thus reducing the total available head. Although this head variation is much less than the variation in flow, it can significantly affect the power available, especially in low-head schemes where every half meter is essential. To assess the available gross head accurately, head-water and tail-water levels need to be measured for the full range of the river flow. In this study, the head of the River Iyi-Ukwu which takes its rise from Onicha-Olono (height) to destination at the River Niger (height) was estimated using the 1:50,000 Onitsha contour map of Nigeria. Topographic maps have the advantage that they allow differences in elevation to be read directly from the contours of the map. They unlike the aerial photograph are not spatially distorted. Figure 5 shows the 1:50,000 edited map of Onitsha showing source to destination of the River Iyi-Ukwu. The contour lines on the map provide the height of the land above sea level, given in feet and head was determined by reading and calculating elevation difference between the points.

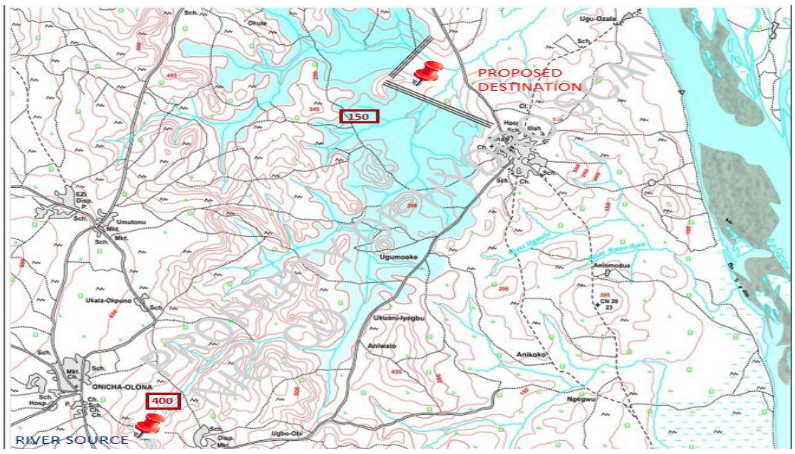

Figure5. *1:50,000 Map of Onitsha, Nigeria showing river source to destination*

3. Results and Discussion

The results of discharge measurement for a period of four months (July – October, 2015) at various sections along the river are presented in Tables 1 – 4.

Table1. *Result of Depth Measurements for July – October, 2015*

S/N	Width, cm	July, 2015 Depth, cm		August, 2015 Depth, cm		September, 2015 Depth, cm		October, 2015 Depth, cm	
		Section 1	Section 2	Section 1	Section 2	Section 1	Section 2	Section 1	Section 2
1	0	0	0	0	0	0	0	0	0
2	20	-92	-65	-90	-60	-90	-59	-90	-59
3	40	-94	-68	-93	-63	-93	-62	-92	-62
4	60	-99	-69	-98	-68	-98	-67	-98	-67
5	80	-99	-69	-97	-70	-98	-68	-98	-68
6	100	-98	-69	-96	-67	-98	-67	-97	-67
7	120	-103	-73	-100	-70	-102	-71	-102	-71
8	140	-114	-72	-112	-69	-113	-68	-113	-68
9	160	-119	-72	-118	-73	-120	-72	-120	-72
10	180	-121	-70	-118	-73	-120	-69	-120	-69
11	200	-119	-69	-117	-75	-120	-69	-119	-69
12	220	-122	-73	-114	-74	-121	-73	-121	-73
13	240	-122	-79	-116	-80	-120	-79	-118	-79
14	260	-120	-80	-120	-82	-120	-79	-120	-82
15	280	-118	-80	-118	-82	-118	-80	-118	-80
16	300	-117	-81	-116	-83	-118	-79	-117	-81
17	320	-116	-81	-114	-82	-117	-81	-116	-81
18	340	-120	-82	-119	-82	-120	-81	-120	-82
19	360	-121	-79	-120	-80	-121	-79	-121	-79
20	380	-120	-74	-121	-75	-120	-74	-120	-74
21	400	-115	-74	-118	-74	-118	-74	-115	-74
22	420	-119	-75	-120	-75	-119	-75	-119	-75
23	440	-118	-76	-113	-76	-118	-75	-115	-76
24	460	-120	-73	-110	-74	-117	-73	-117	-73
25	480	-115	-70	-102	-69	-115	-65	-113	-65
26	500	-111	-67	-100	-68	-110	-66	-110	-66
27	520	-106	-66	-106	-61	-110	-60	-106	-60
28	540	-108	-65	-105	-59	-105	-65	-105	-65
29	560	-102	-69	-100	-60	-100	-68	-100	-68
30	580	-93	-67	-93	-61	-95	-61	-93	-61
31	600	-96	-65	-88	-63	-88	-63	-88	-63
32	620	-94	-65	-90	-62	-89	-62	-90	-62
33	640	-92	-70	-85	-65	-85	-65	-85	-65
34	660	0	0	0	0	0	0	0	0

Table2. *Velocity Measurement for July, 2015*

S/N	Distance, d (m)	Time, t_1 (s) Section 1	Velocity, $V_1 = d/t_1$ (m/s)	Time, t_2 (s) section 2	Velocity, $V_2 = d/t_2$ (m/s)
1	8	22.56	0.355	11.89	0.673
2	8	22.43	0.357	12.02	0.666
3	8	21.98	0.364	12.23	0.654
4	8	22.65	0.353	11.98	0.668
5	8	22.34	0.358	11.88	0.673
6	8	21.93	0.365	12.12	0.660
7	8	21.89	0.365	12.23	0.654
8	8	22.57	0.354	12.19	0.656
9	8	22.76	0.351	12.32	0.649
10	8	22.89	0.349	12.02	0.666
Average Velocity			0.357		0.662

Table3. *Velocity Measurement for August, 2015*

S/N	Distance, d (m)	Time, t_1 (s) Section 1	Velocity, $V_1 = d/t_1$ (m/s)	Time, t_2 (s) section 2	Velocity, $V_2 = d/t_2$ (m/s)
1	8	24.01	0.333	14.23	0.562
2	8	24.89	0.321	13.96	0.572
3	8	24.34	0.329	13.98	0.572
4	8	23.87	0.335	13.69	0.584
5	8	23.98	0.334	14.21	0.563
6	8	23.77	0.337	13.93	0.574
7	8	24.15	0.331	13.85	0.578
8	8	23.92	0.334	14.22	0.563
9	8	24.34	0.329	14.32	0.559
10	8	24.18	0.331	14.01	0.571
Average Velocity			0.331		0.570

Table4. *Velocity Measurement for September, 2015*

S/N	Distance, d (m)	Time, t_1 (s) Section 1	Velocity, $V_1 = d/t_1$ (m/s)	Time, t_2 (s) section 2	Velocity, $V_2 = d/t_2$ (m/s)
1	8	22.87	0.350	12.65	0.632
2	8	22.96	0.351	12.54	0.638
3	8	22.78	0.351	12.98	0.616
4	8	22.65	0.353	12.69	0.630
5	8	22.49	0.356	12.88	0.621
6	8	23.01	0.348	12.65	0.632
7	8	22.88	0.350	12.58	0.636
8	8	22.69	0.353	12.66	0.632
9	8	22.75	0.352	12.64	0.633
10	8	22.67	0.353	12.91	0.620
Average Velocity			0.352		0.629

Table5. *Velocity Measurement for October, 2015*

S/N	Distance, d (m)	Time, t_1 (s) Section 1	Velocity, $V_1 = d/t_1$ (m/s)	Time, t_2 (s) section 2	Velocity, $V_2 = d/t_2$ (m/s)
1	8	23.04	0.347	13.34	0.600
2	8	22.89	0.349	13.65	0.586
3	8	23.23	0.344	13.37	0.598
4	8	23.25	0.344	12.45	0.643
5	8	22.96	0.348	13.89	0.576
6	8	23.63	0.339	13.75	0.582
7	8	23.98	0.334	12.75	0.627
8	8	23.01	0.348	13.04	0.613
9	8	22.78	0.351	13.28	0.602
10	8	22.73	0.352	13.65	0.586
Average Velocity			0.346		0.601

The values of the depth measurements were used to plot the river profile as presented in Figures 6 to 11 and from these, the segment method was used to calculate the cross-sectional area of the river at the various sections.

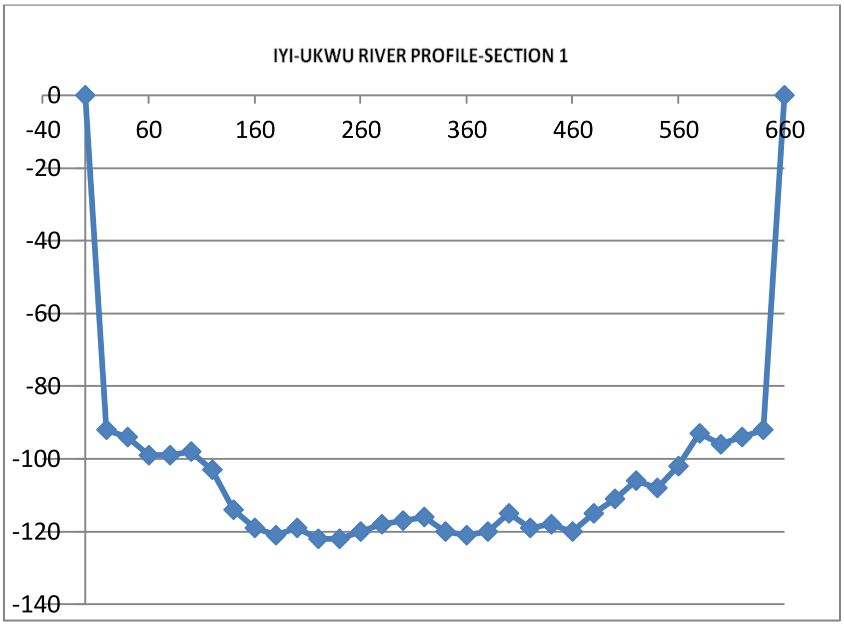

Figure6. *River Profile for July – Section 1*

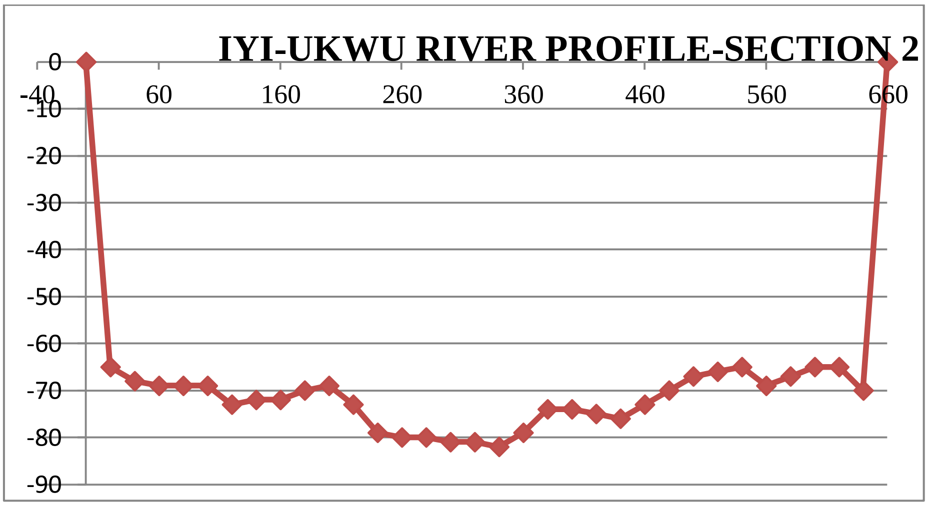

Figure7. *River Profile for July – Section 2*

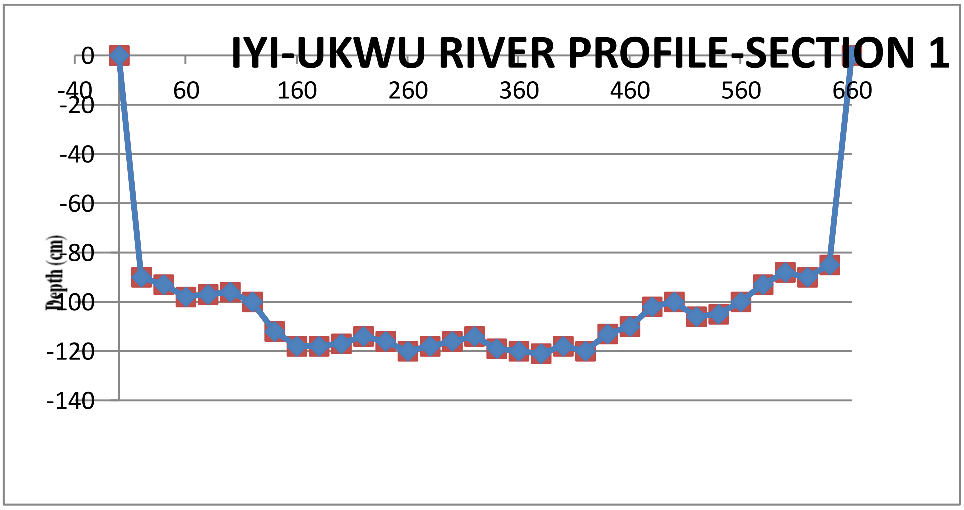

Figure8. *River Profile for August – Section 1*

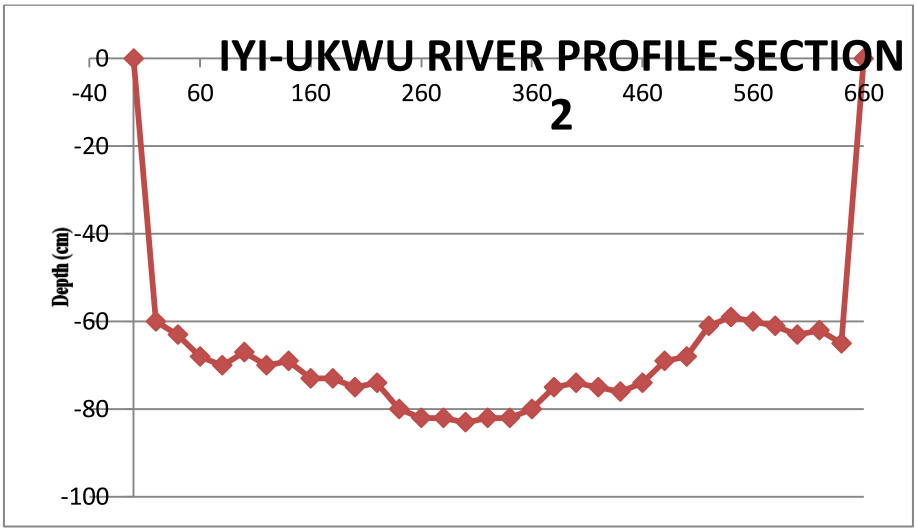

Figure9. *River Profile for August – Section 2*

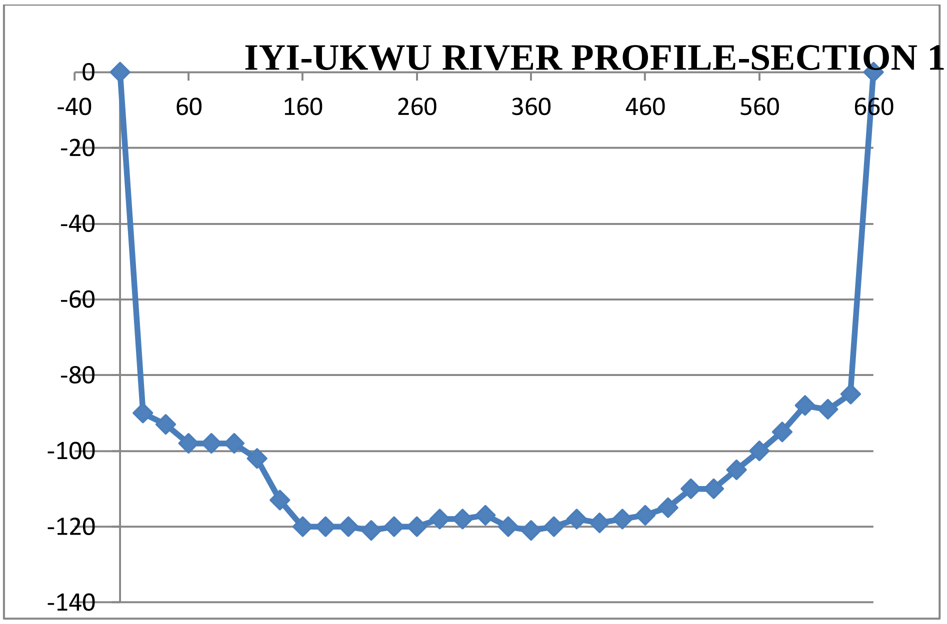

Figure10. *River Profile for September – Section 1*

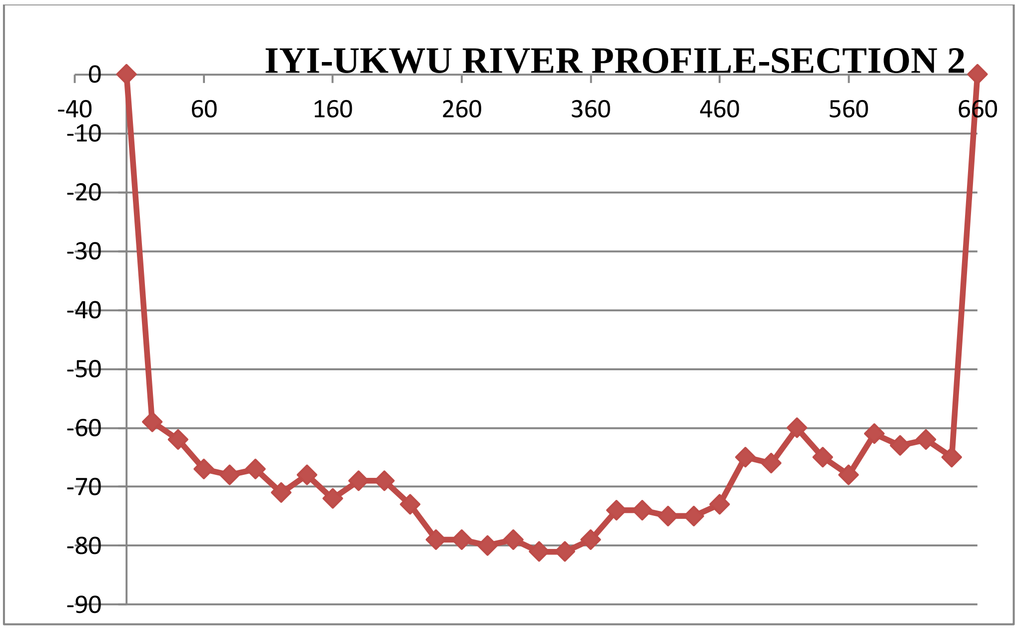

Figure11. *River Profile for September – Section 2*

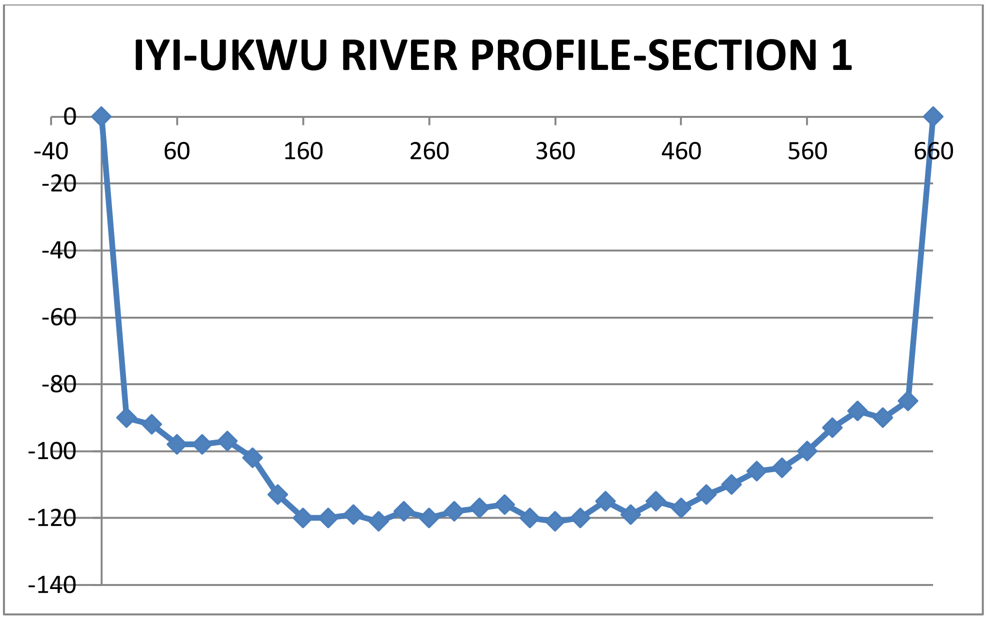

Figure12. *River Profile for October – Section 1*

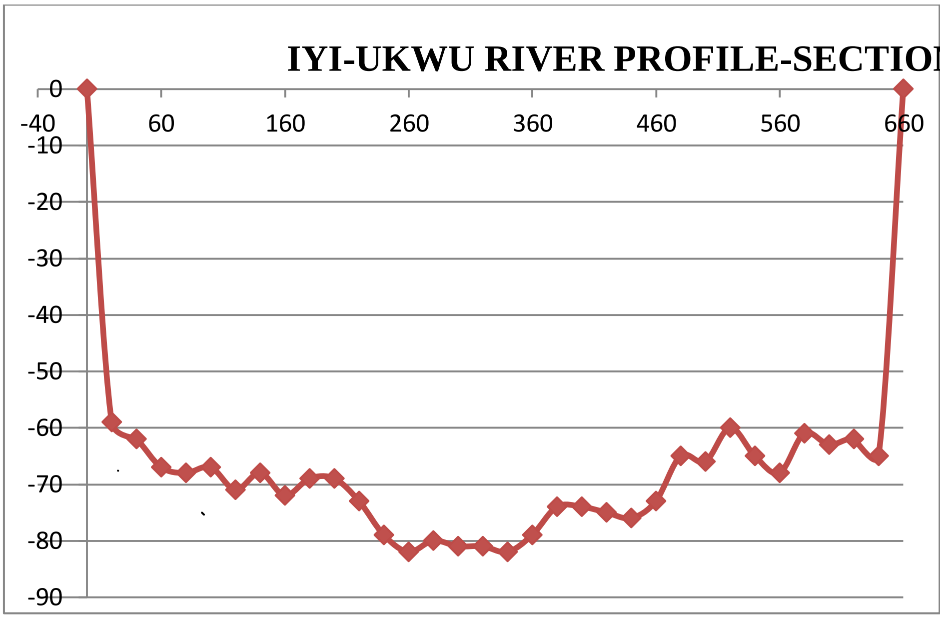

Figure13. *River Profile for October – Section 2*

For the area calculation for Figure 6, the area between 0 and 60 cm width can be assumed a trapezium and similar assumptions are made throughout the width for ease of calculation. Hence, Area (0-60cm) = ½ base (depth1 + depth2) = ½ x 60(92+99) = 5730

Area (60-100) = Rectangle = Base x depth = 99 x 40 = 3960

Area (100-160) = ½ x60(98+119) = 6510

Area (160-260) = 100 x 120 = 12000

Area (260-320) = ½ x 60(120+116) = 7080

Area (320-400) = 116 x 80 = 9280

Area (400-460) = ½ x 60(115+120) = 7050

Area (460-520) = ½ x 60(120+106) = 6780

Area (520-580) = ½ x 60(106+93) = 5970

Area (580-660) = 93 x 80 = 7440

The total cross-sectional area for this section 1 of the river is 71,780 cm2 = 7.178 m2. Similar calculations were made for the other sections in all the months under review and the results along with velocity measurements are presented in Table 6.

Table6. *Summary of Area – Velocity Calculations*

Month	Section 1		Section 2	
	Area, m^2	Velocity, m/s	Area, m^2	Velocity, m/s
July, 2015	7.178 m^2	0.357	4.768 m^2	0.662
August, 2015	7.027 m^2	0.331	4.727 m^2	0.570
September, 2015	6.962 m^2	0.352	4.613 m^2	0.629
October, 2015	7.097 m^2	0.346	4.638 m^2	0.601
Average Area monthly	7.066 m^2	0.347	4.687 m^2	0.616

The volumetric flow rate of River Iyi –Ukwu was estimated using equation 2 at the two sections along the river path. Hence, for section 1,

Volumetric flow rate, Q_1 = V x A = 0.347 x 7.066 = 2.452 m^3/s, while for section 2,

Volumetric flow rate, Q_2 = V x A = 0.616 x 4.687 = 2.887 m^3/s.

As can be seen from Figures 6 to 11, the river profile for section 2 plotted show a higher level of siltation compared to that of section 1. This is due to the fact that section 2 is closer to a culvert constructed across the river path leading to reduced depth as one approaches the culvert. This resulted in a reduced cross-sectional area which in turn increased the flow rate in that section. Due to the irregularity in the river cross-section, an average value for discharge was obtained from the two sections and the higher value for section 2 was used to estimate the power output from the river.

3.1. Result of Head Measurement

From the Topographic Map in Figure 5, the elevation at the source is 400ft and at destination (test point) the elevation is 150ft. The difference in elevation (approximate head from source to destination) is 250ft (76.2 m). So the approximate head for the river that was used to estimate the power output is 76.2 m. This gross head is different from net head which is defined as gross head minus all pipe losses due to friction and turbulence and such net head is used to calculate the available power capacity of the water resource [11]. Since much is involved in determining the losses, the gross head was used to give a rough idea of the power output from the river while further work will be carried out to determine the length of penstock and its characteristics which will be used in estimating the losses.

3.2. Estimation of Theoretical Power

Concisely, gross hydropower potential (GHP) of the River Iyi-Ukwu is proportional to the product of gross head and volumetric flow rate and is given by equation 3 [12].

$$P = \eta \rho g Q H \qquad 3$$

Where P is Power in Watts, η is overall efficiency in %, ρ is the density of water (1000kg/m3), g is the acceleration due to gravity (9.81 m/s2), Q is the volumetric flow rate, m3/s, and H is the head in meters.

Hence, assuming efficiency of 0.85,

P = 0.85 x 1000 x 9.81 x 2.887 x 76.2 = 1,834,382 W = 1.834 MW.

This amount of power can go a long way in solving part of the power need of the host communities.

4. Conclusion

In this study, River Iyi-Ukwu in Oshimili North Local Government Area of Delta State Nigeria was investigated for possible small hydropower development. The results obtained at various sections of the river showed that the river has an approximate gross head of 76.2 m and a discharge of 2.887 m3/s which places the potential power capacity of the river to be 1.834 MW of electricity. It thus showed that the River could be a feasible site for small hydropower development having satisfied the head and discharge requirement. Future work will address the length of penstock and its characteristics so as to account for inherent hydraulic losses in the system which will eventually help in determining accurate head of the River. Also, other accurate means of measuring discharge will be investigated.

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