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RURAL ELECTRIC POWER DEVELOPMENT: FEASIBILITY OF UGWOLAWO MICRO HYDRO ELECTRIC SYSTEM

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Abstract

Micro hydro power represents a viable technological pathway for converting the kinetic and potential energy of flowing water into electrical energy through generator systems. This paper investigates the feasibility of a stand alone micro hydro electric power generation system as an enabling technology for rural electrification at the Ofu stream segment in Ugwolawo, Kogi State, Nigeria. Head elevation was determined using a Garmin GPSmap 76 S Global Positioning System receiver. The float method of stream discharge measurement was adopted and field measurements were conducted over three consecutive years. RETScreen software was applied to assess the feasibility of small scale hydropower renewable energy potential and to conduct Greenhouse Gas (GHG) emission reduction analysis for the site. An Environmental Impact Assessment (EIA) of the studied site was carried out for the anticipated construction and operating phases. The results indicate that the gross hydraulic head elevation and design flow are 4.60 m and 0.793 m^3/s respectively. A total power capacity of 14 kW, firm power of 12 kW, annual energy capture of 224.8 MWh, and GHG emission reduction equivalent to 183 tonnes of carbon dioxide (tCO_2) were estimated. The EIA results yielded negligible impact on the locality. The Ugwolawo site demonstrates strong potential for implementation as a cost effective renewable electric power source for rural settlements.

Keywords: *Micro Hydropower; Renewable Energy; Head Elevation; Flow Discharge; Greenhouse Gas Reduction; Environmental Impact Assessment*

1. Introduction

Hydroelectric power generation depends upon incoming radiant solar energy for the continuous movement of water throughout the hydrological cycle. Approximately one third of the solar radiation reaching the Earth is responsible for driving the hydrologic cycle, which sustains rivers, streams, and precipitation patterns across the globe (Quaranta, 2024). The Global Hydrological Cycle, which illustrates how water circulates through evaporation, condensation, precipitation, and runoff, is depicted in Figure 1.

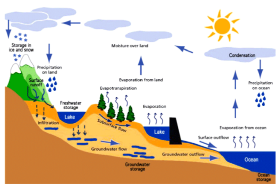

Figure 1: Global Hydrological Cycle illustrating the continuous movement of water through evaporation, condensation, and precipitation processes

Global access to electric energy remains far from reality in many parts of the developing world, particularly in rural areas characterised by sparse population distributions in countries such as Nigeria. According to Peters and Berlekamp (2024), half of the African population currently lacks the minimum level of electricity access as defined by the International Energy Agency. Millions of Nigerians lack access to electricity, and to meet the electricity demands of isolated settlements, the only viable alternative at present is decentralised electricity generation employing renewable energy resources such as hydro, solar, geothermal, wind, and tidal power. Among all renewable energy sources, hydropower has remained the principal renewable resource and occupies the first position globally, contributing approximately 82 percent of total renewable electricity (Peters and Berlekamp, 2024; Patwary et al., 2024).

The water resource base in Nigeria is substantial, as the country possesses numerous streams and rivers distributed across its diverse geographical landscape. Annual rainfall decreases from approximately 3,400 mm depth in the south central shores of the Niger Delta to 500 mm over the northern boundaries of the country, with a localised increase to 1,400 mm over the central Jos Plateau region (Manohar and Adeyanyi, 2009). This abundant water resource presents significant opportunities for small scale hydropower development in rural communities that remain unserved by the national electricity grid.

The Ofu stream runs past Ugwolawo Community in Kogi State and serves as the major source of water supply to the sprawling town. The stream provides a perennial water resource that can potentially be harnessed for electricity generation. Photographs of the Ofu stream segment and Ugwolawo town are presented in Figures 2 and 3 respectively.

Figure 2: Ofu stream segment at Ugwolawo showing the natural channel characteristics of the study site

Figure 3: Panoramic view of Ugwolawo town, the target community for rural electrification

In this study, the Ofu stream segment at Ugwolawo was assessed for the possible development of a micro hydro electric power system. A comparable study by Ochagwuba et al. (2015) led to the design and implementation of a pico hydroelectricity scheme in a remote village. Furthermore, recent advances in small scale hydropower technology have demonstrated the economic viability of such systems in developing nations (Bolarinwa et al., 2023; Bader et al., 2024). The aim of this study is to ascertain the available hydro resource potential at the Ofu stream segment in Ugwolawo towards the realisation of reliable electricity supply for a rural settlement. Specifically, the study objectives include: determining the head elevation and discharge characteristics of the site, evaluating the power generation potential using RETScreen software modelling, assessing the greenhouse gas reduction benefits, and conducting an environmental impact assessment of the proposed development.

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2. Materials and Methods

2.1 Head Measurement

The hydro meteorological data for the studied site was provided by the Nigerian Meteorological Agency (NIMET), Lokoja. In hydropower developments, the two most critical parameters of any site under consideration include the head elevation (*h*) of the stream segment and the flow or discharge rate (*Q*). The Garmin GPSmap 76 S Global Positioning System was employed to determine the head elevation of the stream. The GPS receiver provided accurate elevation readings at multiple points along the stream channel, enabling precise determination of the available hydraulic head. Multiple readings were taken and averaged to minimise measurement uncertainty (Manohar and Adeyanyi, 2009).

2.2 Flow Measurement

Flow or discharge measurements can be carried out using several established methods including the float technique, current meter approaches, salt dilution procedures, and electromagnetic methods. The float method was applied in this study for reasons of its simplicity and the smooth stream bed characteristics of the site. This method involves measuring the cross sectional area of the stream, placing a floating object at the upstream position, allowing it to travel downstream while recording the transit time, and subsequently determining the flow rate after applying a correction factor of 0.75 for smooth stream bed conditions. Field measurements were conducted over three consecutive years to establish reliable flow statistics and capture seasonal variability patterns (ZhiWen and HanYi, 2023).

2.3 Modelling of Hydropower Potential

At any given site, the hydropower potential (*P*) under steady state operation is modelled by the fundamental hydropower equation:

$$P = \rho \times \eta \times Q \times g \times h \; ...(1)$$

where ρ represents the density of water (kg/m^3), η denotes the overall efficiency coefficient of the turbine generator system, Q is the volumetric flow rate (m^3/s), g is the gravitational acceleration (9.81 m/s^2), and h is the net hydraulic head (m). This relationship forms the basis for all subsequent power calculations in the study (Bolarinwa et al., 2023).

2.4 Selection of Turbine

To select the appropriate turbine type while considering the specific site characteristics, the widely accepted application domain chart for turbines was consulted. The turbine selection chart, which maps the relationship between head elevation and discharge values to appropriate turbine types, is presented in Figure 4. Based on the measured parameters of the Ofu stream segment, this chart guided the selection of a suitable turbine configuration for the site (Quaranta, 2024).

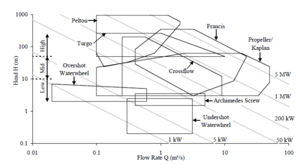

Figure 4: Turbine selection chart based on head and discharge parameters (Source: European Small Hydropower Association, 2023)

2.5 Software Application

The RETScreen Clean Energy Project Analysis Software is a comprehensive clean energy awareness, decision support, and capacity building tool developed by CanmetENERGY under Natural Resources Canada in collaboration with the National Aeronautics and Space Administration (NASA), the Renewable Energy and Energy Efficiency Partnership (REEEP), the United Nations Environmental Programme (UNEP), and the Global Environment Facility (GEF) (RETScreen International, 2025). This software is used worldwide to assess energy production, cost savings, emission reduction, financial viability, risk, and sensitivity analysis for various types of Renewable Energy and Energy Efficient Technologies (RETs). In this study, energy production analysis and Greenhouse Gas reduction assessment were applied to the Ofu stream segment data. The analysis process involved inputting stream data for head elevation and average discharge rate into the cells of

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the RETScreen Energy Model and the Greenhouse Gas reduction analysis worksheets.

2.6 Environmental Impact Assessment

The Environmental Impact Assessment (EIA) is an essential tool used for decision making in developmental projects. It constitutes a systematic process designed to identify, predict, and evaluate the environmental effects of proposed actions and projects. This process is applied prior to major decisions and commitments being made (Ibrahim et al., 2020). EIA check sheets and checklists were used to evaluate potential environmental effects, screen project components, and determine appropriate mitigation measures for both the construction and operational phases of the proposed micro hydro scheme.

3. Results and Discussion

3.1 Head Elevation and Turbine Selection

The stream head elevation measured with the GPS instrument yielded a value of 4.60 m. This measurement indicates that the Ofu site falls within the low head category of hydropower classification. According to the turbine selection chart presented in Figure 4, a propeller turbine represents the most suitable candidate for application at this site. Low head sites such as this one are particularly well suited to propeller and Kaplan type turbines, which operate efficiently under conditions of high flow and low head (Quaranta, 2024). The selection of a propeller turbine aligns with established engineering practice for micro hydropower installations at comparable head values reported in the literature (Bolarinwa et al., 2023).

3.2 Flow Measurement Results

The results of the monthly flow measurements and the average discharge values obtained at the Ofu site over the three year monitoring period are presented in Table 1. The measured discharge values demonstrate a clear seasonal pattern, with peak flows occurring during the wet season months of September and October, and minimum flows observed during the dry season months of February and March.

Table 1: Monthly average flow measurements for Ofu stream

Month	Ave. Discharge (m^3/s)
June	0.899
July	0.913
August	0.975
September	0.985
October	0.961
November	0.910
December	0.822
January	0.692
February	0.692
March	0.781
April	0.781
May	0.860

Source: Field measurements (2012 to 2014)

The data presented in Table 1 reveals that the discharge values ranged from a minimum of 0.692 m^3/s during February and March to a maximum of 0.985 m^3/s in September. The mean annual discharge was calculated as 0.855 m^3/s. This seasonal variation is consistent with the rainfall patterns typical of the Guinea Savannah climate zone in which Ugwolawo is located (Manohar and Adeyanyi, 2009). The relatively narrow range of discharge values across all months indicates that the Ofu stream maintains adequate flow throughout the year, which is a favourable characteristic for micro hydropower development.

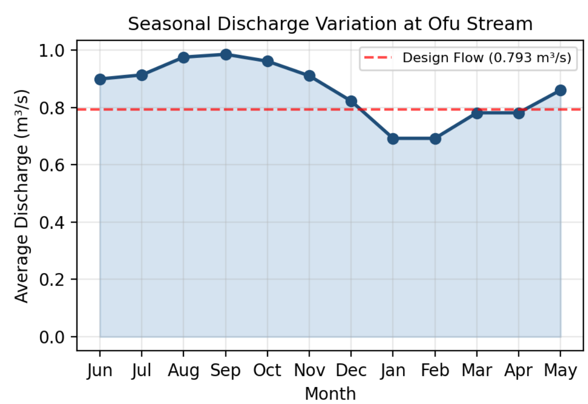

Figure 5: Seasonal variation of discharge at Ofu stream showing the perennial flow characteristics and design flow threshold

3.3 Hydrograph and Flow Duration Curve Analysis

The Ofu stream hydrograph and Flow Duration Curve (FDC) are presented in Figures 6 and 7 respectively. The

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hydrograph confirms that the Ofu stream exhibits a perennial flow regime, meaning that the stream maintains continuous flow throughout all seasons of the year. This characteristic is of paramount importance for micro hydro installations, as it ensures year round power generation capability.

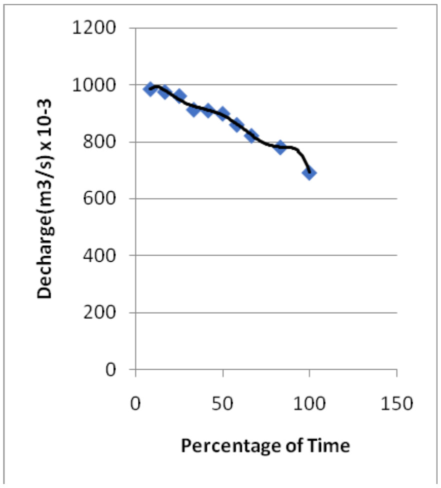

Figure 6: Ofu stream hydrograph demonstrating the perennial flow characteristics of the site

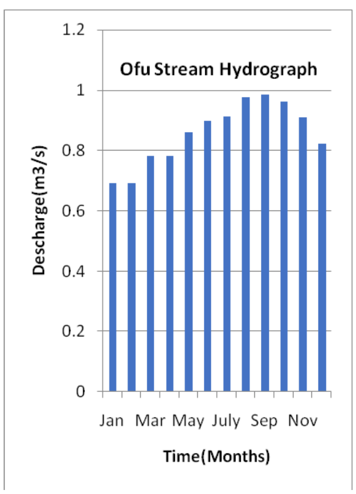

Figure 7: Flow Duration Curve for Ofu stream indicating the probability distribution of discharge values

The steep gradient observed in the Flow Duration Curve (Figure 7) is a significant finding, as it indicates that power generation will be available throughout the year. The FDC shape suggests that the stream maintains relatively stable flow conditions, with the difference between peak and minimum flows remaining within a manageable range. This observation is consistent with findings reported by Peters and Berlekamp (2024) for similar perennial streams in the West African sub region.

The design flow of 0.793 m^3/s was selected based on the FDC analysis, representing the flow that is exceeded approximately 70 percent of the time, which is a standard design criterion for run of river micro hydropower schemes (Quaranta, 2024).

3.4 RETScreen Energy Model Results

The RETScreen Energy Model worksheet output for the Ofu stream at Ugwolawo is presented in Figure 8. The firm flow obtained from the first section of the RETScreen energy model is 0.72 m^3/s. Two standard propeller turbines manufactured by American Hydro Corporation are proposed for application at the Ofu site. Both the turbine peak efficiency and the turbine efficiency at design flow yielded identical values of 82.0 percent. The flow at peak efficiency produced a result of 0.8 m^3/s.

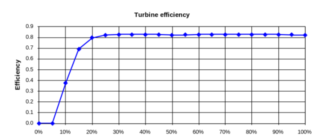

Figure 8: Turbine efficiency curves (efficiency versus percent of rated flow) for the selected propeller turbine at the Ofu stream site

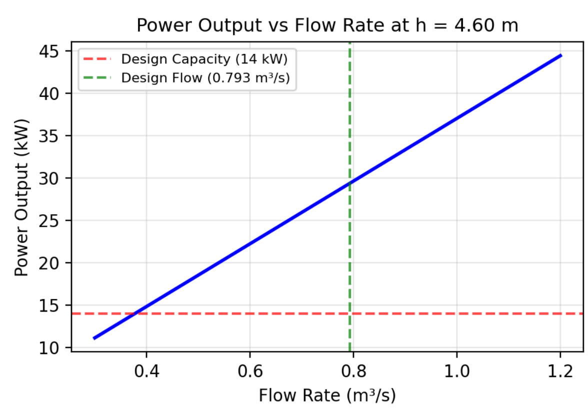

Figure 9: Relationship between power output and flow rate at the measured head elevation of 4.60 m, showing the design capacity of 14 kW at the design flow of 0.793 m^3/s

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The summary of key findings from the RETScreen energy model analysis reveals that the power capacity of the Ofu stream site is 14 kW with a firm power output of 12 kW. These values place the Ofu stream segment at Ugwolawo firmly within the micro hydroelectricity category, which is typically defined as systems generating between 5 kW and 100 kW of electrical power (Quaranta, 2024). This classification indicates that the site, when implemented, can provide the minimal power requirements of the local inhabitants for domestic use, including lighting, refrigeration, and small appliance operation. The capacity factor of 98 percent and the electricity delivered to load of 224.8 MWh annually represent excellent performance metrics for a micro hydropower installation of this scale (Bader et al., 2024).

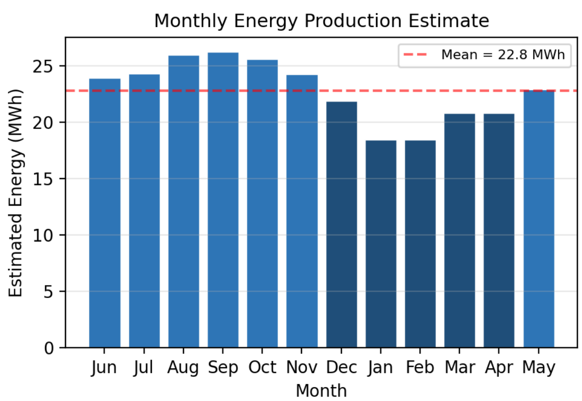

Figure 10: Estimated monthly energy production at the Ofu stream site showing seasonal variations corresponding to discharge patterns

Figure 9 illustrates the relationship between power output and flow rate at the measured head of 4.60 m, while Figure 10 presents the estimated monthly energy production. The monthly energy estimates exhibit a pattern that closely mirrors the seasonal discharge variations, with the highest energy production occurring during the wet season months when stream discharge is at its peak. These results align with similar findings reported by Bolarinwa et al. (2023) in their analysis of prototype hydropower plant development in Nigeria, where seasonal flow variations were found to be the primary determinant of monthly energy output in run of river schemes.

3.5 Greenhouse Gas Emission Reduction Analysis

From the emission reduction analysis worksheet of the Ofu site, the net annual GHG emission reduction was determined to be 183 tonnes of carbon dioxide (tCO_2). This finding is of considerable significance, as it demonstrates that the implementation of the Ofu site micro hydro scheme would prevent the emission of 183 tonnes of CO_2 to the atmosphere annually, in contrast to the use of an equivalent diesel fuel fired generation plant. This environmental benefit represents a substantial contribution to climate change mitigation efforts at the local level.

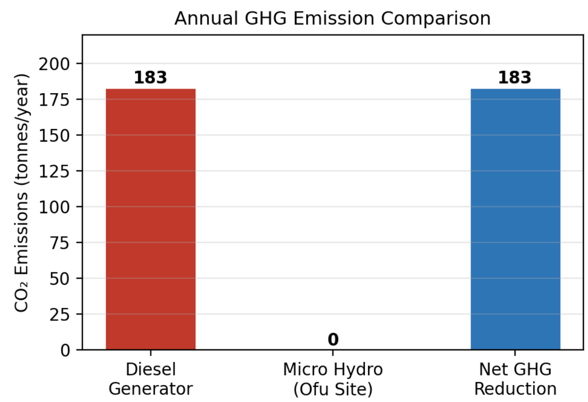

Figure 11: Annual greenhouse gas emission comparison between diesel generation and the proposed micro hydro system at Ofu stream, Ugwolawo

The GHG reduction potential illustrated in Figure 11 underscores the environmental advantages of micro hydropower over conventional diesel generation. In the context of global climate commitments, these emission reductions could be monetised through carbon credit mechanisms under the Clean Development Mechanism (CDM) framework of the United Nations Framework Convention on Climate Change (Patwary et al., 2024). The avoided emissions of 183 tCO_2 per year, when projected over a typical 25 year project lifetime, would amount to a cumulative avoidance of approximately 4,575 tonnes of carbon dioxide. Such reductions are especially meaningful in the Nigerian context, where rural communities often rely on polluting diesel generators for their limited electricity supply (Peters and Berlekamp, 2024).

3.6 Environmental Impact Assessment Results

Based on the outcomes of the environmental screening sheets and the Impact Mitigation Matrix for both the anticipated construction and operation phases of the Ofu site, the results of the EIA are summarised in Table 2 and Figure 12. The assessment covered six major environmental categories and found that the proposed

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micro hydro development would have minimal adverse effects on the local environment and community (Ibrahim et al., 2020).

Table 2: Summary of Environmental Impact Assessment results for Ofu site

Environmental Category	Impact Level
Stream flow regime	Zero
Water quality	Negligible
Farming and local inhabitants	Zero
Forest wildlife and arable land	Negligible
Noise and air pollution	Zero
Marine life and aquatic algae	Zero

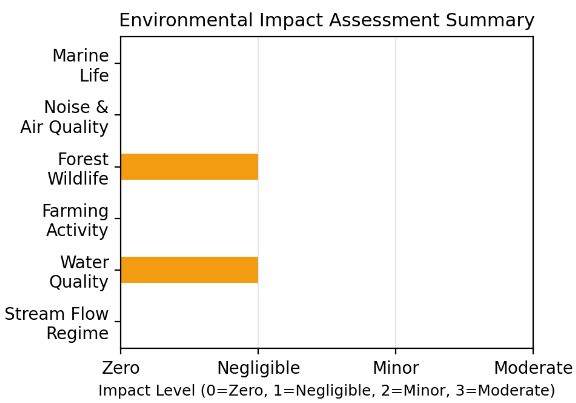

Figure 12: Environmental Impact Assessment summary showing the impact levels across six environmental categories for the proposed Ofu stream micro hydro development

The EIA results demonstrate that the proposed micro hydro development at Ofu stream would have minimal environmental consequences. Four of the six environmental categories assessed yielded zero impact ratings, while the remaining two categories (water quality and forest wildlife) were rated as negligible. These findings are consistent with the generally low environmental footprint associated with run of river micro hydropower schemes, which do not require the construction of large dams or reservoirs (Ibrahim et al., 2020). The absence of significant environmental impacts makes this site particularly attractive for development, as it would not require extensive mitigation measures or lengthy regulatory approval processes.

3.7 Economic Viability Considerations

The economic viability of the studied site is supported by several compelling factors. First, micro hydro systems avoid the damaging environmental and social effects that larger hydroelectric schemes typically cause, thereby eliminating the costs associated with environmental remediation and community resettlement. Second, beyond providing power for domestic lighting and cooling needs, village hydro schemes can also support productive activities such as battery charging, grain milling, and internet connectivity, depending on community requirements (Bader et al., 2024). Third, several catchments were identified upstream of the study site that could serve as supplementary sources of inflow, potentially enhancing the reliability and output of the system during periods of reduced rainfall. The combination of low environmental impact, multiple economic benefits, and reliable water supply makes this site a strong candidate for investment under various funding mechanisms available for rural renewable energy projects in Nigeria (Patwary et al., 2024).

When compared with alternative energy solutions for rural electrification, micro hydro systems offer distinct advantages in terms of longevity, operating costs, and reliability. Unlike solar photovoltaic systems, which require battery storage for continuous supply and face performance degradation over time, micro hydro installations can provide continuous baseload power with minimal maintenance requirements. The capacity factor of 98 percent achieved at the Ofu site is substantially higher than the typical capacity factors of 15 to 25 percent reported for solar installations in similar geographical locations (Peters and Berlekamp, 2024). Furthermore, the levelised cost of energy from micro hydro systems tends to be competitive with or lower than that of diesel generation over the project lifetime, particularly when carbon credit revenues are considered (ZhiWen and HanYi, 2023).

4. Conclusion

This study has investigated the feasibility of implementing a run of river hydropower scheme at the Ofu stream segment in Ugwolawo, Kogi State, Nigeria. The hydrological data and flow measurement parameters of the stream yielded optimum results, with a gross hydraulic head of 4.60 m and a design flow of 0.793 m^3/s. The

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hydrograph and flow duration curve analyses confirmed the perennial nature of the stream, indicating that power generation would be sustained throughout the year. The RETScreen energy model analysis determined a total power capacity of 14 kW and firm power of 12 kW, placing the site within the micro hydroelectricity category with an annual energy capture of 224.8 MWh and a capacity factor of 98 percent.

The greenhouse gas emission reduction analysis revealed that implementation of this site would prevent the annual emission of 183 tonnes of CO_2, which could be traded in the global carbon market through the Clean Development Mechanism of the United Nations. The environmental impact assessment studies conducted at the site yielded negligible to zero impact across all assessed environmental categories, confirming the environmental sustainability of the proposed development.

Based on these findings, the following recommendations are put forward. The Designated National Authority and the Presidential Implementation Committee on Small Hydropower should develop simplified documentation and information dissemination strategies to ensure that local communities and the general public are adequately informed about small hydropower opportunities. Manufacturers of hydroelectric components, including water turbines, nozzles, and penstocks, should be incentivised to establish manufacturing facilities in Nigeria, supported by reduced import duties on essential components. The federal government should ensure that the necessary legal, regulatory, and institutional frameworks are established to attract private sector investment in small hydropower generation. Finally, the United Nations Industrial Development Organisation (UNIDO) Regional Centre for Small Hydropower in Africa, based in Abuja, should consider the Ugwolawo site for priority implementation.

Acknowledgments

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