School of Environmental Technology International Conference Proceedings

ISBN: 978-978-54580-8-4
Received: 29 June 2024; Accepted: 04 October 2024; Available online: 29 November 2024 *Volume 2 proceedings*

Small Hydropower: Nigeria's Untapped Solution to Rural Electrification. A Case Study of River Osun

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Abstract
This study investigates the potential of small hydropower (SHP) as a sustainable solution for rural electrification in Osun State, Nigeria, focusing particularly on river Osun and three rural catchment communities: Aponmu, Awo, and Ileogbo. Using remote sensing and geographic information systems (GIS), the research identified and analyzed potential SHP sites across ten Local Government Areas (LGAs). The study employed a quantitative approach, incorporating descriptive research design and multi-tier analysis techniques to assess current energy access levels. Results revealed 86 viable SHP sites with a cumulative potential of 109.52 MW, with Ayedire LGA showing the highest potential of 37.02 MW. Despite high grid connection rates (Connection Index = 1), the analysis of electricity access revealed concerning patterns of low to moderate access due to poor duration, reliability, and quality indices. The findings indicate that the identified SHP potential could serve between 41,484 to 82,969 households, depending on plant performance capacity. The study utilized Wagner and Mathur's hydropower equation for energy potential calculations and the ESMAP multi-tier framework for energy access assessment. Analysis of current electricity access levels showed an overall moderate access index of 0.58 when considering all four dimensions, but a low access index of 0.44 when excluding connectivity. The research concludes that SHP presents a viable alternative for rural electrification in Osun State, recommending integrated policy frameworks, technical implementation strategies, and community engagement approaches for successful development.

Keywords: Energy Access; Geographic Information System (GIS); Multi-tier Framework; Renewable Energy; Remote Sensing; Rural Electrification; Small Hydropower (SHP); Sustainable Development;

1. Introduction

Nigeria, Africa's most populous nation, continues to grapple with significant electricity access challenges, particularly in rural communities where approximately 60% of the population resides (World Bank, 2023). Recent data indicates that only 55.4% of rural areas have electricity access, compared to 83.9% in urban regions (African Development Bank [AfDB], 2023). Despite the country's abundant water resources and over 278 identified small hydropower sites, with a cumulative potential of about 3,500 MW, only 8.5% of this capacity has been developed as of 2023 (Abdullahi *et al.*, 2022; UNIDO, 2022). The persistent energy deficit has impeded socio-economic development, with rural businesses reporting average losses of 34% in potential revenue due to unreliable power supply (Ohunakin *et al.*, 2023).

Traditional grid extension to remote communities often proves economically unfeasible, with estimated costs of $25,000-$30,000 per kilometer of transmission line (Mohammed *et al.*, 2024). Small hydropower technology presents a viable alternative, offering a decentralized, renewable energy solution that can harness Nigeria's extensive network of rivers and streams, with implementation costs averaging $2,500-$3,000 per kilowatt for systems under 100 kW (Adewuyi *et al.*, 2023). Studies indicate that small hydropower installations have shown a 65% lower environmental impact compared to large hydroelectric projects, with an average project completion time of 18-24 months versus 5-7 years for large-scale dams (Kumar & Sharma, 2023; Oyedepo *et al.*, 2024). With only 8.5% of Nigeria's 3,500 MW small hydropower potential currently harnessed, despite rural businesses losing 34% of potential revenue due to unreliable electricity, there is an urgent need to accelerate SHP deployment. While previous studies have documented the technical feasibility of SHP installations, there remains a significant knowledge gap regarding the comprehensive framework needed to effectively implement and scale these systems within Nigeria's unique socio-economic and geographical context

2. Literature Review

Small hydropower (SHP) presents a viable solution for rural electrification in Nigeria, a country facing significant energy access challenges. The potential of SHP systems is particularly relevant in rural areas where traditional grid extension is often economically unfeasible and technically challenging. The literature indicates that SHP can significantly contribute to alleviating the energy deficit in these regions, thereby enhancing socio-economic development. Edomah *et al*. highlight the role of foreign interventions in Nigeria's renewable energy sector, emphasizing the World Bank and African Development Bank's efforts to improve energy access in rural communities through renewable technologies, including SHP (Edomah *et al*., 2021). This aligns with Chinweoke *et al*.'s findings, which advocate for off-grid power generation via small hydropower plants as a means to provide sustainable energy services to underserved populations in Nigeria (Chinweoke *et al*., 2020). The authors argue that SHP can effectively mitigate the challenges of rural electrification, particularly in isolated areas where grid connections are absent.

Moreover, Odetoye's research supports the economic advantages of small and medium-scale renewable technologies, including SHP, in rural electrification efforts (Odetoye, 2023). The Rural Electrification Agency of Nigeria has identified these technologies as critical for addressing the electricity access gap, particularly in remote communities. Olanrewaju and Olanrewaju further emphasize the socio-economic benefits of electrification, noting that access to reliable electricity can enhance productivity and profitability among rural microenterprises, thereby fostering economic growth (Olanrewaju & Olanrewaju, 2020). The feasibility of SHP systems is also underscored by studies assessing specific sites for potential development. For instance, Fagbohun and Omotoso conducted a viability assessment of the Elemi River in Ekiti State, demonstrating the potential for SHP to provide off-grid electricity and address the persistent power outages affecting local institutions (Fagbohun & Omotoso, 2018). Similarly, Olanrele *et al*. discuss the broader implications of electricity access on education and health in rural communities, highlighting the urgent need for reliable energy sources to support essential services (Olanrele *et al*., 2020).

In addition to SHP, hydrokinetic energy presents another promising avenue for rural electrification. Olatunji *et al*. argue that hydrokinetic systems, due to their simpler design and lower costs, could be more economically viable than traditional small hydropower systems in Nigeria (Olatunji *et al*., 2018). This suggests a diversified approach to harnessing water resources for energy generation, which could complement SHP initiatives. Despite the promising prospects of SHP and hydrokinetic energy, challenges remain in the implementation of these technologies. The literature indicates that the lack of a coherent electrification strategy and investment in infrastructure continues to hinder progress. For instance, Akpojedje and Mormah discuss the systemic issues within Nigeria's electricity transmission framework that complicate rural electrification efforts (Akpojedje & Mormah, 2019). Addressing these challenges requires a multi-faceted approach, incorporating policy reforms, investment in technology, and community engagement to ensure sustainable energy access. In conclusion, small hydropower represents a critical component of Nigeria's strategy for rural electrification. The existing literature underscores its potential to provide sustainable energy solutions, enhance economic development, and improve quality of life in rural communities. However, for SHP to realize its full potential, concerted efforts are necessary to overcome infrastructural and policy-related challenges..

3. Methodology

The study adopts the descriptive research design approach with the use of remote sensing and geographic information system as requisite tool for data collection and analysis. The study focused on river Osun and three rural catchment communities of river Osun, namely; Aponmu, Awo, and Ileogbo. The study had a population of 42,320 households, However, due to the homogeneous nature of the communities, a total of 98 households were sampled across the communities. Remote sensing and GIS data was collected and analysed using ArcGIS and Global Mapper platform to identify suitable and viable Small hydropower potential Sites (Table 1). The flowchart for the The current level of energy access in the communities were estimated using the multi-tier technique developed by ESMAP (2014). Wagner and Mathur, (2011) hydropower equation was adopted to determine energy potentials of the site.

$$Pp = r * g * n_t * n_g * c *. Q * (H_{p.up} - H_p) \quad (1)$$

The estimated number of households that can be served by the potential energy identified across river Osun was estimated at a minimum of 500kWh/per annum as proposed by International Energy Agency (IEA, 2015) for urban households with a household size of 5. The result was presented in Tables and Charts.

Table 1: Remote Sensing Data Collected

S/N	Dataset	Type	Source	Data
1	Digital Elevation Map (DEM-SRTM)	Raster	CGIAR-CSI SRTM 90m Database	Elevation, Gradient, and watershed
2	Global River Network (Hydroshed)	Vector (polyline)	Hydroshed	Natural river network
3	Global Streamflow Characteristics Dataset (GSCD)	Raster	Hydroshed	Natural river flow direction
4	Topographical Map	Raster-Vector	Openstreet Map	River profile/Slope

4. Results and Discussion

4.1 Distribution of small hydropower potentials in Osun State

Table 2 shows that Eight-six (86) small hydropower potentials sites were identified in the river basin within Osun State Boundary. The potential sites were distributed across ten (10) LGAs of Osun State. The minimum small hydropower potential sites in Osun State are in Ejigbo LGA with 0.111mw, while the maximum is in Isokan LGA with 6.459mw. Similarly, Ayedire LGA had the highest total of 37.02mw of small hydropower potential Osun State, followed by Isokan (20.312), and Egbedore (15.096). However, Atakumosa, Ejigbo, and Ola-Oluwa LGAs had the least total small hydropower potential in the State with 1.191mw, 1.358mw, and 1.648mw respectively. The average small hydropower potential available within Osun State region of the river basin is about 1.1598mw. Overall, the findings from Table 2 suggest that there is significant small hydropower potential in Osun State, particularly in LGAs like Ayedire and Isokan. These findings align with the broader literature on hydropower development and its potential benefits for rural electrification and sustainable energy generation.

Table 2: Spatial Distribution Pattern of Small Hydropower Potential in Osun State

No	LGA	Count	Min (mw)	Max (mw)	Sum (mw)	Mean (mw)
1	Ayedaade	4	0.602	1.476	3.499	0.87
2	Ayedire	27	0.272	3.278	37.02	1.371
3	Egbedore	10	0.462	2.949	15.096	1.51
4	Ejigbo	4	0.111	0.877	1.358	0.4
5	Irewole	5	0.57	3.455	9.989	1.998
6	Isokan	6	1.359	6.459	20.312	3.38
7	Atakumosa East	2	0.509	0.682	1.191	0.087
8	Ife South	13	0.167	3.509	13.843	1.064
9	Iwo	11	0.135	1.607	5.563	0.506
10	Ola-Oluwa	4	0.184	0.736	1.648	0.412
	Aggregate	**86**	**0.111**	**6.459**	**109.52**	**1.1598**

4.2 Current Level of electricity access in Osun State LGAs

Table 3 presents a comprehensive evaluation of the level of electricity access in various Local Government Areas (LGAs) within Osun State. The Connection Index (C.I) serves as an indicator of the extent to which households are connected to the electricity grid. In all three LGAs, Apomu, Awo, and Ileogbo. The C.I is uniformly rated at 1, suggesting a complete connection to the grid in these areas. Across the assessed LGAs, the D.I is consistently recorded at 0.4, indicating a moderate duration of electricity availability. Notably, Awo and Ileogbo both exhibit an R.I of 0.4, denoting a moderate level of reliability, while Awo records a slightly lower R.I of 0.3. The Quality Index (Q.I) range from 0.45 to 0.68, with Awo registering the highest Q.I, indicating a comparatively better quality of electricity supply in this LGA. Considering the four indicators of access, the communities in Osun state had a moderate level of access with an index of 0.58. However, excluding connectivity provides a nuanced view of the level of electricity access, which shows that energy access level in the communities is low with an index of 0.44. All the LGAs were low in access to electricity with Ileogbo recording the least electricity access index of 0.42, Apomu 0.43, and Awo 0.49.

Table 3: Level of Electricity Access in Osun State LGAs

Level	C.I	D.I	R.I	Q.I	4D Access	3D Access	Remark
Apomu	1	0.4	0.3	0.58	0.57	0.43	**L.A**
Awo	1	0.4	0.4	0.68	0.62	0.49	**L.A**
Ileogbo	1	0.4	0.4	0.45	0.56	0.42	**L.A**
Mean	**1**	**0.40**	**0.37**	**0.57**	**0.58**	**0.44**	**L.A**
Remark	**A**	**L.A**	**L.A**	**M.A**	**M.A**		

Note: C.I= Connection Index; D.I= Duration Index; R.I=Reliability Index & Q.I.=Quality Index
0.00-0.29= No Access; 0.30-0.49= Low Access; 0.50-0.70= Moderate Access & 0.71-1.00= Access

4.3 Estimated Potential Energy Available to Households

Table 4, presents the estimated household population to be served by small hydropower potential in various Local Government Areas (LGAs) within Osun State. For example, in Ayedaade, with an energy potential of 3.499 MW, the SHP projects are estimated to serve 2,651 households at 100%, 1,988 households at 75%, and 1,325 households at 50%. Similarly, Ayedire, with a substantial energy potential of 37.02 MW, is projected to serve 28,045 households at 100%, 21,034 households at 75%, and 14,023 households at 50%. These figures underscore the significant potential for electricity generation and the consequential reach of the SHP in addressing the household energy needs in these LGAs. The cumulative SHP for Osun State indicates an overall energy potential of 109.52 MW, projected to serve 82,969 households at 100%, 62,227 households at 75%, and 41,484 households at 50% operational capacity. These aggregated figures provide a holistic view of the collective impact of SHP in Osun State region of the basin, showcasing the potential for widespread electrification and contributing to socio-economic development and improved living conditions for the residents if harnessed.

Table 4: Estimated Household Population to be Served by the SHP in Osun State

		Plant Performance Capacity		
Osun State	**Energy Potential (MW)**	**No of Household (100%)**	**No of Household (75%)**	**No of Household (50%)**
Ayedaade	3.499	2651	1988	1325
Ayedire	37.02	28045	21034	14023
Egbedore	15.096	11436	8577	5718
Ejigbo	1.358	1029	772	514
Irewole	9.989	7567	5676	3784
Isokan	20.312	15388	11541	7694
Atakumosa East	1.191	902	677	451
Ife South	13.843	10487	7865	5244
Iwo	5.563	4214	3161	2107
Ola-Oluwa	1.648	1248	936	624
Total	**109.52**	**82969**	**62227**	**41484**

5. Conclusion and Recommendation

5.1 Conclusion

The identification of 86 small hydropower potential sites across Osun State, with a cumulative capacity of 109.52 MW capable of serving up to 82,969 households at full capacity, demonstrates a significant opportunity to address rural electrification challenges. These findings are particularly relevant given the current low electricity access indices (0.42-0.49) across surveyed LGAs, despite their high connection rates, highlighting the critical gap between grid connection and reliable power supply. The study's revelation that even well-connected areas like Apomu, Awo, and Ileogbo experience substantial reliability and duration constraints (R.I: 0.37, D.I: 0.40) aligns with previous findings of 34% revenue losses in rural businesses due to unreliable power supply (Ohunakin *et al*., 2023). With implementation costs of $2,500-$3,000 per kilowatt for small hydropower systems being significantly lower than the $25,000-$30,000 per kilometer for traditional grid extension (Mohammed *et al*., 2024; Adewuyi *et al*., 2023), the identified sites, particularly in high-potential LGAs like Ayedire (37.02 MW) and Isokan (20.312 MW), present cost-effective opportunities for decentralized power generation.

5.2 Recommendations

Based on the findings of this study, several key recommendations are proposed to facilitate the successful implementation of small hydropower (SHP) projects in Osun State. Primarily, there is an urgent need for the government to establish a comprehensive policy framework specifically tailored for SHP development. This framework should include clear guidelines, streamlined approval processes, and attractive incentives such as tax breaks to encourage private sector participation in rural electrification projects. From a technical perspective, implementation efforts should initially focus on high-potential areas identified in this study, particularly Ayedire and Isokan LGAs, which demonstrate the highest SHP potential.

References

Abdullahi, D., Muhammad, Y. S., & Sani, Z. M. 2022, Assessment of small hydropower potential and development status in Nigeria: A comprehensive review. Renewable and Sustainable Energy Reviews, 156, 111963.

Adewuyi, O. B., Kiptoo, M. K., & Afolayan, A. F. 2023, Techno-economic analysis of small hydropower development for rural electrification in Nigeria. Energy Strategy Reviews, 45, 100915.

African Development Bank [AfDB]. 2023, Nigeria Economic Outlook 2023: Energy Access and Development Report. African Development Bank Group Publication.

Akpojedje, F. and Mormah, E. 2019, Transmission system and rural electrification scheme in nigeria: issues, challenges, constraints and way forward. Journal of Advances in Science and Engineering, 2(2), 9-28

Chinweoke, O., Chigozie, E., & Chike, e. 2020, Evaluation of mini-hydro power for off grid electrification in rural/isolated areas in africa. Advances in Science Technology and Engineering Systems Journal, 5(2), 703-710.

Edomah, N., Ndulue, G., & Lemaire, X. 2021, A review of stakeholders and interventions in nigeria's electricity sector. Heliyon, 7(9), e07956.

Fagbohun, O. and Omotoso, T. 2018, Small hydro power viability assessment of elemi river in ekiti state of nigeria. Journal of Energy Research and Reviews, 1-12.

Kumar, A., & Sharma, M. P. 2023, Environmental impact assessment of small hydropower projects: A comparative analysis with large hydropower installations. Sustainable Energy Technologies and Assessments, 54, 102875.

Mohammed, Y. S., Mustafa, M. W., & Bashir, N. 2024, Grid extension challenges and alternatives for rural electrification in Nigeria: Technical and economic perspectives. Renewable Energy Focus, 38, 22-35.

Odetoye, O. 2023, Multi-year techno-economic assessment of proposed zero-emission hybrid community microgrid in nigeria using homer. Heliyon, 9(9), e19189.

Ohunakin, O. S., Adaramola, M. S., & Oyewola, O. M. 2023, Impact of energy deficit on rural business development in Nigeria: An empirical assessment. Energy Policy, 175, 113487.

Olanrele, I., Lawal, A., Dahunsi, S., Babajide, A., & Iseolorunkanmi, J. 2020, The impact of access to electricity on education and health sectors in nigeria's rural communities. Journal of Entrepreneurship and Sustainability Issues, 7(4), 3016-3035.

Olanrewaju, E. and Olanrewaju, O. 2020, Rural electrification and profitability among rural women - owned microenterprises in nigeria. Shanlax International Journal of Economics, 8(4), 1-11.

Olatunji, O., Raphael, A., & Yomi, I. 2018, Hydrokinetic energy opportunity for rural electrification in nigeria. International Journal of Renewable Energy Development, 7(2), 183-190.

Oyedepo, S. O., Adaramola, M. S., & Paul, S. S. 2024, Comparative analysis of renewable energy technologies for rural electrification in Nigeria. Renewable and Sustainable Energy Reviews, 178, 114091.

UNIDO. 2022, World Small Hydropower Development Report 2022: Africa. United Nations Industrial Development Organization, Vienna.

World Bank. 2023, Nigeria Power Sector Recovery Program: Technical Report. World Bank Group, Washington, DC