

Research Article

Assessment of Hydropower Potential for Rural Electrification: A Case Study of the Waleme River

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Abstract

The research will focus on the assessment, feasibility, and hydropower potential estimation in the Gedeo zone Dilla Ethiopia with an analysis of the viability of the systems for rural community electrification. Waleme River Catchment is located in the Rift Valley basin, covering an area of around 80 km² and It extends up to 30 km with a river basin This hydropower plant considers the reliability, sustainability, and environmental protections of supplying electricity to the village, particularly for remote communities where grid extension is not suitable. The hydropower renewable energy system will be the best solution for the off-grid areas. Due to international policy and the reduction of carbon dioxide emissions, the generation of electricity using renewable energy sources has become more significant. Currently, it is among the most intriguing and eco-friendly technology solutions. The hydropower potential of the site will be analyzed by measuring the gross head with the help of a Geographical Position System (GPS) and stream flow data analysis. The proposed research will be completed within two years with a total estimated budget of 363,075 ETB, by site surveying, data collection, and estimating the hydropower potential of Waleme River and finally the paper will be prepared for publication.

Keywords

Renewable Energy, Rural Electrification, Hydropower Potential, Waleme River

1. Introduction

1.1. Background

Energy serves as an integral part of modern civilization and a key indicator of socioeconomic growth [1]. In both the developed and many developing nations, there was an increase in the need for energy. Between 2000 and 2030, it had been predicted that global energy demand would double, growing at 2.4% per year [2]. It was crucial for achieving economic, environmental, and social growth. Ethiopia's en-

ergy economy, like many other Sub-Saharan African countries, relies heavily on biomass.

The majority of developing countries are facing an energy crisis due to the depletion of local energy sources and their reliance on imported fuels. The importance of energy is especially significant for developing countries like Ethiopia. On-demand electricity and modern fuels are essential for economic development and job creation [3]. According to estimates from the International Energy Agency (IEA), around 1.5 billion people, or more than one-fifth of the

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world's population, lacked electricity in 2008. In Sub-Saharan Africa and South Asia, in instance, about 85% of people without power lived in rural areas [4].

In Ethiopia's rural areas, the scarcity of energy supply has become a persistent issue. Approximately 85% of Ethiopians reside in rural areas with less than 1% access to electricity [5]. This may be because these regions are either too sparsely populated or too remote from the national grid. Due to the high transmission costs and extremely low load factor in these places, the nation cannot afford to extend the national grid to them [15].

To meet their energy demands, rural communities frequently rely on firewood, cow dung, and other traditional biomass resources, as well as kerosene. Rising fuel prices are causing kerosene to become increasingly expensive. These practices contribute to deforestation, soil erosion, and other environmental problems. The Ministry of Water, Irrigation, and Energy (MWIE) is addressing this issue. It has identified potential locations for small hydropower plants in rural areas across the country. To meet the growing electricity demand, the country needs to expand the use of hydropower generating systems and fully utilize renewable energy sources.

Hydropower systems offer a reliable and renewable energy source that can support rural electrification efforts. These systems are particularly advantageous in remote areas where extending the national grid is economically impractical. In rural regions such as the Gedeo Zone, residents often depend on unsustainable energy sources such as kerosene for heating and cooking and cow dung. The introduction of hydropower systems can provide clean, affordable energy while reducing reliance on harmful fuels.

1.2. Statement of the Problem

Despite Ethiopia's abundant renewable energy resources, many rural communities remain underserved due to inadequate power generation capacity and logistical challenges in extending the national grid. The majority of Ethiopians reside in rural areas with limited access to electricity. These communities primarily rely on natural resources such as biomass, fuels, crop residue, charcoal, and dung. However, the use of these resources contributes to deforestation, soil erosion, Degradation of the environment and greenhouse gas emissions.

In the rural areas of the Gedeo Zone, access to electricity is particularly low despite the abundance of energy from natural sources. This imbalance leads to environmental issues such as deforestation, soil erosion, global warming, and increased greenhouse gas emissions. To address this issue, it is essential to explore alternative renewable energy sources, such as small-scale hydropower systems. These systems can help bridge the energy supply gap from the national grid while improving energy access in rural areas and reducing environmental impacts.

Although Ethiopia has abundant renewable energy resources, the energy demands of most rural communities remain unmet. This is due to insufficient power generation and the challenges of supplying electricity to remote and scattered

communities. Extending the transmission and distribution network to these areas requires significant time and financial investment, including the construction of substations and lengthy distribution lines.

To meet their energy needs, rural communities often rely on kerosene, which has become increasingly unaffordable due to rising fuel prices. They also utilize conventional biomass resources like firewood and cow dung, which leads to soil erosion, deforestation, and other environmental issues.

The reliance on traditional biomass resources not only poses significant health risks but also exacerbates environmental degradation. The growing demand for energy, driven by socioeconomic development, further intensifies these challenges. Therefore, the adoption of off-grid renewable energy solutions, such as small-scale hydropower systems, is necessary to meet the energy needs of rural communities while mitigating environmental damage and supporting sustainable development.

1.3. Objectives

1.3.1. General Objective

The overall objective of this study is to assess the Hydropower Potential of Waleme River using Hydrological Model (SWAT) and Geographic Information System (GIS).

1.3.2. Specific Objectives

- 1) To identify suitable potential sites along the Waleme River.
- 2) To estimate the stream flow generated at each selected site.
- 3) To estimate the power potential communities of selected sites.
- 4) To assess the energy demand of local community.

1.4. Significant of the Study

In order to electrify rural populations in the Gedeo zone, the study will concentrate on evaluation, hydropower system analysis, and hydropower potential estimation. This study can be used as a practical problem-solving method for related and/or comparable research and rural electrification by policymakers, nongovernmental organizations, and interested parties. In order to address electrification issues related to long-distance grid extensions, power supply shortages, and emission reduction, the research will make use of renewable energy sources like hydropower. It will also improve the frequent energy shortfall that occurs when a renewable energy source power outage occurs and the battery is unable to supply the necessary energy.

The best option for remote locations is a hydropower energy system. As a result of global policies, reducing carbon dioxide emissions and producing electricity from renewable energy sources has become more significant and is now one of

the most intriguing and eco-friendly technological solutions.

To overcome the energy problem especially, Gedeo zone for rural communities generating electricity from natural resources in nearby areas is the best solution. Hydropower generation is the convenient solution for the shortage of energy problem especially for areas with numerous rivers and streams. The supply of improved renewable energy services has benefits in creating new job opportunities, simplifying rural human life, and creating a good job atmosphere.

Generally, the study will address the energy needs of the Gedeo zone community, provided that a relevant governmental or non-governmental entity is available to assist with the research's practical application.

2. Materials and Methods

2.1. Description of the Study Area

Waleme River is a perennial river located in the Dilla Woreda Gedeo zone. The coordinates of the river are Latitude 6°15'30" to 6°28'30"N and Longitude 38°19'30" to 38°27'30"E (Figure 1). The Waleme River Catchment is located in the Rift Valley basin, covering an area of around 80 km². It extends up to 30 km with a river basin, which is the largest river basin area in the Gedeo zone. It is located at a distance of 365 km from Addis Ababa.

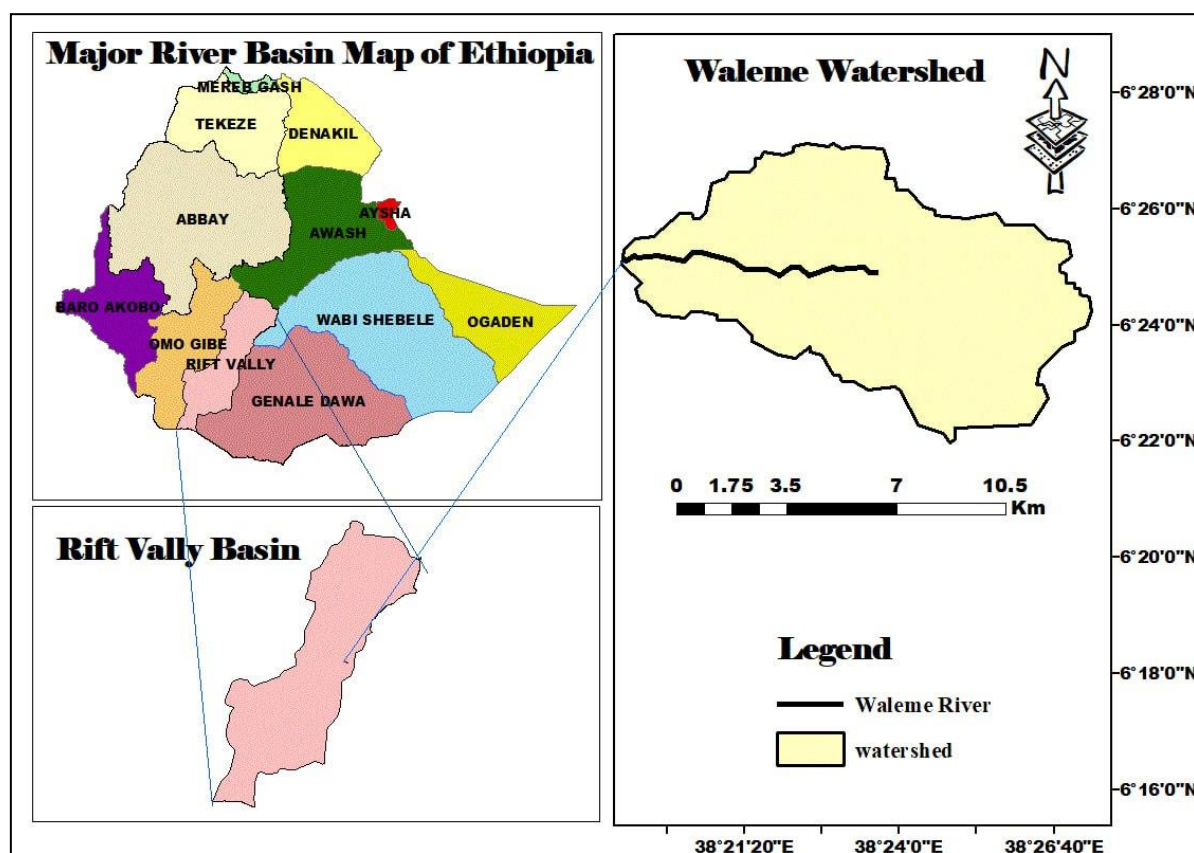


Figure 1. Location map of Waleme Watershed.

2.2. Data Collection

Data collection will involve gathering spatial and temporal information relevant to hydropower assessment from various organizations and local authorities.

2.2.1. Meteorological Data

The meteorological data is among the most prerequisite parameter of the SWAT model. This data will be collected from Ethiopian National Metrological Agency for stations located around the watershed and within the watershed. The

pattern's uniformity, which may be indicative of the Waleme River watershed, will be the basis for gathering the data. The following meteorological data will be gathered: sun radiation, wind speed, relative humidity, maximum and minimum temperatures, and precipitation.

2.2.2. Hydrological Data

Stream flow data will be used for comparisons against the model generated in calibration and validation. Daily stream flow data for the Waleme River at the gauging station will be collected from the Ministry of Water, Irrigation and Energy (MoWIE).

Table 1. Type of Data, Source, and Availability of the Data.

No	Data Types	Sources	Purpose
1	DEM	Alas Ka. S. F. https://search.asf.alaska.edu/	12.5*12.5 m resolution, used to delineate the Watershed, to analyze the spatial information
2	Land use/land cover raster map	Esri Portal (Global Land Cover)	10*10 m resolution map of 2022
3	Soil Data	Food and Agricultural Organization of the United Nations (FAO)	1*1km (tentative) resolution map, soil layer attributes for each soil layer
4	Daily precipitation data	National Meteorological Service agency (NMSA)	Daily precipitation around the waleme watershed
5	Daily stream flow data	Ministry of Water, Irrigation, and Electricity (MoWIE)	Daily stream flow for the outlet of the watershed for calibration and validation
7	Daily weather data	National Meteorological Service agency (NMSA)	Daily wind speed, minimum and maximum temperature, and relative humidity

2.3. Hydrological Modeling and Site Assessment Techniques

Hydrological modeling will be conducted using Soil and Water Assessment Tool (SWAT) to estimate discharge along river. Field measurements will be taken using GPS tools to determine river head. The first step to assess hydropower potential is collect spatial and temporal data on the watershed. In order to estimate the discharge along the river lengths, a hydrological model will be constructed using SWAT. In order to construct the hydrologic model, the SWAT model needs certain specialized data. These data include soil type, land use/land cover (LULC) maps, digital elevation models (DEM), stream flow data, and meteorological information such as temperature, precipitation, solar radiation, wind speed, and relative humidity.

2.4. Materials

To assess the hydropower potential of the Waleme watershed, data collection, processing, and evaluation will require specific equipment, models, and software. The following materials and software will be needed for this study:

- 1) Arc-GIS 10.4.1 will be used to digitize and analyze both spatial and non-spatial information about the catchments in the study area.
- 2) Soil and Water Assessment Tool (SWAT) will be used to determine the stream flow or catchment discharge of the sub-basin.
- 3) Rainbow software will be used to test the homogeneity of stream flow.
- 4) SWAT-CUP will be used for calibration and uncertainty analysis of Arc SWAT simulation and output data.
- 5) MWSWAT will be used to build a hydrological model.

Before starting the modeling work at SWAT.

- 6) Google Earth will be used for visualizing extracted shape files and to validate the head measurements in ArcGIS.
- 7) GPS, for collecting special data like the location of the river gauge and outlet of the watershed.

2.5. Identification of Potential Sites

The following three factors will be taken into account while choosing possible locations that meet the requirements [6].

- 1) Order of stream: Higher-order streams will be considered to guarantee sufficient water flow.
- 2) Head availability: To ensure sufficient potential head for hydropower generation, a location with a high average gradient along the stream will be selected.
- 3) Site spacing: The minimum distance between hydropower sites will be maintained at least 1000 meters to allow the river ecosystem to recover between sites.

2.5.1. Computation of Stream Order

Stream order is a technique that indicates the volume of flow within a given stream network by classifying rivers into reaches or stream networks. The Waleme River will be ordered using the Stahler technique, which has several uses and is the simplest of the stream ordering methods (including the Shreve, Horton, and Strahler methods). According to this method, the intersection of two streams of equal order will result in a higher stream order; for example, two first-order streams next to each other produce a second-order stream, and so on. As a result, when stream order increases, flow magnitude increases as well, and vice versa [7]. According to the Strahler method, Stream order will be used as a numerical classification system to categorize streams based on their size and flow accumulation. Higher stream orders will represent

larger streams with more tributaries, making them more suitable for hydropower generation [8].

2.5.2. Head Measurement

The gross head is a critical parameter for hydropower potential assessment and will be determined using either direct measurement or topographic maps. Both methods will be considered suitable for site assessment [9].

Direct measurement, though highly accurate, can be time-consuming and difficult to implement under specific conditions. Topographic maps, on the other hand, will provide an estimate of the gross head by measuring the elevation difference between the hydropower plant's intake and outlet. While less precise than direct measurement, topographic maps will offer a more convenient and readily accessible approach. Topographic maps assist in estimating the amount of head drop in rivers by overlaying DEMs of the basin, sub-basins, and river network. Extracting raster values at upstream and downstream locations on the network reveals the head drop in each sub-basin [10].

2.6. Hydrological Models and Model Selection

Hydrological models have become an essential tool for studying and understanding hydrological processes at the catchment or watershed level; however, hydrological models are approximations of reality in which the output of the model depends on hydrological phenomena [11].

The selection of hydrological models requires multiple selection criteria that can be used for choosing the 'right' hydrological model. Every project has different requirements; hence the selection criteria are always project-specific. Of the different selection criteria, four standard and essential ones are [12].

- 1) The outputs are estimated by the model and the importance of the output for the project objectives.
- 2) In order to accurately estimate the intended outputs, hydrologic processes must be modeled.
- 3) The accessibility of input data.
- 4) Cost.
- 5) The SWAT model is selected for this study due to its ability to simulate multiple hydrological components, perform large-scale simulations, and facilitate long-term impact studies with readily available information. It is freely available, compatible with ArcGIS, and supported by a vibrant and supportive user community.

2.7. SWAT Model Set Up

SWAT models will be established for each sub-basin to evaluate the discharge at various hydropower potential locations. Stream networks will be defined using stream network

threshold values specified during watershed delineation. Data on the distribution of soil, slope, and land use within the watersheds will be included in HRU reports. The simulation duration, rainfall distribution, and possible evapotranspiration technique will be selected in the SWAT Setup prior to model execution.

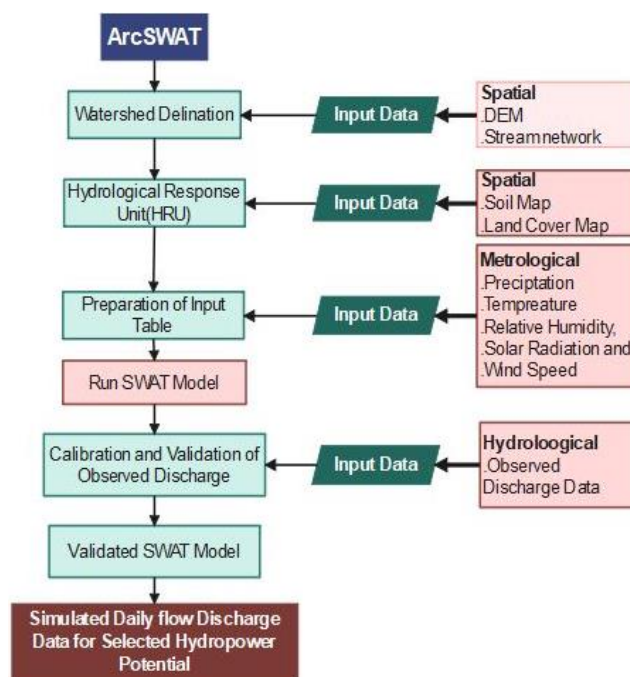


Figure 2. SWAT Model Set up and Simulation.

2.8. Selecting Suitable Site Using Analytical Hierarchy Process (AHP)

A mathematical technique for multi-criteria decision-making, the Analytic Hierarchy Process (AHP) organizes decision considerations in a hierarchical issue structure [13]. AHP's primary objective is to help decision-makers solve complicated issues by organizing the multi-criteria decision-making criterion hierarchy. The best possible locations for hydropower will be chosen using the AHP, a multi-criteria decision-making process. The possible locations will be assessed based on four factors [16]: accessibility, head, discharge, and power. These criteria will be used by the AHP to rank the sites and choose the top ones. There are four processes involved in applying AHP to decision-making [14]:

- 1) Using a hierarchical model to structure the choice problem.
- 2) Comparing the criteria in pairs and generating the matrix.
- 3) Comparing possibilities pair wise and producing a matrix.
- 4) Combining all of the priorities.

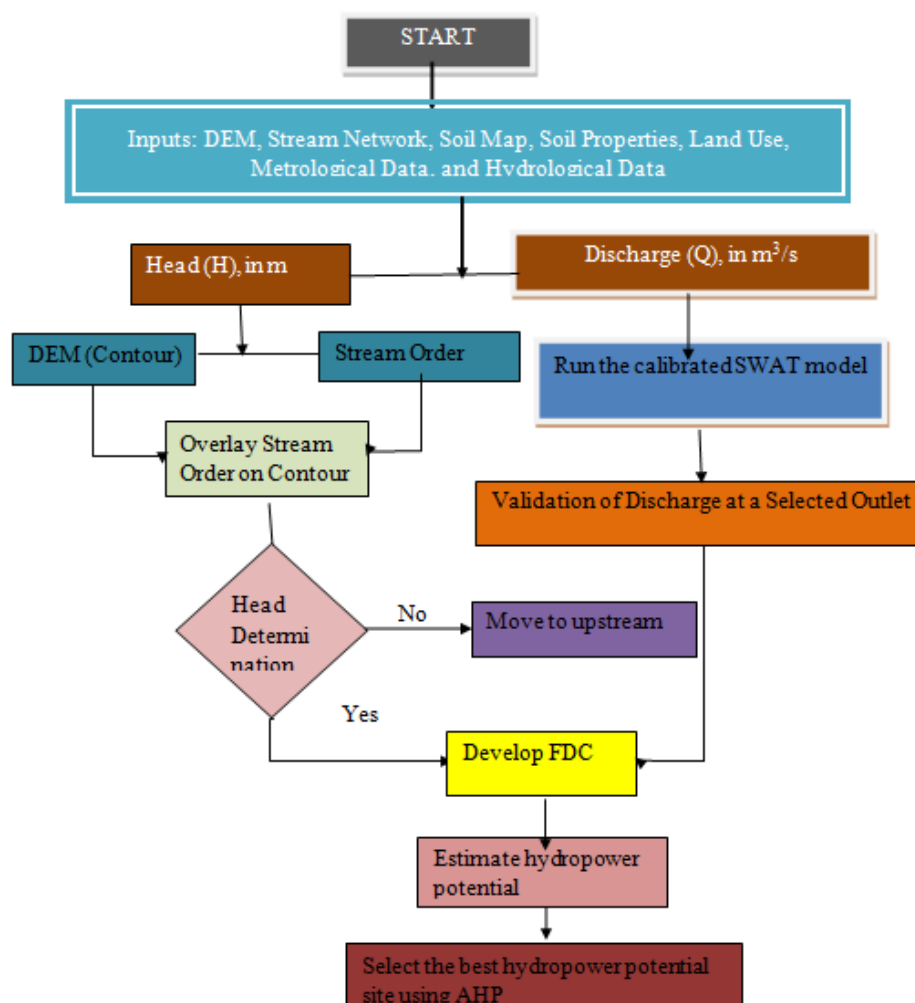


Figure 3. Flowchart for Hydropower potential, Source [6].

2.9. Estimation of Power Potential and Community Demand

The study will be estimate stream flow at selected sites and calculate community electricity demand based on pressure head and flow values. To estimate the power potential of hydropower systems, two critical parameters must be assessed: stream flow (discharge) and pressure head. The theoretical power (P) generated by a hydropower system can be expressed mathematically as:

$$\text{Power (P)} = \rho * g * Q * H * \eta \quad (1)$$

Where: ρ = Density of water (approximately 1000 kg/m³)

g = Acceleration due to gravity (9.81 m/s²)

Q = Flow rate (m³/s)

H = Effective head (m)

η = Overall efficiency of the hydropower system (typically 0.7 - 0.85)

The annual energy production from the hydropower system can be expressed as:

$$\text{Annual energy (E)} = P * t \quad (2)$$

Where: E = Energy produced (kWh)

P = Power in kW

t = Time (hours), typically one year (8760h)

This estimation will provide insights into whether the hydropower potential meets community demand.

The study will estimate the community's electricity demand based on the number of households and their average consumption. The Community Electricity Demand can be expressed mathematically as:

$$\text{Total Demand (kW)} = \sum (\text{Power of each appliance}) * \text{Number of appliances} \quad (3)$$

This requires a detailed inventory of appliances and their power ratings in each household and community facility.

3. Expected Outcomes

- 1) The best suitable hydropower potential site will be se-

lected.

- 2) Estimate the stream flow generated at each selected site.
- 3) The electricity demanded for the community will be calculated.
- 4) The hydropower capacity of each selected site will be calculated.
- 5) Rank and select the best hydropower potential sites using a suitability index.

4. Conclusion

This research proposal outlines a comprehensive plan to assess hydropower potential along the Waleme River for rural electrification purposes in Ethiopia's Gedeo Zone region. By leveraging local water resources through sustainable practices, this project aims to provide clean energy solutions that address both community needs and environmental concerns while contributing to Ethiopia's broader renewable energy goals.

Abbreviations

DEM	Digital Elevation Model
GIS	Geographic Information System
GPS	Global Positioning System
LULC	Land Use Land Cover
MoWE	Ministry of Water and Energy

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Author Contributions

Aynadis Ejargew: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft

Amsayaw Genet: Data curation, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – review & editing

Moges Tariku Tegenu: Data curation, Funding acquisition, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing

Data Availability

Data can be acquired upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] K. C. Surendra, D. Takara, A. G. Hashimoto, and S. K. Khanal, "Biogas as a sustainable energy source for developing countries: Opportunities and challenges," *Renew. Sustain. Energy Rev.*, vol. 31, no. November 2017, pp. 846–859, 2014, <https://doi.org/10.1016/j.rser.2013.12.015>
- [2] F. Birol, "Power to the people," *IAEA Bull.*, vol. 46, no. 1, pp. 9–12, 2004.
- [3] A. Tilahun, "Assessment of Micro Hydro Power Potential of Selected Ethiopian Rivers-a Case Study in the North-West Part of the Country," *East African J. Energy*, vol. 14, no. 5, pp. 670–679, 2011.
- [4] N. C. Office, "world bank 2010," *EPPO Bull.*, vol. 41, no. 3, pp. 467–476, 2011, <https://doi.org/10.1111/j.1365-2338.2011.02492.x>
- [5] W. J. Klunne, "Small hydropower in Southern Africa - An overview of five countries in the region," *J. Energy South. Africa*, vol. 24, no. 3, pp. 14–25, 2013, <https://doi.org/10.17159/2413-3051/2013/v24i3a3138>
- [6] B. C. Kusre, D. C. Baruah, P. K. Bordoloi, and S. C. Patra, "Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India)," *Appl. Energy*, vol. 87, no. 1, pp. 298–309, 2010, <https://doi.org/10.1016/j.apenergy.2009.07.019>
- [7] E. Arthur *et al.*, "Potential for small hydropower development in the Lower Pra River Basin, Ghana," *J. Hydrol. Reg. Stud.*, vol. 32, no. November, p. 100757, 2020, <https://doi.org/10.1016/j.ejrh.2020.100757>
- [8] A. N. Strahler, "Geological Society of America Bulletin DIMENSIONAL ANALYSIS APPLIED TO FLUVIALLY ERODED," no. January 2009, 1958, [https://doi.org/10.1130/0016-7606\(1958\)69](https://doi.org/10.1130/0016-7606(1958)69)
- [9] C. A. Kouadio *et al.*, "Assessing the Hydropower Potential Using Hydrological Models and Geospatial Tools in the White Bandama Watershed (Côte d'Ivoire, West Africa)," *Front. Water*, vol. 4, no. March, pp. 1–14, 2022, <https://doi.org/10.3389/frwa.2022.844934>
- [10] I. Bajracharya, "Assessment of run-of-river hydropower potential and power supply planning in Nepal using hydro resources," *Inst. für Energietechnik und Thermodyn.*, no. April, pp. 9–10, 2015.
- [11] S. G. Setegn, R. Srinivasan, and B. Dargahi, "Hydrological Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model," *Open Hydrol. J.*, vol. 2, no. 1, pp. 49–62, 2008, <https://doi.org/10.2174/1874378100802010049>
- [12] S. P. S. G. M. J. M. Cunderlik, "Hydraulic Model Selection for CFCAS projects Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions," *coundruk*, p. 282, 2003.
- [13] T. L. Saaty, "The analytic hierarchy process : planning, priority setting, resource allocation," pp. 109–121, 1980.

- [14] K. Upadhyay, "Application of Analytical Hierarchy Process in Evaluation of Best Sewage Treatment Plant," *Int. J. Sci. Res.*, vol. 6, no. 6, pp. 2319–7064, 2015.
- [15] A. Genet and A. Bulti, "Assessment of Head for Hydropower Potential Using DEM, Google Earth, and GPS in the Furfuro Watershed, Ethiopia," *SSRN Electron. J.*, no. January, 2025, <https://doi.org/10.2139/ssrn.5030295>
- [16] A. Genet, A. Tadesse, T. Zelalem, T. Kifle, and A. Ejargew, "Prioritization Suitable Hydropower Potential Sites Along the Furfuro River, Ethiopia," *Int. J. Environ. Chem.*, vol. 9, no. 1, pp. 1–8, 2025, <https://doi.org/10.11648/j.ijec.20250901.11>