Assessing Renewable Energy Potential in Vhembe District using GIS and Remote Sensing

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Abstract

Recently, there has been an increase in interest in using alternative, effective, and renewable energy supplies for various power applications in residential, commercial, industrial, and agro-processing settings. To offer communities small-scale production and low-consumption systems using these renewable resources—which include solar, wind, biomass, hydro, and geothermal systems—has demonstrated a strong interest in providing heat or power at residences in micro-generation. Such technological solutions can improve energy security and supply by encouraging appropriate and sustainable community energy sources. The methodology used in the wind, solar, hydro, and biomass fields was based on energy estimation. It evaluated the theoretical, technical, and energy potential in determining the best places for their potential. In the Vhembe District Local Municipality, the assessment was conducted utilizing geographic information system (GIS) tools and analyzing remote sensing (RS) data. The outcomes were attained through regionally scaled optimal use of the available renewable options. From the perspective of spatial planning maps, they calculated and mapped the theoretical potential for solar, wind, hydro, and biomass/biogas energy and data maps and identified the environmental and land suitability to locate the best places for deployment. The study demonstrates the potential applications of GIS for spatial analysis, assessment, modeling, and decision support, shows its user-friendly interface, and illustrates its straightforward access to renewable energy.

Keywords: Energy Estimation and Modeling, Geographic Information System Tool, Land Suitability, Optimal Location, Remote Sensing and Spatial Maps, Renewable Energy Sources and Potentials, Sustainable Energy Supply

1. Introduction

The significant increase in urban and rural energy demand and the case of deploying renewable energy penetration to the grid make improving the transmission grid and off-grid systems inevitable. Hence, the assessment, estimation, and modelling of renewable energy sources using geographic information system (GIS) and remote sensing (RS) as a tool for the decision support system (DSS) for renewable energy potentials and optimal locations is a suitable methodology to implement for this study [1] - [3]. The research focuses on the wind, solar, hydro, and biomass/biogas energy potential and estimation in the Vhembe District Local Municipality, as shown in Figure 1. The purpose was to identify potential locations of renewable energy resources and the possible application of small-scale power plants using the GIS and RS tool for the data analysis in the area under study. This area primarily comprises rivers utilized by farmers for people, cattle drinking, and irrigation farming in the surrounding areas of Mutale, Mbewdi, Tshinane, and Luvuvhu. The study domain and characteristics form part of the Limpopo province, which Botswana, Zimbabwe, and Mozambique border through the Kruger National Park, and is divided into four local municipalities, namely: Makhado, Thulamela, Musina, and Mutale [2], [10]. The district has the second lowest access to infrastructure among the communities in the province. With a high unemployment rate of 53% and a poverty rate of 32%, it is one of the lowest socioeconomic areas in the Limpopo province. The land is very fertile and suitable for agriculture [3]. However, much of the land falls under tribal authorities [4], [10].

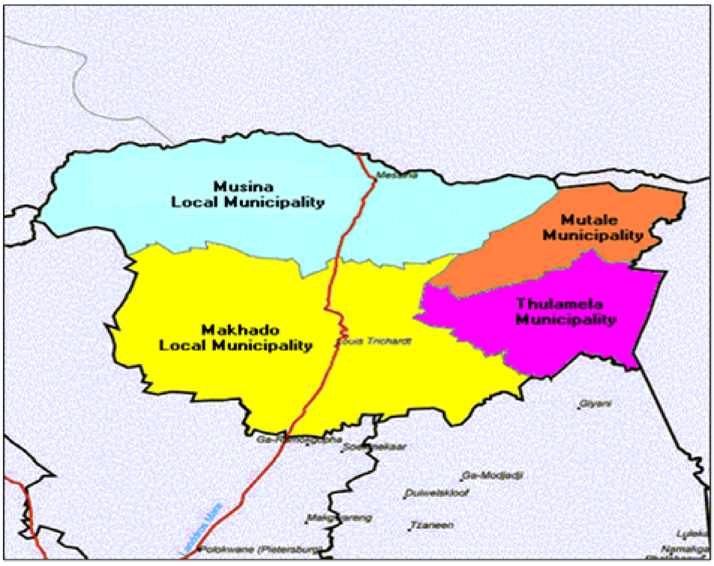

Figure 1: The topographic Map of the Vhembe Local District Municipality [2]

In assessing and modelling renewable resources, using programming systems for renewable energy planning has been considered by reviewing different approaches. For example, linear programming seeks to minimize capital investment in new sources, minimize energy flow costs, or maximize renewable energy use [5].

The GIS was used as the tool to create a map book combining renewable energy resources (i.e., wind, solar, biomass, geothermal, biofuel, and hydropower) and transmission, parcel, and road data [6]– [9]. Countries can visualize renewable energy resources and transmission lines with this functionality, making nearly all facility layouts visual and locating the right site quickly and accurately with publicly available data and GIS technology. This will help researchers, academics, investors, as well as commercial, industry, private, local, and government members and developers, locate the best renewable energy resource areas in the four municipalities within Vhembe District Municipality to obtain the overall renewable energy potentials, maps, and weather patterns.

To quantify, assess, and model the mapped wind, solar, hydro, and bioenergy potentials, the analyses of land suitability and the environment are required to find the optimal locations for deployment of the plants. This paper describes the application of RS and mapping for energy assessment and the potential use of the conceptual framework for identification of the rural energy deployment applications tool in

Figure 2 by supporting the community and the decision-makers in implementing renewable energy projects. This tool can help decision-makers and communities identify the feasible locations for all available renewable energy potentials suitable for deployment and small-scale energy generation.

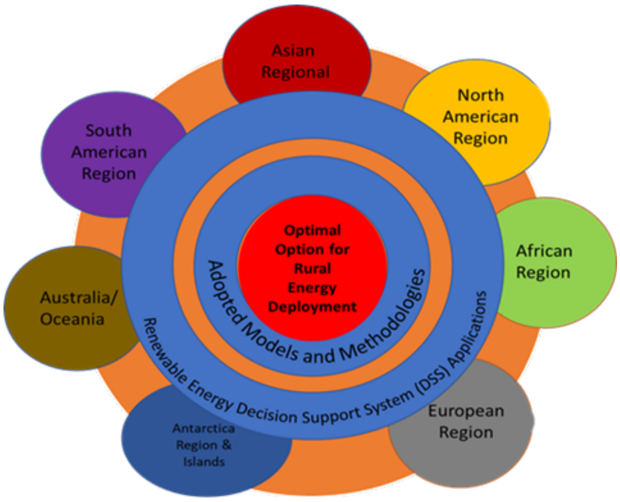

Figure 2: Conceptual Framework for Identification of the Rural Energy Deployment Applications

2. Experimental and Methodology

The assessment and estimations for possible deployment of the renewable energy potentials focus on the available and acquired data, capacity, yields, access, and optimal locations in deploying these renewable supplies for commercial and domestic use. The analysis for the data sources is conducted throughout the year and harvested from January to December 2018 (that is, daily, monthly, quarterly, and annual variations during the measurements and recordings) to obtain measurements to determine energy potentials.

The district has four municipalities at 22.7696° S Latitude and 29.9741° E 25 Longitude in the Limpopo province. It is 250m above mean sea level with limited electricity grid access and continuous energy challenges, especially on their socio-economical balance.

To quantify and map wind, solar, hydro, and biomass potential, several aspects must be considered when planning the locations of such power plants [11]– [14]. Different standards and methods are considered when determining the areas of wind, photovoltaic (PV), hydro, and biomass power plants. Thus, the geographical potential of wind, solar, and hydro is expressed in the area. Figure 3 and Figure 4 show the status maps from low to high potentials and locations suitable for wind energy deployment and optimal locations. Figure 5 and Figure 6 show the available and potential vegetation and solid-to-waste (biomass) materials found in the district.

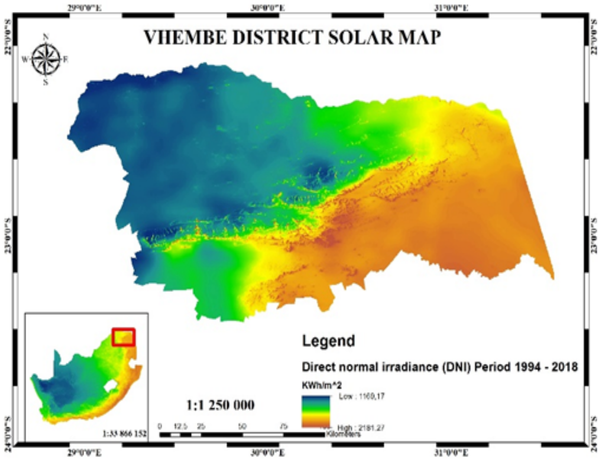

Figure 3: The solar map of the Vhembe District area

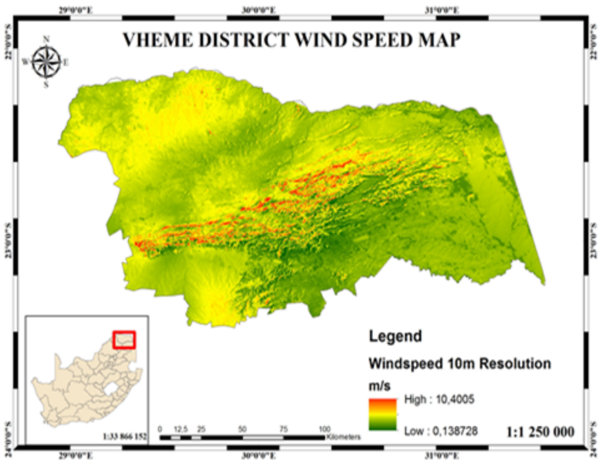

Figure 4: The wind speed map of the Vhembe District

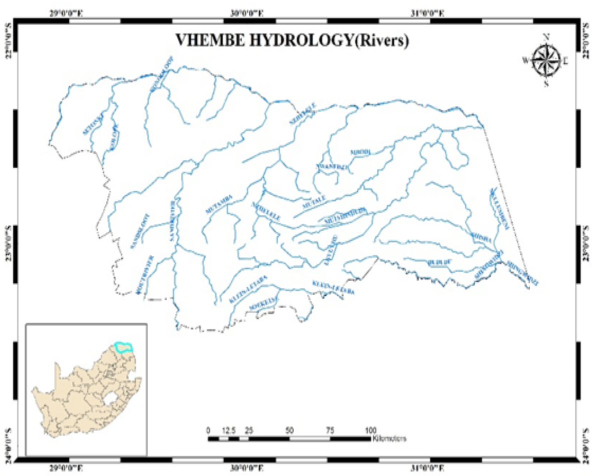

Figure 5: The hydro map of the Vhembe District

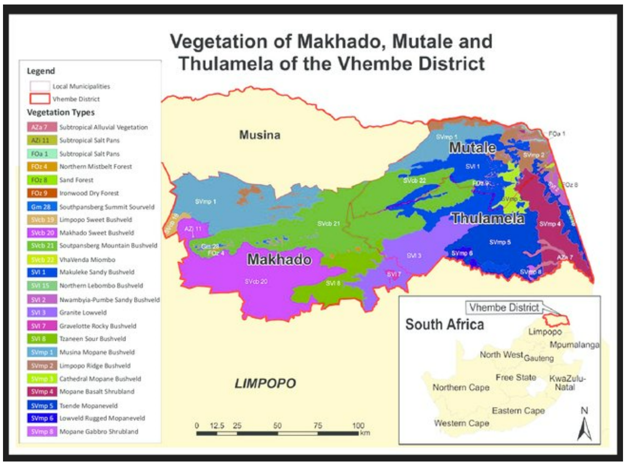

Figure 6: The vegetation map of the Vhembe District

Different standards and methods are considered when determining the locations of wind, solar, hydro, and biomass power plants. These diverse restrictions should be considered when positioning power plants in the communities and finding optimal sites for biomass power plants and suitable areas for wind and PV power plants. RS and mapping were used to obtain wind, solar, hydro, and biomass maps. The wind variations referenced to the 10m height were obtained to determine the wind potential using the kinetic energy flux for the total available energy to provide the wind turbines to generate electricity, with the estimation that it will be operating at optimal efficiency.

The Vhembe District was selected as it forms part of the rural area that constitutes major agricultural activities that also use water irrigation for communities and farming. In addition, all the water and rivers were captured from upstream and downstream in the area for their potential and availability for domestic and commercial use. These were captured using the GIS and RS mapping tools, such as the wind and solar potentials. The duration, directions, and frequency distribution were exploited to assess the wind availability for the power generated at the sites on the installed weather stations (WS) and permittable wind machines to be installed.

In measuring solar radiation and its potential for PV applications in the area, the primary solar irradiance measurements and solar radiation intensity were predicted and determined from the installed WS, and data acquisition of meteorology data was done through computational solar analysis using MATLAB.

Biomass power generation is a crucial component of the energy mix in a developing nation like South Africa. Rural communities, especially in the Vhembe District, will be lifted out of poverty and move towards a wealthy and equal future using biomass as an energy system. Access to affordable, reliable energy is essential for sustainable growth on both an economic and environmental level, as the most prevalent crops in the district in terms of biomass are mangos, oranges, apples, litchis, bananas, and sugar cane, which are produced in large quantities in an agricultural area. There are many different estimates of the total biomass capacity of the leading agricultural crop in the area, which can be processed to provide electricity from leftovers and waste on farms.

Biogas digesters have a high potential to turn waste, such as kitchen scraps and cow dung, into methane gas that can be used for cooking and heating. Biomass can be supplied by dedicated agricultural crops of arboreous and herbaceous species, such as annual crops (corn, soy, sunflower, and sorghum).

As several models for biomass and biofuels have been developed to support the decisions over which species to grow, the local climate, morphology, soil characteristics, water, and nutrient needs are commonly used to identify the set of species suitable for a specific area [15].

3. Modelling and Simulation

Measurements were remotely captured throughout one entire year. The data acquisition (DAQ) system was used to obtain data from the nine WS used during the data collection (i.e., Hanglip, Shefeera, Tsianda, Thohoyandou WO, Dzanani Biaba Agric, Mphefu, Joubertstroom Plantation, Vondo – Bos, and Tshivhasie Tea Venda). This was to determine the annual weather changes and patterns for the ranges during the annual session, as shown in Figure 7 and Figure 8.

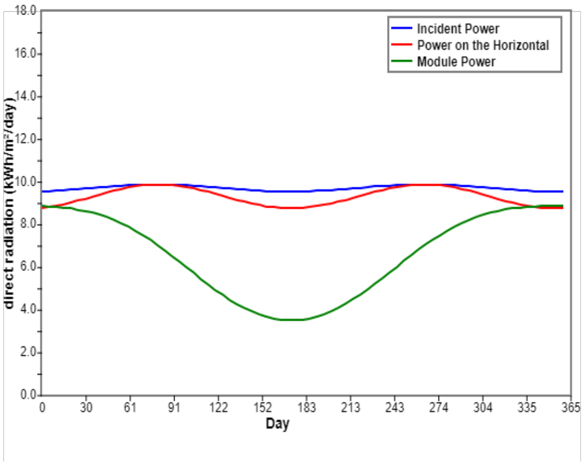

Figure 7: The daily incident power generation per direct intensity

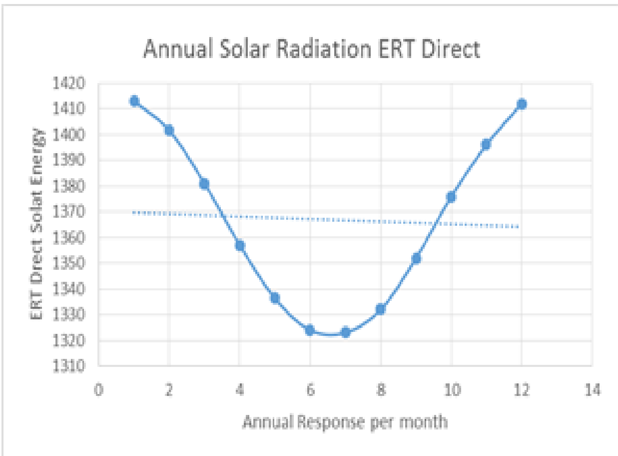

Figure 8: Energy trends for solar radiation in Vhembe District

Regarding the results, with reference to the measurements obtained, the data were used to determine the solar energy potential for the Vhembe District at specified locations to evaluate its amount for power generation. The assessment and estimations for possible wind energy deployment focus on the 10m height allowance for typical wind farm systems, data assessment, capacity, annual energy, and energy outputs. The weather conditions and data sources were harvested from January to December 2018 (that is, daily, monthly, quarterly, and annual variations during the measurements and recordings) to obtain average wind measurements to determine wind potentials. Various measures were conducted and recorded to determine the wind speed potential in the Vhembe District and estimate its energy potential, as Figure 9 illustrates.

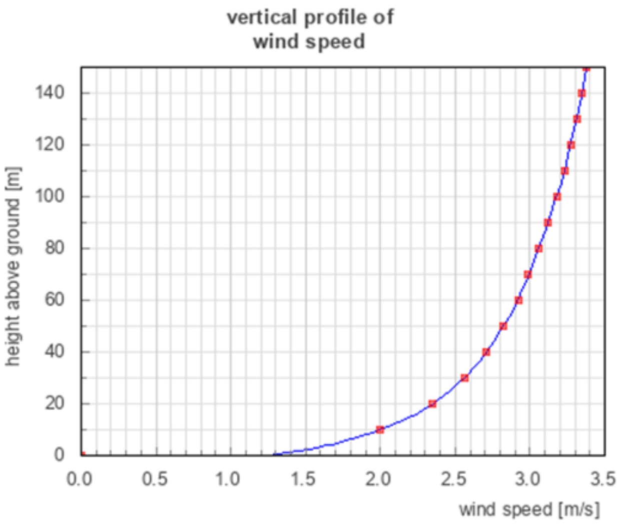

Figure 9: The wind profile speed is under 10m height above the ground.

4. Results and Discussions

The methodology was carried out using the ARGIC GIS software tools, techniques, and demand-supply matching tools on all the renewable energy resources. Microsoft Visual Basic and Webcast tools were used in the database to develop the framework model. Once all data were collected, the demand on energy potential and its profile was established and analysed for optimal energy use at present and at the identified site. All stages were conducted by collating data to achieve optimal demand-supply. These were carried out in all the energy potentials through the GIS-based energy tool for solar, wind, biomass, and the hydro system. This methodology is helpful and realistic for implementing microgeneration energy technologies.

The data demand was accessed from all the Vhembe District Councils. The Google Earth Map and database were used to gather geographical data for potential sites, as well as other databases such as SAWA, NREL, ERENA, and NASA metrology. The data acquired for the renewable energy evaluation are shown in Table 1. In addition, the comprehensive site selection for the proposed solar, wind, biomass, and hydro generation plants was followed by the environmental and economic feasibility criteria as demonstrated by the obtained results from Figure 3 to Figure 9.

Table 1: Units for Magnetic Properties

Data	**Data Format**
Solar, wind, biomass, and potential hydro atlases	MapInfo
Forest areas	MapInfo and Geodatabase
River/water basin areas	MapInfo and Geodatabase
Agricultural (i.e., fruits and crops) areas	Geodatabase
Farmers’ areas	Geodatabase

The data measurements of the global solar radiation that were used were directly from locations where data were taken from the extra-terrestrial radiation and metrology data during sunshine and cloudiness as empirical data. As a result, the thematic maps were generated from the GIS to access the availability and variation of global solar radiation. As such, the solar potential was identified for the specific area or location. The data included the sites' temperature, relative humidity, rainfall, and hourly sunshine, as illustrated in Figure 7 and Figure 8.

The wind energy potential was determined by calculating the annual average wind speed for a specified location. This wind speed was obtained from the SAWA metrological data and local government. It was grouped into seasonal times, such as winter, summer, spring, and autumn, to analyse and assess the wind data. The maps were generated through the ARGIC GIS to help identify the most and the least suitable potential wind energy mappings, as shown in Figure 3. The constraints, such as topography, wind speed, and direction, were not considered.

Hydropower is one of the most renewable, nonradioactive, and non-polluting sources of energy. Water is pumped from a lower reservoir to a higher one, utilizing low-cost dump power produced during periods of low demand by a power plant that can be operated economically at a constant load. Throughout the Vhembe District, the distribution of the river basins and water resources can be accessed by the municipalities, and the capacity of the dams, rivers, and water basins would account for the variations of hydro energy generation. The data were used to be implemented in the GIS to evaluate the hydro potentials and possible micro generations.

The biomass or bioenergy potentials were assessed through the compilation and computation of the bio-resource supply of all the available waste, agricultural residue, fruits and crops, forest, horticulture residue, plantation and livestock dung, and municipal wastes. The data for these bioenergy resources were collected from the Department of Agriculture and Forestry, the Department of Waste Management and Sustainability, and the Vhembe District Municipalities. Implementing GIS, the bioenergy availability maps, and statistical data represented the thematic maps of the total biomass or bioenergy potential in the location identified. Figure 6 shows the workflow for the bioenergy data collection methodology and the potential analysis in GIS.

It is observed that the availability of biomass in the district is mainly on the use of biomass being degraded into biogas as the potential technology suitable for using cow dung, chicken manure, and organic waste (i.e., fruit, such as bananas, oranges, mangos, litchis, and apples, and vegetables) as the substrates that are popular for the economic upliftment of communities and farmers. Furthermore, over the area, the waste is the traditional biomass used for cooking and heating in most rural communities, dominated by poor households with limited or no access to energy services. This lack of access to energy services drastically affects economic production and is also a critical challenge for essential services (such as health care and education) in the area.

5. Conclusions

GIS is used to create a map book combining renewable energy resources (i.e., wind, solar, biomass, geothermal, biofuel, and hydropower) and transmission, parcel, and road data. Thus, countries can visualize renewable energy resources and transmission lines with this functionality, which makes nearly all facility layouts visual. Locating the right site quickly and accurately with publicly available data and GIS technology will help investors and developers discover the best renewable energy resource areas. This study highlighted the potential role GIS plays in renewable energy.

For these reasons, it is a valuable solution to energy resource exploration as it has multiple benefits or capabilities, such as spatial analysis, modelling, decision support, a friendly user interface, and easy access. However, there have been minimal applications. It is still a relatively new research field that integrates GIS, the Internet, databases, technical reports, maps, and modelling to create a virtual instrument for the region's DSS on renewable energy potentials.

However, there are alternatives to traditional biomass, such as biogas technology, which can provide clean and reliable energy services.

This study's assessment technique is a model for estimating the potential effects of the available renewable resources, climate, environment, landscape, and possible change on the livelihood of the specified area. It also highlights the methods for understanding climate change in the district.

Solar

The assessment and estimation model using the weather data, GIS maps, and environmental conditions are the most recent data measured (from January to December 2018) of the meteorological data obtained in the nine installed WS. The duration, seasonal, and annual analyses have been presented in this work. The high solar radiation was recorded from January to April and September to December, while the lower solar radiation was recorded from April to August. The results of the analysis demonstrate that the required solar radiation values for potential use in the field are estimated by the geological environment and temperatures commonly measured by the installed WS around the Vhembe District. As such, the obtained results can be employed as the best example for solar estimation at different geographical locations and climatic locations. A location's suitability for maximizing solar energy received and power generated at the chosen position must be determined to obtain the optimal and prospective PV radiation.

Wind

The wind energy potential in the Vhembe District area concluded with the following assessments: It was found that most wind energy systems in the district were used for water pumping in rural areas for small farming and domestic use. Locating the right site can be done quickly and accurately with publicly available data and GIS and RS technology obtained in the study. This will help communities, decision-makers, investors, and developers locate the best location for wind energy resources in the district. The presented estimation and modelling of wind energy is a valuable tool in wind energy assessment and power estimation for domestic and small farmers to benefit from economic energy applications. The wind data has been used for wind estimations, assessment, calculations, and modelling through nine installed WS.

Biomass

In today's fast-paced society, alternative fuel alternatives are essential. To replace fuel, which is required in households and businesses, we must develop a sustainable renewable energy source. Biomass, which comes in many forms, is necessary for biofuel. We will always have a fuel alternative if there is animal and plant waste. It will be necessary to increase the growth of feedstock and the effectiveness of conversion routes if biomass energy is set to a level where it can influence the world's emissions of greenhouse gases. A biorefinery system's capacity to remain economically viable can be significantly impacted by quantifying and planning for the uncertainties included in a biomass feedstock supply system.

Building reliable supply system designs that can survive a multitude of unknowns requires an understanding of uncontrollable variabilities, such as weather conditions (bale moisture, crop production) and their impact on feedstock logistics.

In addition, in the study, we developed a model for evaluating the hydropower potential to support decision-makers and energy planning. Furthermore, we directly considered all variables in a GIS environment, accounting for their spatial variability and including information such as the distance from urban areas or the dependency of civil engineering work costs on land use. Consequently, this study will be helpful to the authorities in developing potential water resources in the district for hydropower generation in support of improving the electricity generation for small-scale farmers and communities. As a result, the GIS software can help identify sites with hydropower potential using several datasets and potential sites for mini and small hydropower deployment.

Finally, at present, about 57% of the population in sub-Saharan Africa needs access to electricity. Thus, rapid electrification efforts will assist in decentralized hydropower as an effective solution for rural electrification, especially when its deployment is the result of structured and well-informed action plans. Similarly, small-scale hydropower can be a plausible electrification option in today's electrification challenge. To this end, proper planning is essential, and so are new data and tools that can better inform electrification policy.

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