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Research Article

Exploring the Feasibility of Small-Scale Hydropower in Vhembe: A GIS-Driven Approach

Clement Matasane [1], Mohamed Tariq Kahn [2]
[1, 2] *Department of Electrical and Electronic Engineering (DEEC), Energy Institute and Centre for Distributed Power and Electronic Systems (CDPES), Cape Peninsula University of Technology (CPUT), Symphony Way, Bellville, South Africa*
Email: [1] matasanec@cput.ac.za, [2] khant@cput.ac.za

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ABSTRACT

Small-scale hydropower (SHP) presents a promising avenue for sustainable and cost-effective electricity generation. However, its development must be carefully considered alongside other water demands. This study investigated the SHP potential within the Vhembe District Municipality in South Africa. Utilizing geographical and spatial information systems (GIS), the research assessed factors such as water availability, topography, and environmental impact. The findings revealed significant SHP potential in the region, identifying promising sites with minimal environmental disruption. This study demonstrates the feasibility of SHP development in Vhembe, contributing to local economic growth and South Africa's green energy transition. The findings provide valuable insights for policymakers and stakeholders in Vhembe and other regions considering SHP development.

Keywords: Geographical and Spatial Information (GIS), Small-scale hydropower (SHP) plants, Remote Sensing and Spatial Mappings, Water Management.

INTRODUCTION

Small-scale hydropower is now the world's most cost-effective energy technology and most widely used renewable energy source through identification of potential locations for run of river hydropower plants using a GIS-Based models [1]. The benefits and drawbacks of small-scale hydropower, as well as determining which small-scale hydropower facilities presently represent the best keys to providing a reliable, cost-effective, and environmentally friendly source of energy [2]. In developing countries, the fundamental distress that distinguishes the energy emergency is the loss of locally accessible energy, which is dependent on the importance of fuel.

The main principle of small-scale hydropower is to harness the energy stored in flowing water as it descends in height. Water moving carries a vast amount of energy, and when it runs down a steep slope, the amount of energy increases. The research regions' geography, notably in the high lands and natural drainage system, provides ideal conditions for local power generation [3]. As a result, small-scale hydropower schemes are the best alternative for meeting power demand because they require little capital investment and can be completed in a short period of time with minimal negative environmental repercussions [4]. In addition, when properly gathered and utilized, the energy generated can help meet local demand while also improving the country's quality of life and living standards [5].

South Africa's Renewable Energy Future

South Africa faces a growing demand for sustainable energy solutions due to rising energy demands and environmental concerns associated with fossil fuel dependence and shifting demographics. In addition, fossil fuel dependence poses challenges related to environmental degradation, fluctuating prices, and limited long-term availability. Small-scale hydropower (SSH) projects offer a promising solution. These projects are cost-effective, reliable, and utilize a renewable resource. However, identifying suitable locations for SSH development is crucial

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for maximizing their effectiveness. These challenges also present an opportunity for a shift towards renewable energy sources. Renewable energy sources offer a promising solution, and small-scale hydropower (SSH) holds potential in regions with suitable water resources. The study explores the research on SSH potential assessment, focusing on the application of Geographical Information Systems (GIS) and spatial data in context to the Vhembe District Municipality (VDM) and its potential for SSH development. Furthermore, supportive government policies, combined with the abundance of renewable energy resources, create a promising future for clean energy development in South Africa.

STUDY AREA

The Vhembe District Municipality, situated in Limpopo Province, South Africa, is depicted in Figure 1. The municipality comprises various local municipalities, including Thulamela, Musina, Makhado, and Collin Chabane.

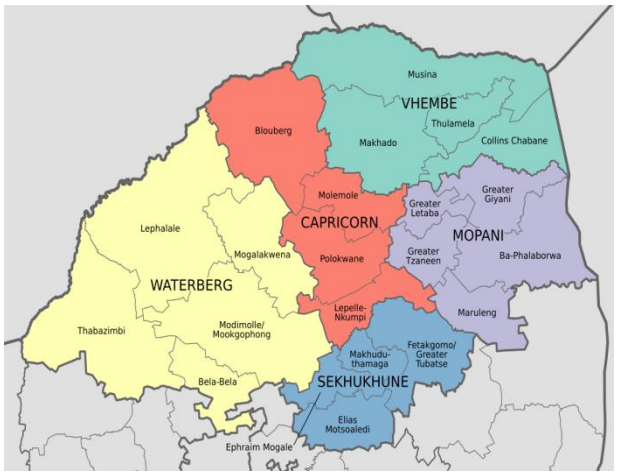

Figure 1. Area view of the Vhembe District Municipality [6]

The assessment encompasses the entire Vhembe District Municipality, meticulously evaluating its small-scale hydropower potential. The municipality is home to several rivers and streams that have the potential to be harnessed for hydroelectric power generation [7]. The municipality have several potential sites that include Letaba River, Olifants River, Luvuvhu River, Musina River, Shingwedzi River and Mulobezi River, as per Figure 2 depicts the municipality's river network data derived from remote sensing and spatial mapping techniques.

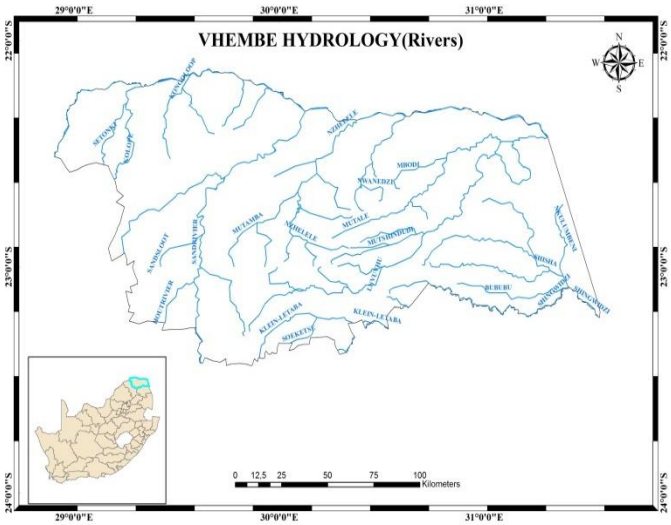

Figure 2. River network data for Vhembe District municipality

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METHODOLOGY

A geographical and spatial information (GIS) approach was used to assess the SSH potential in Vhembe District Municipality.

The following sources (river network, catchment areas, average annual climate, and rainfall) of data were used for the assessment of the small-scale hydropower potential in the Vhembe District Municipality:

- Environmental feasibility: Temperature and precipitation patterns in the region and the area's topography and its influence on climate.
- Topographic maps: These maps show the physical features of the rivers. These characteristics were leveraged to pinpoint potential sites for small-scale hydropower development.
- Hydrological data: This data includes information about the water resources in the municipality, such as the location of rivers. It was used to assess the availability of water for small-scale hydropower development.
- Data collection: Data on rivers, streams were collected from satellite imagery.
- Data analysis: The collected data was analyzed using GIS software to identify potential SSH sites. The analysis considered factors such as streamflow, head, and catchment area.

RESULTS

Figures 3 and 4 illustrate the environmental conditions of the area, focusing on average temperature and day length, which are both impacted by climate change.

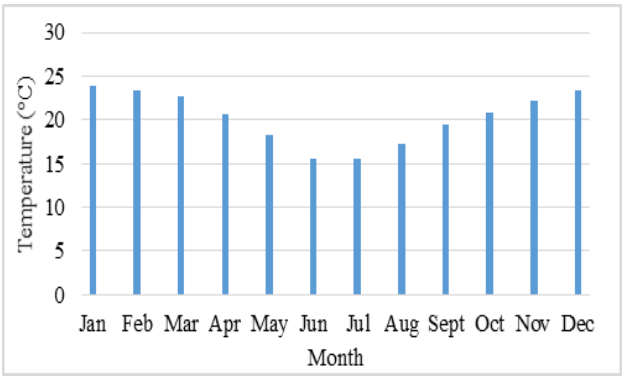

Figure 3. The monthly temperature measurement (Average - 20 °C)

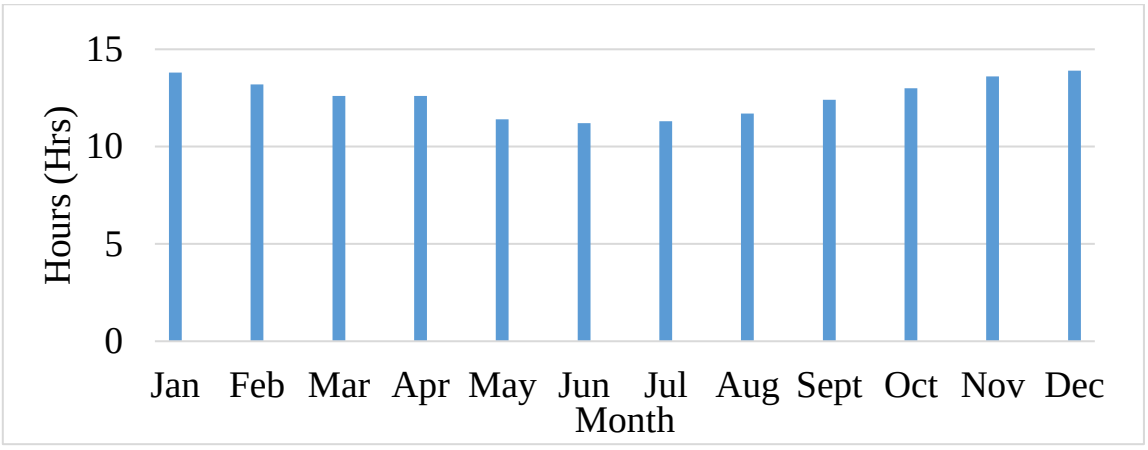

Figure 4: Average Daily Hours of Sunlight (12.5 hours)

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The region experiences distinct temperature variations throughout the year. The hottest months are January to April and September to December, coinciding with the summer and spring seasons. Conversely, the coolest temperatures occur during the winter months of May to August. Table 1 is the key environmental and climate data for the Study Area.

Table 1: Summary of environmental conditions in the region

Mnth	Air Temp.(°C)	Dew Point (°C)	Rel. Hum. (%)	D.S.R. - Direct (MJ/m²/d)	Length of Day (Hrs)
Jan	23.9	17.4	67.2	20.6	13.8
Feb	23.4	17.7	70.2	19.6	13.2
Mar	22.7	17	70.4	19.2	12.6
Apr	20.6	14.7	69	20.8	12.6
May	18.2	11.2	63.6	23.4	11.4
Jun	15.6	8.1	60.8	22.3	11.2
Jul	15.6	7.7	59.4	23.3	11.3
Aug	17.3	8.6	56.5	24	11.7
Sept	19.5	10.4	55.6	23.6	12.4
Oct	20.9	12.9	60.3	20.1	13
Nov	22.1	15.1	64.5	19.4	13.6
Dec	23.3	16.7	66.4	19.7	13.9
Total Avg.	20.3	13.2	63.7	21.3	12.5

During the collected geographical and spatial data for the municipality, the topographic maps obtained show the physical features of the land against the rivers. This hydrological data includes information about the water resources in the municipality, such as the location of rivers. In addition, the river network data shows the location of rivers and streams in the municipality.

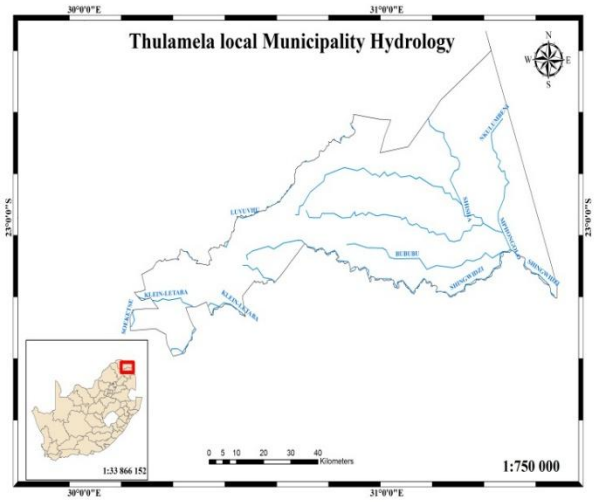

Figure 5. Thulamela local municipality hydrological data

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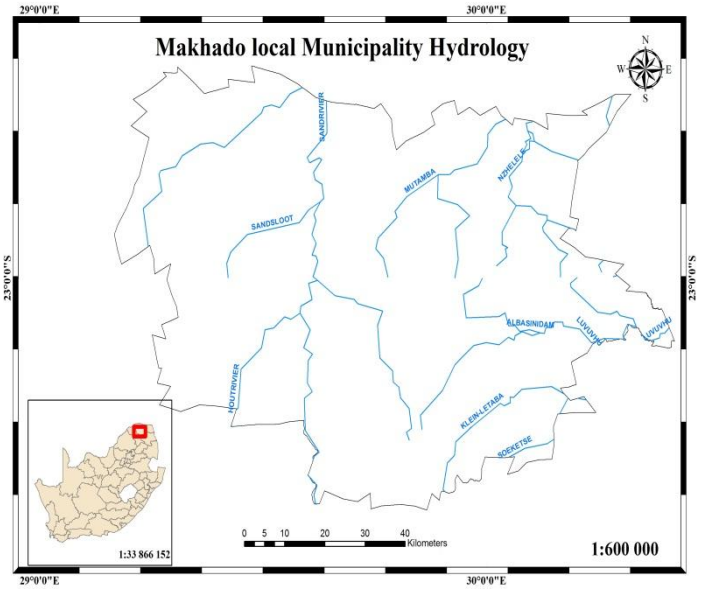

Figure 6. Makhado local municipality hydrological data

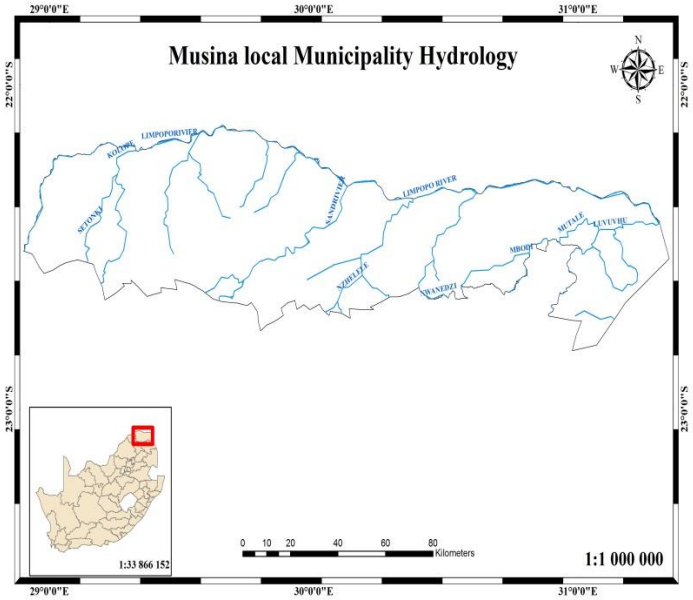

Figure 7. Musina local municipality hydrological data

Leveraging data from various sources, this assessment examined the potential for small-scale hydropower development within the municipality. The findings reveal that small-scale hydropower offers a viable option for electricity generation. However, careful consideration must be given to several factors, such as water resource availability, construction costs, and potential environmental impacts, to ensure project sustainability.

DISCUSSION

Geographic Information Systems (GIS) empower users to integrate diverse data types into a single platform. This capability fosters powerful multi-perspective analysis of a specific geographic region. The results of this study show that Vhembe District Municipality has significant potential for small-scale hydro development. The Small-scale

hydro projects can provide a clean and renewable source of energy to rural and remote communities in the municipality. The small-scale hydro projects can also create jobs and stimulate economic development.

While this study highlights the potential of utilizing GIS for exploring SSH potential in the VDM, the accuracy and comprehensiveness of the spatial datasets used in the GIS analysis can significantly impact the results. Limited access to high-resolution data or data with inconsistencies might require estimations or adjustments, potentially affecting the precision of site selection. Secondly, while GIS excels at spatial analysis, incorporating detailed social and environmental impact assessments requires additional studies. These might involve community consultations, ecological surveys, and cultural heritage evaluations for a more holistic understanding of potential project impacts. Hence a complete assessment requires economic feasibility studies to determine the cost-effectiveness of potential projects. This would involve factors like construction costs, operation and maintenance expenses, and energy generation potential.

While our study lays a valuable groundwork for exploring SSH potential in the VDM, it's important to acknowledge some limitations. Data availability, particularly detailed precipitation information, could influence the accuracy of our findings. Additionally, our GIS assessment might not have captured all potential environmental concerns. Further studies on potential impacts on aquatic ecosystems and water quality might be necessary.

Furthermore, without a cost-feasibility analysis, it's difficult to determine if the identified SSH sites are financially viable. These limitations can affect how we interpret the results. For example, limited data might lead to identifying sites with seemingly good potential, but which could be less feasible due to unidentified environmental or economic constraints.

CONCLUSION

This study explored the potential of utilising Geographical Information Systems (GIS) for exploring and assessing small-scale hydropower (SSH) potential in the Vhembe District Municipality (VDM) of South Africa. While previous studies have demonstrated the effectiveness of GIS for SSH potential assessment in various regions, our research focuses specifically on the VDM. We contribute to existing knowledge by applying GIS methodologies to a unique geographical context, considering the specific hydrological and topographical characteristics of the region. This allows for a targeted assessment of SSH potential within the VDM.

Furthermore, our findings suggest that GIS can be a valuable tool for identifying promising locations for SSH development in the VDM. Based on this research, policymakers should prioritize acquiring and maintaining high-resolution spatial datasets relevant to SSH potential assessment. This data can be crucial for informing accurate site selection and minimizing project risks. Provide training programs and capacity building initiatives to equip relevant stakeholders with the skills and knowledge to utilise GIS effectively for SSH exploration. These fosters informed decision-making at various levels. Policy frameworks should encourage the integration of SSH development plans with broader regional development strategies. This ensures alignment with socio-economic goals, promotes community participation, and maximizes the overall benefits of SSH projects for the VDM.

By implementing these recommendations, policymakers can create an enabling environment for the exploration and development of SSH in the VDM. This will contribute to a more sustainable and reliable energy future for the region, while minimizing environmental and social impacts.

Conducting further research with high-resolution spatial data focusing on specific river segments or potential dam locations within the Vhembe District Municipality (VDM). This will provide a more granular understanding of the feasibility and environmental impact of potential SSH projects. As a results, by utilising GIS, researchers would need a more comprehensive and data-driven assessment of SSH potential within a specific region. This approach would lead to the identification of the most suitable locations for project development, maximizing the benefits of SSH for renewable energy generation. Ultimately, this research would contribute to a more sustainable and reliable energy future. Furthermore, an in-depth assessment of potential environmental and social impacts of specific hydropower projects are crucial for sustainable development. This includes studies on potential impacts on aquatic

ecosystems, local communities, and cultural heritage. Integrating these considerations into the GIS analysis will lead to more responsible project development.

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Institutional Review Board Statement: Not applicable as the study does not involve humans or animals.

Informed Consent Statement: The study does not involve human subjects or any health-related matters.

Data Availability Statement: The research data and results are found within the article.

Conflicts of Interest: The authors have no conflict of interest to declare.

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