# Exploring and Assessment of Small-Scale Hydropower Potentials in Vhembe District Municipality Using Geographical and Spatial Information

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***Abstract.*** *Harnessing the power of water to generate electricity is one of the most cost-effective and sustainable methods of energy production. Small hydropower plants are gaining prominence due to their ability to generate electricity with lower hydraulic heads and smaller flow rates, making them suitable for a wider range of applications. However, the growing global population and its associated demands for water for drinking, agriculture, and industrial purposes are putting increasing pressure on rivers. It is crucial to strike a balance between utilizing river waters for hydropower generation and preserving its availability for essential human needs. The study explored and assessed the small-scale hydropower potentials in the Vhembe District Municipality. The study used geographical and spatial information to identify potential sites for small scale hydropower projects. The study also considered several factors, such as the availability of water, the topography of the area, and the environmental impact of hydropower development. The study identified significant potential for small-scale hydropower development within the Vhembe District Municipality. It pinpointed several promising sites with minimal environmental impact. Developing small-scale hydropower in this area is presented as a viable option that could contribute to the local economy and South Africa's green energy transition. The study recommends that the Vhembe District Municipality further explore this potential and develop a plan for sustainable small-scale hydropower development in the region. These findings can inform similar projects in the region and beyond, becoming a valuable contribution to the national understanding of small-scale hydropower potential in South Africa.*

**Keywords:** Energy Production, Geographical and Spatial Information, Renewable Energy, Rural Electrification and Development, Small and Micro-hydropower plants, Remote Sensing and Spatial Mappings

## 1. 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 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.

Wind, solar, and biomass energy, all powered by the sun's energy, have immense potential to meet South Africa's needs [6]. The first crucial step is to scientifically assess and map these resources across the country. This allows for targeted development and efficient use of renewable energy sources.

*Planning for a Sustainable Future*

Energy efficiency should be considered from the very beginning of land-use planning. This ensures development is directed towards areas with the most potential for small-scale, renewable energy generation. GIS combined with multi-criteria evaluation

methods can be powerful tools for optimizing new settlements for multi-functionality and sustainable renewable energy use [7], [8]. Research shows success stories of using these techniques in collaborative decision-making processes, allowing stakeholders to explore, understand, and define housing location with sustainability in mind.

The abundance of renewable energy resources in South Africa presents a powerful opportunity to reshape the nation's energy landscape, society, and economy. This vision was echoed by Deputy President Kgalema Motlanthe at the 2013 South African Green Energy Youth Summit. He emphasized that renewable energy can not only diversify South Africa's energy mix, but also unlock sustainable growth through the responsible use of the country's natural resources. With this vast potential, South Africa has the chance to become a global economic leader while addressing environmental issues and securing a clean energy future for all [9].

The VDM in Limpopo Province exemplifies the potential of renewable energy. Numerous rivers and streams within its borders offer promising locations for small-scale hydropower projects [10]. The mountainous topography provides ideal conditions for these projects, and the average annual rainfall provides a reliable water source. Studies estimate the Vhembe District's (VD) small-scale hydropower potential at over 100 MW, enough to generate electricity for local communities, businesses, and industries. These studies identified specific rivers like Luvuvhu, Shingwedzi, and Nwanedi as particularly suitable for hydropower development.

Small-scale hydropower projects are not just cost-effective; they're also reliable, unaffected by fossil fuel price fluctuations. The VD stands to gain significantly from embracing this clean energy source:

- Increased Access to Electricity: Local communities would gain access to reliable and affordable electricity, reducing dependence on fossil fuels.
- Economic Growth: Development of this sector can stimulate economic growth and create jobs in the region.
- Environmental Protection: Lower greenhouse gas emissions contribute to a cleaner environment for everyone.

While the potential is vast, some hurdles need to be addressed. Limited access to financing, lack of technical expertise, and environmental considerations pose challenges to development. However, with proper planning and collaboration, these hurdles can be overcome. South Africa has a wealth of renewable energy resources, and the VDM serves as a prime example. By embracing these resources and overcoming challenges, South Africa can transform its energy sector, drive economic growth, and secure a sustainable future for all.

The municipality is a mountainous topography which provides a lot of potential for headwater hydropower projects. The average annual rainfall in the municipality is 1,000 millimetres that provides a reliable source of water for hydropower generation [10],[11]. A 2017 study by the Council for Scientific and Industrial Research (CSIR) estimated the Vhembe District Municipality's small-scale hydropower potential at 100 MW [11],[13]. This potential could be used to generate electricity for local communities, businesses, and industries. The CSIR study identified several sites in the Vhembe District Municipality that are suitable for small-scale hydropower projects.

Further bolstering the case for hydropower, a recent assessment pinpointed over 1,000 potential sites within the VDM. Each of these sites has the potential to generate up to 100 kW of electricity [12],[17],[18]. The total potential capacity of these sites is estimated to be over 100 MW, and most suitable sites for small-scale hydropower generation are those that have a minimum head of 10 meters and a minimum flow of 1 cubic meter per second. The most promising rivers for small-scale hydropower generation in the Vhembe District Municipality include the Luvuvhu River, the Shingwedzi River, and the Nwanedi River [13],[14].

*Small-Scale Hydropower Potential Assessment*

Furthermore, several studies have explored methodologies for assessing small-scale hydropower potential. Common approaches include field surveys as the traditional methods involve on-site data collection, including river flow rates, topography, and potential dam locations. These methods are often time-consuming and expensive [14] – [16], [19]. In addition, the hydrological modelling is used to simulate river flow patterns and identify potential sites with sufficient water resource. However, this model requires accurate input data and can be complex to implement [20].

To support the need of small-scale hydropower (SSH) projects as the compelling solution for electricity generation and unaffected by fluctuating fossil fuel prices, numerous studies have explored the potential of SSH using GIS tools in diverse regions. Desalegn et al. (2022) employed GIS to identify potential sites for small-scale hydropower plants along Ethiopia's Fetam River basin. This research effectively demonstrated the effectiveness of GIS in evaluating various criteria for selecting optimal locations [21]. Sammartano et al. (2018) developed an approach that combines GIS tools with a hydrological model. This method allows for identifying potential locations for run-of-river plants that can achieve various power generation thresholds [22]. Korkovelos et al. (2018) conducted a study utilizing open-source geospatial datasets to assess SSH potential across Sub-Saharan Africa. Their research highlighted the potential of GIS in identifying suitable locations for renewable energy development in regions with limited resources [23]. These studies, along with the work of Jung et al. (2020), who emphasized the potential of SSH to expand renewable energy use in the context of climate change [24], demonstrate the importance of exploring and developing SSH as a sustainable energy source.

The other study conducted by the VDM in collaboration with the Limpopo Department of Economic Development, Environment and Tourism, used a variety of data sources, including topographic maps, river flow data, and environmental impact assessments [23], [25]. The study identified 1,023 sites with the potential to generate up to 100 kilowatts (kW) of electricity and the total potential capacity of these sites is estimated to be over 100 megawatts (MW), which most suitable sites for small-scale hydropower generation are those that have a minimum head of 10 meters (m), and a minimum flow of 1 cubic meter per second [26]. This could generate enough electricity to power over 100,000 households. The CSIR study identified several sites in the municipality that are suitable for small-scale hydropower projects, including the Luvuvhu River, the Nzhelele River, and the Olifants River [27],[13] – [18].

A separate study by the University of Limpopo highlighted that the Vhembe District Municipality's significant small-scale hydropower potential remains largely unrealized [27],[14] – [16]. The study found that there are several challenges that need to be addressed to develop small-scale hydropower projects in the municipality. Several hurdles hinder development,

including limited access to financing, a lack of technical expertise, and environmental considerations [25] – [27]. Moreover, by integrating various spatial datasets, GIS facilitates a more comprehensive and data-driven approach.

*Benefits of Using GIS*

Employing GIS offers several advantages for SSH potential assessment:

- Improved Site Selection: GIS allows for overlaying various datasets to identify areas with optimal water flow, suitable topography, and minimal environmental impact.
- Data-Driven Analysis: GIS facilitates data analysis and visualization, enabling researchers to make informed decisions based on a variety of factors.

Increased Efficiency: Compared to traditional methods, GIS can streamline the assessment process, saving time and resources.

Enhanced Decision-Making: Visualization tools within GIS help stakeholders visualize potential hydropower sites and their impact, facilitating informed decision-making.

While existing research suggests good potential for SSH in the VDM, further research is needed to address knowledge gaps, such as a detailed site-specific assessment focusing on specific river segments or potential dam locations within the VDM and for more granular understanding of the feasibility of projects.

By utilizing GIS, researchers can conduct a more comprehensive and data-driven assessment of SSH potential within a specific region. This approach leads to the identification of the most suitable locations for project development, maximizing the benefits of SSH for renewable energy generation. Ultimately, this research contributes to a more sustainable and reliable energy future.

*Vhembe District Municipality: Poised for Clean Energy*

The VDM in Limpopo Province is brimming with potential for small-scale hydropower development. This renewable energy source offers a compelling solution, promising multiple benefits for the region. Local communities would gain increased access to reliable and affordable electricity, reducing dependence on fossil fuels. Furthermore, small-scale hydropower development can stimulate economic growth and contribute significantly to lowering greenhouse gas emissions. With its abundant rivers and streams, Vhembe is well-positioned to harness clean, sustainable energy for a brighter future.

*Focus on Vhembe District Utilising GIS/Spatial Data*

As the result, previous studies on small-scale hydropower potential have been conducted on a national or regional scale, overlooking the specific conditions of the Vhembe District, and relied on traditional methods for hydropower potential assessment. This study zooms in on the Vhembe District, potentially providing a more detailed and localized assessment by emphasizing the use of GIS and spatial data. The approach allows for the following: -

- Data-driven analysis: GIS allows for overlaying various spatial datasets like river networks, elevation, rainfall patterns, and land use. This provides a more comprehensive picture of potential hydropower sites.
- Improved site selection: GIS tools helps identify areas with optimal water flow, suitable topography for dam construction, and minimal environmental impact.
- Enhanced decision-making: Visualization tools within GIS helps stakeholders visualize potential hydropower sites and their impact.

This study contributes to the development of small-scale hydropower in the Vhembe District by identifying specific locations with high potential for sustainable hydropower generation, providing data-driven insights for planning and development of hydropower projects, and highlighting potential environmental and social impacts for informed decision-making.

The development would have a significant positive impact on the local community and the environment, and several benefits including improve air quality, increased access to electricity for rural communities, reduced reliance on fossil fuels for electricity generation, increased economic development and creation of jobs in the region.

## 2. 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.

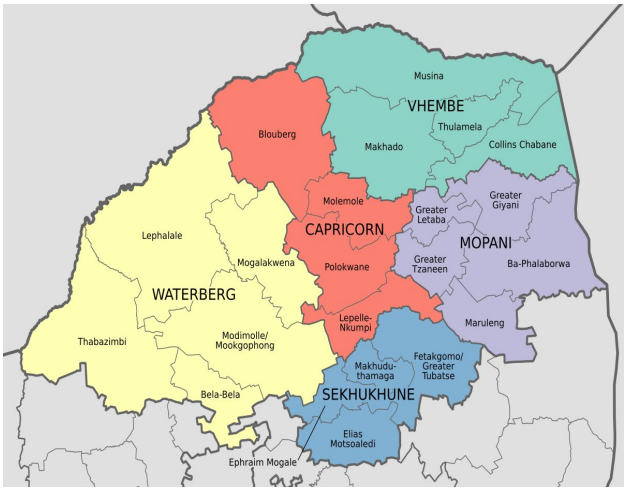


Figure 1. Area view of the Vhembe District Municipality [12]

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. 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.

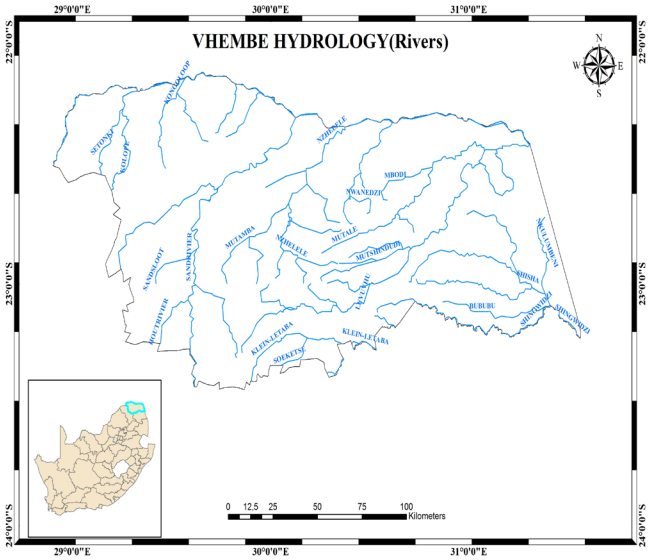


Figure 2. River network data for Vhembe District municipality

These sites have environmental impacts that include changes in water flow patterns, sedimentation, impacts on fish and other aquatic life, vegetation, and visual impacts for tourism. The data from these sources was used to identify potential sites for small-scale hydropower projects and to assess their feasibility.

## 3. 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.

## 4. 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.

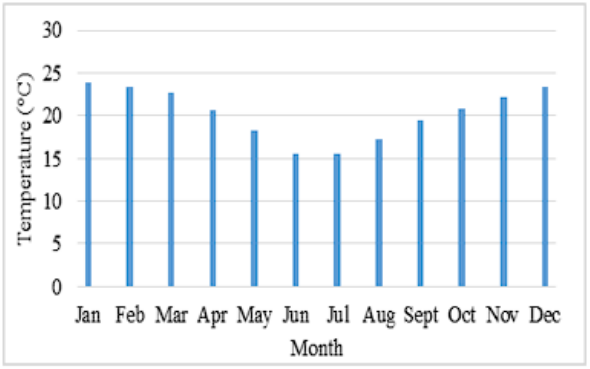


Figure 3. The monthly temperature measurement (Average - 20 °C)

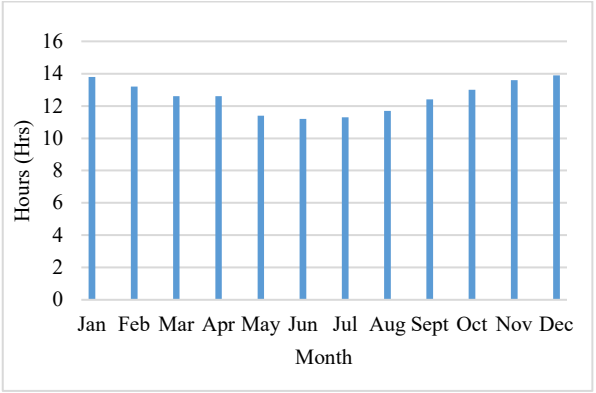


Figure 4: Average Daily Hours of Sunlight (12.5 hours)

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

| Month | 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.

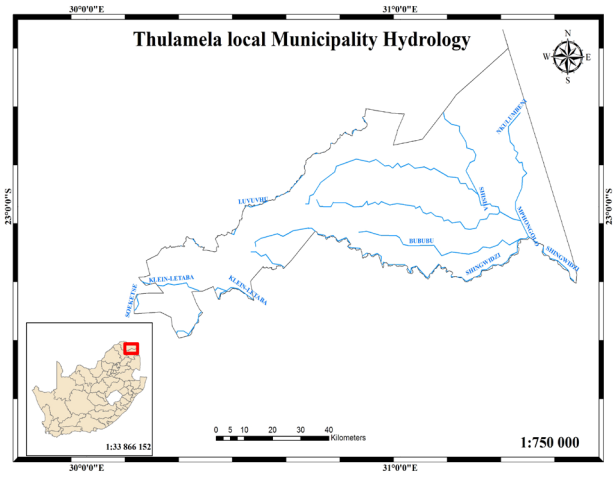


Figure 5. Thulamela local municipality hydrological data

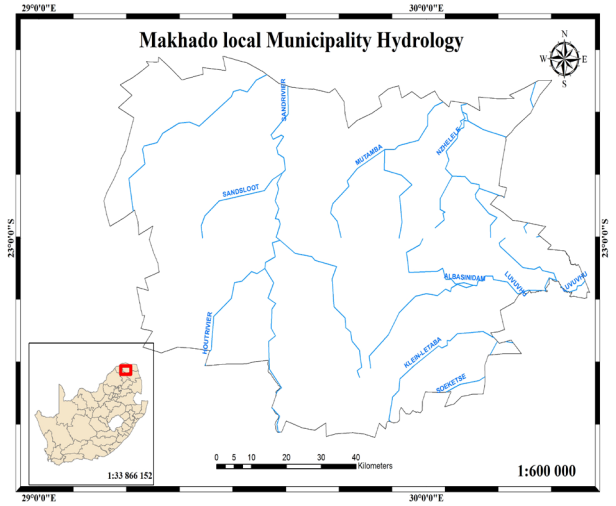


Figure 6. Makhado local municipality hydrological data

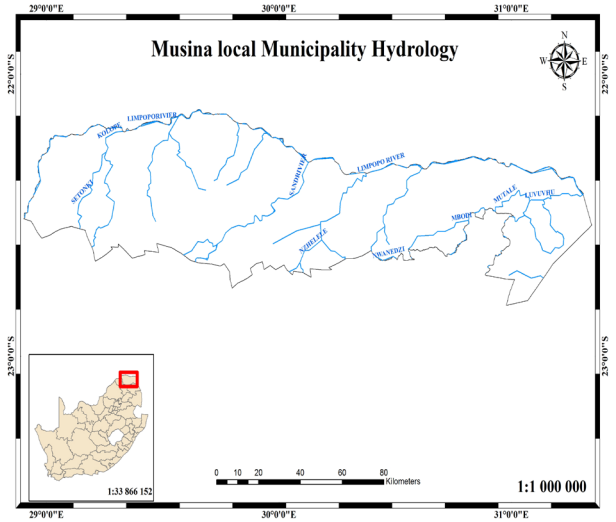


Figure 7. Musina local municipality hydrological data

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.

## 5. 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.

To refine our understanding of SSH potential in the VDM, several next steps are recommended:

- Enhanced Data Collection: Efforts to acquire more detailed precipitation data and conduct ecological surveys would improve the accuracy and comprehensiveness of the assessment.
- Economic Feasibility Analysis: An analysis of construction, operation, and maintenance costs is essential to determine the financial viability of identified SSH sites.
- Prioritized Investigation: Based on our findings, focusing on areas with the most promising SSH potential and the fewest limitations would be a productive next step.

By acknowledging these limitations and outlining clear next steps, we ensure that this GIS-based exploration provides a strong foundation for informed decision-making on SSH development in the VDM. The potential benefits of clean, renewable energy generation from SSH are significant. Further studies can help unlock this potential in a way that is both environmentally and economically responsible.

# 6. Conclusion

This study explored the potential of utilizing 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.

As discussed in the limitations section, further research can address data availability, social and environmental considerations, and economic feasibility studies. By pursuing these directions, we can gain a more comprehensive understanding of SSH potential in the VDM and pave the way for responsible and sustainable project development. In addition, it emphasizes the unique contribution of the research to the existing body of knowledge and proposes concrete policy recommendations based on the findings. It also reiterates the importance of future research directions for a more comprehensive assessment of SSH potential in the VDM.

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 utilizing 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.

Research exploring ways to integrate SSH development plans with broader regional development plans is valuable. This ensures alignment with socio-economic objectives, fosters community participation, and maximizes the overall benefits of SSH projects for the VDM. By implementing these recommendations, researchers and stakeholders can utilize GIS to its full potential for exploring and assessing SSH potential in the VDM. This will contribute to the development of a sustainable and reliable energy future for the region, while minimizing environmental and social impacts.

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

## References

[1] R.P. Tarife, A.P. Tahud, E.J.G. Gulben et al., Application of geographic information system (GIS) in hydropower resource assessment: a case study in Misamis Occidental, Philippines. Int. J. Environ. Sci. Develop. 8, 507 (2017)
[2] V. Sammartano, L. Liuzzo, G. Freni, Identification of potential locations for run-of-river hydropower plants using a GIS-based procedure. Energies 12, 3446 (2019)
[3] P. Punys, A. Dumbrauskas, A. Kvaraciejus et al., Tools for small hydropower plant resource planning and development: a review of technology and applications. Energies 4, 1258–1277 (2011)
[4] Y. Tian, F. Zhang, Z. Yuan et al., Assessment power generation potential of small hydropower plants using GIS software. Energy Rep. 6, 1393–1404 (2020)
[5] Desalegn, H., Damtew, B., Mulu, A. et al. Identification of Potential Sites for Small-Scale Hydropower Plants Using a Geographical Information System: A Case Study on Fetam River Basin. J. Inst. Eng. India Ser. A 104, 81–94 (2023). https://doi.org/10.1007/s40030-022-00692-8
[6] CSIR (2015). Assessment of the Small-Scale Hydropower Potential in the Vhembe District Municipality, Limpopo Province, South Africa. Pretoria: Council for Scientific and Industrial Research.
[7] Mandaza, T., Moyo, S., & Nkala, B. (2017). Small-scale hydropower development in South Africa: A review of the challenges and opportunities. Renewable and Sustainable Energy Reviews, 70, 1025-1035.
[8] Mavhunga, T., & Mbedzi, G. T. (2018). The potential of small-scale hydropower in the Vhembe District Municipality, Limpopo Province, South Africa. Journal of Sustainable Development, 11(1), 37-48.
[9] Mbedzi, G. T., & Mavhunga, T. (2017). Small-scale hydropower development in the Vhembe District Municipality, Limpopo Province, South Africa: Challenges and opportunities. Journal of Energy in Southern Africa, 28(2), 26-33.
[10] Mbedzi, V. T., & Maphanga, P. (2017). The potential of small-scale hydropower development in the Vhembe District Municipality, Limpopo Province, South Africa. Journal of Energy in Southern Africa, 28(2), 11-19.
[11] Mhlongo, S., & Ndou, S. W. (2016). Small-scale hydropower potential in the Vhembe District Municipality, Limpopo Province, South Africa. International Journal of Energy Economics and Policy, 6(6), 100-109.
[12] Moyo, M. N., & Maponga, T. S. (2018). Small-scale hydropower development in the Vhembe District Municipality, Limpopo Province, South Africa: A review of the environmental and social impacts. Environmental Science and Pollution Research, 25(12), 10834-10845.
[13] Moyo, M. N., & Maponga, T. S. (2019). The role of small-scale hydropower in rural development in the Vhembe District Municipality, Limpopo Province, South Africa. Renewable and Sustainable Energy Reviews, 109, 827-838.
[14] Moyo, T., & Ndou, S. W. (2019). Small-scale hydropower development in the Vhembe District Municipality, Limpopo Province, South Africa: A review of the literature. Journal of Sustainable Development, 12(1), 1-12.
[15] Ngwenya, P., & Sithole, S. (2016). Small-scale hydropower development in the Vhembe District Municipality, Limpopo Province, South Africa: A review of the challenges and opportunities. Energy Policy, 99, 364-372.
[16] Ntshangase, V., Masuku, M., & Sithole, M. (2018). The potential of small-scale hydropower in the Vhembe District Municipality, South Africa. Journal of Renewable and Sustainable Energy, 10(1), 013101.
[17] Tshivhase, T., & Mhango, K. (2019). Small-scale hydropower development in the Vhembe District Municipality, South Africa: A review of the policy landscape. Energy Policy, 133, 111295.
[18] Van Wyk, J., & Van Zyl, J. (2019). The potential of small-scale hydropower in South Africa: A review of the literature. Renewable and Sustainable Energy Reviews, 106, 91-100.
[19] Tefera, W. M., & Kasiviswanathan, K. (2022). A global-scale hydropower potential assessment and feasibility evaluations. Water Resources and Economics, 38, 100198. https://doi.org/10.1016/j.wre.2022.100198.
[20] Fasipe, O.A. & Izinyon, O.C. & Ehiorobo, J.O., 2021. "Hydropower potential assessment using spatial technology and hydrological modelling in Nigeria river basin," Renewable Energy, Elsevier, vol. 178(C), pages 960-976. https://doi.org/10.1016/j.renene.2021.06.133.

[21] [3] Desalegn, H., Damtew, B., Mulu, A. et al. Identification of Potential Sites for Small-Scale Hydropower Plants Using a Geographical Information System: A Case Study on Fetam River Basin. J. Inst. Eng. India Ser. A 104, 81–94 (2023). https://doi.org/10.1007/s40030-022-00692-8.

[22] [4] Sammartano, V., Liuzzo, L., & Freni, G. (2018). Identification of Potential Locations for Run-of-River Hydropower Plants Using a GIS-Based Procedure. Energies, 12(18), 3446. https://doi.org/10.3390/en12183446.

[23] [5] Korkovelos, A., Mentis, D., Siyal, S. H., Arderne, C., Rogner, H., Bazilian, M., Howells, M., Beck, H., & De Roo, A. (2018). A Geospatial Assessment of Small-Scale Hydropower Potential in Sub-Saharan Africa. Energies, 11(11), 3100. https://doi.org/10.3390/en11113100.

[24] Jung, J., Jung, S., Lee, J., Lee, M., & Kim, H. S. (2020). Analysis of Small Hydropower Generation Potential: (2) Future Prospect of the Potential under Climate Change. Energies, 14(11), 3001. https://doi.org/10.3390/en14113001.

[25] C. Matasane, C. Dwarika, R Naidoo (2014). Modelling the Photovoltaic Pump Output Using Empirical Data from Local Conditions in the Vhembe District. ICSEC 2014 Conference, 6 – 7 November 2014, Cape Town, South Africa.

[26] Hoogwijk, M. (2004). On the Global and Regional Potential of Renewable Energy Sources. Utrecht University, Department of Science, Technology and Society, Utrecht, The Netherlands.

[27] Malczewski, J. (2006). GIS-Based Multicriteria Decision Analysis: A Survey of Literature. International Journal of Geographical Information Science, 20, 703-726. https://doi.org/10.1080/13658810600661508.