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Concept Paper

HYDROPOWER POTENTIAL MAPPING USING HEC-HMS AND HEAD MATCHED INLET-OUTLET SITE PAIRING ALONG CLAVERIA, MISAMIS ORIENTAL RIVERBANKS

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ABSTRACT

Despite the promising hydroelectric resource potential of Claveria, Misamis Oriental, the region remains underrepresented in hydropower development due to the absence of a systematic, technology-driven assessment framework. This study develops a framework for hydropower potential mapping along riverbanks by integrating the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) with a head-matched inlet-outlet site pairing technique. This study aims to accurately identify and assess feasible hydropower sites by combining hydrologic modeling with automated spatial analysis using GIS and Python tools. HEC-HMS simulations provide detailed watershed hydrology and streamflow data, which are then processed through Python scripts within a GIS environment to automate the identification of inlet and outlet site pairs that maximize elevation head differences, ensuring optimal hydraulic potential. This approach enhances the efficiency and accuracy of detecting small-to medium-scale hydropower opportunities, thereby supporting sustainable energy resource planning. This study offers a replicable and scalable methodology for hydropower site selection and resource management, facilitating informed decision-making in renewable energy development.

CHAPTER I

INTRODUCTION

1.1 Background of the Study

Hydropower, which represents approximately 16% of global electricity generation, is acknowledged as one of the most consistent and renewable energy sources available today. As the world shifts toward more sustainable energy solutions, the Philippines presents a landscape that is ripe for hydropower development, particularly in rural regions such as Claveria, Misamis Oriental. This geographic area offers unique topographical features conducive to hydroelectric generation but remains underexplored in current hydropower assessments (Yap et al., 2021).

Historically, the Philippines has made strides in hydropower development since the 1970s, with numerous large-scale projects. However, many potential sites remain unutilized because of insufficient data and inadequate assessment methodologies (Tarife et al., 2022). The Renewable Energy Act of 2008 aimed to attract investment in renewable technologies, but the true potential of water resources in areas such as Claveria remains largely untapped (Jung et al., 2021). The incorporation of advanced tools, such as Geographic Information Systems (GIS) and Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), can significantly enhance the precision of hydropower potential assessments and address the intricate factors influencing water dynamics and availability in mountainous terrains (Chongco et al., 2022; Ghazali et al., 2024).

Current trends in renewable energy development underline the importance of automating data analyses and site assessment processes. Studies indicate that hydropower's share within the renewable sector is expected to grow; however, research emphasizes the need for automated approaches that can systematically evaluate potential hydropower sites (Bhandari et al., 2018). For instance, GIS technologies integrated with programming algorithms can streamline processes such as terrain analysis, enabling more precise identification of inlet-outlet pairings essential for efficient hydropower generation (Xuan, 2024; Agaton & Karl, 2018). Statistical analyses suggest that approximately 33% of the identified basins in the Mindanao area could support hydropower projects; however, many still lack comprehensive assessments covering the terrain and watershed hydrodynamics (Mina & Tayactac, 2024).

Notably, the gap in technical evaluation methodologies presents a substantial barrier to the effective harnessing of hydropower resources, particularly in isolated regions (Wahyuono & Julian, 2018). Prior research has highlighted the potential benefits of using hydrological models in conjunction with GIS to enhance the accuracy of site evaluations (Kiliç, 2024). Moreover, studies have effectively utilized multi-criteria analyses within GIS platforms to gauge the suitability of various locations for hydropower development. Such models allow for the cohesive visualization of environmental data, assisting decision-makers in identifying optimal site locations (Kouadio et al., 2022; Ahad & Shams, 2024).

The importance of this study is underscored by the pressing need for localized hydropower assessments that integrate comprehensive hydrological modeling with advanced GIS techniques. Current methodologies must evolve to enhance the evaluation of Claveria's unique topographical features, addressing the significant gap in existing research (Sammartano et al., 2019). This study aims to leverage programming to automate the mapping and assessment of hydropower potential in Claveria, effectively employing a hydrological model for real-time data representation and site optimization (Tauš & Beer, 2022). By executing a multi-criteria suitability analysis, this study will not only generate detailed spatial maps but also contribute significantly to the technical understanding necessary for future hydropower site selection.

Thus, this study is pivotal in addressing the gaps in hydropower assessments within Claveria, aiming to propel the search for sustainable energy solutions.

1.2 Statement of the Problem

The assessment of hydropower potential in Claveria, Misamis Oriental, remains underexplored despite the region's significant hydroelectric resource potential. Existing methodologies for hydropower site identification often lack the integration of advanced tools, such as Geographic Information Systems (GIS) and hydrological modeling, which are crucial for accurate data representation and decision-making (Sammartano et al., 2019; Kouadio et al., 2022). The absence of a comprehensive hydrological model and effective inlet-outlet pair identification hampers the ability to accurately evaluate water flow dynamics and availability, leading to missed opportunities for renewable energy generation. Without addressing this gap, the region's hydropower potential will remain untapped, ultimately prolonging reliance on fossil fuels and stalling progress toward sustainable energy goals (Butt et al., 2023).

Moreover, prior research has largely focused on generalized evaluations without local specificity, failing to incorporate local terrain features and contextual hydrological data relevant to Claveria (Spanoudaki et al., 2022). This oversight can significantly affect the viability of proposed hydropower sites, as localized environmental factors often dictate their effectiveness. Thus, a research gap exists regarding a methodical approach to hydropower potential mapping and suitability analyses that leverage contemporary technologies, such as Python programming, within a GIS framework. This study aims to fill this gap by automating the mapping and assessment process, thereby providing detailed spatial maps of potential hydropower sites that can guide future energy projects in Claveria, ultimately bolstering the region's commitment to renewable energy development (Tamaddun et al., 2023).

1.3 Objectives of the Study

The main objective of this study is to automate the mapping and assessment of hydropower potential in Claveria, Misamis Oriental, through the integration of Geographic Information Systems (GIS) technology and Python programming. This approach will facilitate the generation of accurate and actionable data necessary for identifying viable hydropower sites in the region. The specific objectives of this study are as follows:

1. To implement a hydrological model using the HEC-HMS framework to conduct detailed hydrological and terrain analyses of the Claveria watershed, thereby accurately representing water flow dynamics and availability in the area.

2. To determine inlet-outlet pairings through the development and application of a Python algorithm, which will enhance the hydropower site assessment process by optimizing location selections based on water flow characteristics.

3. To conduct a multi-criteria suitability analysis within the GIS platform, which will evaluate and generate detailed spatial maps of potential hydropower sites throughout Claveria. This analysis will integrate all relevant data, allowing for a comprehensive assessment of site suitability.

1.4 Significance of the Study

The study on hydropower potential mapping using HEC-HMS and head-matched inlet-outlet site pairing along the Claveria Riverbanks will significantly benefit various stakeholders, including researchers, policymakers, and environmental planners. For researchers and students in the fields of renewable energy and hydrology, this study serves as a vital resource, enhancing theoretical knowledge through advanced methodologies and providing a framework for future research on hydropower assessment (Belivestre & Panganoron, 2024). The integration of GIS technology and Python programming is particularly beneficial for academic advancements in understanding complex hydrological processes (Arefiev et al., 2015).

For policymakers, this study aligns with the United Nations Sustainable Development Goals (SDGs), such as SDG 7, which focuses on affordable and clean energy, and SDG 13 for climate action (Kouadio et al., 2022). By providing precise hydropower potential assessments, this study supports the Philippine government's National Renewable Energy Program, advocating for a greener energy landscape and reduced reliance on fossil fuels. The potential sites identified in this study could facilitate the development of localized energy projects, which are crucial for energy security and sustainability in the region (Bhattarai et al., 2024).

Practically, the study's findings can guide investments in hydropower infrastructure, directly impacting local communities by promoting energy accessibility, reducing energy poverty, and supporting socio-economic development (Torrefranca et al., 2022). The theoretical contributions related to applied hydrological modeling and spatial analyses have broader implications beyond academia, driving innovations in renewable energy development strategies in the Philippines and similar contexts (Ahad & Shams, 2024).

Overall, this research not only addresses the assessment gap in hydropower potential in Claveria, but also contributes to advancing sustainable energy practices, ultimately supporting the country’s commitment to transitioning towards a low-carbon economy (Wangchuk et al., 2024).

1.5 Scope and Delimitations

1.5.1 Scope

This study focuses on the hydropower potential mapping of the Claveria Riverbanks in Misamis Oriental, specifically targeting the hydrological modeling and site assessment processes using advanced GIS technology and Python programming. The geographic scope is limited to the Claveria Watershed, where hydrological and terrain analyses will be implemented to accurately represent water flow dynamics and availability. This study will utilize the HEC-HMS framework to simulate hydrological processes, thereby ensuring detailed and localized assessments. The timeframe of the study is contemporary, leveraging the most recent data that reflect current hydrological conditions while considering seasonal variations and climatic impacts relevant to hydropower generation (Zhou et al., 2018; Spanoudaki et al., 2022).

This research will encompass specific factors such as inlet-outlet site pairing and multi-criteria suitability analyses, which are critical for accurately identifying viable hydropower locations. However, this study does not include socioeconomic assessments or the implications of hydropower development on local communities, emphasizing a strictly technical evaluation. This focus on purely hydrological and geospatial aspects is intended to provide clear and actionable insights for future energy projects while mitigating the complexity associated with socioeconomic factors that may detract from the primary objectives (Magnúsdóttir & Winkler, 2017; Ruz et al., 2024).

1.5.2 Delimitations

The delimitations of this study encompass the intentional exclusion of socioeconomic factors and environmental impact assessments related to hydropower development. This choice was made to concentrate on the technical processes involved in hydropower potential assessment, which are crucial for enhancing localized energy strategies. By focusing solely on hydrological modeling, site suitability analysis, and data mapping, this study seeks to provide a clear framework that can readily inform policymakers and energy planners without the ambiguity that socio-economic considerations might introduce (Spanoudaki et al., 2022; Zhang et al., 2022).

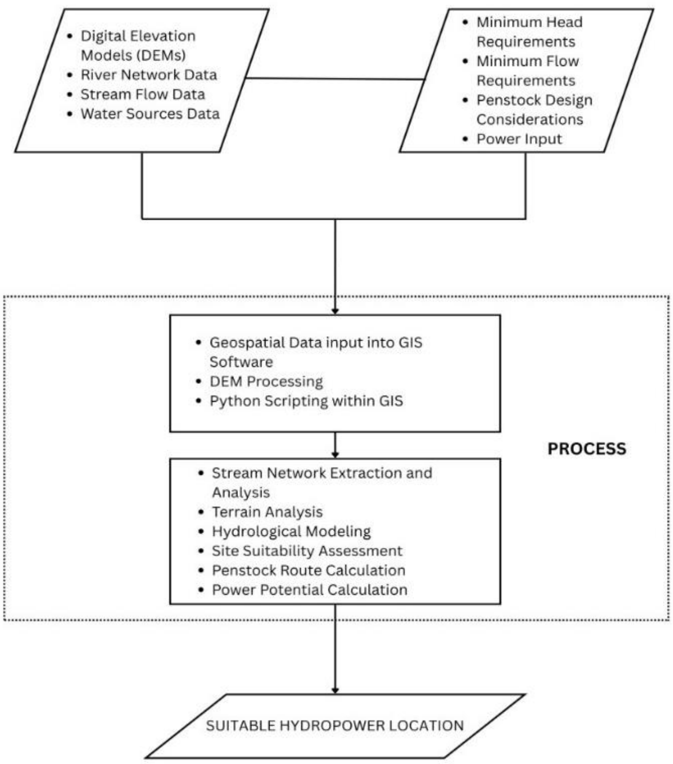
Furthermore, the study does not extend its scope to areas outside Claveria, meaning that the findings may not be directly applicable to different regions or basins unless similar methodologies and local conditions are considered. Limitations may arise from the availability and accuracy of hydrological data, as well as computational capabilities concerning the sophistication of the GIS tools employed in the analysis (Zhang et al., 2022; Gernaat et al., 2017). These factors may influence the generalizability of the results to wider hydropower contexts or different geographic terrains; however, they remain within the established boundaries set by the study's focused objectives.

1.6 Conceptual Framework

The conceptual framework for this study on hydropower potential mapping focuses on integrating hydrological modeling and Geographic Information Systems (GIS) to enhance the site assessment process for potential hydropower locations. The framework is based on the hydrological cycle, emphasizing the critical relationship between rainfall, runoff, and water resources. It utilizes the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) to simulate hydrological dynamics, enabling the assessment of water flow, availability, and site suitability for hydropower generation (Leta et al., 2022). Furthermore, the integration of Python programming within the GIS platform facilitates the automation of data analysis and mapping processes, allowing for efficient inlet-outlet pairing, which is necessary for optimal hydropower site identification.

This conceptual framework is relevant because it provides a structured approach to assess Claveria's hydropower potential. By capturing and analyzing data that reflect watershed characteristics, actionable insights can be obtained to guide the technical evaluation of hydropower development (Spanoudaki et al., 2022). The expected outcomes include enhanced visualization of hydropower resources and the identification of suitable sites based on hydrological criteria and terrain analysis. Therefore, this framework not only informs the study's methodology but also helps interpret the findings in the context of localized hydropower potential, paving the way for informed decision-making in energy resource management (Bista et al., 2021).

Fig 1. Conceptual Framework for Hydropower Potential Mapping and



1.7 Theoretical Framework

1.7.1 Power Generation Principles

The assessment of hydropower potential in this study is fundamentally rooted in the principles of fluid mechanics and energy conversion. The theoretical power output (P) from a run-of-river hydropower plant is calculated using the following formula:

Equation 1

$$P = \rho \times g \times Q \times H \times \eta$$

Where:

- P = Power output (Watts)
- ρ = Density of water (1000 kg/m^3)
- g = Acceleration due to gravity (9.81 m/s^2)
- Q = Flow rate (m^3/s)
- H = Effective head (m)
- η = Overall efficiency of the system (typically 0.7-0.9)

This formula serves as the foundation for calculating the energy potential of identified sites within Claveria, allowing for a quantitative evaluation of their viability based on hydrological and topographical data. The automated GIS-based approach of this study will precisely derive the Q and H values from the gathered spatial datasets, feeding them into this theoretical model to estimate potential power output.

CHAPTER II

REVIEW OF RELATED LITERATURE

The assessment of hydropower potential using advanced methodologies, such as Geographic Information Systems (GIS), the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS), and Automation of Head Determination in hydropower systems, is crucial for enhancing water resource management in the Philippines. This review explores relevant local studies that converge on these themes, emphasizing analytical techniques and frameworks that are adaptable to the Claveria, Misamis Oriental context.

Local investigations focusing on hydrological modeling provide insights into the specific methodologies that are suited for the Philippine setting. Cacal et al. conducted an analysis in the Irawan watershed in Palawan, demonstrating the integration of GIS with the HEC-HMS model for extreme event-based rainfall-runoff simulation. Their study effectively utilized geospatial analyses to derive hydrological parameters influenced by soil type and land use, which are crucial for producing reliable hydrological inputs (Cacal et al., 2023). This methodology can be adapted to the Claveria area, where topography and land classifications influence river flow dynamics.

Moreover, Pulcha et al. conducted a hydrological assessment using HEC-HMS and HEC-RAS models to address the hydrological challenges associated with riverine infrastructure. Their approach incorporated field data and remote sensing techniques to calibrate hydrological models, providing insights relevant to addressing hydropower challenges in Claveria, including flooding and infrastructure resilience (Pulcha et al., 2023). This substantiates the need for empirical calibration and validation in local hydrological models to ensure that simulations closely reflect the observed variability in river systems influenced by climatic and anthropogenic factors.

The importance of local application and its implications for hydropower prospective sites were further substantiated by the findings of Sempio et al., who estimated outflows in the Iponan watershed using hydrometeorological techniques integrated with HEC-HMS. Their work emphasized the necessity of utilizing local data for effective runoff and hydropower estimations, showcasing the challenge of balancing model-driven predictions with empirical observations (Sempio et al., 2015). The methodologies presented offer a blueprint for establishing hydropower potential in Claveria through an adapted HEC-HMS modeling approach.

Furthermore, Jayadeera and Wijesekera's research on the Ratnapura watershed in Sri Lanka provides valuable insights into the optimization of hydrological modeling for water management. Their evaluation of HEC-HMS for flood management under varying climatic scenarios presents opportunities for similar applications in the Philippine context, particularly regarding flood peak estimations (Jayadeera & Wijesekera, 2019). This comparative analysis highlights the need for local practitioners to engage in continuous learning from global best practices, particularly in adapting modeling frameworks to local hydrological conditions.

Nujhat et al. extended this theme by employing HEC-HMS in the context of sustainable water resource management in the Gumti River Basin in Bangladesh, demonstrating the utility of hydrological models in simulating rainfall-runoff dynamics under various land-use scenarios. Their analysis highlighted the adaptive capacity of hydrological modeling frameworks to integrate changes in land use and climate, allowing for a more robust approach to hydropower site selection, which is essential for areas such as Claveria (Nujhat et al., 2024). This emphasizes the potential of local hydrological models to inform sustainable energy strategies and enhance community resilience amid changing climatic conditions.

In another study, Leta et al. examined the effects of land use and land cover changes on hydropower generation in the Blue Nile River Basin. Their work underscored the significance of incorporating ecological dynamics when modeling hydrological processes, a perspective that holds value for similar studies within the watershed management frameworks in Claveria (Leta et al., 2022). The challenges posed by ecological and anthropogenic changes necessitate a nuanced approach to hydropower assessments that evolve in line with land-use modifications, ensuring a balanced approach to energy and environmental sustainability.

In contrast, Abera et al. focused on operational strategies for hydropower reservoirs facing climate change impacts, emphasizing the need for adaptive management practices in hydropower systems. Their research highlights the interplay between hydrological modeling and ecological management, signifying the importance of developing hydropower systems that are robust against climatic volatility and adaptable to environmental changes experienced in local contexts (Abera et al., 2018).

Moreover, the application of integrated hydrological modeling systems, as discussed by Konečná et al., in assessing episodic hydrological events aligns with the need for advanced modeling techniques to understand the nuances of hydrological dynamics in specific catchments pertinent to Claveria (Konečná et al., 2020). Their approach, which utilizes HEC-HMS with real-time environmental data, can significantly improve the accuracy of hydropower potential assessments by minimizing uncertainty from extreme weather events.

The body of local research, alongside international comparisons, solidifies a comprehensive understanding of how insights drawn from diverse hydrological models can enrich hydropower assessments in Claveria, Misamis Oriental, Philippines. This demonstrates an evolution in modeling, necessitating adaptations to local contexts while leveraging global knowledge to improve energy sustainability within the region. Ultimately, the synthesis of these research efforts points toward developing a multidimensional framework for hydropower potential mapping that addresses not only the technical aspects but also the underlying hydrological signatures that are unique to the Philippine landscape.

Furthermore, hydropower potential assessment significantly relies on accurately determining the hydraulic head, which plays a vital role in estimating the energy-generation capacity of river systems. The automation of head determination can enhance the efficiency and accuracy of hydropower evaluations, making it essential to explore local studies that address these methodologies. This literature review synthesizes various relevant local references that elaborate on techniques used for automating head determination in hydropower potential assessments, providing a nuanced understanding of the state-of-the-art practices and technologies applied in the Philippines.

Wahyuono and Julian noted the challenges in estimating hydro energy potential, specifically emphasizing that traditional calculations often neglect kinetic energy contributions arising from water flow dynamics. Their findings indicate that incorporating both potential and kinetic energy components is crucial for comprehensive hydropower assessment methodologies (Wahyuono & Julian, 2018). This critical insight highlights the necessity for accurate calculations of head based on not only static measurements but also flow conditions, an approach that can strengthen hydropower project feasibility studies in local river systems.

Similarly, Bayazıt et al. focused their investigation on small-scale hydropower plants and their relationship with geographic information systems (GIS). They demonstrated that the integration of GIS improves the identification of potential hydropower sites through spatial analysis, which is crucial for determining the hydraulic head at various locations along river spans (Bayazıt et al., 2017). Additionally, they documented methods for using spatial data to calculate river discharge and assess head, thereby providing a framework for future studies aimed at increasing automation in head measurement techniques.

Moreover, the research conducted by Sammartano et al. discussed a GIS-based methodology to effectively identify potential run-of-river hydropower plant locations. Their study elucidated how automated procedures for head determination could integrate hydrological modeling with river flow estimations to optimize site selection (Sammartano et al., 2019). This approach exemplifies how the automation of head determination can be crucial for scaling up hydropower generation, particularly in developing regions of the Philippines with abundant river systems.

In the context of micro hydropower system design, Albreem and Aspan emphasized that a rigorous approach to identifying head and flow rates is critical for determining site potential (Albreem & Aspan, 2018). Their study highlighted the importance of using computational tools to automate hydropower assessments, facilitating rapid evaluations that can accommodate the local peculiarities of water flows and topography. This framework underscores the importance of creating automated tools that help streamline the assessment process and ensure reliable outputs for renewable energy projects in resource-scarce environments.

Kretschmer et al. explored automation in hydropower operational conditions, outlining how advanced computational techniques can enhance energy production by reconciling hydraulic data inputs with operational feedback (Kretschmer et al., 2015). Such mechanisms are essential for improving the economic efficiency of hydropower operations, particularly in river systems, where natural fluctuations influence head conditions and energy yield.

Building on these concepts, Bernardes et al. reviewed how machine learning optimization can be harnessed to streamline the operational facets of hydropower generation, including real-time head calculations (Bernardes et al., 2022). Their findings suggest that integrating intelligent analytical frameworks can augment traditional hydrologic models, reinforcing the automation possibilities in head determinations. Implementing machine-learning algorithms in hydropower assessments could lead to smarter systems capable of responding to dynamic environmental conditions and ensuring the optimization of hydro potential.

Further emphasizing automation in hydropower assessments, Edeoja et al. elucidated the importance of head determination in predicting net head and flow rates within simplified pico hydro systems (Edeoja et al., 2018). They focused on developing techniques for the accurate assessment of hydropower potential through site-specific considerations, advocating for automated systems capable of delivering precise measures of head losses and energy yields.

Moreover, Torrefranca et al. undertook a comprehensive study that combined GIS and spatial analysis with automation, making significant strides in identifying hydropower potential in riverine systems, such as those in Bohol. Their methodologies illustrate the synergy between GIS technologies and automated modeling systems in determining the hydraulic parameters necessary for effective site location assessments (Torrefranca et al., 2022). This study provides a pertinent foundation for conducting similar investigations in regions such as Claveria, where local terrain and hydrological conditions can significantly guide automated head analysis.

Finally, Yang et al. explored a mixed-integer linear programming model for optimizing hydropower operations, highlighting structured approaches to meet operational demands, such as head-dependent constraints (Yang et al., 2020). Their work indicates that automation can lead to more efficient operational strategies for hydropower facilities by dynamically adjusting the head and output in relation to demand profiles.

The integration of automation in head determination for hydropower potential assessment represents a significant advancement in the Philippines' renewable energy landscape. The synergy of GIS technologies, machine learning, and empirical modeling can significantly enhance the accuracy and efficiency of hydropower evaluations, particularly in complex hydrological settings such as Claveria in Misamis Oriental. By drawing from these local studies, it becomes evident that constructing a pathway for sophisticated methodologies that incorporate automated systems could yield substantial benefits towards realizing the Philippines' hydropower potential and promoting sustainable energy development.

Geographic Information Systems (GIS) have proven invaluable in hydropower potential assessment, particularly in the Philippines, where biodiversity and renewable energy are critical considerations. A noteworthy study by Sahu and Prasad showcased the application of integrated GIS tools to assess the hydropower potential in the Hasdeo River catchment in Chhattisgarh, India. Their research emphasized the incorporation of various geospatial parameters, such as elevation, rainfall, soil quality, and land use, in GIS analyses Sahu & Prasad (2018). By leveraging these datasets within a GIS framework, researchers have systematically identified potential hydropower sites based on multiple criteria, thereby enhancing both efficacy and efficiency in project planning. This method is relevant for similar assessments being developed in the Philippines, where analogous geophysical and environmental factors can optimize the identification of hydropower sites.

Torrefranca et al. focused on integrating GIS with landscape dynamics to identify optimal small-scale hydropower locations in Bohol, Central Philippines. Their approach highlighted the effectiveness of spatial visualization tools in assessing environmental impacts and the feasibility of hydropower projects (Torrefranca et al., 2022). By applying GIS to spatially analyze topographical data, hydrological criteria, and ecological sensitivities, their work not only informed site selection but also underscored the importance of sustaining biodiversity while pursuing renewable energy goals. This integrative approach could similarly enhance hydropower assessments in Claveria, Misamis Oriental, promoting environmental stewardship alongside energy development.

Kouadio et al. provided an insightful case study on the use of hydrological models and geospatial tools to evaluate hydropower potential in the White Bandama watershed of Côte d'Ivoire. Their findings underscored the collaboration between hydrological models and GIS, yielding comprehensive insights into watershed behavior (Kouadio et al., 2022). Such strategies resonate within the Philippine context, where the use of GIS alongside hydrological simulations can identify potential hydropower sites that are viable and considerate of local water dynamics.

Palla et al. highlighted a GIS approach tailored to assess mini hydropower potential across varying landscapes. Their research emphasized the integration of catchment morphometric analysis and hydrological modeling within a GIS platform to facilitate site evaluations based on crucial indicators such as topography and hydrological flow (Palla et al., 2016). This methodology can serve as a model for future studies in the Philippines, reinforcing the utility of GIS in promoting sound project decision-making processes by effectively utilizing local data.

The use of GIS as a decision-support tool in hydropower planning was elaborated by Butt et al. They developed a location search algorithm for the Hunza River Basin in Pakistan and deployed GIS to evaluate high-potential hydropower sites through a systematic spatial analysis framework (Butt et al., 2023). This study elucidates the versatility of GIS in conducting spatial decision-making processes in hydropower assessments, highlighting the need for Philippine research to adopt similar systematic methodologies that facilitate comprehensive evaluations.

In terms of methodological advancement, Kayastha et al. demonstrated a GIS approach for the rapid identification of run-of-river hydropower potential sites through an expansive search methodology across the Bhote Koshi watershed in Nepal. Their innovative approach identified numerous highly potential sites while minimizing the resource-and time constraints typical of conventional assessment methods (Kayastha et al., 2018). This model can inspire improvements in hydropower site evaluations in the Philippines, emphasizing the potential of GIS to streamline the site selection process and enhance the efficiency of renewable energy development.

Transitioning to applications of multi-criteria analysis (MCA), Vassoney et al. examined the integration of MCA with GIS for sustainable hydropower planning in Cameroon. This technique enables a rigorous evaluation of different hydropower projects by weighing environmental, social, and economic factors accordingly (Vassoney et al., 2017). Adopting such methods could be instrumental in the Philippines for aligning hydropower development with ecological sustainability and community interests and embedding participatory approaches into project planning.

The development of effective assessment frameworks was illustrated in an investigation by Chelelgo et al., who leveraged GIS to identify micro hydropower potential sites for climate change mitigation within the River Perkerra catchment. Their approach demonstrated how GIS can be integrated with hydrological models to effectively ascertain potential sites (Chelelgo et al., 2016). Given the current challenges posed by climate change, the utilization of GIS tools in the Philippines can catalyze adaptations to renewable energy strategies, ensuring the sustainability of hydropower generation.

Finally, Dilnesa adopted GIS and hydrological modeling to assess hydropower potential across the Temcha watershed in the Blue Nile Basin. Their analysis demonstrated how GIS facilitates the assessment of temporal and spatial variations in hydropower, showcasing its utility in generating detailed evaluations (Dilnesa, 2022). Such methodologies can augment local assessments in the Philippines, enabling stakeholders to visualize hydropower potential alongside hydrological and ecological conditions, thus fostering informed decision making.

This proves that GIS plays a crucial role in enhancing hydropower potential assessment methodologies, offering powerful tools for spatial analysis, data integration, and visualization that cater to the local context. The highlighted references reflect the diversity of applications within hydropower assessments and reinforce the necessity of leveraging GIS technologies to facilitate informed decision-making in the Philippines' renewable energy sector. As the nation moves towards optimizing its hydropower potential, integrating robust GIS-based methodologies will be essential to ensure sustainable energy development that accommodates ecological balances and community needs.

In addition, multicriteria site suitability analysis has garnered increasing attention across various research fields, including environmental science, urban planning, and renewable energy development. In particular, hydropower potential assessments in the Philippines show promise for employing multicriteria decision-making (MCDM) techniques alongside Geographic Information Systems (GIS) to enhance the precision and reliability of site selection processes.

Bojer et al. highlighted that various multicriteria decision-making techniques, particularly the Analytic Hierarchy Process (AHP), have been employed to address site selection challenges in multiple domains Bojer et al. (2023). Their insights highlight a significant gap in the systematic application of these techniques in the Philippine context, particularly for hydropower development. There is a pressing need to validate context-driven methodologies based on the unique socioeconomic and ecological aspects of local hydropower assessments.

Additionally, Yao et al. stressed that using multicriteria analysis in isolation has limitations and recommended integrating GIS to enhance the results in site selection (Yao et al., 2024). Local studies frequently overlook the combination of GIS and MCDM frameworks in hydropower assessments.

The integration of spatial analytic capabilities with multicriteria decision-making can assist local stakeholders in optimizing site selection processes for hydropower plants, considering critical factors such as biodiversity, land use, and community impacts that are often overlooked in traditional assessments.

Similarly, Dwivedi et al. examined site suitability for municipal solid waste management systems using AHP as a multicriteria decision approach (Dwivedi et al., 2024). Their study showcased the utility of MCDM frameworks for determining optimal locations for complex projects, an approach that could also be applied to hydropower site assessments. However, the absence of local applications utilizing these methodologies to assess regional hydropower potentials indicates a gap in employing robust decision-making frameworks for energy planning in the Philippines.

In urban planning, Lai and Low integrated multicriteria analyses to evaluate site suitability for accessible play spaces in densely populated areas (Lai & Low, 2019). Applying similar frameworks to hydropower site selection could refine the assessment process by addressing the social implications of hydropower development for local communities. There is an opportunity to explore the intersectionality of environmental, economic, and social factors to construct a holistic approach that embraces the discourse on environmental justice and fosters sustainable energy development aligned with community needs.

Htoo et al. utilized GIS for cluster and suitability analyses of agricultural waste treatment facilities, emphasizing the necessity of geospatial considerations in site selection (Htoo et al., 2022). This focus on geospatial analysis underscores the potential for adopting similar techniques to enhance hydropower assessments in the Philippines and other developing countries. A notable gap exists in leveraging geospatial tools to identify hydrological features, land use patterns, and socio-environmental constraints within the local context, indicating the necessity for refined methodologies that fully embrace GIS capabilities in hydropower site suitability analyses.

Susiati et al. demonstrated the application of multicriteria analysis for evaluating the suitability of sites for nuclear power plants in Indonesia (Susiati et al., 2022). This systematic evaluation of risks through multicriteria decision-making can inform hydropower site assessments in the Philippines, particularly as climate risks and the environmental impacts of hydropower development are becoming increasingly significant. Their findings highlight the importance of incorporating disaster risk management alongside site selection processes, especially in regions prone to natural calamities, such as earthquakes and typhoons.

The analysis conducted by Łaska on the determination of wind farm locations using multicriteria methods signifies the applicability of MCDM frameworks across various energy sectors (Łaska, 2020). This adaptability illustrates the broader applicability of these frameworks to hydropower assessments within the Philippines, highlighting the limited application of such frameworks specifically for hydropower site suitability amidst rapidly evolving renewable energy contexts, which can prevent stakeholders from fully optimizing suitable locations for sustainable energy generation in the Philippines.

Prasai's exploration of web-based tools for spatial multicriteria analysis emphasized the increasing importance of technological advancements in decision-making processes (Prasai, 2022). Developing an integrated platform could equip stakeholders with the tools necessary to conduct site suitability analyses for hydropower efficiently. The current gap is the slow adaptation of such technologies to local contexts, necessitating user-friendly, localized decision support systems capable of facilitating informed energy planning through effective information aggregation.

Sheoran and Parmar discussed the complexities associated with landfill site selection using GIS and MCDM techniques to enhance decision-making processes (Sheoran & Parmar, 2020). This approach highlights the opportunities for similar studies in hydropower assessments, which frequently encounter numerous environmental challenges. Addressing the gaps in the application of multicriteria decision-making strategies within the hydropower sector will require a structured approach that integrates engineering, ecological, and socio-economic perspectives to inform sustainable energy development decisions.

Indeed, the existing literature offers substantial insights; however, definite gaps remain, particularly regarding methodologies and technologies that can enhance hydropower metrics, site evaluations, and overall energy management strategies.

Zhou et al. emphasize how varying data quality can significantly impact the estimations of gross hydropower potential, particularly with respect to runoff data (Zhou et al.,2015). In the Philippines, where hydrological datasets may not be as extensively developed as in other regions, the accuracy of these assessments is paramount. There is a gap in local studies that adequately address variations in runoff estimation methods. By recognizing and calibrating the local context and runoff variability, future research could significantly improve hydropower potential assessments, ensuring that they align with empirical field data specific to Philippine watersheds.

Kouadio et al. emphasized the necessity of hydrological modeling and geospatial tools to evaluate hydropower potential but admitted the absence of comprehensive hydrological analyses in their findings (Kouadio et al., 2022). Local studies must bridge this gap by integrating GIS techniques with robust hydrological models to enhance the accuracy and reliability of hydropower assessments. A framework that supports both geospatial and hydrological aspects can significantly contribute to the successful development of hydropower projects in the region.

Finally, Arefiev et al. discussed the potential benefits of automating methodologies for estimating hydropower potential (Arefiev et al., 2015). Although automation can streamline data analysis, local hydropower assessments often rely on manual techniques that introduce delays and discrepancies. The research gap entails developing automated assessment methods through GIS frameworks tailored to the Philippine context, which can effectively sample vast geographical extents while maintaining data integrity and analytical precision.

The exploration of innovative methodologies such as Geographic Information Systems (GIS), Python algorithms, and multicriteria site suitability analysis in hydropower potential assessments exemplifies significant advancements in energy resource management in the Philippines. Although foundational research exists, there remain considerable gaps in effectively applying these methodologies to optimize hydropower utilization, which is essential to address the country's pressing energy demands.

The strategic use of GIS has been well documented, particularly in the site identification of hydropower plants. However, many studies have not integrated GIS capabilities with robust multicriteria decision-making frameworks. Such integration would facilitate comprehensive evaluations of potential sites based on environmental, economic, and social metrics that are crucial for sustainable development.

Moreover, the use of Python algorithms to automate the inlet-outlet pairing process represents a valuable opportunity to enhance operational efficiency. Automating data handling and decision-making using Python can streamline processes, enabling stakeholders to make informed decisions while improving overall infrastructure management.

The potential for multicriteria site suitability analysis to transform site selection methodologies in hydropower development lies in its ability to address multidisciplinary factors, including ecological integrity and community impacts. By adopting a more dynamic approach, researchers can foster energy strategies that are both sustainable and socially acceptable to the local population.

In conclusion, the collaboration between GIS, Python, and multicriteria analysis is pivotal for optimizing hydropower potential assessments in the Philippines. Addressing existing research gaps and enhancing methodological frameworks will ensure that the country's energy landscape evolves in alignment with sustainability and community welfare goals. Future studies should aim to integrate these methodologies comprehensively, which is vital for developing resilient hydropower solutions that bolster energy security and contribute to the overarching goals of environmental protection and social equity.

CHAPTER III

METHODOLOGY

This study adopts a quantitative Geographic Information System (GIS) based methodology, employing numerical data alongside rigorous statistical analyses to examine and visualize spatial phenomena. This approach enables the systematic measurement, quantification, and spatial assessment of factors in hydrological and topographical characteristics. By leveraging these analytical techniques, this research endeavors to identify and evaluate prospective sites for hydropower development in Claveria, Misamis Oriental.

The methodology employs spatial analysis techniques to process data essential for hydrological modeling, utilizing GIS extensions and specialized tools tailored for precise data acquisition. This study integrates multi-criteria decision analysis (MCDA) to systematically evaluate the study area, enabling the ranking of potential sites based on measurable and objective parameters. Such an approach is particularly appropriate for hydropower site selection, as it facilitates the integration of heterogeneous spatial datasets and the execution of complex terrain analyses required to identify optimal sites characterized by favorable combinations of hydraulic head and flow within Claveria, Misamis Oriental, Philippines.

This study is exploratory and analytical in nature, and aimed to identify potential hydropower sites. It also analyzes the interrelationships among geographical, hydrological, topographical, and infrastructural factors that influence the site suitability. Furthermore, this study adopts an applied approach by developing a practical, web-based decision support system to aid future hydropower development planning within the basin.

The research process adheres to a systematic workflow, commencing with the acquisition of geospatial data for Claveria, Misamis Oriental, followed by comprehensive topographic and hydrological analyses. The process culminated in the creation of a decision support tool designed to assist stakeholders involved in hydropower development within the watershed.

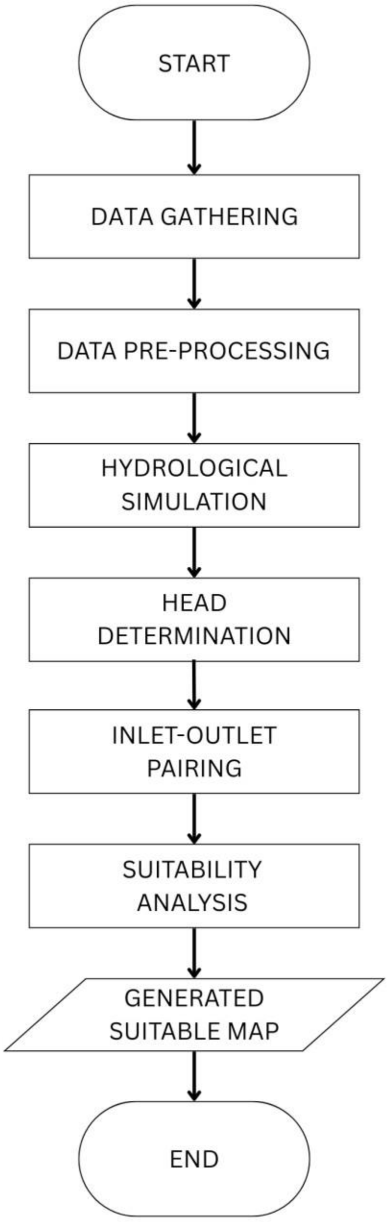


Fig 2. Study Design Flowchart illustrating key concepts and relationships in this study.

3.1 Data Gathering

3.1.1 Study Area

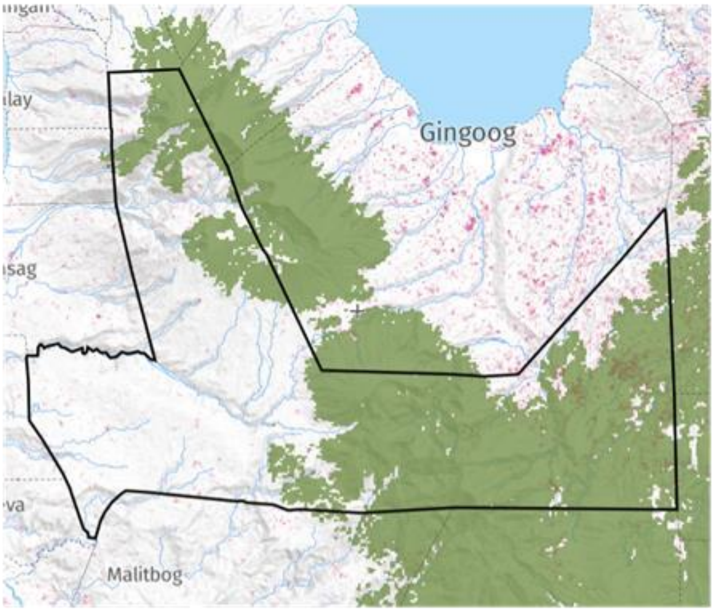


Fig 3. Claveria, Misamis Oriental

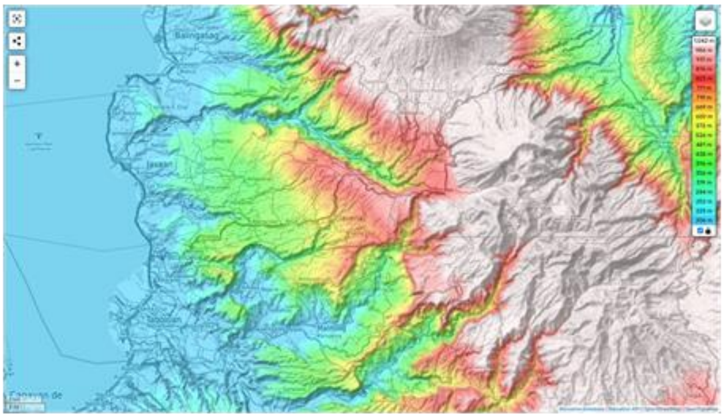


Fig 4. Claveria, Misamis Oriental Topographic Map

Claveria is a landlocked municipality located in the northern part of Misamis Oriental, Northern Mindanao, Philippines, covering an area of approximately 825 square kilometers, making it the largest municipality in the province and accounting for about one-third of its total land area. It is geographically bounded by the municipalities of Villanueva and Gingoog City to the north and northwest, Bukidnon Province to the south, and Agusan del Norte to the east.

Topographically, Claveria is characterized by a predominantly rugged and mountainous terrain, with elevations ranging from 255 m to a maximum of approximately 950 m above sea level, and an average elevation of approximately 663 m. The landscape features gently rolling hills, steep slopes, cliffs, and escarpments, with a complex topography that includes both broad smooth areas and highly dissected terrain.

3.1.2 Data Requirements

This study uses spatial and climate datasets to characterize the Claveria watershed and support GIS-based hydropower modeling. The key data types include topography (DEM), hydrometeorological data, land cover, soil, hydrography, administrative boundaries, and infrastructure. Tarife et al. similarly noted that hydropower assessment requires a Digital Elevation Model (DEM), land use-land cover, soil map, watershed boundary, and weather data [2]. Each dataset is sourced from free repositories and preprocessed in GIS before use in HEC-HMS.

A. Topographic Data

High-resolution terrain data are required to compute the slopes, flow paths, and hydraulic heads. Digital Elevation Models (DEMs) will be acquired from national LiDAR programs or global sources. The DEM must be projected and hydrologically conditioned to ensure a continuous flow.

• **Digital Elevation Model (DEM)**

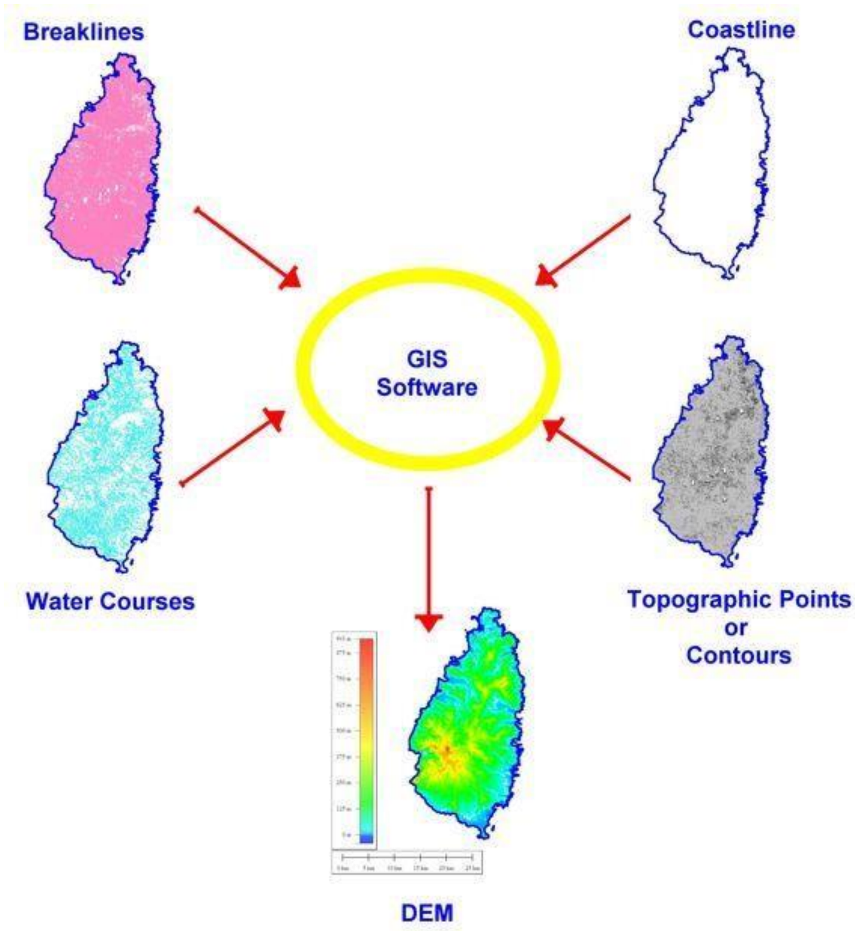


Fig 5. Generation of a Digital Elevation Model (DEM) from various GIS data layers.

The development of Digital Elevation Models (DEMs) for assessing hydropower potential, breaklines, coastlines, watercourses, topographic points, and contours plays distinct yet complementary roles that critically affect the accuracy and reliability of terrain representation.

1. **Breaklines** serve as linear features that capture abrupt changes in terrain slope, such as ridges or riverbanks, ensuring that DEM interpolation preserves these critical discontinuities, which directly influence the calculation of hydraulic head and flow paths essential for hydropower site evaluations.
2. **Coastlines** act as natural boundary breaklines between land and water, maintaining sharp elevation transitions that improve coastal topography

representation and prevent DEM artifacts, thereby supporting accurate hydrological modeling near the shorelines.

3. **Water Courses**, including river and stream channels, are vital for hydro enforcement in DEMs, guaranteeing realistic flow directions and continuity of drainage networks, which are fundamental for estimating flow rates and energy potential in hydropower analyses.
4. **Topographic Points** or **Contours** provide precise elevation anchors from surveyed or GPS data, while contours offer continuous linear elevation information that outlines terrain shape and slope gradients; together, they form the foundational data for DEM interpolation, preserving terrain features and ensuring elevation accuracy. The integration of these elements enhances DEM quality, enabling the reliable identification and assessment of hydropower sites by accurately modeling terrain and hydrological characteristics.

• **Topographic Wetness Index (TWI)**

The Topographic Wetness Index (TWI) functions as a representation metric for identifying regions that accumulate runoff potential. It is used to elucidate the dynamics of water flow and accumulation. TWI values are extracted from the DEM using the following equation:

Equation 2

$$TWI = \ln\left(\frac{A}{\tan \beta}\right)$$

Where:

- TWI = Topographic Wetness Index
- A = Catchment Area
- β = Slope Gradient in Degrees

B. Hydrometeorological Data

Precipitation is essential for estimating hydropower. Gridded rainfall from

PAGASA's CliMap provides high-resolution daily rainfall data for the Philippines. Temperature and humidity records are also gathered from

PAGASA or global datasets to estimate evapotranspiration. Remote-sensing ET products can provide monthly ET maps. Any available river discharge records from the DPWH or PAGASA gauges would be collected for model calibration.

• **Rainfall**

Rainfall intensity significantly influences peak discharge. An increase in rainfall directly affects increased river discharge, including peak discharge. The potential for electricity generation in an area depends on the rainfall volume, intensity, and spatial distribution. In this study, the rainfall criteria were represented by the Standard Precipitation Index (SPI).

The SPI assesses the deviation of precipitation data from its long-term average, thereby providing insights into the variability and intensity of precipitation events. It also considers the temporal distribution of precipitation and is applicable over a variety of timescales. Rainfall intensity significantly influences peak discharge. The Standard Precipitation Index (SPI) is calculated for periods of the dataset using the following equation:

Equation 3

$$SPI = \ln\left(\frac{X_i - X}{\sigma}\right)$$

Where:

- SPI = Standard Precipitation Index
- Xi = Monthly Rainfall
- X = Mean Monthly Rainfall

C. Land Use / Land Cover (LULC)

Land cover information is required to estimate the canopy, imperviousness, and curve numbers. National LULC maps from Phil-LiDAR land cover, DENR surveys, or global products will be used. Authoritative datasets, such as the ArcGIS Living Atlas, include land cover for hydrologic modeling, which can also be sourced from freely available libraries. The LULC raster is reprojected and reclassified into hydrologic categories in ArcGIS or other GIS platforms, such as QGIS.

D. Soil Data

Soil texture and type determine the infiltration and storage properties. Global soil grids and national soil surveys, such as those of the Bureau of Soils and Water Management, will be used. The Harmonized World Soil Database (HWSD) provides a consistent global map of soil units. Soil maps are clipped to the study area, reprojected, and converted to hydrologic groups for HEC-HMS based on categories.

E. Stream Flow and River Network

Although the hydrography will ultimately be derived from the DEM, any existing river/stream shapefiles from national surveys or other sources are obtained for reference. The DEM is processed to produce a conditioned terrain. This involves filling sinks, removing pits, and computing the flow direction and flow accumulation raster. The processing of DEM follows standard hydrologic GIS steps, such as filling sinks, flow direction, flow accumulation, stream definition, stream segmentation, and catchment delineation. Using a chosen flow-accumulation threshold, the stream network and contributing catchment polygons are delineated automatically. The watershed boundary of the Claveria Basin is thus defined.

• **Stream Power Index (SI)**

The Stream Power Index (SI) is a valuable tool for quantifying the potential for low erosion at a specific location on a topographic surface. The corresponding rise in the volume of water contributed by the upslope catchment area and the velocity of water flow are followed by an increase in the upslope catchment area and slope gradient, resulting in an increase in the SI values and potential erosion effects.

The equation used to calculate the SI value based on the DEM dataset is as follows:

Equation 4

$$SI = \ln[A \times tan(\beta)]$$

Where:

- SI = Stream Power Index (SI)
- A = Catchment Area
- β = Slope Gradient in Degrees

F. Administrative Boundary Area

Shapefiles of the administrative units of Claveria, Misamis Oriental will be downloaded from public sources such as GADM, PhilGIS, NAMRIA, or other alternative sources to contextualize the results. Protected area boundaries are acquired to mask conservation zones during the site suitability analysis. These layers are reprojected and clipped to the region, particularly in Claveria, Misamis Oriental.

3.1.3 Data Sources

All datasets will be obtained from freely accessible repositories. Primary geospatial data will be obtained using a combination of airborne and satellite remote sensing technologies. Airborne Light Detection and Ranging (LiDAR) and Synthetic Aperture Radar (SAR) datasets are utilized to generate 30 m resolution Digital Elevation Models (DEMs) and Digital Terrain Models (DTMs) with vertical accuracies within 1 m root mean square error (RMSE), and horizontal accuracies of approximately 2 m RMSE. These datasets provide detailed topographic and hydrological information that is critical for watershed delineation and terrain analysis.

Rainfall and climate data are sourced out from PAGASA and other global products. LULC and soil datasets from global sources, such as HWSD, or national (Phil-LiDAR, NAMRIA) sources will be acquired. Furthermore, river networks will be taken from GIS databases. Finally, administrative boundaries are to be obtained from the Global Administrative Areas Database (GADM) or government geoportals. The ArcGIS Living Atlas, Geofabrik, and other GIS libraries also provide convenient downloads for land cover, elevation, and soil. Each dataset is reviewed for currency and coordinate systems.

3.1.4 Data Acquisition Process

The collection of authoritative spatial data from agencies such as NAMRIA and DENR, supplemented by 30 m resolution LiDAR and SAR data, is to establish a comprehensive and reliable foundation. This foundation supports a detailed analysis of terrain, hydrology, land use, soil, and climatic factors essential for assessing hydropower potential. Preprocessing key datasets—especially a hydrologically conditioned 30 meters resolution Digital Elevation Model (DEM)— enables precise watershed delineation and stream network generation, which are critical for evaluating hydraulic head, flow accumulation, and stream power, all vital parameters in hydropower site selection

GIS-based modeling integrates multiple spatial and environmental criteria using multi-criteria decision analysis (MCDA) methods. This integration allows for the systematic evaluation of factors, including geomorphometry, land cover, soil texture, and accessibility, which influence the feasibility and sustainability of hydropower sites. Hydrologically conditioned 30 m resolution DEMs ensure that watershed boundaries and stream orders are represented, which directly affects the calculation of potential hydraulic head and flow discharge, which are key determinants of site suitability.

By leveraging GIS to process and analyze these datasets, the methodology overcomes the limitations of traditional ground surveys, offering a cost-effective, consistent, and scalable approach for identifying suitable hydropower sites. This enhances the reliability of site selection, supports sustainable watershed management, and optimizes hydropower resource utilization, ultimately contributing to renewable energy development and national electricity sustainability.

3.2 Data Processing and GIS Integration

This section outlines the comprehensive data processing procedures necessary to prepare spatial and tabular datasets for integration into a Geographic Information System (GIS), hydrologic modeling, and site suitability analysis for the study. The hydrologic model selected for this study is the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), which simulates rainfall-runoff processes. The choice of GIS platform ensures compatibility across leading open-source and proprietary systems. This methodology is designed to maintain interoperability across systems, while ensuring technical accuracy. The goal is to derive structured spatial and attribute data for watershed modeling, flow simulation, and suitability analysis of hydropower potential installations in Claveria, Misamis Oriental.

3.2.1 Geospatial Standardization and Projection

The initial phase of data preprocessing involves reprojecting and resampling all geospatial datasets to ensure spatial uniformity. The use of different projections can result in misalignments and inaccurate area or flow calculations.

A. Coordinate System

All layers are first transformed and standardized to WGS 1984 UTM Zone 51N, the most appropriate UTM zone for Claveria, Misamis Oriental, since it minimizes distortion in Northern Mindanao and allows accurate distance, slope, and area calculations.

B. Resampling and Resolution Matching

The DEM and raster layers, particularly river shapefiles are resampled to 30 m to ensure that all data share the same pixel size and alignment. This is critical when performing map algebra operations, such as overlay, classification, or zonal statistics.

3.2.2 Digital Elevation Model (DEM) Conditioning

Digital Elevation Models (DEMs) are the foundation for hydrologic modeling, serving as the basis for extracting flow direction, flow accumulation, watershed boundaries, slope, and stream networks.

A. DEM Mosaicking

- After a 30 m resolution Digital Elevation Model data for Claveria is obtained, multiple DEM tiles are then mosaicked using *gdal_merge*, QGIS “Merge,” or ArcGIS “Mosaic to New Raster” to create a seamless elevation layer covering the Claveria watershed.

B. DEM Clipping and Conditioning

• The DEM is clipped specifically to the Claveria watershed boundary to focus the analysis, which is then sink-filled to remove pits. Natural depressions (or errors) in the DEM are filled to avoid incorrect flow routing using the following options:

1. ArcGIS “Fill” tool
2. QGIS/SAGA “Fill sinks”

C. Hydrologic Derivatives from DEM

• To proceed with hydrological analysis using HEC-HMS, several raster derivatives are required from the DEM.

1. Flow Direction

This is to define the steepest downslope path for water movement using the D8 or D∞ routing algorithms. Furthermore, deriving the flow direction is essential for determining how water moves through the landscape.

2. Flow Accumulation

Flow accumulation calculates the number of upstream cells that contribute to flow into a given point in a Digital Elevation Model (DEM). This helps define stream channels by identifying locations where a significant number of cells accumulate, indicating areas of potential water flow. This is essential for hydropower site selection and watershed analyses.

3. Stream Network Generation

A threshold value is selected for flow accumulation to define the streams. Streams are then converted into vector data for visualization, analysis, and integration into the hydrological model HEC-HMS.

4. Watershed and Sub-basin Delineation

Watershed and sub-basin delineation involves using flow direction and pour points to define watershed boundaries and subdivide them into smaller sub-basins. This process is essential for hydrological modeling and water resource management. Various GIS tools can be used for this task.

- ArcGIS + HEC-GeoHMS for a detailed hydrological analysis.
- QGIS + GRASS or SAGA for open-source watershed delineation.
- WhiteboxTools or TauDEM in Python or the command line for automated terrain processing.

These tools will help create accurate watershed maps, which are crucial for hydropower site selection, flood modeling, and environmental planning.

D. Land Use / Land Cover (LULC) Processing

• This processing is crucial for hydrological modeling, as it influences surface runoff and infiltration rates, which are essential for assigning Curve Numbers (CN).

1. Classification

LULC data is from sources such as Phil-LiDAR LULC or other sources. The land cover is then simplified into hydrologically relevant classes and reclassified into categories such as Urban, Agriculture, Forest, Grassland, and Water to support runoff and infiltration analyses. This helps assign Curve Numbers (CN) for hydrological modeling.

2. Rasterization and Alignment

Rasterization converts vector-based Land Use/Land Cover (LULC) data into raster format to match the resolution and extent of the Digital Elevation Model (DEM). This ensures compatibility with hydrological modeling. To maintain spatial accuracy, the raster layers are aligned using:

- Snap Raster (ArcGIS) for precise grid-matching.
- GDAL “align” (QGIS) for consistent spatial congruence.

This process ensures that LULC data are integrated seamlessly with elevation models, improving hydrological analysis and runoff simulations.

E. Soil Data Processing

- Soil texture and infiltration properties influence runoff and are used to classify Hydrologic Soil Groups (HSGs), which range from A (high infiltration) to D (low infiltration).

1. Interpretation

Soil data is sourced from the Harmonized World Soil Database (HWSD) and the Bureau of Soils and Water Management (BSWM), as these datasets provide information on soil texture, permeability, and drainage class, which are essential for hydrological analysis. Soil attributes are classified into Hydrologic Soil Groups (HSGs).

Table 1. Hydrologic Soil Groups (HSGs).

HSG	Infiltration Rate	Runoff Potential	Soil Characteristics
A	High	Low	Sand, Loamy Sand, Well-Drained Soils
B	Moderate	Medium	Sandy Loam, Moderately Well-Drained
C	Low	High	Clay Loam, Poorly Drained Soils
D	Very Low	Very High	Clay, Compacted Soils, Very Poorly Drained

2. Reclassification and Overlay

Reclassification converts soil maps into Hydrologic Soil Group (HSG) rasters, categorizing soils based on infiltration rates. These reclassified soil maps are then overlaid with Land Use/Land Cover (LULC) rasters to refine the hydrological analysis. To perform this overlay, tools such as the following are used:

- Raster Calculator (QGIS/ArcGIS) for mathematical operations on raster layers.
- *gdal_calc.py* (Python) for automated raster calculations.
- Zonal Statistics to compute Curve Numbers (CN) for runoff estimation.

F. Curve Number Assignment and Composite CN Calculation

• The SCS Curve Number method estimates runoff potential based on land cover and soil properties.

Equation 5

$$CN_{composite} = \sum \left(\frac{A_i \times CN_i}{A_{total}} \right)$$

This is done by intersecting Land Use/Land Cover (LULC) and soil rasters and assigning CN values using lookup tables. Once the CN values are assigned, they are aggregated at the sub-basin level using Zonal Statistics, producing a single average CN per sub-basin. This aggregated CN is then used as the input for HEC-HMS.

G. Rainfall and Meteorological Data Processing

• Rainfall and meteorological data processing is essential for HEC-HMS, which requires time-series precipitation data and, optionally, evapotranspiration data for hydrological modeling.

1. Data Formatting

After time-series rainfall data (precipitation) are gathered from meteorological stations or satellite sources, the collected data are formatted for compatibility with HEC-HMS, ensuring compatible hydrological simulations when integrated for rainfall-runoff modeling and watershed analysis. To link rainfall to sub-basins, Thiessen polygons or Inverse Distance Weighting (IDW) interpolation methods are used in GIS to ensure accurate spatial distribution.

H. Sub-basin Parameter Calculation

• Sub-basin parameter calculation assigns key hydrologic properties to each sub-basin for HEC-HMS modeling.

1. Area and Slope

The area and slope are calculated using Zonal Statistics on the Digital Elevation Model (DEM) and sub-basin boundaries. These parameters help estimate the runoff behavior, flow accumulation, and drainage characteristics within each subbasin.

2. Time of Concentration

This is the time required for runoff to travel from the hydraulically most distant point in a watershed to its outlet. It is estimated using empirical equations such as

• **Kirpich Formula** (suitable for small watersheds):

Equation 6

$$TC = 0.0078 \times L^{0.77} \times S^{-0.385}$$

• **NRCS Lag Equation** (if CN is known)

Equation 7

$$T_{lag} = \frac{L^{0.8}\,(S+1)^{0.7}}{1900(S)^{0.5}}$$

Where:

- *L*: hydraulic length (m)
- *S*: slope (m/m)
- *S+1*: curve number

3.3 Hydrologic Simulation

The hydrologic simulation in this study is implemented using the Hydrologic Modeling System (HEC-HMS) developed by the U.S. Army Corps of Engineers. HEC-HMS was selected for its capability to simulate the complete hydrologic cycle, including rainfall-runoff processes, in a semi-distributed or fully distributed framework. This allows for modeling the Claveria watershed in response to rainfall events, estimating streamflow in major tributaries, and deriving discharge values necessary for assessing hydropower potential. The sub-basin discretization, routing networks, and parameterization are based on Digital Elevation Model (DEM) derivatives, land use, soil, and rainfall data processed in GIS.

3.3.1 Hydrologic Model Structure in HEC-HMS

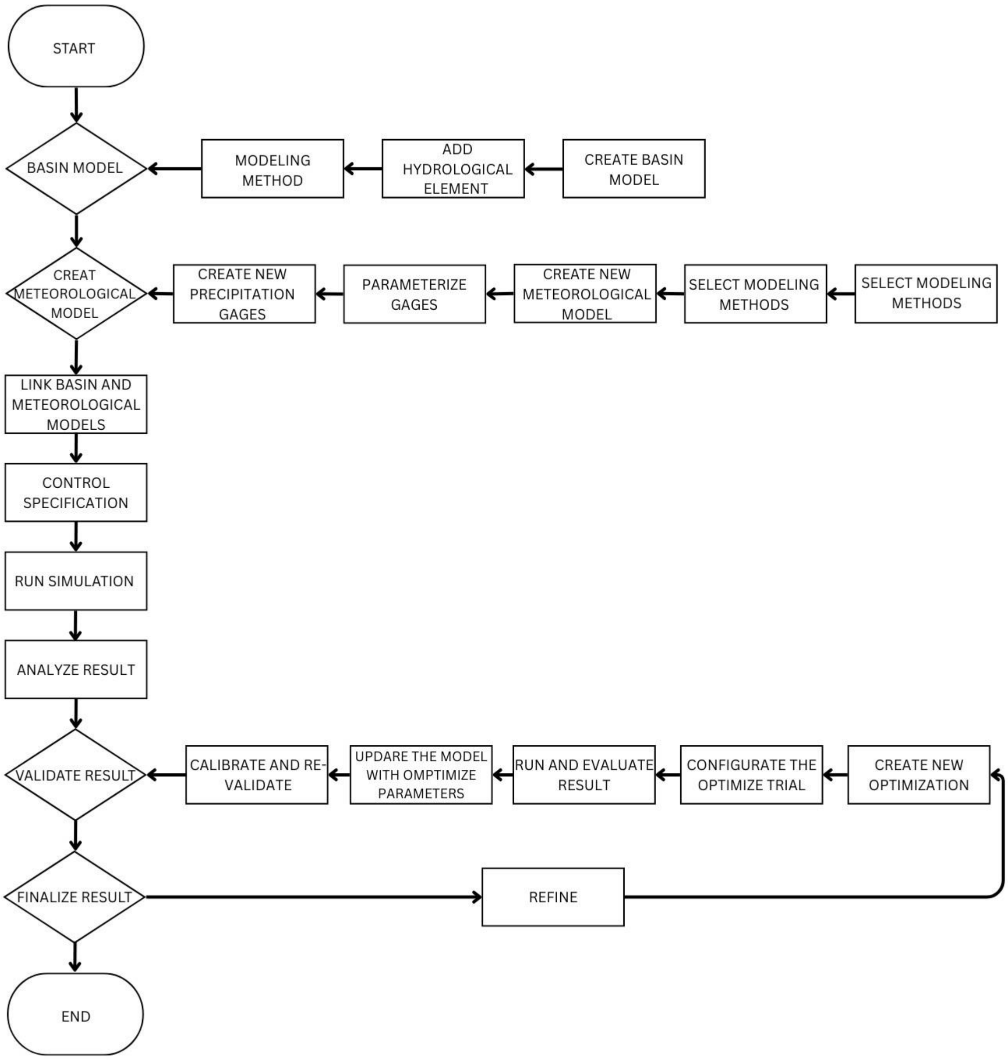


Fig 6. Hydrological Modeling Flowchart in HEC-HMS

A. Basin Model Construction

The Basin Model in HEC-HMS represents the physical and hydrologic layout of the watershed, which was derived from GIS-processed data.

- **Sub-basins**: Hydrologically homogeneous zones. Each is linked to a rainfall input and contains hydrological elements.
- **Reaches**: Stream channels between sub-basins.
- **Junctions**: Points at which multiple flows converge.
- **Outlets**: Terminal point of the basin, typically a gauging station or potential hydropower intake site.

B. Meteorologic Model Construction

The meteorological model contains precipitation and, optionally, temperature/ET data.

- **Rainfall Time Series:** Hourly or daily rainfall data from PAGASA or gridded sources are formatted into.DSS or CSV files.
- Each sub-basin is linked to a rainfall gauge or interpolated value based on proximity or isohyetal interpolation.

C. Control Specification

- Define simulation time period, time step, and output resolution.
- The timeframe corresponds to significant historical rainfall events or design storms.

D. Hydrologic Methods and Parameterization

Each sub-basin uses standard HEC-HMS hydrologic methods suited to the Philippine conditions:

Table 2. Standard HEC-HMS Hydrologic Methods.

Process	Method Used	Description
Rainfall Loss	**SCS Curve Number (CN)**	Based on LULC and HSG, determines initial abstraction and retention.
Direct Runoff	**SCS Unit Hydrograph**	Derives runoff from excess rainfall, requires time of concentration (Tc).

Baseflow	**Constant or Recession Method**	Estimates subsurface flow; optional depending on desired precision.
Channel Routing	**Muskingum or Kinematic Wave**	Simulates flow travel through streams and rivers.

E. Simulation Execution

After the model setup, the following were required for execution:

1. Calibration (if historical discharge is available)
    - The simulated flow is compared with observed data from NAMRIA, DPWH, and PAGASA sources. Model parameters are then adjusted to minimize error using metrics such as NSE (Nash-Sutcliffe Efficiency), RMSE, and R^2.
2. Validation
    - Using a different set of events, time periods, or considering an existing hydropower plant to test the model robustness.

3. Simulation Run

- If no observed data are available, the model can still simulate runoff based on rainfall input and loss/runoff parameters.
- The outputs included hydrographs, peak discharges, runoff volumes, and flow durations.

3.4 Head Determination Using GIS and PyGIS through Deterministic Algorithm

In the context of hydropower potential assessment, the hydraulic head (H) represents the vertical drop of water available for energy generation, which, together with discharge (Q), determines the theoretical power output. This section describes how the head is determined automatically and systematically using GIS-based elevation data processed through a deterministic algorithm implemented in Python.

Unlike empirical models, a deterministic algorithm calculates head values using actual topographic and hydrologic parameters derived from high-resolution Digital Elevation Models (DEMs) and processed spatial layers. The algorithm operates within a hydrologic context, tracing the flow direction and elevation differences to extract realistic gross and net head estimates suitable for assessing run-of-river installations.

The head is the vertical distance between two points (intake and turbine). It can also be defined as the pressure created by the elevation difference between the intake and turbine. A focal statistics function is applied to the digital elevation data. This function computes the necessary statistics (i.e., minimum, maximum, and sum of all values) for the neighboring cells surrounding each individual cell. A run-off river plant does not require space for water storage, and a 500 m horizontal distance between two plants is usually considered feasible.

In the contemporary analysis, the minimum function is applied to a rectangle containing 17 × 17 cells around each cell to find the minimum number of cells around each raster cell (lowest neighboring cells).The minimum neighbors dataset is then subtracted from the DEM (without sink), which had a resolution of 30m*30m resolution, in order to determine the drop elevation of each cell to its minimum neighbors. The output is the height value "head," which is then used in the equation to calculate the potential energy. The head difference between the DEM without a sink and the DEM, which contains a pixel value of the minimum elevation of a neighboring particular cell within a 500m increment, was considered in this study.

Equation 8

$$H(x, y) = DEM(x, y) - Neighbors_{min} DEM$$

3.4.1 Head Determination Workflow

A. Algorithm Overview

The deterministic head estimation algorithm in Python executes the following steps.

1. **Snap candidate outlet points** to the nearest high-flow stream pixels.
2. **Trace upstream** using the flow direction raster to a user-defined maximum distance or elevation drop.
3. **Calculate head** as the elevation difference between the outlet point and the upstream reference point.
4. **Filter and store** the head values that meet the minimum hydropower feasibility thresholds.

This algorithm assumes a steady flow regime and focuses on the gross head, which may be corrected to the net head by applying an efficiency or loss coefficient.

3.4.2 GIS Integration and Visualization

The results of the deterministic head estimation are reintegrated into GIS, where they are used to:

- Overlay with infrastructure layers
- Apply exclusion buffers

Candidate sites with sufficient net head and adequate discharge from HECHMS simulations are then flagged as high-potential hydropower sites.

3.5 Inlet – Outlet Pair Determination

In hydropower planning, an inlet-outlet pair refers to the upstream and downstream points along a stream segment that define the location of the intake where water is diverted and the tailrace where water is returned. The elevation difference (head) between these two points, along with the streamflow (discharge) through the system, determines the hydropower generation potential.

This methodology outlines how a deterministic algorithm is used to automatically identify feasible inlet-outlet pairs from stream networks and topographic data using GIS and Python-based processing. The procedure is designed to be automated, objective, and scalable, particularly in mountainous regions such as Claveria, where field-based identification is not feasible.

3.5.1 Objectives of Inlet-Outlet Pairing

- Systematically scan the stream network for high-head, short-reach segments.
- Pair inlet (upstream) and outlet (downstream) points that satisfy
  1. A minimum gross head threshold.
  2. The maximum penstock length.

3.5.2 Algorithm

A. Stream Path Tracing

A stream network is generated using a predefined flow accumulation threshold from the flow direction raster. Each pixel with a high accumulation is considered a potential outlet candidate.

B. Outlet Candidate Identification

For each outlet, the coordinates must be extracted,, given that it must be validated as lying on a stream and not near the catchment boundaries. Points that are too close to the watershed outlet must be discarded to avoid any redundancy.

C. Upstream Search for Inlet Points

Using the D8 and D-infinity flow direction rasters, we traced upstream paths from each outlet candidate up to the maximum horizontal or Euclidean distance. Elevation must be extracted for each upstream pixel. To proceed, the gross head must be calculated using the following equation:

Equation 9

$$H = Elevation_{in} - Elevation_{out}$$

Measure the horizontal or path distance. After identifying whether the pair is feasible, the feasible pair is stored. The set criteria were used to identify whether the pair is feasible in terms of the head, distance, and slope within the acceptable range.

D. Filter Pair and Scoring

Each inlet-outlet pair is scored or ranked based on the following:

- Head-to-length ratio for efficiency of water use
- Land use constraints are excluded if they are in protected areas.
- Streamflow potential (from HEC-HMS outputs at the outlet).

Low-scoring or infeasible pairs are discarded to avoid false positives.

3.6 Power Computation and Classification Integration

The theoretical hydropower potential for each identified site within the study area will be computed using available spatial analysis tools. This process involves integrating key hydrological and topographical parameters, namely hydraulic head, discharge (flow), and in-stream power, within a geospatial framework to estimate site-specific power generation capacity.

A. Calculation of Hydropower Potential

Each validated inlet-outlet pair can be linked to the corresponding streamflow data from the HEC-HMS simulations. The hydropower potential (P) at each site is calculated using the following standard formula:

Equation 10

$$P = \rho \times g \times Q \times H \times \eta$$

Where:

- P = Power output (Watts)
- ρ = Density of water (1000 kg/m^3)
- g = Acceleration due to gravity (9.81 m/s^2)
- Q = Flow rate (m^3/s)
- H = Effective head (m)
- η = Overall efficiency of the system (typically 0.7-0.9)

B. Evaluation and Ranking

Potential hydropower sites are then evaluated and ranked based on their calculated power outputs. This allows for the prioritization of sites that demonstrate the highest energy-generation potential. While other factors may act as exclusionary filters to refine the final selection, the core suitability assessment is driven by the quantifiable power production capability of each location.

Table 3. Hydropower Potential Classification

Hydropower Scale	Capacity Range	Typical Min Head (m)	Typical Max Head (m)	Typical Flow Rate (m^3/s)	Efficiency (%)
Large	>50 MW	>30	>300	High (varies widely)	85-95
Medium	10-50 MW	20-50	100-200	Moderate to high	80-90
Small	1-10 MW	10-30	50-100	Moderate	75-90
Mini	100 -1 MW	5-20	30-50	Low to moderate	70-85
Micro	5-100 kW	2-10	20	Low	60-80
Pico	<5 kW	1.5-5	10	Very low	50-75

3.7 Map Generation

The culmination of the data processing and site suitability analysis phases is the generation of a series of comprehensive spatial maps. These maps serve as the primary visual output of this study, effectively communicating the identified hydropower potential and site suitability in Claveria, Misamis Oriental. All maps are generated using Geographic Information System (GIS) software to ensure accuracy, clarity, and adherence to cartographic standards. The set of generated maps includes a foundational base map depicting the geographical extent of Claveria, Misamis Oriental, including key administrative boundaries, major water bodies, and topographical features, which provides essential context for subsequent analyses.

A map illustrating the various processed input data layers utilized in this study will be generated. The core output map is the Hydropower Potential Layout Map, which specifically illustrates the identified potential hydropower sites from the basin (intake) to the powerhouse, including the critical elements of the proposed layout. Each site is clearly delineated and symbolized based on its calculated power output, allowing for a visual hierarchy of suitability and effectively translating the quantitative suitability analysis into an easily interpretable spatial format. These maps are essential tools for visualizing the study's findings, facilitating a clear understanding of the spatial distribution of hydropower potential, and supporting informed decision-making for future renewable energy development in the region.

3. 8 Sequential Process Overview

Data processing and analysis follows a systematic workflow to transform raw data into actionable insights.

1. First, GIS analysis will be performed to process the topographical data and prepare it for hydrological modeling.
2. Second, to implement a hydrological model through hydrological and terrain analyses to represent water flow dynamics and availability in the Claveria watershed using HEC-HMS.
3. Third, to create an algorithm in Python for head determination, inlet–outlet pairing, and energy potential estimation to support hydropower site assessment
4. Fourth, multi-criteria decision analysis will be applied to evaluate potential sites based on weighted criteria.

5. Finally, spatial maps were generated to illustrate potential hydropower sites across Claveria, Misamis Oriental.

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