DETERMINATION OF THE POTENTIAL HEADS FOR HYDROPOWER PLANTS USING GEO-SPATIAL TECHNOLOGY: A CASE STUDY OF THE 8 MAJOR RIVER BASINS OF MINDANAO, PHILIPPINES

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ABSTRACT: Mindanao in the south is the second largest island in the Philippines and consumes 13% of the national electricity output. With few Renewable Energy (RE) resources developed in the region so far, hydropower with an abundant resource still provides 80% of its total electricity requirement. The Department of Energy (DoE) projects that hydropower is expected to be still a major source of RE thus adding areas of potential sources is still needed even in micro-scale uses. Efforts to make it economic, flexible and damaging to the environment is a major factor its construction is still favored in the region. In every hydropower development, one parameter that helps to determine available hydraulic power inherent in the system is the available elevation head. In this study, the focus will be on the measurement of available head of the 8 Major River Basin in Mindanao. The available head is defined as the vertical distance where the water should be allowed the maximum vertical displacement and the shortest path to travel. The maximum vertical displacement accounts for the high water head. Large water head accounts for higher power potential. Hydropower projects (HPP) can be classified in many ways: by size (large, medium, small and micro-scale); by purpose (single or multi-purpose); and by the way incoming river flows are regulated to generate energy. The intention of this study is to locate potential elevation head processed from SAR data further developed in Geographic Information System (GIS) environment. With the use of the GIS, it can be used to form a core of practical methodology that will result in more resilient in less time and can be used by decision-making bodies to assess the impacts of various scenarios. Further this can be used to review, cost and benefits of decisions to be made in assessing HPPs. It offers means of an initial assessment for accessing and interpreting information for the purpose of decision making.

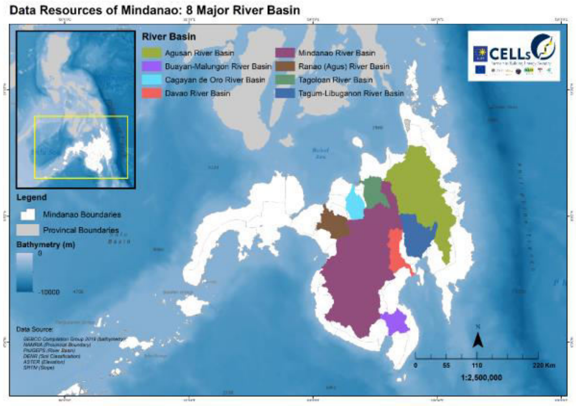
1. Introduction

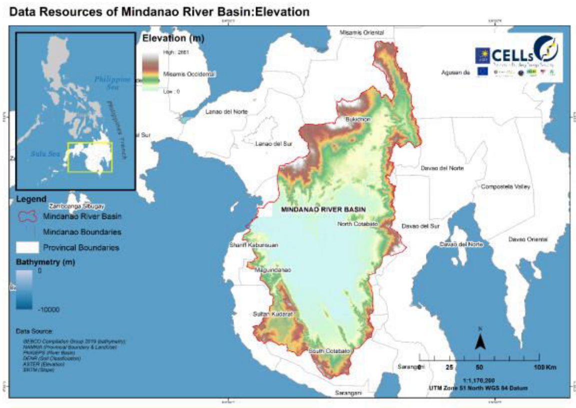
1.1 Power demand and the need for Renewable Energy

Mindanao in the south is the second largest island in the Philippines and consumes 13% of NPC's national electricity output. With few other energy resources developed so far, one main source of electricity in Mindanao relies on hydro power which provide 80% of its total electricity requirements (International Water Power & Dam Construction, 2002). Hydropower is one of the most common renewable sources abundantly available in the hilly region particularly in Mindanao. According to the Department of Energy (DoE) hydro power is expected to account for 4% of the Philippines' primary energy mix in 2002. This compares with indigenous natural gas which is forecasted to account for 7% of primary energy while geothermal power is projected at 5%, local oil 3% and domestic coal 2% of primary energy (Rudnick & Velasquez, 2019). Hence, the Department of Energy's power development plan aims to increase energy capacity while simultaneously making it more economic, flexible and less polluting especially in Mindanao but finding a suitable location to construct Hydropower has become an obstacle to development in some places in Mindanao and this has raised doubts about contribution of this mature storage option to future energy systems.

1.2 Study Area

The study area is focused in the 8 Major river basin of Mindanao, namely: Agusan River Basin, Buayan-Malungon RB, Cagayan de Oro RB, Davao RB, Mindanao RB, Agus RB, Tagoloan RB, and Tagum-Libuganon RB (Figure 1). These are all identified base from the document of DENR. These river basins are located in the south most part of the Philippines which lies within longitudes 125.78°–124.021°E and latitudes 9.129°– 5.948°N. The Major River Basins of Mindanao is a perennial watersheds and is flashy and effluent; it provides an important natural resource for the economic development of the people in the different provinces.





Watersheds	Provinces	Area sq.km.
Agusan River Basin	Compostela Valley, Davao Oriental, Davao del Norte, Agusan del Sur, Agusan del Norte, Surigao del Sur, Misamis Oriental, and Bukidnon	11,936.55 sq. km.
Agus River Basin	Lanao del Norte, Lanao del Sur	1,987.08 sq. km.
Buayan-Malungon River Basin	Davao del Sur, Davao Occidental, Sarangani, South Cotabato	1,505.09 sq. km.
Cagayan de Oro River Basin	Misamis Oriental, Bukidnon, Lanao del Norte	1,373.83 sq. km.
Davao River Basin	Bukidnon, Davao del Sur	1,759.6 sq. km.
Mindanao River Basin	South Cotabato, Sultan Kudarat, Maguindanao, North Cotabato, Lanao del Sur,	20,859.41 sq. km.
Tagoloan River Basin	Misamis Oriental, Bukidnon	1,373.83 sq. km.
Tagum-Libuganon River Basin	Davao del Norte, Compostela Valley, Agusan del Sur	3,119 sq. km.

Figure 1.0, Upper left shows the 8 river basins in Mindanao, lower left shows the elevation and watershed boundary of Mindanao river basin. Table 1.0 shows the tabulated list of watershed in Mindanao.

In every hydropower development, one parameter that helps to determine available hydraulic power inherent in the system is the available elevation head. In this study, the focus will be on the measurement of available head of the 8 Major River Basin in Mindanao. The available head is defined as the vertical distance where the water should be allowed the maximum vertical displacement and the shortest path to travel. The maximum vertical displacement accounts for the high-water head. Large water head accounts for higher power produced. Hydropower projects can be classified in many ways: by size (large, medium, small and mini-scale); by purpose (single or multi-purpose); and by the way incoming river flows are regulated to generate energy.

Mini Hydro Power Plant (MHPP) is characterized by river discharge and head profile. However, the lack of discharge data and river head information becomes barriers in developing MHPP. In this research, GIS approach is used to assess MHPP potential by analyzing spatial data. Head calculation was conducted using neighborhood statistical method while river discharge was approached using SCS-CN equation. Potential sites were determined using potential energy formula. The results showed that study area has 18 potential sites from 100 kW to 5.2 MW. This method is suitable for initial screening only. Further in-depth feasibility study is needed to develop MHPP (Setiawan, 2015).

Pumped hydro energy storage (PHES) is the most widespread and mature utility-scale storage technology currently available and it is likely to remain a competitive solution for modern energy systems based on high penetration of solar PV and wind energy. This study estimates the technical potential of PHES in Iran through automatized GIS-based models based on four topologies. Two topologies focus on the transformation of existing reservoirs while the third topology which is developed based on permanent rivers of the country offers more alternative sites. The fourth topology assesses the potential of seawater PHES plants as a potential solution for regions characterized by freshwater scarcity. The TOPSIS method is applied to the discovered feasible sites to integrate an economic sensitivity into the evaluation process. Results show that Iran has a favorable topography for PHES, and the technical potential of the studied topologies reaches up to 5108 GWh from 250 discovered sites, compared to the existing 5.1 GWh PHES capacity, while a maximum distance of 20 km is considered between reservoirs of a PHES plant

(Ghorbani, Makian & Breyer, 2018).

The intention of this study through the MindaCELLs project is to detect potential elevation head for Hydropower Electricity by developing methods, based on Geographic Information System (GIS) tools. With the use of the Geo-Spatial Technology (GIS), it can be used to form a core of practical methodology that will result in more resilient in less time and can be used by decision-making bodies to assess the impacts of various scenarios and to review, cost and benefits of decisions to be made in assessing Hydropower plant. It offers means of entering, accessing and interpreting the information for the purpose of decision making which is also possible to integrate all physical events leading to better simulation of physical world using GIS and hydrological modelling.

1.3 Objective:

The objective of the study is to evaluate and identify the potential elevation heads for Hydropower in the 8 major River Basin in Mindanao using the Geo-Spatial Technology (GIS). The study aims to explore the application to assess the temporal and spatial variability of hydropower potential heads which provides a tool for studying an assessment of hydropower potential particularly in the potential resources for the Mindanao River Basins namely: Agus River Basin, Buayan-Malungon River Basin, Cagayan de Oro River Basin, Davao River Basin, Mindanao River Basin, Tagoloan River Basin, Tagum River Basin

1.3 Significance

GIS is highly compatible with interfacing hydrological models to facilitate the processing, management, and interpretation of hydrological data particularly in the resource potential which has the ability to describe the topography area. The potential elevation heads will be useful to hydrologists, decision-makers, and planners for quickly identifying areas with the highest potential for hydropower development Assessments of theoretical hydropower are currently possible based on this principle by using a geospatial dataset and watershed modelling climate inputs in combination with a geographic information system (GIS). Investigate the possibility of the stand-alone hydro for low-cost electricity production which can satisfy the energy load for a community due to the potential heads generated

2. Methodology

Delineated Watersheds and River Networks

The watersheds in the study area were delineated using the topography derived DEM as the main input data which process through GIS with the aid of GEO-HMS. The Digital Elevation Model (DEM) for the area of study has been extracted from the Interferometric Synthetic Aperture Radar (IFSAR) product (15 × 15 m). It is used to generate the river network and create watershed delineation accessed from the characteristics of the topography.

Head Calculation

Riverhead calculation can be approached using GIS methods. First, DEM data which contains elevation information is clipped with river network to generate riverbed topographic profile. Finally, river head is calculated using Focal Statistic through "neighbourhood" analysis tool in ArcGIS. The analysis calculated elevation range between "neighbourhood" pixels in riverbed topographic profile. The nearest "neighbor" output data were then subtracted from original DEM data using raster calculator to get drop in elevation.

Potential Heads

To assess potential hydraulic head along the river, computations were started at the main outlet of the watershed and then proceeded in the upstream direction. A location is identified as a potential hydropower site when a head of 20 m or more is available in a stream and the distance between the current location and the site immediately downstream exceeds 500 m (Kusre et al. 2010).

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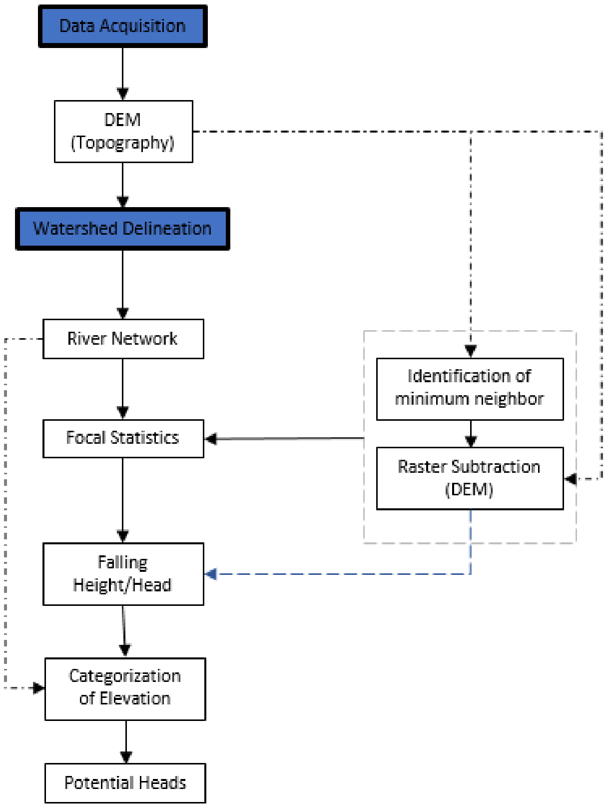

Figure 2.0 Process flow of the study

3.0 Resilient Energy Policy

Mindanao, Philippines is abundant with several river basins which are potentially useable as source of hydropower in the island However, the geographical location of the island also possess threat in terms of hydrometeorological hazards which requires preparation of action plans for adaptation and resiliency against adverse impacts (Lagmay & Baldago, 2020). Given this, putting up a hydropower plant also attributes to threat of flooding, despite its great advantage in the energy mix of the country.

In 2013, it was reported that aside from the heaviest rainfall recorded in that year, the mismanagement of hydropower plants contributed to the flooding in the Himalayan State of Uttarakhand in India which caused to thousands of deaths and missing. Situation as such was greatly considered by the government. Thus, in 2018, the Department of Energy released the Department Circular No. DC 2018-01-0001 or the Adoption of Energy Resiliency in the Planning and Programming of the Energy Sector to Mitigate Potential Impacts of Disaster.

The main aim of the circular is to institutionalize, the development, promotion and implementation of a Resilience Compliance Plan (RPC) to strengthen the capacity, safety culture and disaster preparedness and response capability of the energy sector by ensuring resilient energy infrastructure. With this, the four main principle of the circular states that the adoption of the resiliency planning and program in the energy industry shall:

1. Strengthen existing infrastructure facilities to adapt and withstand adverse conditions and disruptive events;
2. Incorporate mitigation improvements into the reconstruction and rehabilitation of damaged infrastructure in accordance with the Build Back Better principles;
3. Improve operational and maintenance standards and practices to ensure efficient restoration of energy supply in the aftermath of disruptive events; and
4. Develop resiliency standards for future construction of energy facilities to ensure minimal damage and adoption of measures for timely recovery and restoration of energy supply.

3.0 Results and Discussion

River head calculation can be approached using GIS methods. First, a 10-m DEM was used to identify potential sites in the 8 Major River basin which contains elevation information is clipped with river network to generate riverbed topographic profile. Finally, river head is calculated using focal statistics neighbourhood analysis tool in ArcGIS. The analysis calculated elevation range between "minimum" neighbourhood pixels in riverbed topographic profile (Figure 8) and then subtracted from original DEM data using raster calculator to get drop in elevation head (Figure 9).

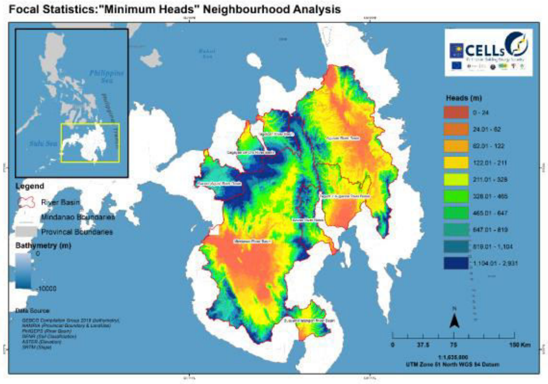

Figure 8. The Focal Statics: "Minimum" Neighbourhood Analysis

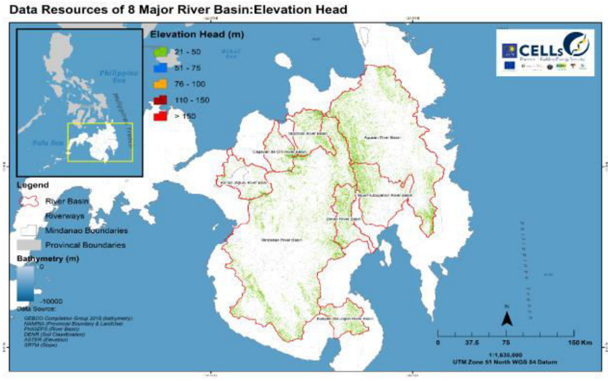

Figure 9. The Mindanao Elevation Head

A head is identified as a potential head when a head of 20 m or more is available in the stream, with a separation of at least 500 m between two sites. The assessment for the potential is carried out from the last selected site and the process continued until the stream end; thus potential heads were identified in the following watershed and their locations along with the stream network are presented. It needs to be highlighted that, as well as hydrological, many other criteria (e.g. geological suitability, vicinity to important places) have to be met to finalize the site of hydropower projects. The methodology presented here is a systematic way to identify potential heads from a topographic angle using Geo- Spatial analysis and these heads could be further examined using other criteria to arrive at a different list. An optimization study could also be carried out by varying the norm for the head (20 m in the present case) and spacing (500 m) to develop an optimal basin development plan.

4.0 Conclusion

One of the common factors involved in hydropower potential determination is the falling height of river/streams. And using the Geo-Spatial Technology, a pour point has successfully generated potential sites with good head along the stream which will be further use to calculate power potential. Potential elevation heads are one factor to develop an efficient analysis for a hydropower development. The tool discussed in this study is automated tool which requires some initial data such as DEM that performs its function efficiently and generated potential elevation heads. Since the tool integrates many tools in one master tool it significantly reduces effort and time used for such analysis This research also showed that the elevation heads with good value do not always have to be considered as potential head due to some factors particularly it's not along in the river streamlines.

The energy industry is now gearing towards mainstreaming disaster risk reduction programs into planning and investments to ensure continuous delivery and enhance existing energy infrastructure. With existence of the RPC it intends to mainstream both engineering and non-engineering measures to ensure infrastructure and human resource disaster preparedness.

The determination of potential head output in the 8 Major River Basin along the streamlines are to show that the identified sites have the capability of producing such output for power plant development. But further consideration of adverse impacts have to studied for safety of residents living in proximity to potential sites should dams be built for the purposes of HPPs. Higher accuracy of the model and detailed evaluation of potential heads can also achieved by using other data sources like high resolution images and up to date terrain data.

5.0 Acknowledgement

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