Hydropower Generation Potential of Samar River System Based on GIS and SWAT Model

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ABSTRACT

Samar is one of the poorest provinces in the Philippines and yet rich in water resources. Tapping these resources for hydropower generation is one way to address the poverty incidence of the province and to meet the nation's electricity demand by 2030 using renewable energy resources. Assessment and identification of potential sites for hydropower is needed but there is lack of reliable and accurate observation data. Hence, this study aimed to determine the hydropower potential of Samar major rivers using GIS-based spatial tool and Soil and Water Assessment Toll (SWAT). Results indicates that Samar major rivers has a potential hydropower generation capacity of 622.925MW. In particular, Gandara River basin has the highest power generation capacity at 561.908 MW as compared to other river basins. Furthermore, one of Gandara river sub-basin reflects to have the highest hydropower generating capacity which is greater than 100M.

1. INTRODUCTION

The rising dependence of economic activity to electricity – the electrification of transport system, the proliferation of digital system transaction and, the rising popularity of Internet of Things (IoT) among others is causing to further increase the demand for electricity. In fact, it has been estimated that the world electric demand is increasing at a rate of 2.4% annually [1]. And it is unfortunate to note, that in todays' situation, while the demand and consumption of electricity is increasing, its sources are depleting.

Increasing demands for energy is a consequence attributable to the devastating effects of climate change. This situation has in fact spurred researches on energy from renewable sources [2]. Along with this, countries were compelled to revisit their renewable energy resources in order to determine its potential and its possibility for development [3]. However, it is noted that from among other forms of renewable energy resources, hydropower is found to be the most cost effective, and reliable energy source for power generation. [4].

In the Philippines, hydropower generation is relatively low at around 13.31% versus its total generated power. However, the country's energy sector is targeting to triple its renewable energy generation capacity – particularly aiming to increase hydropower generation capacity of approximately 5394 MW [5]. Therefore, at present, it is important for the country to assess all its water resources in order to locate and determine its hydropower potential. Information derived from assessment is fundamental and key information for the country's energy planning and hydropower plant site development.

Samar in particular is one of the Philippine islands that lies Southeast of Luzon. It occupies the Northern most section of Eastern Visayas or Region 8. The province of Samar occupies the Southwestern part of Samar Island that has the largest land area at 13,428.8 km^2 among the three provinces [6]. The province is practically covered by watershed areas; thus, it is said to have abundant source of water resources. It has three proclaimed watersheds - Catbalogan, Pan-as, and Loog watershed forest reserved, covering a total area of 7803 hectares. The province's watersheds is a home of several numbers of popular water falls - the Lulugayan falls, Pinipisakan falls, Darusdus falls, Pan-as falls and Ton-oc falls, among others which becomes the very reason why the province was called as the province of water falls [7]. Moreover, the province has also five major rivers: Basey River, Calbiga River, Ulot River, Gandara River and Jibatang River.

Hence this study aims to investigate the hydropower potential of the said rivers. In fact, utilizing the rivers of Samar as source for Hydropower could also minimize or prevent flooding and can otherwise boost its agriculture [8]. In other words, development of hydropower plant and facilities will not only augment the depleting energy supply of the country but it will also serve as an avenue to improve the country's economic activity and boost its agricultural productivity.

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However, critical to the establishment of hydropower plant and facilities is the identification of potential site for hydropower development vis-à-vis power site power generation capacity. Thus, this mechanism requires a necessary observation and analysis of parameters attributed to hydropower generation. Unfortunately, Samar Rivers has no existing or limited information which make it difficult to assess its hydropower potential. Thus, this study explores the use of GIS and SWAT Model in in the determination of its hydropower potential.

In general, the study aims to assess the theoretical run-of-river hydropower potential of the five major river systems in Samar using Geographic Information System (GIS) and Soil and Water Assessment Tool (SWAT) Modelling. Specifically, the study intends to determine the specific potential site for hydropower plant development.

2. LITERATURE REVIEW

Hydropower is a power that is being derived from the force of energy of the moving water and is categorized as renewable energy source. It is usually an outcome of water moving from higher to lower elevations [8]. It considered as one of the most important renewable energy sources in the generation of electricity. Electric generation from hydropower is due to the kinetic energy of flowing water that drives the turbines that is responsible in generating the electricity [9-10].

Note that hydropower plant electric generation is dependent and directly proportional to the product of water flow with that of the net available hydraulic head [11-15]. The actual output of energy at a dam is determined by the volume of water released (discharge) and the vertical distance the water falls (head) [16]. Hence, water falling at a given distance will produce a certain amount of energy. More head or faster flowing water means more power.

Hydropower potential is traditionally calculated with reference to historical data of discharge. However, there is a very limited tools that can be used in estimating the stream flow of the ungauged river, just for and in the case of Samar Rivers where data are unavailable. In fact, discharge estimation of a specific hydropower site poses uncertainties – in terms of accuracy and reliability when traditional method is used. It is because assessment based on location specific does not cover the entire potential basin. On the hand, assessment based on observed data from a large number of gauging stations is not cost-effective.

However, with the proliferation of computer-assisted computational and simulation tools today, estimation and modelling become straightforward. Having a very high accuracy and reliability results, this tool addresses the issues and constraints presented previously. Some of this computational and modelling tools include but not limited to GIS, Remote Sensing (RS) Devices, and Hydrological Modelling Software among others. GIS is a computer-based maps processing and simulation analysis tool used for capturing, storing, checking, and displaying data related to positions on Earth's surface. GIS is dependent to RS devices that collects and interprets information about the environment and the surface of the earth from a distance,

As such, GIS becomes a popular computational and simulation tool used for hydrologic modelling. Thus, it is unarguable that this can be used also in modelling and estimating hydropower potential of rivers and its sub-basins. Specific research along on this are already presented includes reservoirs designs and models for irrigation and its effects on hydropower production [17]. Along with this, hydrological and hydropower modelling and reservoir operation on catchment scale based on GIS was likewise undertaken. In particular, the study of [18] deals on the assessment of hydropower potential of the rivers on the island of Saint Lucia utilizing only available satellite and local rainfall data. The study, successfully modelled the hydropower potential of the river based on a hydrological model with reference to regional climate conditions.

Note that GIS coupled with RS, can be used also in locating and selecting hydropower sites. In particular, the study of [19] uses GIS in locating and assessing the hydropower potential of Hornád river basins for possible small hydropower site development. Similar studies are likewise undertaken by [20-22].

On the other hand, SWAT model is used in the analysis of large watershed as influenced by land management practice on water, sediments, and agricultural yields. The model is particularly useful in modelling long period of time and for semi-distributed hydrological model [23]. If SWAT model is used, watersheds are divided into multiple sub-watersheds. Sub-watersheds are further divided into Hydrologic Response Units (HRUs). HRUs consist information such as homogenous land use, management, topographical, and soil characteristics [24]. With SWAT Model, the runoff is predicted from each sub-basin, then it is being routed to the basin in order to determine the total runoff of the basin itself. This particular model was used by in various studies that deals on sediment and agricultural chemical runoff, hydropower potential determination, etc. [25-29].

In particular, SWAT hydrological model have been used also on estimating the river discharge. In fact, the study of [30], SWAT model was utilized in estimating the river discharge of Kopili River basin in India, and use the said simulated discharge in the assessment of the basins' hydropower potential. Furthermore, SWAT hydrological model was also used to estimate the stream flow of small hydropower scheme in an ungauged mountainous watershed in the Western Ghat, India. Also, it is being used to map suitable sites for Run of River hydropower plants in Wyra basin of Krishna River, Telanga, India. [31].

SWAT Model was also use in identifying and classifying the theoretical hydropower potential sites in Misamis Occidental, a province located in the region of Northern

Mindanao in the Philippines. Likewise, the same study was made by [32] in estimation and assessment of hydropower potential in Western Visayas region of the Philippines. Also, similar study was made by [33] in obtaining the gross naturally occurring theoretical hydrokinetic potential of some selected rivers in the Lower Nigeria River Basin in North Central Nigeria.

3. METHODOLOGY

The study covers the Samar five major rivers as follows: (1) Basey River, located in the Municipality of Basey; (2) Calbiga River in the Municipality of Calbiga; (3) Gandara River which covers the Municipality of St. Margarita, Gandara, and San Jorge; (4) Jibatang River located in Calbayog City; and (5) Ulot River which covers the Municipalities of Paranas and Can-avid. Figure 1 shows the specific site location of the said river.

Primarily, GIS software was used in the processing, simulation and analysis of data [34]. With this, four major GIS data were used as indicated in Table 1. The 30-meter elevation data, used as elevation reference map; the Land Use and Cover Raster Map as the Base Map; the Soil Data Map as the soil characteristic/ classification map; and the Daily Weather Map as basis for Hydrological Map Analysis.

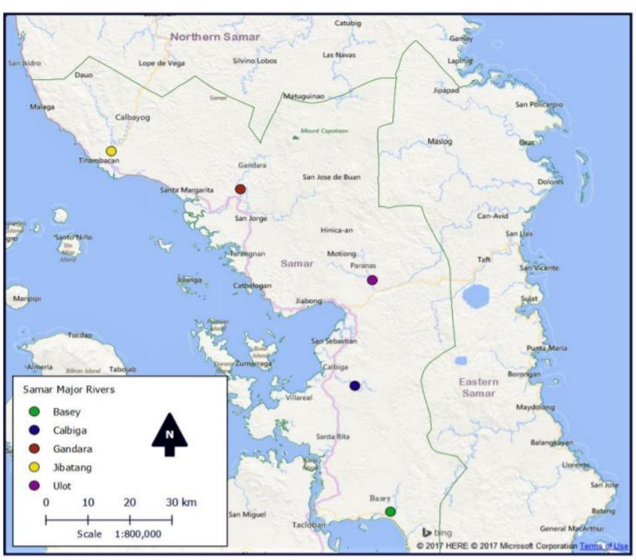

Fig. 1. The Samar Five Major River System.

In particular, the SWAT model setup with Digital Elevation Model (DEM) was utilized in delineating the watershed. A point network shape file was then used in defining the water outlet – the process results to the division of given watershed into a number of sub-basins in reference to the specified threshold value of the catchment area. Figure 2 depicts the Samar watersheds and their extent of flow. A Hydrologic Responses Unit (HRU) analysis was then utilized to the further divide the sub-basin into areas of similar land use, soil, and slope in order to determine the different study sites attributes. Land use and Soil Map was used an input in HRU analysis. HRU generated data are further simulated using the weather data in determining the accumulated flow to sub-basins. The hydraulic head was calculated from segment length and slope-based software defined parameters and simplicity of computation.

Table 1. Data Types and Sources

	Data Type	Source
1	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) - GDEM Raster 30m	ASTER Global Digital Elevation Model (METI and NASA, 2011)
2	Land Use/ Land Cover Raster	Global land Cover 2000 (European Commission, 2015)
3	Soil Data (Raster)	Food and Agriculture Organization (FAO) Digital Soils Map of the World (UN FAO, 2007)
4	Daily Weather Data (Text)	Global Weather Data for SWAT

Moreover, the annual mean discharge and hydraulic head were used in the computation of theoretical hydropower potential. The theoretical hydropower potential was calculated using the equation indicated below.

$$P_{th} = \gamma \times Q \times \Delta H \quad (1)$$

where, P is the theoretical power in Watts, γ is the specific weight of water (9807 N/m^3), Q is the volumetric flow rate in cubic meters per second, and ΔH is the hydraulic head in meters. If there are numbers of sub-basins in a given basin, the total power of the basin can be calculated by summing the potential of all sub-basins. The computations were done using MS Excel spreadsheets. Once the theoretical power was obtained, the river with the highest potential was identified.

Specifically, the determination of hydropower generation potential of Samar River System was based on the defined workflow indicated in figure 3. The process involves Elevation Modelling where QGIS and QSWAT was tilized. Then the watersheds were analyzed where the land use and soil map was used as inputs data. Furthermore, Hydrological Response Unit (HRUs) was considered where the weather data was used. Derived models from the said process was used as basis in the computation of hydraulic parameters values and the theoretical hydropower potential.

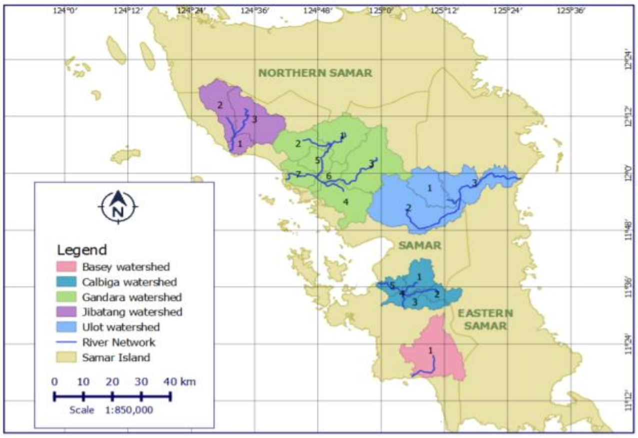

Fig. 2. Samar Major Watersheds.

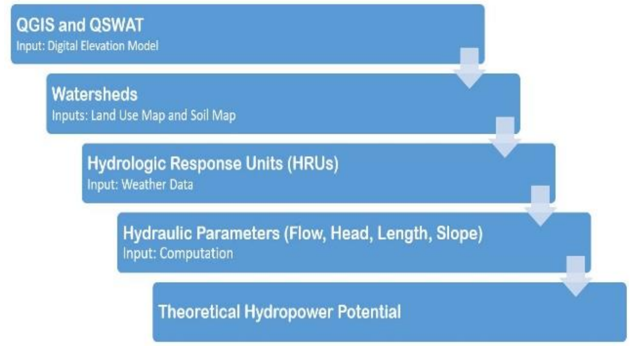

Fig. 3. Hydropower Potential Determination Workflow.

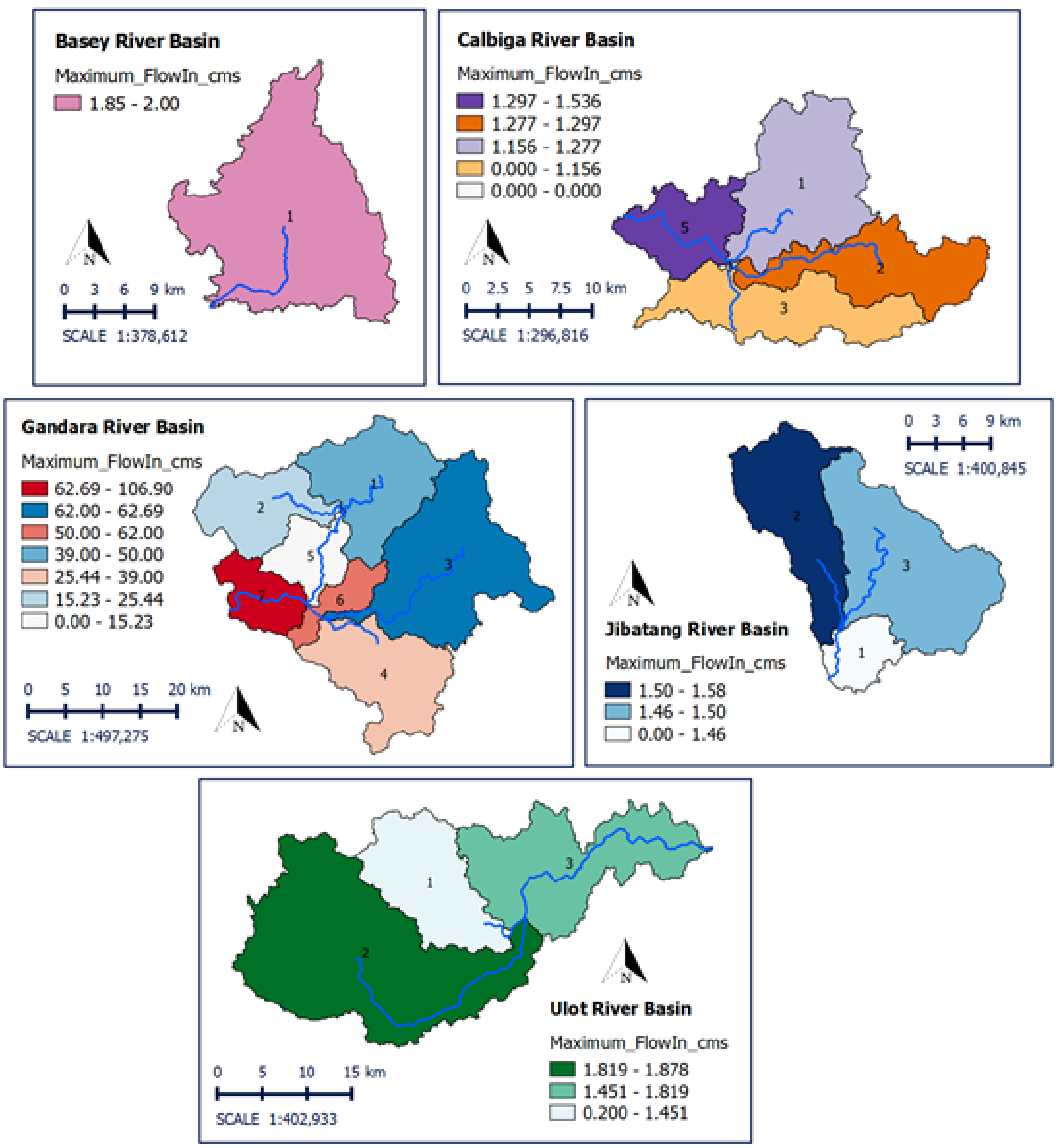

Fig. 4. The rivers sub-basins and maximum flowrate

4. RESULTS AND DISCUSSIONS

4.1 River and Sub-basin, Flowrate and Discharge

Flowrate is essential parameter in determining the hydropower. As such the different maximum flowrate of the different rivers covered by the study has been determined relative to its different sub-basins. Based on the different geographic attributes and parameters of the different river sites location, the maximum sub-basins and flowrate has been determined.

Figure 4 shows the different sub-basins and maximum flowrate of the different major river of Samar. Gandara river basin has the most number of sub-basins and registered to have the maximum flowrate between 62 – 106.90 m^3/s. While the Calbiga River basin has the lowest maximum flowrate between 1.297 – 1.536 m^3/s. On the other hand Basey River basin is the only river basin having a single sub-basin though it is the second to Gandara river basin in terms of flowrate estimated to be between 1.85 – 2.00 m3/s.

Moreover, the total annual average discharge of the said major rivers across it watershed is computed and the said results was reflected on figure 5. Figure 5 indicates that the Gandara river has the highest average annual discharge at 1,851.203. m^3/s, while Basey river registered to have the lowest average annual discharge at 14.599 m^3/s. On the other-hand, the average annual discharge along sub-basins of each said identified rivers is reflected in figure 6. Figure 6 indicates that Gandara river sub-basins reflects to have the highest average annual discharge between 50 m^3/s – 610 m^3/s as compared to other sub-basins of other major rivers under study.

4.2 Rivers Hydraulic Parameters

Theoretical hydropower potential of the rivers is determined based on different hydraulic parameters. Table 2 shows the different hydraulic parameters of the five major rivers of Samar. As indicated in table 2, Ulot River is the longest river stretching a total length of 33,937.1 into one of its sub-basins. It is being followed by Gandara River having a total length of 31,291.5 meters. While Calbiga registered to be the shortest having a length of 16,585.6 meters

In terms of elevation, Calbiga river sub-basin 2 has the highest elevation at 211.96 meters, while Gandara River sub-basins 4 and 6 does not shows any changes in elevation including that of Jibatang river sub-basin 2.

Moreover, Calbiga river sub-basin 2 registered to have the highest slope also at 0.01278. Note that hydropower computation is dependent also on the elevation, slope and length river.

4.3 Theoretical Hydropower Potential

The theoretical hydropower potential was calculated based in annual average flow. Figure 6 shows the hydropower potential of Samar and its location. Three (3) sub-basins of Calbiga river can generate between 1-25 MW hydropower, while one of its sub-basin can generate between 100KW – 1MW hydropower. Three sub-basins of Gandara river can generate between 25-100MW hydropower, One sub-basin can generate greater than 100MW, and one sub-basin can generate between 100KW – 1MW hydropower. Three sub-basin of Ulot river can generate between 1-25MW and one sub-basin can generate less between 1KW-1MW. Two of Jibatang river sub-basin can generate between 1-25MW and 100KW-1MW hydropower. While Basey River can generate between 1-25MW hydropower.

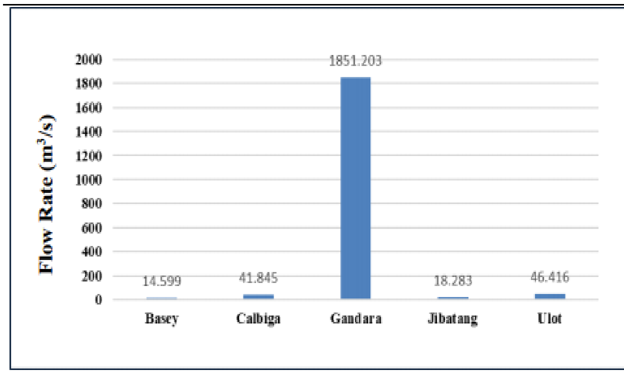

Fig. 5. Average Annual Discharge of Five Rivers.

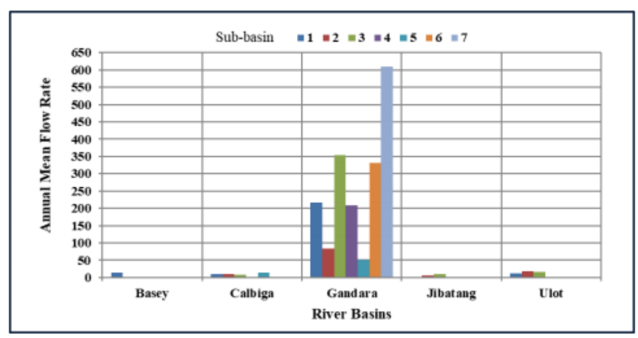

Fig. 6. Average Annual Discharge of Rivers Sub-basins.

Table 3. Computed Hydropower Potentials

	River Basin	Catchment Area (km^2)	Considered River Length (km)	Computed Theortical Hydropowere Potential (MW)
1	Basey	322.74	17.015	1.996
2	Calbiga	313.41	44.225	42.186
3	Gandara	1,127.09	91.552	561.908
4	Jibatang	446.54	26.426	2.002
5	Ulot	784.22	75.171	14.833
Total Theoritical Hydropower Potential				**622.925**

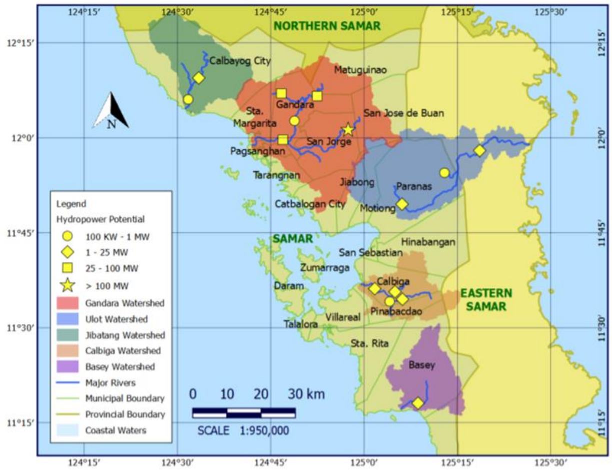

Fig. 7. The Hydropower Potential Site Location.

5. CONCLUSIONS

The following are the summary of the simulation results: Gandara River has the greatest number of river sub-basins, while Basey River has no sub-basins. Gandara River also registered to have the highest flowrate between 62 – 106.90 m^3/s while Calbiga River has the least flowrate at 1.297 – 1.536 m^3/s. Also, Gandara River has the highest average annual discharge 1,851.203m^3/s while Basey river has the lowest average annual discharge at 14.599m^3/s.

Furthermore, Ulot River is the longest river with a length of 33,937.1 meters while Calbiga River has the shortest with the length of 16,585.6 meters. In addition, Calbiga River sub-basin 2 has the highest elevation at 211.96 meters.

The estimated total theoretical Run-of-River (ROR) hydropower potential of the five major rivers in Samar is 622.925 Mega Watts (MW). The Gandara sub-basin 7 has the greatest river discharge of 608.989 m^3/s followed by its sub-basin 3 with discharge of 352.963 m^3 /, while Jibatang sub-basin 1 has the least river discharge of 2.707 m^3/s. Calbiga subbasin 2 has the highest hydraulic head followed by Gandara sub-basin 3 while Gandara sub-basin 5 has the lowest. The Gandara river basin has the highest hydropower potential of 561.908 MW.

Anchored to the results of the study, it is therefore recommended that Gandara River should be tapped for hydropower generation considering its hydropower potential. Likewise, Calbiga River can also be considered by the local government unit as possible source of power.

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Table 2. Hydraulics Parameters of Five Major Rivers in the Samar Province

River	Sub Basins	Length (m)	Slope (m/m)	ΔH (m)
Basey	1	17,015.2	0.00082	13.95
Calbiga	1	9216	0.01128	103.96
	2	16,585.6	0.01278	211.96
	3	6,314.6	0.00174	10.99
	4	12,109.1	0.00702	85.01
Gandara	1	13,618.2	0.00176	23.97
	2	14,397.1	0.00243	34.98
	3	31,291.5	0.00412	128.92
	4	10,712.2	0	0
	5	16,848.8	0.00012	2.02
	6	3,674.5	0	0
	7	15,366.8	0.00039	5.99
Jibatang	1	7,327.8	0.00191	14.0
	2	9,892.1	0	0
	3	19,098.3	0.00094	17.95
Ulot	1	6,984.8	0.00100	6.98
	2	33,937.1	0.00083	28.17
	3	3,4249	0.00169	28.17

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