ESTIMATION OF HYDROPOWER POTENTIAL ENERGY USING GIS AND SWAT HYDROLOGIC MODEL IN WESTERN VISAYAS

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ABSTRACT: The Philippines is abundantly endowed with water resources. However, electricity shortage is one of the biggest problems the country is currently facing. In order to help address this problem, assessment and identification of potential sites for hydropower energy is needed. Since the Western Visayas is one of the water resources region in the country, it is considered to have high potential for hydropower. Hence, hydropower resource assessment and site suitability analyses were conducted in this region. In order to estimate and assess the hydropower potential of the Western Visayas region, geospatial techniques and input datasets were used. The theoretical potential of hydropower was computed using the ArcSWAT (Soil and Water Assessment Tool) hydrologic model in ArcGIS. This model generates the flow values using different input datasets like river basin boundaries, soil dataset, Synthetic Aperture Radar - Digital Elevation Model (SAR-DEM) raster, weather datasets, etc. Then, terrain analysis algorithm using Python was used to generate the head or difference in elevation. From the two values (flow and head) obtained hydropower potential with detailed classification for mapping can be computed and identified. These results can be used to select the best areas for setting up hydropower plants in the Western Visayas Region. Moreover, this hydropower potential assessment can be used by planners and developers for future development of the region.

1. INTRODUCTION

The Philippines, by nature, is endowed with abundant water resources. These include the rainfall, surface water resources, i.e. rivers, lakes, and reservoirs, and groundwater resources. As a tropical country, the average annual rainfall is about 2,500 millimeters. Dependable supply from rivers is estimated at about 700 million cubic meters per day, which is more than twice the needs of the whole country for the next twenty years (Alejandro 1979). The Philippines has 18 major river basins and 421 principal river basins as defined by the National Water Regulatory Board (NWRB). Three of the major river basins are located in the Western Visayas, namely, Panay river basin, Jalaur river basin, and the Ilog-Hilabangan river basin. The Western Visayas is one of the water resources region endowed with high potential source of surface water (Greenpeace Southeast Asia, 2007).

However, as the 12th largest nation in the world, the Philippines is facing growing concerns over resource adequacy in its power sector. Supply concerns have already led to recurring announcements of rolling power outages (U.S. Energy Information Administration). Thus, sourcing out viable sources of energy in the country is encouraged. The Negros Occidental, one of the provinces in Western Visayas, is being tapped to promote and advocate renewable energy projects. The province's various resources, particularly its potential in providing hydroelectric power, can be seen as a good choice of power generation in nearby area. (Alex B. 2012)

This research aims to give insight in the potential of hydropower energy in the Western Visayas region and to distinguish the power capacity from pico, micro, mini and up to large hydropower. In order to assess the hydropower potential, Soil and Water Assessment tool (SWAT) hydrologic model method has been used to simulate input data and check whether there is hydropower at a specific location.

2. MATERIALS AND METHODS

2.1 Study Area

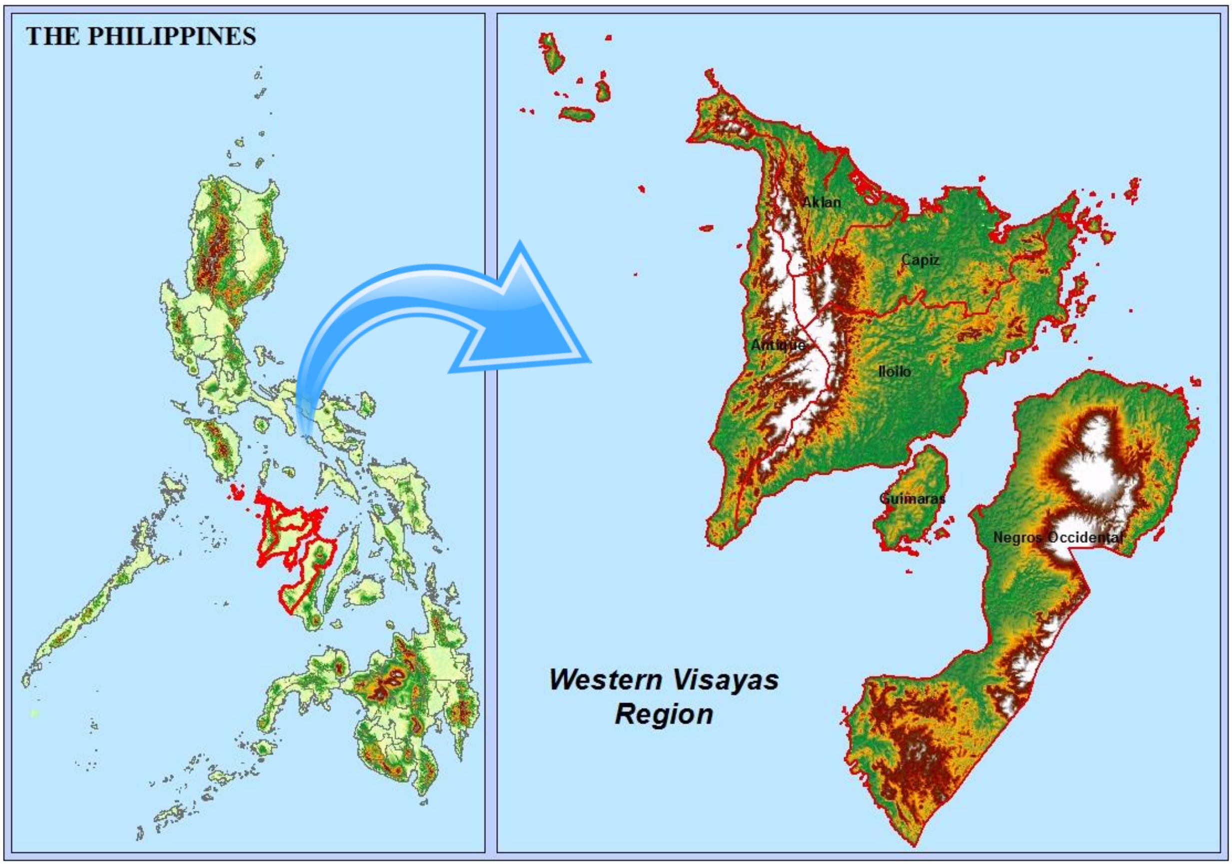

Figure 1. Map of the Philippines and the Western Visayas Region

The study area is focused on Western Visayas region in the Philippines composed of 6 provinces (Aklan, Antique, Guimaras, Iloilo, and Negros Occidental). It has a total land area of 20,168 square kilometers with a total of 16 cities and 117 municipalities in the region.

2.2 Source of Data

The data used in this research was obtained from different government agencies and provided by the implementing university (Training Center for Applied Geodesy and Photogrammetry of the University of the Philippines Diliman) that was involved in the nationwide project entitled Nationwide Detailed Resources Assessment Using LiDAR.

The following are the data used:

- Digital Elevation Model (DEM) derived from a RADARSAT Synthetic Aperture Radar (SAR) image with a 10m resolution
- The soil dataset, from soil survey reports of the Bureau of Soils and Water Management (BSWM), and other supplemental data downloaded from Digital Soil Map of the World (DSMW) (h ttp://www.fao.org)
- The landuse dataset which is in 2010 was obtained from National Mapping and Resource Information Authority (NAMRIA)
- Provincial boundaries from GADM
- Other datasets (such as weather, temperature, precipitation, etc.) are provided by Training Center for Applied Geodesy and Photogrammetry of the University of the Philippines Diliman

The datasets were projected with the World Geodetic System (WGS) 1984 as the horizontal datum and Universal Transverse Mercator (UTM) Zone 51 projection. The SWAT model simulation was done for the years 2000 to 2015. The simulated flow was calibrated to the actual average monthly data of the Department of Works and Highways Bureau of Research and Standards (DPWHBRS).

2.3 SWAT Model Using Input Datasets

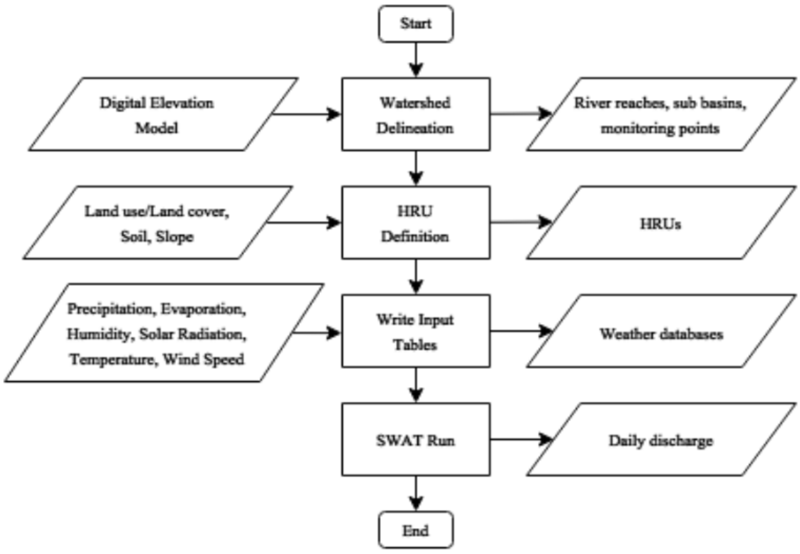

Figure 2. SWAT process flow diagram

Hydrological models are applied as tools for analysis of water resources and are used to simulate river and stream flow. The Soil and Water Assessment Tool (SWAT), specifically ArcSWAT tool was used in this study in ArcGIS software because of its features, physical model, geographic in nature, and considered useful in watershed modelling. It is a climate model data for hydrologic modelling that can delineate and simulate watershed. First, the DEM data was clipped for processing by province with a buffer of 1000 meters and used as one of the input raster in SWAT model. Each watershed in the Western Visayas region is divided into subbasins, which are primarily based on topography. These are then divided into Hydrologic Response Units (HRUs) based on land use, soil and slope. Then, each HRU's are simulated on the daily time step using weather datasets particularly, precipitation, humidity and temperature. Finally, flow is accumulated to subbasins after simulation.

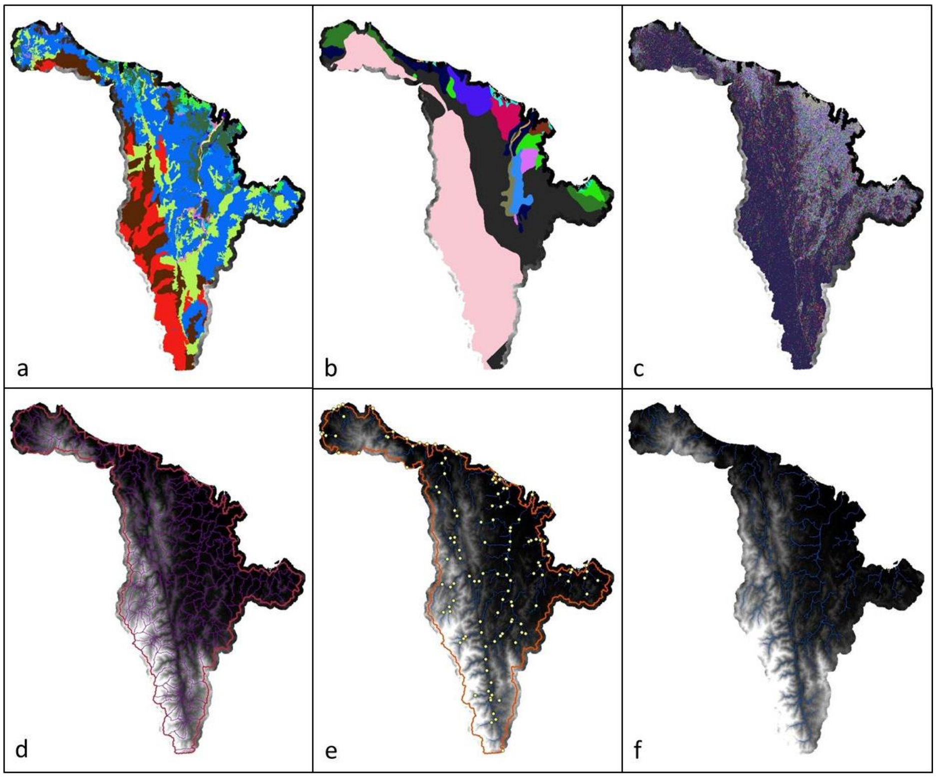

Figure 3. The sample input datasets and some outputs generated in SWAT model in the province of Aklan: (a-c) are input datasets used for HRU analysis – landuse, soil, and slope, respectively; (d-f) are outputs from watershed delineation – subbasins, monitoring points, and river reaches, respectively.

2.4 Head Determination

After the SWAT model simulation, a head determination algorithm that was developed by Bergstrom and Malmros that is applied using Python scripts was used for the initial methodology for hydropower resource site selection. The program prompts for the input data for the river cells, the preference for minimum head of 20m, and the preference for maximum horizontal distance between the virtual intake and virtual powerhouse which in this study we used 100m distance.

The main input for the algorithm were the river cells which are raster dataset containing the elevations along the rivers. These terrain data were derived from the source DEM by extracting the elevations using the delineated river reaches. The program then sorts all the river cells and stores the coordinates and the elevations to a list. It sorts the list in a descending order and proceeds to the computation beginning from the cell with the highest elevation. The computation searches the river cells for the neighboring cells that satisfy the user-defined minimum head but the search is limited to the range of distance satisfying the user-defined length between the virtual intake and virtual powerhouse. In this case, the virtual intake is the cell with the highest elevation. Once the search is done from the current virtual intake, the program iterates through the list to search for the next cell with the succeeding highest elevation. The iteration is terminated only when all the river cells have been taken into account. The result of the algorithm is the raster and vector files representing the segments connecting the virtual intakes and virtual powerhouses that satisfy the specifications. (Cuasay, et.al., 2016)

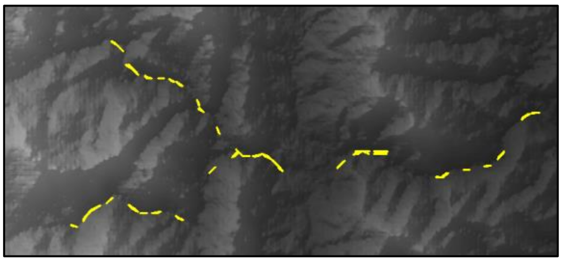

Figure 4. A sample output for head determination

2.5 Power Calculation

The head values generated by the head algorithm were spatially joined in ArcGIS to the discharged values from hydrologic model to compute for theoretical hydropower potential for each river segments. The following equation is used to calculate the theoretical power potential:

$$P = \rho \times g \times Q \times h \times \eta \qquad (1)$$

where P is the theoretical power in watts, ρ is the density of water (1000kg/m3), g is acceleration due to gravity (9.81 m/s2), Q is the volumetric flow rate in cubic meters per second, h is the head in meters, and η is the dimensionless combined turbine and generator efficiency (0.8). All the segments that met the set preference for the head determination algorithm but have zero corresponding dependable flow will yield zero power potential and thus excluded from the final results. Once the theoretical power potentials were obtained, the potential sites were classified into different types based from the power output ranges indicated in Table 1.

Table 1. Classification of Theoretical Power Potential

Power (kW)	Classification
Less than 5	Pico
5 to 100	Micro
101 to 1000	Mini
1001 to 3000	Small
3001 to 10000	Medium
Greater than 10000	Large

Large-hydropower are only few in the world. They are usually huge electricity producers, large dams and structures. Medium, small, and mini-hydropower are most common and they are large contributor. Micro-hydropower can be found mainly in small community and mostly remote areas; it can be off grid and on grid while pico-hydropower is off grid and useful in remote small community or single houses that require only a small amount of electricity (Meijer, L., 2012).

3. RESULTS AND DISCUSSION

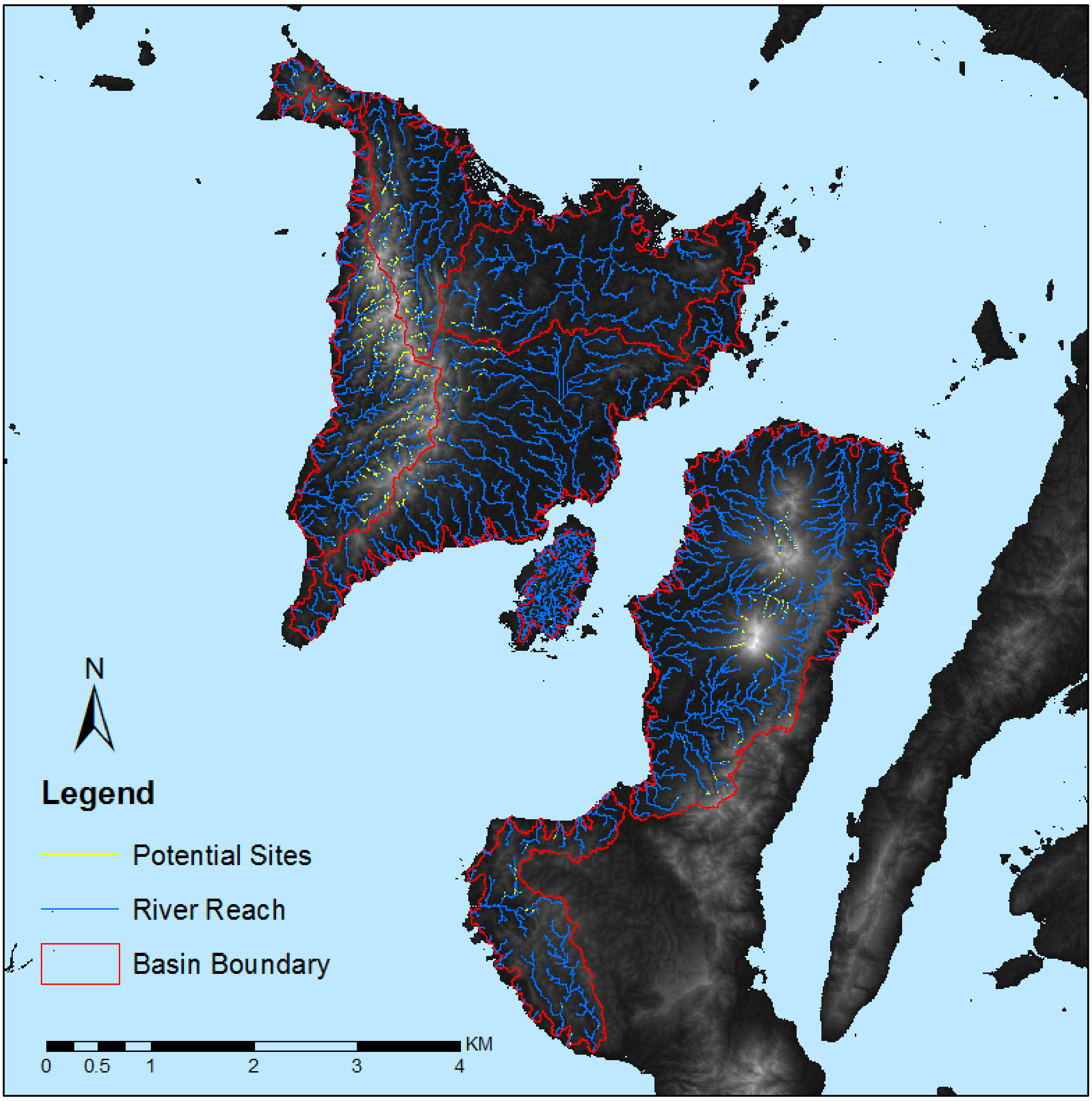

Figure 5. Detailed map of potential sites and river reaches in Western Visayas

The map shown above indicates the possible sites for hydropower development in the Western Visayas region. A total of 13,570 river segments were delineated for possible sites with an average theoretical power of 32.14kW. Antique has the most number of potential river segments of 7,455; followed by Aklan with 2,507; then Negros Occidental with 1,790; Iloilo with 1,433; and lastly Guimaras with 67 potential river segments.

Capiz has the highest average theoretical power with an estimated value of 394.88kW; followed by Aklan with 45.87kW; then Negros Occidental with 20.11kW; Antique and Iloilo with 17.95kW and 17.86kW respectively; and lastly, Guimaras with 1.31kW.

Estimated potential annual generation, with the capacity factor not considered, was also computed using the formula:

$$Potential\ Annual\ Generation(kWh) = Theoretical\ Power\ (kW) \times \frac{24hours(h)}{1\ day} \times \frac{365\ days}{1\ year} \quad (2)$$

Table 2. Number of river segments in 100m horizontal distance per class with corresponding theoretical power and potential annual generation by province in Western Visayas

Province	Class	Number of river segments	Theoretical Power (kW)			Potential Annual Generation (kWh)		
		100m	Minimum	Maximum	Average	Minimum	Maximum	Average
Aklan	Mini	235	100.32	584.41	221.48	878,771.87	5,119,415.16	1,940,194.28
	Micro	2,240	5.45	99.99	28.05	47,700.54	875,951.99	245,705.68
	Pico	32	2.34	4.69	3.63	20,467.62	41,063.39	31,812.19
		2,507			45.87			401,812.68
Antique	Mini	45	100.95	196.34	127.29	884,327.75	1,719,916.61	1,115,103.59
	Micro	5,547	5.00	99.22	21.99	43,800.99	869,193.85	192,676.18
	Pico	1,863	1.22	5.00	3.28	10,666.47	43,798.99	28,755.58
		7,455			17.95			157,280.49
Capiz	Mini	230	233.88	967.79	523.91	2,048,809.79	8,477,872.57	4,589,447.11
	Micro	88	15.70	98.52	57.65	137,490.04	863,048.38	504,972.74
		318			394.88			3,459,152.31
Guimaras	Micro	4	12.07	12.75	12.53	105,704.25	111,715.18	109,721.48
	Pico	63	0.16	1.62	0.60	1,439.02	14,203.48	5,243.24
		67			1.31			11,480.75
Iloilo	Mini	5	101.65	435.36	212.47	890,490.73	3,813,748.68	1,861,245.90
	Micro	1,313	5.00	96.89	18.32	43,800.39	848,780.04	160,464.25
	Pico	115	2.13	5.00	4.14	18,692.10	43,795.47	36,259.39
		1,433			17.86			156,431.00
Negros Occidental	Mini	73	130.00	601.65	248.12	1,138,840.69	5,270,414.18	2,173,553.60
	Micro	1,170	5.00	84.77	13.79	43,815.03	742,562.39	120,771.53
	Pico	547	1.01	5.00	3.20	8,805.32	43,765.26	28,061.08
		1,790			20.11			176,157.27
TOTAL		**13,570**			**32.14**			**281,513.43**

The table shows that Capiz province, which contains one of the major river basins – Panay river basin – in the Philippines, has the highest estimated average power capacity, with a value of 3,459,152.31kWh per year, and has the highest potential in mini hydropower development in the region, with a value of 4,589,447.11kWh per year. It is followed by Aklan, having the 2nd highest estimated annual average power capacity and 2nd highest in terms of the number of potential river segments.

Negros Occidental, Antique, and Iloilo province, which rank 3rd, 4th and 5th respectively, has more or less equal in estimated power potential ranging from 157,280.49kWh per year – 176,157.27kWh per year.

Antique province has the most number of potential river segments but can only generate an average power of 157,280.49kWh per year, which ranks 4th in the region. Guimaras province has the least number of potential river segments and has the lowest average potential power capacity with an estimated value of 11,480.75kWh per year.

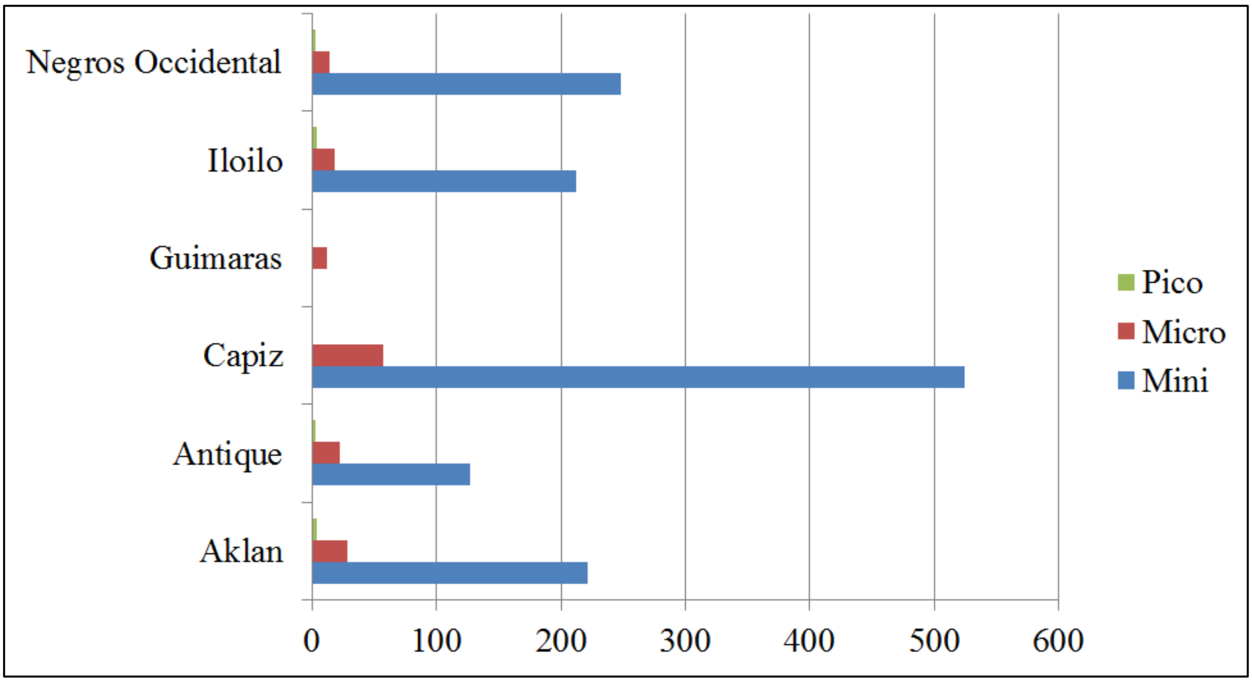

Figure 6. Summary of theoretical power capacity in kW by classification per province in Western Visayas

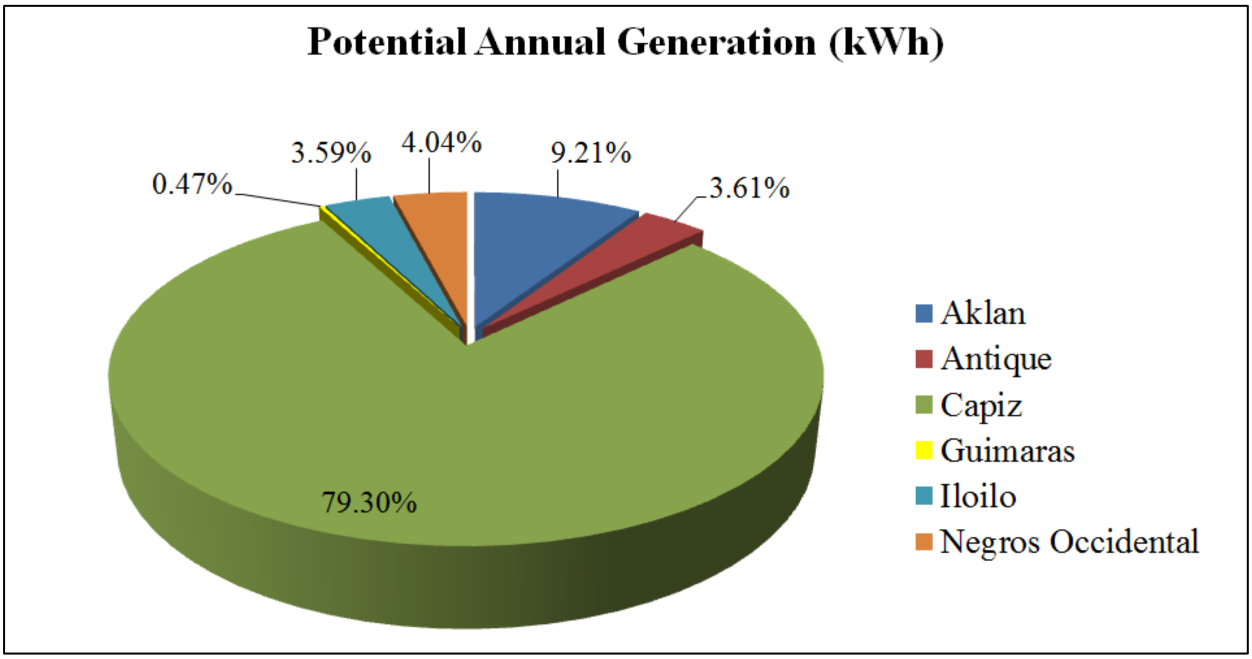

Figure 7. Estimated share of potential power generated per year in kWh per province in Western Visayas

4. CONCLUSIONS

For this study, the Western Visayas region has a total of 13,570 potential sites where we can select the best suitable sites for hydropower development. For a minimum head of 20m and a maximum horizontal distance between the virtual intake and virtual powerhouse of 100m that we used, there is no small, medium, and large hydropower classified. The classification of potential sites resulted only from pico, micro, and mini hydropower. Capiz province as the top in the region has no pico-hydropower classified and Guimaras province in the bottom with no mini-hydropower classified. The minimum theoretical power is in Guimaras province with 0.16kW and the maximum theoretical power is in Capiz province with 967.79kW. The province of Capiz has the highest average theoretical power of 394.88kW and can generate average potential power of 3,459,152.31kWh per year. Overall, Western Visayas has an average theoretical power of 32.14kW and estimated to generate an average potential power of 281,513.43kW or 281.51MW annually.

5. FURTHER STUDIES

For further studies, by using different values for head and a maximum horizontal distance can be another basis for estimation of power and identifying potential sites in the region and conduct site suitability analysis. Assessment of suitable locations for hydro power plants can also be done. The analysis of the potential sites and their corresponding potential power production can serve as reference for the private and public sectors for the sustainable management of water resources. However, site attributes and suitability factors, such as wild/scenic protection, cultural and historic values, fish presence value, geologic value, and recreation value should be considered. Another study to consider is the suitability and evaluation of pico-hydropower in remote areas most especially in rural areas where there are small amount of electricity needed to power houses and communities.

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