Rapid Hydropower Potential Assessment for Remote Area by using Global Data

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Abstract. Indonesia currently is facing an energy crisis due to depletion of oil reserves and rapid growth in conventional energy consumption. The declining fossil energy potential especially oil and gas has encouraged the government to put new renewable energy (NRE) as the main priority to maintain energy security for national supply in the future. NRE in Indonesia is generated from bioenergy power, hydro power, solar power, tidal power, wind power, and potential. However, NRE utilization in Indonesia is only about 11% from the total potential. This study assesses the hydropower production capacity of Ayung River Basin, the biggest Basin in Province of Bali. The assessment is carried out by utilizing global data that can be easily accessed. It was found that there are several potential mini-hydropower locations around the Ayung River Basin, with the biggest potential is around 2 MW.

1. Introduction

Indonesia is the top 4 most populous country in the world with approximately 260 million people to date [1]. With this number, meeting the basic needs is an important focus of this country. Based on data released by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, the electrification ratio in Indonesia rose into 98.89% in 2019 [2].

In addition, fossil-based power plants still dominate in Indonesia. Based on the 2019 Electricity Statistics, around 85% of the total installed capacity of power plants in Indonesia is fossil fuelled [2]. This is not a fun fact, because it has the potential to put Indonesia into an energy-crisis situation in the future. Therefore, exploration and studies in the development of renewable energy need to be encouraged, one of which is hydropower.

The study location took place in Bali Province. From the electricity aspect, Bali Province still relies on energy generation from outside the island to fulfil their region demand. Currently, Bali has energy generation capacity more than 1,200 MW, with maximum requirement around 980 MW, and 350 MW comes from the Paiton plant in East Java which still uses coal [3]. As an area which is well known for its tourism, it’s very important for Bali Province to be energy independent.

The availability of the infrastructure has not matched the need for electrical energy. Difficulty and high data need to determine the potential for electrical energy are a challenge in developing electricity...
supply in a region [4]. However, the rapid development of remote sensing technology and information and communication technology (ICT) has also contributed to global data development [5]. This causes the need to use global data to predict the potential for electrical energy in a region, especially energy that comes from water.

The aim of this study is to assess the point potential of mini-hydropower in the Ayung River Basin. The study was carried out by utilizing global data as input, including in the form of Multi-Error-Removed Improved-Terrain (MERIT) DEM. It was developed by removing multiple error components from SRTM+AW3D DEM. MERIT DEM has a significant improvement at flat land [6]. The river flow is generated from hydrological data processing using the SWAT, while the head is obtained by DEM processing used Geospatial Information System (GIS) software. Based on these two main inputs, the power generated by the hydropower can be calculated.

1.1. Study Area

The study area of this potential energy assessment is one basin in the Province of Bali, Ayung River Basin as in figure 1. Ayung River basin has an area around 302.9 km², with the highest elevation about 2,900 m above mean sea level.

Figure 1. Study area

Ayung River Basin is chosen as the location of study because it is the biggest basin in the province of Bali. Moreover, Ayung river is located near the residence area, which means it must be located near the actual electricity grids as well. The size of Ayung River Basin also makes the discharge production as big as its size.

2. Method and Data

2.1. Methodology

Generally, the study process is based on the stages that have been compiled and illustrated in the flow chart as presented in figure 2.
The study begins with a literature study, both previous studies in the study area and studies related to methods or theoretical studies. From the literature study activities, steps will be taken to work on the following research software used in this study. Then hydrological modeling to find out which water can be used for electricity generation activities.

The water discharge generated by modeling runoff rainfall is calibrated with observational discharge data obtained from related authority. Then the calculation of the potential height of falling water (head) using a diversion algorithm. After obtaining the height of the fall and the dependable discharge, the power calculation is carried out. The modeling and calculation process carried out using numerical methods and models that have been used in previous studies obtained from the literature study process.

Some of the processes carried out at the simulation stage are:
- Rainfall-Runoff Model: SWAT Model
- Head Calculation: Diversion Algorithm (Kardhana, 2017)

2.2. Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is semi distributed hydrology model that use hydrological response unit (HRU) as a unit calculation [7]. There are three calculation processes experienced by each HRU in runoff rainfall modeling: direct runoff, lateral flow, and base flow.

2.2.1. Direct Runoff. Direct runoff is surface runoff from rainfall excess. If the rainfall is zero there will no direct runoff. This calculation used SCS curve number equation which is provided in equation (1) and (2).

\[ Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)^2} \]  
\[ S = 2.54 \left( \frac{1000}{CN} - 10 \right) \]

Where
- \( Q_{surf} \) = direct runoff (mm)
- \( R_{day} \) = rainfall (mm)
- \( I_a \) = initial abstraction (mm)
- \( S \) = retention parameter (mm)
- \( CN \) = curve number

2.2.2. Lateral Flow. In areas with high hydraulic conductivity soil, lateral flow will be significant in the surface layer and the impermeable or semipermeable layer at shallow depths. SWAT uses the combination of a kinematic storage model for subsurface flow developed by Sloan et al. (1983). This model simulates subsurface flow in a two-dimensional cross-section along a flow path down a steep hillside as in equation (3). The kinematic approach is used in its derivation.

\[ Q_{lat} = 0.024 \sqrt{SW_{u,excess} \frac{K_{sat,HP}}{\theta_d - I_{hill}}} \]

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**Figure 2.** Workflow diagram
Where

\[ Q_{\text{hat}} = \text{lateral flow (mm)} \]
\[ K_{\text{sat}} = \text{saturated hydraulic conductivity (mm/hour)} \]
\[ \text{slp} = \text{tangent slope} \]
\[ \phi_d = \text{drainable soil porosity (mm/mm)}, \]
\[ L_{\text{hill}} = \text{hillslope length (m)} \]
\[ SW_{\text{ly,excess}} = \text{drainable volume of water stored in the saturated zone (mm)} \]

2.2.3. Base Flow. Shallow aquifers provide base flow to the main river or reach within sub-basins. The base flow is allowed to enter the range only if the amount of water stored in the shallow aquifer exceeds the threshold value. The steady-state response of groundwater flow to recharge is stated in equation (4) (Hooghoudt, 1940).

\[ Q_{gw} = \frac{8000 \cdot K_{gw} \cdot h_{wth}}{L_{gw}^2} \]  
(4)

Where

\[ Q_{gw} = \text{ground water flow or base flow (mm)} \]
\[ L_{gw} = \text{the distance of sub-catchment to main channel (m)} \]
\[ h_{wth} = \text{water table height (m)}, \]

2.3. Diversion Algorithm

The diversion algorithm is used to find potential head spatially [8]. This algorithm will look for the optimal path between the diversion and the powerhouse location in the MHP system. This diversion path optimization requires several aspects such as headloss, the ratio between the length of the waterway and the head, and hill cuts. The main inputs of the calculation based on the diversion algorithm are digital elevation model (DEM), the grids of river, and the flow accumulation (flowacc) map. The diversion algorithm can be seen at figure 3.

Source: Kardhana et.al., 2017

**Figure 3.** Diversion algorithm
2.4 Potential Power Calculation

The firm power equation can be determined by following equation (5).

\[ P = \eta \rho g Q H_n / 1,000 \]  \hspace{1cm} (5)

Where

- \( P \) = firm power (kW)
- \( \eta \) = system efficiency
- \( \rho \) = water density (1,000 kg/m\(^3\))
- \( g \) = local gravity acceleration (9.78 m/s\(^2\))
- \( Q \) = dependable flow (m\(^3\)/s)
- \( H_n \) = net potential head (m)

2.5 Data

The data are used in this study are data on rainfall, dem, land cover and soil types.

2.5.1. DEM. The digital elevation model (DEM) data are used in this study obtained by Merit DEM (Fig 1). Merit DEM is a global flow direction map at 3 arc-second resolution (~90 m) derived from the latest elevation data and waterbody. This data will be used in slope analysis and catchment area delineation.

2.5.2. Rainfall and climate data. The rainfall and climate data are used in this study obtained by CFSR (Climate Forecast System Reanalysis), figure 1. Climate data are used in this study is temperature, relative humidity, solar radiation, and wind velocity. CSFR data are used because they are presented in a form suitable for the SWAT hydrological model. In addition, the CSFR data proved to be good enough to be used to predict the value of rain in remote areas or do not have observation stations [9], especially if the distance between the station from the watershed within radius 10 km [10].

2.5.3. Land cover. The land cover maps obtained from Ministry of National Development Planning/National Development Planning Agency (BAPPENAS), mapping result in 2018, figure 4 (i).

2.5.4. Soil types. The soil types map is used in this study is hydrologic soil group by The Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC), figure 4 (ii).

This data is used in the entire analysis process, from hydrological models to head calculations. Topographic data, land cover data, and soil group data were used to determine the hydrologic response unit (HRU) of the Ayung River Basin. Topographic data are also used for head computation in the diversion algorithm.

3. Result and Analysis

3.1. Hydrologic model

Rainfall-runoff modeling is carried out using the SWAT model. The model is used rainfall and climate data for 10 years (2004-2013). The land cover data used comes from Bappenas with an update in 2018. Based on the hydrologic modeling, the runoff used has an exceedance probability of 85% (Q\(_{85}\%\)). That discharge value will be used to generate electricity.
Figure 4. (i) Land cover map; and (ii) HSG map

Figure 5. Dependable flow map with probability 85%
Before being used, the discharge value generated by the SWAT model is verified using data obtained from the Ayung River Authority, BWS Bali-Penida as in table 1. The verification processes used flow measurement data at the Tukad Ayung Hulu station in the range 2008-2015. Generally, the discharge value with the probability exceedance of 85% is above 2.3 m$^3$/s, except in 2009 it was only 0.96 m$^3$/s. If we look at the results of the SWAT model in figure 5, the flow with exceedance 85% around the Tukad Ayung Hulu station is greater than 1.5 m$^3$/s. This shows that the resulting flow from model is quite good and not overestimate.

### 3.2 Slope Analysis

Slope analysis is carried out to determine locations that have good head potential. GIS software is used to determine the slope value. The slope calculation mechanism is to calculate the slope of a grid against the surrounding grid. Due to this mechanism, the resulting slope value is not specific only to rivers but also around rivers. This causes there may be an area having a higher slope than the river. To identify the potential slope of the river, the calculated slope value is extracted based on the existing river location. Existing river locations were obtained from previous SWAT modeling.

This river slope analysis is instrumental as an initial filter in determining which basin has a good potential for electrical energy from water resources. This is because, with a river that has a high slope, this means it has a high potential head as well, this can be illustrated in figure 6.

![Figure 6. Potential Head analysis due to River slope condition](image)

The existence of a river segment with a high slope indirectly indicates the high potential for falling between before and after. this can be exploited by diverting the water before passing steep river...
segments. Then, after being diverted, the water is carried downstream by a waterway with a low slope to be dropped on the part of the river after passing this steep river segment. Certainly, not all steep river segments will be accompanied by land that has a gentle slope. Nonetheless, at least this analysis will ease the effort in calculating the potential energy that was previously carried out in a large area into a more specific area.

After obtaining the slope of the river, the slope values were filtered based on several criteria. The slope criteria used to determine a good head potential for a mini-hydropower is the ratio between length and height difference \((L/H) < 25\) [11], or slope range \(12.5\% - 25\%\) [12] as in figure 7.

3.3. Potential Point

Some of the data needed to calculate the energy potential include DEM data, planned discharge data with a probability of being exceeded 85\%, river data, and flow accumulation in ASCII raster data. Then the data will be processed using the Diversion Algorithm, which is implemented into a numerical model. In the calculation process, there are several steps, starting from selecting the location with the fall height to calculate the potential energy.

According to the name of the method, this algorithm focuses on selecting the optimal potential head location. Determination of the optimal head location is determined based on the head height with several criteria used. First, the weir/diversion location is determined based on the river’s discharge value \((Q_{\text{85\%}})\) greater than \(0.1\ \text{m}^3/\text{s}\). Second, based on the divert location points determined, the location of the headpond with a minimum elevation difference aims to minimize headloss with a maximum distance of 3,000 m. This process aims to eliminate paths that are far from rivers and obstructed by hills. Third, from the headpond location, the tailrace location, where the powerhouse is located, has the lowest elevation with a distance not more than 2 pixels (180/2 m). If the head is less than 3 meters is considered to have no potential because almost all types of turbines cannot operate at that head [13]. The calculation process has been clearly illustrated as shown in the figure 6.

After obtaining these locations, the value of the potential energy is calculated using the net head value. The calculation process is repeated on each grid to get the location of as many potential points.
as possible. Then, all potential hydropower points are presented on a map so that they can be presented informatively.

![Map of Hydropower Potential Ayung Basin](image)

**Figure 8.** (i) Potential point of mini-hydropower; and (ii) Identified potential hydropower in Bali, by World Bank

Based on the study process carried out, it was found 6 potential locations for mini-hydropower as can be seen in figure 8 (i). If you pay attention to the potential head image from the slope analysis process with the potential hydropower location image, not all river segments with a slope of 12.5% - 25% have hydropower potential. This is possible because the location determination and calculation of the hydropower potential are based on the river segment's location with a predetermined slope. The existence of a processing process using diversion algorithms with the criteria in it causes the hydropower potential to be obtained not as much as the potential head based on the river's slope.

If seen in figure 8, there are similarities between the potential locations generated by this study and the World Bank studies. There are differences in the study's data sources, such as rainfall, climate, soil type, and DEM data. While the land cover data used has more or less the same source. In this study, the largest potential value is 1,571 kW or almost equivalent to 2 MW, while the lowest potential is 63 kW which located at the upstream. Meanwhile, based on a study conducted by the World Bank in Bali province [14], the greatest potential value is greater than 15 MW, and the smallest value is in the range of 2-5 MW. The most obvious thing that can be compared with the difference in the potential value of the energy produced is the data source used.

**4. Conclusion**

Combining the hydrological model and the diversion algorithm used is advantageous in predicting hydropower potential points. Moreover, global data availability makes it very easy to assess the potential of electrical energy in remote areas with limited data availability.

Based on the study process carried out, it was found 6 potential locations for mini-hydropower. The six locations were declared technically feasible. The largest potential value is 1,571 kW or almost equivalent to 2 MW, while the lowest potential is 63 kW, located upstream. Comparing by the location, there are similarities at several potential points between this study and the world bank's study. Therefore, with all the existing limitations, this study can be said that by utilizing global data, the assessment of hydropower potential is possible.
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