Potential Sites Screening for Mini Hydro Power Plant Development in Kapuas Hulu, West Kalimantan: a GIS approach

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Abstract

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 analysing 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.

Keywords: ASTER Digital Elevation Model; GIS; mini hydro power plant; watershed.

Nomenclature

ADB Asian Development Bank
ASTER Advanced Spaceborne Thermal Emission and Reflection
BAPPEDA Regional Development Planning Agency

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1. Background

Indonesia is one among few countries in the world which shows stable economic growth in the midst of global crisis. Research conducted by ADB revealed that areas outside Java and Sumatra have inadequate infrastructure [1]. Electricity is considered as the main constraint, which is characterized by a low electrification rate, low consumption, and high inefficiency in transmission and distribution. In West Kalimantan for example, most of power plants are based on diesel generator which the production cost is higher than selling price.

Government is planning to develop coal and gas based power plant besides importing electricity from Malaysia for peaking in West Kalimantan region [2]. This idea can be considered as short-term solution because using imported non-renewable energy source. Government needs to formulate long-term strategy by identifying the opportunity to implement renewable energy, such as hydropower.

Indonesia has abundant potential of hydropower, approximately accounted as 75 000 MW [3], which makes Indonesia rank 4th in Asia. Even in mini hydropower plant (MHPP) range, the potential is quite big with 7 500 MW potentials are considered economically feasible (4). However, the development of MHPP is site-specific. Every site has different condition in terms of topographic characteristic and hydro-climatologic condition.

Some researchers developed methods to find potential sites for MHPP development [5,6]. The availability of observation discharge data is one of the barriers in screening the potential sites. Identifying suitable location with good head is another issue. In this research, the potential site for mini hydro power plant (MHPP) development is identified by using GIS approach. The focus of this study is assessing the methods for finding head and calculating river discharge using spatial data.

Kapuas Hulu District, particularly in part of Tanjung Lokang, South Putussibau, was chosen as a case study due to its mountainous topographic condition [7] which is good for MHPP besides its inadequate infrastructure such as inefficient diesel generator power plant. MHPP is proposed as alternative power plants for scattered remote areas which currently run on diesel power plants [8].

2. Material and method

2.1. Material

ASTER Digital Elevation Model (30 m × 30 m spatial resolution) [9] was used to generate river network and delineate watershed as well as to assess topographical characteristic of the study areas. Soil type map (5′ × 5′ spatial resolution) [10] and land cover shape file from Ministry of Forestry were also inputted to calculate runoff fraction of annual rainfall.
2.2. Watershed delineation

In order to build hydrological model in a watershed, it is necessary to delineate the watershed using watershed delineation function in SWAT (Soil and Water Assessment Tools) model. ASTER Digital Elevation Model (DEM) data was used as input to delineate watershed. However, the DEM data must be projected to UTM projection format before conducting watershed delineation. The output of the watershed delineation is sub-watershed and river network.

2.3. Head calculation

Based on potential energy formula, MHPP is characterized by two major factors: head and river discharge. River head 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 neighbourhood analysis tool in ArcGIS. The analysis calculated elevation range between neighbourhood pixels in riverbed topographic profile. Head calculation methods in this research is an improvement of the methods used by Bergstrom and Malmros [5].

2.4. River discharge

General water balance equation in a watershed was formulated by Davie [11],

\[ P = E + I + Q + Q_{TF} + Q_{G} \]  \hspace{1cm} (1)

Where \( P \) is precipitation (mm), \( E \) is evaporation (mm), \( I \) is Interception (mm), \( Q \) is runoff (mm), \( Q_{TF} \) is throughflow or sub-surface runoff (mm) and \( Q_{G} \) is groundwater (mm). However, in spatial analysis the portion of \( I, Q_{TF} \) and \( Q_{G} \) are neglected as proposed by Hasenmueller and Criss [12]. So, the equation will be

\[ P = E + Q \]  \hspace{1cm} (2)

River discharge was assumed as the accumulation of runoff in a sub-watershed. Runoff was approached using SCS Runoff Curve Number (CN) equation formulated by SCS [13] with rainfall and curve number as input. The equation is shown below,

\[ Q = \left[ P - 0.2 \left( \frac{100}{CN} - 10 \right) \right]^{2} / \left( P + 0.8 \left( \frac{100}{CN} - 10 \right) \right) \]  \hspace{1cm} (3)
Where \( Q \) is runoff (mm), \( P \) is precipitation (mm) and \( CN \) is curve number. In this research, average annual precipitation map during normal years was used as precipitation input. Then, curve number was determined based on land cover, hydrological soil group (HSG) and hydrologic condition [14]. HSG was determined based on composition of sand and clay in the first soil layer (see Table 1).

| Hydrological Soil Group (HSG) | Column A (t) | Column B (t) |
|------------------------------|--------------|--------------|
| Group A                      | > 90 %       | < 10 %       |
| Group B                      | 50 % to 90 % | 10 % to 20 % |
| Group C                      | < 50 %       | 20 % to 40 % |
| Group D                      | < 50 %       | > 40 %       |

Once spatial runoff map was generated, sub-watershed runoff accumulation was calculated by multiplying runoff (mm) with area of sub-watershed (m²). Then, final runoff was calculated by dividing runoff (m³) with total seconds per year (365 \( \text{d} \) \( \times \) 24 \( \text{h} \) \( \times \) 3600 \( \text{s} \)). Final runoff has m³ \( \text{s}^{-1} \) unit.

Sub-watershed river discharge has two water sources, sub-watershed runoff and upper sub-watershed river discharge. River discharge was produced by summing sub-watershed runoff and upper sub-watershed discharge using following scheme (see fig 2).

Fig. 2. River network.

2.5. MHPP potential

MHPP potential (Watt), was calculated using potential energy formula, \( W = m \times g \times h \), where \( m \) is water mass or river discharge (L \( \cdot \) s⁻¹), \( g \) is gravity (9.81 m \( \cdot \) s⁻²) and \( h \) is head (m). The efficiency of turbine, generator and transmission losses were neglected because further assessment in choosing turbine and other electromechanical components is completely needed in order to determine their efficiency.
3. Discussion

The study area consists of primary forest and shrub cover. Primary forest is distributed evenly in every part of watershed while shrub is only found on downstream. The majority of forest cover in the watershed has positive impact to the MHPP operation as it maintains the base flow of the river, resulting in constant water supply, even in dry season [15].

From composition of sand and clay in soil map, it is identified that all areas in the watershed are categorized in B hydrological soil group (HSG). This category is characterized by moderately low runoff potential when thoroughly wet and water transmission through the soil is unimpeded [13].

Precipitation in Kapuas Hulu is quite high with 3 300 mm to 5 000 mm annual rainfall [16]. It has equatorial precipitation type with obvious distribution of two peak (maximum) which happens to coincide when the sun near the equator that is circulated in March–April and October-November [17]. In this research it is assumed annual rainfall to be 4 000 mm as also analysed by Risdiyanto [18] in precipitation map.

Watershed delineation process resulted in 41 sub-watershed with various shape and area. Each sub-watershed accumulates runoff fraction of the rainfall in the sub-watershed area and store it to each river passing it. After delineating watershed, river head was identified by using statistical neighbourhood analysis where 79 sites were found having good head condition. Sites with head above 20 m were considered as the good head sites [5]. However, most of these sites have head between 20 m and 30 m (see Table 2).

| Head            | Number of sites |
|-----------------|-----------------|
| 20 m to 30 m    | 69              |
| 30 m to 40 m    | 7               |
| 40 m to 50 m    | 2               |
| 50 m to 60 m    | 1               |

Fig. 3. Location of sites with good head.
Based on land cover and HSG, the curve number in the watershed only consists of 55 and 48. It means that the watershed stores a moderate portion of runoff. Runoff in the sub-watershed was then accumulated to generate river discharge. In this study area, discharge varies between 0.45 m³ · s⁻¹ to 25.26 m³ · s⁻¹.

After analysing head and river discharge, MHPP potential was calculated by using Equation 3. The results showed that there are only 18 MHPP potential sites which vary from 110 kW to 5.2 MW (see Table 3 and Fig. 4). Although 79 sites were considered to have good head (see Table 2), most of them have under-30 m head and are located in the upper watershed (see Fig. 3). As the catchment area in the upper watershed is smaller, the accumulated discharge tends to be very low and the final potential was calculated to be under 100 kW. Thus, they are not considered as MHPP potential sites.

Table 3. Potential sites for MHPP characterized by good head and river discharge

| Potential       | Number of sites |
|-----------------|-----------------|
| 100 kW to 250 kW| 2               |
| 250 kW to 500 kW| 3               |
| 500 kW to 1 MW  | 4               |
| 1 MW to 2.5 MW  | 6               |
| 2.5 MW to 5.3 MW| 3               |

Fig. 4. Potential sites for MHPP development in Kapuas Hulu district, West Kalimantan.

4. Conclusion and suggestion

The methods in this research have successfully generated potential sites with good head and river discharge. This research also showed that sites with good head do not always have good river discharge which resulted in low
potential. After analysing study area it is found that there are 18 potential sites which range from 100 kW to 5.2 MW. Nevertheless, there are still limitations in this research, such as some neighbourhood sites are identified to be separated whereas they can be single potential site with bigger potential. Besides that, runoff fraction calculation using SCS CN formula with annual rainfall input need further assessment as it generates higher value.

This method is suitable for initial screening MHPP potential in a small watershed only. There must be more detailed assessment and in depth feasibility study in order to develop MHPP in the potential sites which employ direct measurement and observation data analysis.

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