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Geological aspect analysis for micro hydro power plant site selection based on remote sensing data

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ABSTRACT

Geological characters analysis is essential for micro hydropower plant (MHP) development planning. This paper presents an analysis of the geological aspect to determine the layout of MHP components based on remote sensing data as part of a solution to addressing power shortages in Sungai Are District, South Ogan Komering Ulu Regency, South Sumatra Province. Remote sensing and topographic map were extracted to identify the potential site. The topographic map and geological analysis were used to calculate the potential of electrical energy and the geological hazard risk, particularly floods and landslides. The results of the study identified four potential sites. Site 1 (Luas River, Ulu Danau Village) and site 3 (Putih River, Gintung Village) are suitable for MHP with a low cost of construction. Site 2 (Pecah Pinggan Village) and site 4 (Simpang Luas Village) are prone to flooding and landslides that makes it suitable for MHP but with a high cost of construction. Based on the geological aspect analysis, it is possible to optimize the hydropower capacity, by adding the volume of water flow from several nearby tributaries channeled into the hydropower flow system through civil construction engineering or by making a cascade design on the tailrace water flow.

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1. INTRODUCTION

Hydro energy is currently the largest renewable energy source in the world, which meets about 16-17% of the world's electricity needs [1]. With abundant hydropower potential, which is around 75,000 MW, Indonesia ranks 4th in Asia [2]. Amongst renewable energies in Indonesia, hydropower is the most extensively used, after which geothermal, solar, wind, and biomass are respectively [3].

Micro hydropower plant (MHP) is a clean energy source generated from falling water through an opened or closed waterway and eventually rotating the turbine connected to an electric generator. MHP is thought to be suitable renewable energy for homes, ranches, and distant settlements. MHP technology is the most mature one among other renewable energy power plants with higher efficiency (70-90%) compared to wind, wave, and solar power plants [3]. The electric power generated by MHP can be used for various needs. With proper system planning and design, MHP can generate electricity continuously and connected directly to the load without having to go through an energy storage system [4]–[6]. MHP efficiency and stability of power networks can be improved by applying a variable speed mechanism [7].

The main criteria for the development of MHP in an area are hydrological characteristics with water flow and head that match the electrical energy requirements and have geological natures that support the development of MHP components with an environmental carrying capacity that is free from floods and landslides [8], [9]. The geological profile can be obtained by taking measurements in the field. However, this method is time-consuming and expensive, so the initial study is usually carried out by remote sensing and field measurement is used for verification. Together with a topographic map, remote sensing is also helpful to determine the energy potential of various energy sources such as hydropower [10], wind energy [11], and photovoltaic solar energy [12]. Satellite images depict the entire or a portion of the world, and the images obtained can be used to create topographic maps, military maps, and weather forecast maps [13].

The study of hydropower potential with remote sensing technology is generally only to identify potential locations and get information about the amount of generated power, as was done by [10], [14]–[17]. In references [18] and [19], remote sensing is deployed to quantify and detect the sedimentation in hydropower dams. Related to hydropower components, remote sensing-based disaster risk analysis is more focused on dams or reservoirs, as discussed in [20], [21]. Their research includes finding potential dam-building areas by prioritizing the primary water management approach to solve floods and drought [20] and observing three forms of erosion in a reservoir in southwest China [21]. Remote sensing is also applied to investigate how the Belo Monte hydroelectric dam-building gives an impact on land-cover alterations [22]. In [23] proposed a new method to map landslide obtained from a large-scale remote profile using contour based morphological operations and digital elevation model. Meanwhile, remote sensing combined with a geographic information system (GIS) is employed for landslide hazard zoning mapping [24], [25], land-use change mapping and its dynamics in Awash River Basin [26], and studying the Tana River along Saka-Mnazini ranges in terms of the time-based and spatial channel fluctuations and their dynamics [27]. Another study combines the hydrological model coupled routing and excess storage snow with remote sensing to evaluate climate- and human-induced influences on the Lancang River within 1980-2014 [28].

The utilization of renewable energy, such as MHP, can be optimized primarily in remote locations having no electricity service network [29]. Rural residents deserve a sustainable, reliable, and cost-effective energy system to function as an alternative to the environmentally unfriendly and expensive electricity supplied by conventional energy systems [30]. The site of this study is in South Sumatra Province. With an electricity deficit of 4.1%, this province is subjected to a rolling blackout daily [31]. Therefore, an additional electrical power supply is crucial. One of the rivers having the potential to become a source of electrical energy generation is the Luas River located in remote areas, precisely in Sungai Are District, the westernmost of the South Ogan Komering Ulu (OKU) Regency, South Sumatra Province. The district requires electrical energy for household needs and processing plantation products, such as coffee, rubber, and palm oil. In respect of that, this research is part of a solution to addressing electricity demand in the area.

The hydroelectric potential of Sungai Luas will be finding out by applying remote sensing technology along with geological analysis supported field checks at potential locations. It emphasizes image interpretation and geological aspects to optimize the layout of MHP components, including weir, waterway, penstock, and powerhouses, and select the MHP potential site's best location. Analysis of the geological features will reveal the surface soil and rocks' physical and technical characteristics, beneficial to minimizing floods and landslides hazard. The geological aspect will explain rock types, structural patterns, and geological processes that affect the layout of the MHP components. It will also optimize the interpretation of satellite imagery emphasized on the analysis of rock and soil conditions, structural patterns, landslides, and floods on the placement of MHP components. In addition to the potential of electrical energy, the combination of satellite imagery interpretation and geological analysis will also result in the security of the MHP component building against flooding, landslides, and earthquakes. In this regard, the impact on component construction cost will also be included, whether high or low.

2. MATERIAL AND METHOD

2.1. Research method

The research methodology as shown in Figure 1 was carried out in three stages: data collecting, data processing, and data analysis. Sungai Are District was selected as a case study area because it is presumed to have a good hydropower potential for electric power generation. Data collection in stage 1 includes topographic maps, remote sensing data, and field measurement. The 2013-2019 electricity situation issued by Bappeda is utilized as a reference for predicting the growth of the customer numbers, installed capacity, electricity sold, and electricity production until 2030. Landsat 8 and Shuttle Radar Topography Mission (SRTM) download data from USGS-USA. The topographic map was extracted from Rupa Bumi Indonesia (RBI), published by the Geospatial Information Agency (BIG), Indonesia. The rainfall map and Earth Quake Hazard potential map were obtained from Regional Development Planning Agencies (Bappeda), South OKU Regency. Measurement data of head and water flow are obtained from the fieldwork in August 2019, during the dry season when the river experienced minimum discharge. The water flow was measured using a current meter and a stopwatch to determine the water velocity. The cross-sectional area is obtained by measuring the average breadth and depth in several points along the river. The head of MHP is measured using Theodolite. Data processing in stage 2 covers geological and land use mapping, head and water flow calculation, and data verification. The head and water flow can be extracted from remote sensing data and topographic maps. A topographic map was utilized to calculate the head height. Digital elevation model (DEM) data was used for the head estimation, in which the higher the DEM resolution, the more accurate the head value acquired. The SRTM-DEM was used in this study because it has a good, precise resolution of 1 arcsec (30×30 m). The weakness of Landsat is the presence of clouds [32]. The water flow was obtained through the analysis of rainfall data. The field measurement data verified the interpreted and estimated data.

A geological survey was conducted to verify the interpretation of remote sensing data regarding the layout of the MHP components, which are related to geological, geomorphological, and disaster environmental conditions. RS satellite imagery for geological applications assists in cost-effective energy exploration and identifying geothermal and other energy potentials [33]. The combination of interpretation of satellite imagery and field geological surveys can determine the layout of the MHP components that are efficient and low cost or high cost. The emphasis of geological surveying is on the physical appearance of recorded morphological features and other parameters such as river patterns, shape, and disaster risk, which includes land changes, flooding, and faults. Water flow was estimated based on the area of the watershed together with the volume of water rainfall, geological and land use map was interpreted regarding Landsat 8 remote sensing satellite data [21], [34]–[36], while geological map and land use map were employed as a reference for mapping of Geotechnical engineering, the potential hazard of flood and landslide.

The growth trend forecast of customer numbers, installed capacity, electricity sold, and electricity production until 2030 is performed by employing linear, quadratic, and exponential mathematical models. Furthermore, the errors are compared using the equations mean absolute error (MAE) and mean absolute percentage error (MAPE). The best curve is selected based on the smallest percentage of error.

In stage 3, data analysis consists of predicting electrical situations until 2030, the design of hydropower output, and components layout. The location of the MHP components is determined using global positioning system (GPS). Some recommendations were proposed to develop MHP on the four potential sites based on geological aspect analysis.

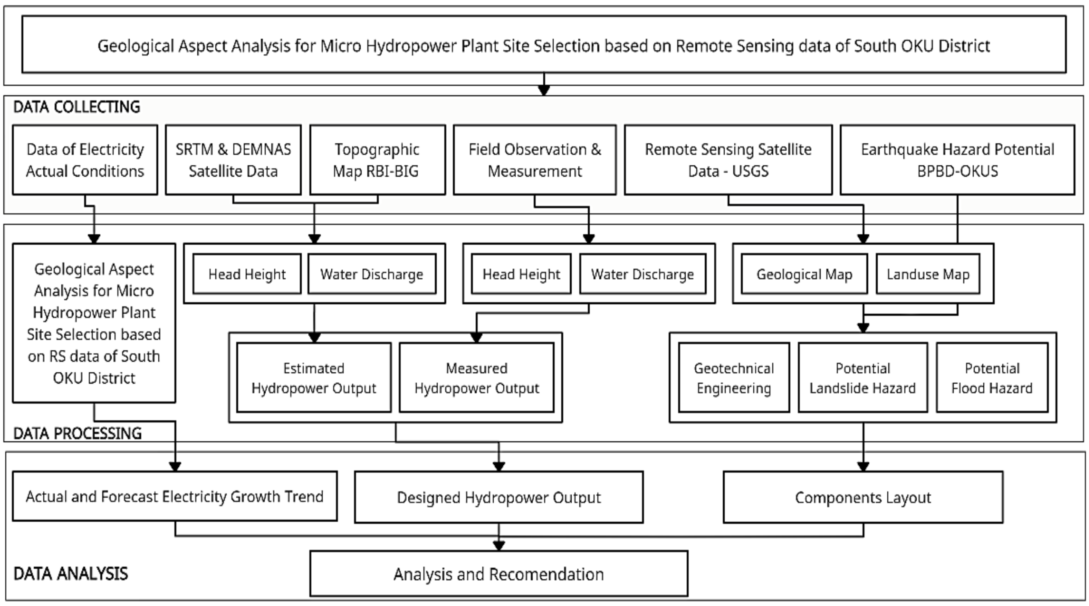


Figure 1. Research method

2.2. Electricity condition in South OKU District

Sungai Are District is the westernmost area of South OKU Regency, which is directly adjacent to the Bengkulu province. Sungai Are District can be reached by local land transportation from Muaradua. The distance from Muaradua, the capital regency, is approximately 60 km, which makes it costly for MHP development. In 2013, only 153 of the 262 villages had electricity service. Of the 80.7% who have benefited electricity as shown in Table 1, only 56.69% are served by the state electricity company (SEC). A total of

26.01% of households in South OKU regency receive non-SEC electricity. Until now, there are 19.3% of households whose source of lighting is non-electricity. Until 2016, Sungai Are District has no electricity service. People in this district use oil lamps or candles for lighting. A total of 1143 households spread across nine villages use the non-SEC electricity. In 2018, there are only 2492 (87%) out of 2832 families got the electric supply. The surrounding villages, such as Pecah Pinggan, Gintung, and Simpang Luas, are also remote and have no electricity.

The availability of electrical energy becomes a measure of the standard of living of the community. Unfortunately, South OKU is one of the regencies that are yet incapable of meeting the electricity needs of all its community. The mathematical models to forecast the growth of the electricity situation of South OKU Regency in 2013-2019 are presented by the (1), (2), and (3) as shown in Table 1 [37]. The mean absolute error and mean absolute percentage error were calculated to decide the best model for the forecasting analysis expressed by (4) and (5) [38].

Linear model:

$$Y' = a + bt \tag{1}$$

quadratic model:

$$Y' = a + b1\,t + b2\,t^2 \tag{2}$$

exponential model:

$$Y' = ae^{bt} \tag{3}$$

$$MAE = \frac{1}{n}\sum_{t=1}^{n} |Y_t - \dot{Y}_t| \tag{4}$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} \frac{|Y_t - \dot{Y}_t|}{Y_t}\ x\ 100\% \tag{5}$$

where Y' is trend value, t is time period, a is constant, b is gradient, Y_t is actual value, $\dot{Y}_t$ is the prediction of the value of t, n is the amount of data.

Table 1. Number of customers, installed capacity, electricity sold and electricity production of South OKU Regency, year 2013-2019 [39]

Year	Number of customers (Household heads)	Installed capacity (VA)	Electricity sold (kWh)	Electricity production (kWh)
2013	37,180	31,997,100	38,233,167	49,353,063
2014	37,576	35,443,250	39,531,550	52,147385
2015	45,504	40,506,600	47,739,479	60,457,708
2016	47,164	42,088,800	46,112,246	62,852,300
2017	52,074	47,199,555	48,263,607	64,947,259
2018	57,315	52,382,650	54,446,345	66,257,498
2019	63,946	63,379,123	63,379,123	71,712,491

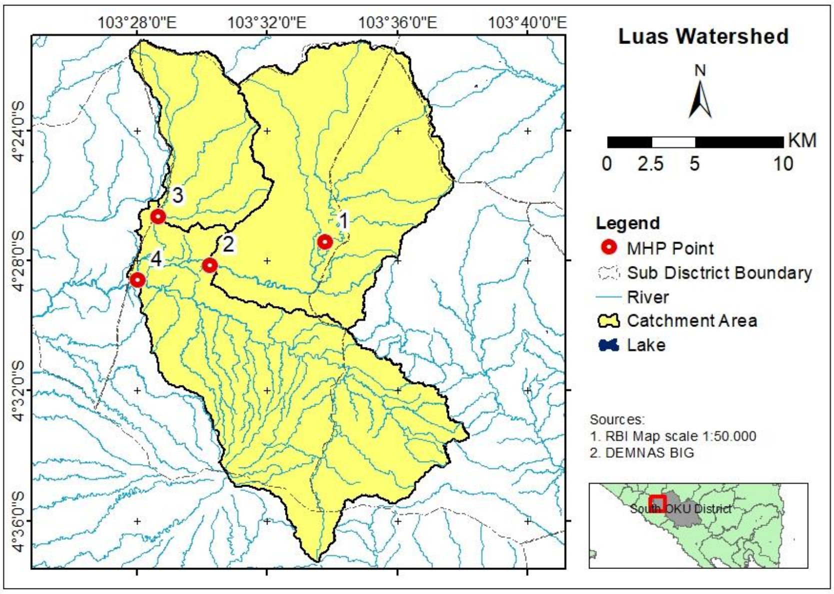
2.3. Hydrological condition

Sungai Are District having two main rivers, namely Luas and Are River. Luas River is sited between coordinates 4° 28' 38.1" S 103° 31' 25.6" E and 4° 28’ 46.4" S 103° 26' 43.9" E, has 36,113 ha water catchment and has a continuous discharge that is suitable for MHP as shown in Figure 2(a). Luas River originates from Mount Garanggahan located in the north of South OKU Regency and flows westward and disembogues into the Indonesian Ocean. Luas and Are rivers have a steep valley with plenty of heavy river flow and waterfalls in several spots that provide opportunities for the use of MHP. The geological characteristics dominated by young and old volcanic rocks also bolster the development of MHP in this area. The landscape strongly influences the availability of water sources for MHP. These geomorphological characteristics will determine the quantity of electrical energy that can be exploited.

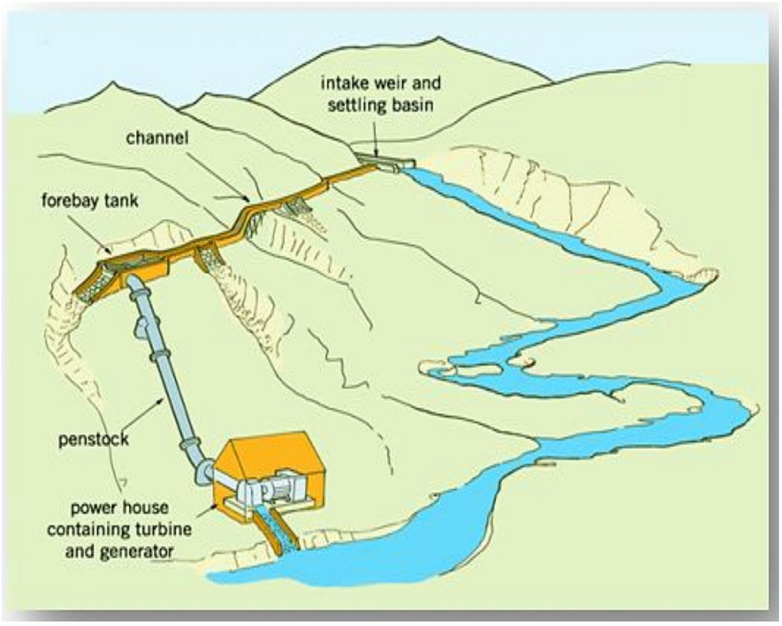
The main components of MHP as shown in Figure 2(b) are the dam, water intake, channel, forebay tank, penstock, and powerhouse. The power generated is proportional to the flow rate and head. Therefore, these two parameters can be adjusted according to site conditions to gain the desired capacity. The hydropower output expressed by the (6) is [40]:

$$P = \rho \times g \times Q \times H_{\text{eff}} \times \eta \tag{6}$$

where P is the hydropower output (W), ρ is the mass density of water $= 1000\ kg/m^3$, g is the gravitation $= 9.81\ m^2$/s, Q is the discharge (m^3/s), H_{eff} is the effective head height (m), and η is the efficiency = 80%.



(a)



(b)

Figure 2. Study area and schematic diagram (a) potential site of luas watershed and (b) layout of MHP components [41]

2.4. Remote sensing application and geological conditions of Sungai Are District

Physiographically, Sungai Are District is located in the Barisan Mountains System with hilly and mountainous morphology with a slope angle of 10°-70°. The hilly area with a waterfall in the canal drops is a suitable location for MHP. The employment of satellite imagery has the advantage of covering a large field with adequate accuracy in describing the landscape of the earth's surface. By deploying this satellite image, environmental conditions can be mapped quickly, such as morphological, geological conditions, and river flow patterns. A combination of Landsat 8 bands of near infra-red (NIR) and short wave infrared (SWIR) can be employed to extract information about rocks and geology [41]–[43]. The combination of NIR and SWIR produces optimal reflection against rocks so that rock type information can be recognized well, while the variation of visible and NIR Bands is applied to extract information about vegetation for making land use maps and estimating water discharge [44]–[46]. Geospatial data generated from remote sensing analysis can be used widely in various fields, one of which is disaster mitigation of the infrastructure to be built [47].

This study emphasizes the interpretation of satellite imagery to obtain geological conditions, morphology, and potential areas for landslides and other disasters. From the satellite data, thematic maps are made, such as geological maps, land cover maps, river flow maps, and several other MHP related maps. The interpretation of satellite images is employed to determine the locations of the weir, waterway, and powerhouse. Afterward, a site survey was performed for verification. The head and the area of water catchment were estimated by referring to contour maps. Water discharge is calculated based on the watershed area multiplied by the average annual rainfall.

Information on the potential for the geological hazard of an area is essential as the basis for development planning consideration of the region. The potential site with the high vulnerability of geological hazards will have a high-cost construction. The geological aspect is one of the fundamental parameters for MHP design, especially regarding the component layout. The feasible site of MHP has to have a proper geological condition [48], [49].

Geological aspect analysis of MHP components refers to the interpretation of satellite images, topographic maps, and visual reading of field observation. Analysis of the geological characteristics is descriptive-observative so that the data source relies on the results of field observations, which are then supported by other field data. The analysis was executed by observing cases or geological issues encountered in the field and related to the position of the MHP components. Several geological assessments in determining the location of the power plant components include: i) Field observations based on the interpretation of satellite images cover river conditions, measurement of discharge, and slope of river valleys; ii) Detail observation of the geological environment, such as rock types, geological structures, and technical properties of soil and rocks; and iii) Geomorphological interpretation of river environmental conditions related to vulnerability to landslides, floods and other disasters. Geologically, the Luas watershed area has very distinctive rock characteristics because almost all the rocks are the result of volcanic eruptions, both old and young volcanoes shown by the topography, which are mostly mountainous and hilly areas with deep valleys and high slope angles. The application of satellite imagery is utilitarian to delineating areas that are prone to disasters, such as floods, landslides, and others.

3. RESULTS AND DISCUSSION

3.1. Forecast of electricity growth trend

The actual and forecast of electricity condition of South OKU Regency are displayed in Figure 3. Based on the statistical modeling, the growth trends are quadratic for customer numbers, exponential for installed capacity and electricity sold, and linear for electricity production. Electricity sold represents electricity demand consumed by the customers. The graphs show that before 2021 there is a surplus of electricity production. Unfortunately, after mid-term 2021 a meeting point occurs between electricity production and electricity sold that signifies the start of a deficit in electricity production. In this regard, there must be a scenario to keep the electricity supply able to meet demand on an ongoing basis.

3.2. Hydrological analysis

The SRTM data as shown in Figure 4(a) and the Landsat 8 satellite data as shown in Figure 4(b) shows the Luas watershed is weak to stiff undulating hills with a height difference between hills and valleys of approximately 20-120 m and slope angles between 20°-70°. The morphology of the mounts includes in the Barisan mountain system that stretches northwest-southeast, which is shown by the very tight contours of the elevation on the topographic map of this area. The morphology that is usually arranged by volcanic-rock-Garanggahang Hill, Cabut Hill, Mount Besar, Pandan Hill, and other hills are in the Luas River watershed. The Luas River originates in Garanggahang Hill, Besar Hill, and Cabut Hill, to south, turns west in the village of Pecah Pinggan in the same direction as the Sumatra Fault and turns back south and empties into the Indian Ocean. The area of Luas watershed catchment is 36,113 ha and the precipitation is 100-150 mm/month. This area is a high-risk area of earthquake potential hazards.

The land use map as shown in Figure 4(c) presents the current land use, while the land allocation map indicates the allocated land for future development plans. In determining the land use of an area, it is necessary to know the land use map. Climatic factors considerably affect the type of land cover. The Luas watershed area, especially in the northern part, has a dry climate so that it is dominated by plants, which generally do not have wide canopies to reduce evaporation. Based on the land cover classification, the Luas watershed area consists of nine classes of land covers, namely forests, swamp forests, lakes, rivers, settlements, rice fields, plantations/gardens, shrubs, and moor/fields. Land cover in the form of forests and vegetation is in the northern and southern parts of the Luas watershed, which are rain forest catchments that serve to conserve water sources.

The slope map of the Luas watershed as shown in Figure 4(d) shows that site 1 and 3 has a slope of 15-25%, while site 2 and 4 have a ramp of 0-8%. Mountain slopes are generally steep. The slopes formed by volcanic rocks are mostly quite steep. The flow pattern of the river follows the morphological conditions that are usually formed by volcanoes. Where the cone shape is still clearly visible, a radial flow pattern develops, and in other places, the river tends to be a dendritic pattern.

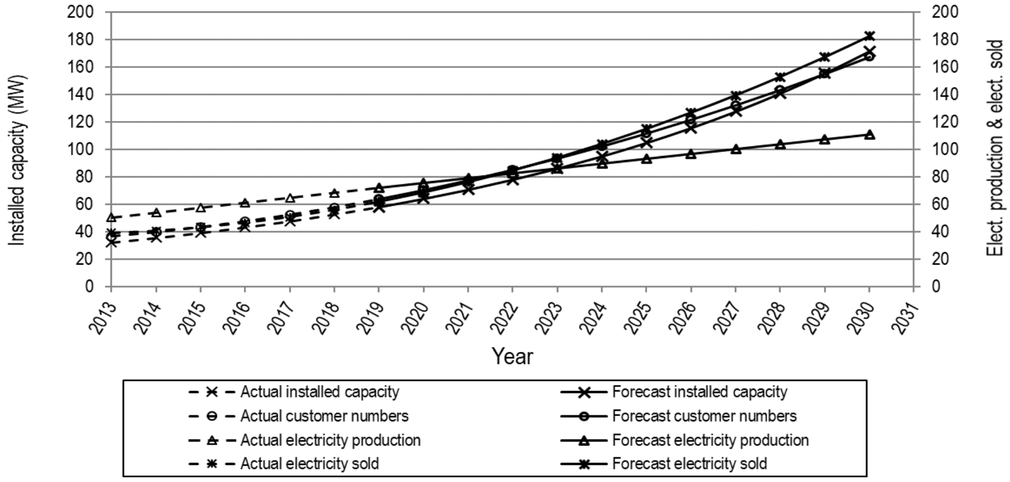


Figure 3. Electricity condition of South OKU Regency

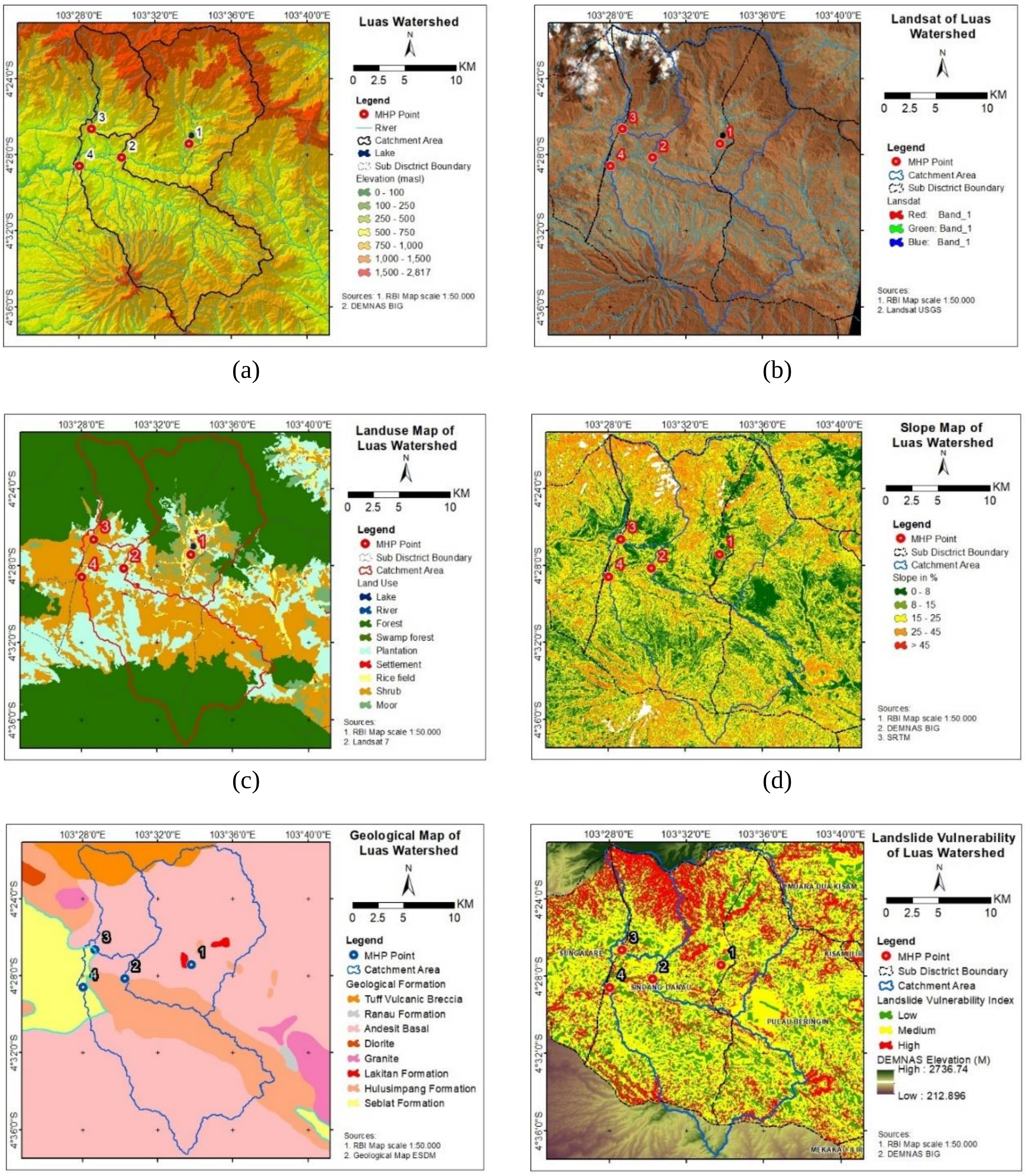
3.3. Geological aspects analysis

The geological condition of the Luas watershed as shown in Figure 4(e) was obtained from Landsat 8 satellite data interpretation and field observation for the ground truth check. Geological condition analysis refers to the geological maps of Manna and Enggano Sheet as well as the Baturaja Sheet. Imaging and interpretation of geological structures can be obtained through the digital elevation model (DEM), displaying the geomorphology, in which the geological structures of hard rock and sediments are represented [50].

The Luas watershed is an area with very distinctive rock characteristics since almost all of the rock in it comes from volcanic eruptions, either old or young volcanoes. These characteristics are clarified by the topography, which are mostly mountainous and hilly areas with deep valleys and high slope angles. The shape of the Luas River resembles the letters "V" and "U" that indicates that the vertical erosion is more dominant than the horizontal one. Landscapes immensely affect the availability of water sources for power plants; the geomorphological characteristics will determine the capacity of the generated electric power.

The geology of the Luas watershed is composed of units of breccias, lava, and tuffs from the Hulusimpang formation with its spread in the middle part of the east-west, then sandstone, claystone, shale, and conglomerate units of the Seblat Formation with an extension in the center and west, and a few breccias with intercalation of sandstones and claystone from the Lakitan Formation with local distribution in the northern part, as well as young volcanic rock units covering most of this watershed area in the north and south consisting of andesitic, tuff, and breccia. Geological analysis indicates that there is a lineament, which is probably a fault in the Northwest-Southeast direction. Fortunately, the lineament is far from the location of the power plant, so that the vulnerability to earthquakes is small. However, civil construction still has to follow the principles of earthquake-resistant buildings based on the applicable Indonesian National Standard (SNI) provisions. The power plant construction in this area could have a long operating life.

Figure 4(f) shows the map of landslide vulnerability, where the high potential for landslides is found in the hills/mountains north of Sungai Are District (red color), which is characterized by a steep slope and volcanic rock types that are not yet compact, so this amplifies that the soil is still loose. Meanwhile, other areas in the watershed have medium landslide hazards (light brown color) characterized by moderate slopes, and the constituent rocks are old volcanic rocks, which are relatively compact. The risk of landslides of sites 1 and 3 are at the medium level, while sites 2 and 4 are at the high one.



(a) (b)

(c) (d)

(e) (f)

Figure 4. Thematic map of Luas watershed (a) SRTM satellite data, (b) landsat 8 satellite data, (c) land use map, (d) slope map, (e) geological map, and (f) landslide vulnerability map

3.4. Hydropower output and layout of MHP components

The integration of geological data and image interpretation shows that four locations in the Luas River have the potential to build MHP. The four potential sites of MHP were analyzed to obtain the estimated, measured, and designed of hydropower output. Head and water flow data obtained from the estimation, measurement, and designs, and their associated hydropower output, are presented in Table 2. Estimated hydropower output is overestimate compared to measured hydropower output because the reference topographic map is less detailed, which is on a scale of 1:25,000, and the applied average rainfall data has a low level of accuracy to determine the rainfall value in the watershed area. The design of hydropower output takes smaller values of Q (50% of the measured value) because it considers the risk of minimum discharge in the dry season and anticipates land-use changes and population growth in the area. Figure 5 presents the layouts of the MHP components of the four potential sites. The geological aspect analysis using the integration of geological data and image interpretation shows that there are four potential sites of MHP in the Luas River as shown in Table 3.

Table 2. Estimated, measured and designed of hydropower output

Site	Watershed Area (ha)	Estimated			Measured			Designed		
		H_{eff} (m)	Q (m^3/s)	P (kW)	H_{eff} (m)	Q (m^3/s)	P (kW)	H_{eff} (m)	Q (m^3/s)	P (kW)
1	7,417.460	25	1.717	337	22	1.500	259	20	1.000	188
2	14,399.990	75	3.333	1,962	82	1.870	1,203	75	0.935	881
3	5,225.860	100	1.209	949	112	1.490	1,310	100	0.745	935
4	36,113.550	50	8.359	3,280	52	5.310	2,167	50	2.665	1,667

Table 3. Geological aspect analysis of MHP potential site

Site	Designed			Analysis	Hazard vulnerability		
	Power (kW)	Water way(m)	Penstock (m)	Geology Aspect	Land-slide	Flood	Recommen-dation
1. Ulu Danau Village S 103° 33' 46,89" E 4° 27' 26,30"	188	500	40	Quarternary Andesitic lavas, tuff, volcanic breccia products of Bt Garanggahang (Qv).	Low	Low	Suitable, Low cost construction
2. Pecah Pinggan Village S 4° 28' 11.5" E 103° 30' 36.0"	881	2,800	142	Tertiary Andesitic lava, volcanic breccia, tuff and intercalation of sand stone (Hulusimpang Formation)	High	High	Suitable, High cost construction
3. Gintung Village S 4° 26' 40.9" E 103° 28' 38.9"	935	1,000	145	Quarternary Andesitic lavas, tuff, volcanic breccia products of Bt Garanggahang (Qv).	Low	Low	Suitable, low cost construction
4. Simpang Village S 4° 28' 38.0" E 103° 27' 59.9"	1,667	3,490	110	Tertiary Alternating sandstone, siltstone, claystone with intercalation of thin limestone (Seblat Formation)	High	High	Suitable, High cost construction

Site 1, Luas River, Ulu Danau Village, as shown in Figures 5(a) and 5(b) and site 3, Putih River, Gintung Village, as shown in Figures 5(c) and 5(d) have the same characteristics, which are in high elevation locations with steep slopes, have low power potential due to small water flow. The geological condition is mainly lava rock and massive volcanic breccias, which have relatively thin weathering soil thickness. This location is safe against flood and landslide hazards, suitable for MHP with a low cost of construction. Site 2, Pecah Pinggan Village, as shown in Figures 5(e) and 5(f) and site 4, Simpang Village as shown in Figures 5(g) and 5(h) are located at a small degree of elevation zone with a flat slope and have substantial potential power due to heavy water flow. The constituent rocks consist of sandstone, siltstone, and clay from the Hulusimpang Formation and Seblat Formations, which are fragile and easily weathered, and their thick soil is weathered. This location is prone to flooding and landslides, suitable for MHP with a high cost of construction.

The best spot is site 3 (Gintung Village), a tributary of the Luas River, precisely at the confluence of the Putih and Gintung. The weir is at coordinates 4° 26' 40.9" S and 103° 28' 38.9" E with an altitude of 655 msl. The water flow and the head of the Putih River are 1.49 m^3/s and 50 m consecutively. The hydropower generated is 935 kW with 1000 m waterway length. The short and straight conduit is preferable to increase the energy generated by the proposed MHP.

Site 3, Putih River, Gintung Village, consisted of sandstone, claystone, and conglomerate units, as well as alluvial, which was dominated by loose gravel and andesite hunk. The morphology in the power plant area is undulating hills-mountains with slopes ranging from 20°-45°. The U-shape river basin of the Luas watershed provides an advantage in reducing the risk of landslides.

For the continuity of the hydropower generation, the head and water flow must be in a stable condition. The stability of the head height depends on the robustness of the penstock construction to withstand a certain level of landslides, floods, or earthquakes. Meanwhile, the stability of the water flow is dependent on the rainfall and the type of land cover in the area. Therefore, it is necessary to monitor the land cover and keep it having an infiltration coefficient that is sufficient to absorb water that produces water flow according to the hydropower needs. The land-use alteration will not be a problem as long as the infiltration coefficient does not decrease the water flow in the area.

The impact of climate change on precipitation also needs to be considered out to ensure the water flow at the hydropower site is not lower than the designed discharge. It is necessary to install a rainfall station and flow meter at the plant site. If there is a decrease in precipitation and water flow in the area, balancing action must be taken by increasing the land cover with a higher infiltration coefficient (planting trees with thick roots and canopy) so that the discharge is maintained.

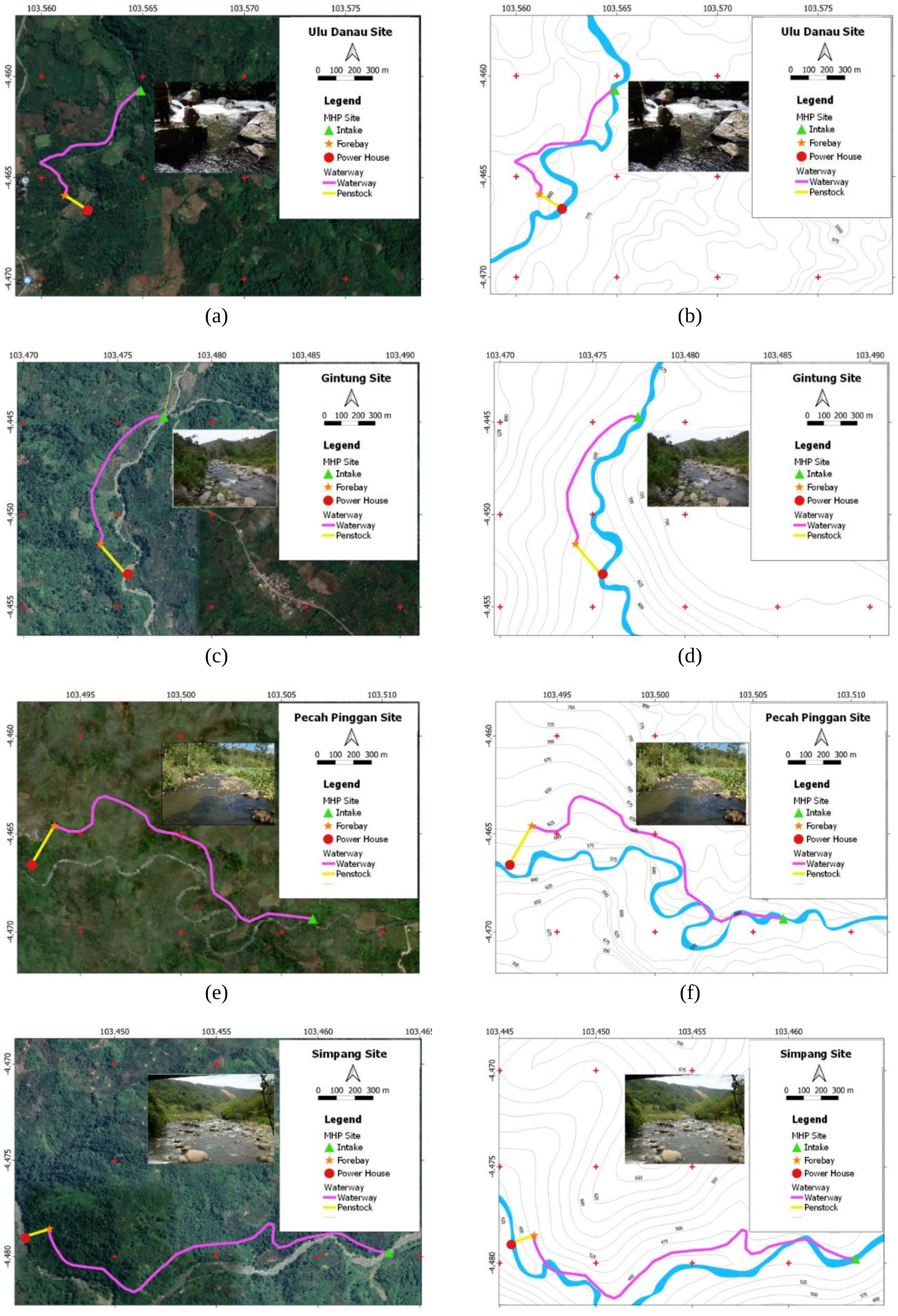


Figure 5. Layout of MHP components based on RS satellite and contour data (a) remote sensing data of Site 1, Ulu Danau Village, (b) countur map of site 1, (c) remote sensing data of site 2, Gintung Village, (d) countur map of Site 2, (e) remote sensing data of Site 3, Pecah Pinggan Village, (f) countur map of site 3, (g) remote sensing data of site 4, Simpang Village, and (h) remote sensing data of site 4

4. CONCLUSION

This paper has evaluated micro-hydropower potential on the Luas River. The interpretation of topographic maps and remote sensing satellite imagery are integrated with a site survey to obtain: the best spot for the MHP components and the potential of electric power. A geological aspect interpretation was conducted to minimize the disaster risk. The area of South OKU Regency, especially in the Luas watershed area, has a high potential for MHP development, which is supported by relatively stable morphological, geological, and river flow conditions. Designed power at the 4 locations observed ranged from 188-1,667 kW. The integration between satellite image analysis and geological aspects is significantly helpful in determining the layout of MHP components covers weirs, waterways, penstock, and powerhouses. It is found that Ulu Danau and Gintung Villages have low hazard vulnerability, which means the power plant's construction cost will be low as well. Exploiting the potential of MHP in this area will help to overcome the problem of lack of electricity production in this area. Based on the geological aspect analysis, it is possible to optimize the hydropower capacity, which is by adding the volume of water flow from several nearby tributaries channeled into the hydropower flow system through civil construction engineering or by making a cascade design on the tailrace water flow.

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