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# Feasibility of Geoscience to Determine the Location of Micro-hydro Power Potential for Rural Areas

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***Abstract** – The micro-hydro power plant (MHPP) is a viable solution to the electricity crisis in rural areas. However, the lack of application is due to the constraints of the location review, which is expensive and time-consuming. To increase the efficiency of its application, it is necessary to ascertain the methods of reducing the costs and times. The feasibility of an analytical hierarchy process (AHP) based on the geographical information systems (GIS) to determine the ideal location of micro-hydro power was proposed. Based on the geoscience approach, surface mapping (lithology) and GIS (morphology, morphometric, and topography) visualize case study areas accurately and precisely to accurately determine the ideal areas. The ideal area is one containing a good potential head and hard rock plain (granodiorite). The ideal area is to be determined through field observations. According to these observations, the potential head was 4 m, the discharge was 0.83 m$^3$/s, and the field contained a plain type of granodiorite. The estimated hydropower of 32.15 kW (micro-scale), has the potential to supply electricity to 35 households with 50% efficiency and power of 0.45 kW/house. In consideration of energy losses and investment costs, the propeller turbines were proposed for this case. Thus, the AHP method based on GIS to determine the ideal locations of micro-hydro power in rural areas can be utilized.*

***Keywords** – geographical information system, lithology, micro-hydro, morphometry, rural areas topography.*

## 1. INTRODUCTION

In 2019, according to reports by the World Bank, there are presently many people in South and Southeast Asia without access to electricity. The electrification ratio (ER) in these locations is 91.6% and 98%, respectively. Reportedly, the four countries with the lowest ER in South Asia: Bangladesh having 95.2%; Nepal of 93.9%, India of 95.2%, and Bhutan of 100% [1]. Meanwhile, in Southeast Asia: Myanmar has the lowest ER of 66%, Cambodia of 91.6%, the Philippines of 94.9%, and Indonesia of 98.5% [1]. Factually, electrification is an effective method for improving prosperity, and it is performed through three methods in rural areas: off-grid, on-grid, and mini-grid. The off-grid process is more desirable because its civil, electrical, and mechanical construction is more manageable (cheaper) than on-grid and mini-grid.

The off-grid systems utilize micro-hydro as an independent power plant, often used in rural areas than a wind turbine and solar photovoltaic [2]. Since per-kW the life cycle cost of micro hydro is more profitable than wind and solar photovoltaic [2]. This is the rationalization of some developing countries using micro-hydro as independent power plants for their rural areas [3]-[7]. Therefore, micro-hydro is a possible solution for covering areas facing an electricity crisis in South and Southeast Asia. Hence the potential to exploit and manufacture energy from water in these countries is large: Bangladesh generates 330 MW [8], Nepal of 83,300 MW [8], India 148,700 MW [8], Myanmar of 39,624 MW [9], Cambodia of 10,000 MW [1], Philippines of 15,393 MW [10], and Indonesia of 81,100 MW [11]. However, in South and Southeast Asia, the energy generated from water exploitation (installed capacity) is presently low [1]: Bangladesh generates of 69.7% (230 MW), Nepal of 1.3% (1059 MW), India of 33.67% (50,066 MW), Myanmar of 8.2% (3255 MW), Cambodia of 13.8% (1380 MW), Philippines of 24.1% (3708 MW), and Indonesia of 6.84% (5548 MW).

The micro-hydro power plant (MHPP) is an independent power plant that harnesses energy from local water depending on its flow and slope structure [12]. Furthermore, previous studies focused on examining the mechanical and electrical feasibility of MHPP. On the mechanical side, Williamson and Simpson [13] proposed selecting turbine technology by qualitative and quantitative analysis, where they concluded that Turgo turbines are more applicable in rural areas. Additionally, they also recommended a method for calculating the diameter of a penstock, and suggested the head loss limit for the penstock system to be set at 10%. Adanta, *et al.* [2] discussed the effect of

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turbulence modeling on the performance of MHPP using the computational method, where they identified that the turbulence model influenced the prediction error. On the electrical side, Haidar, *et al.* [14] suggested the generator type for MHPP to be direct current (DC) for the off-grid system while the mini-grid can use either alternating current (AC) or DC. Febriansyah, *et al.* [15] tested the feasibility of a storage system applicable in rural areas and concluded that an off-grid system with a DC was the proper solution.

Although studies have been carried out comprehensively, the lack of application of MHPP is believed to be due to the constraints of location review, which is expensive and time-consuming. The analytical hierarchy process (AHP) based on geographic information system (GIS) overlay was proposed because it helps determine a standard construction layout for the micro-hydro. It is also used to ascertain plains' strength, riverbed morphometry, and topography around the river. Thus, this study aims to examine the feasibility of GIS-based on the AHP method in determining the ideal MHPP location.

## 2. DESCRIPTION OF STUDY AREA

To ascertain the reliability of the AHP method, the Kikim river in Lubuk Tuba villages, Lahat-South Sumatra, Indonesia, was used as a case study. The Kikim river was chosen because its flow passes through a village with an electricity crisis in Lubuk Tuba village, Pseksu district, Lahat-South Sumatra, Indonesia [16]. Although there is a national electricity grid supply in Lubuk Tuba villages, the distributed capacity is low and is only six hours daily [16]. It is expected that the results of this study can provide a suggestion to the Lahat district government in overcoming the energy crisis in its areas. Furthermore, this method can be applied to areas with similar conditions (rural areas with rivers).

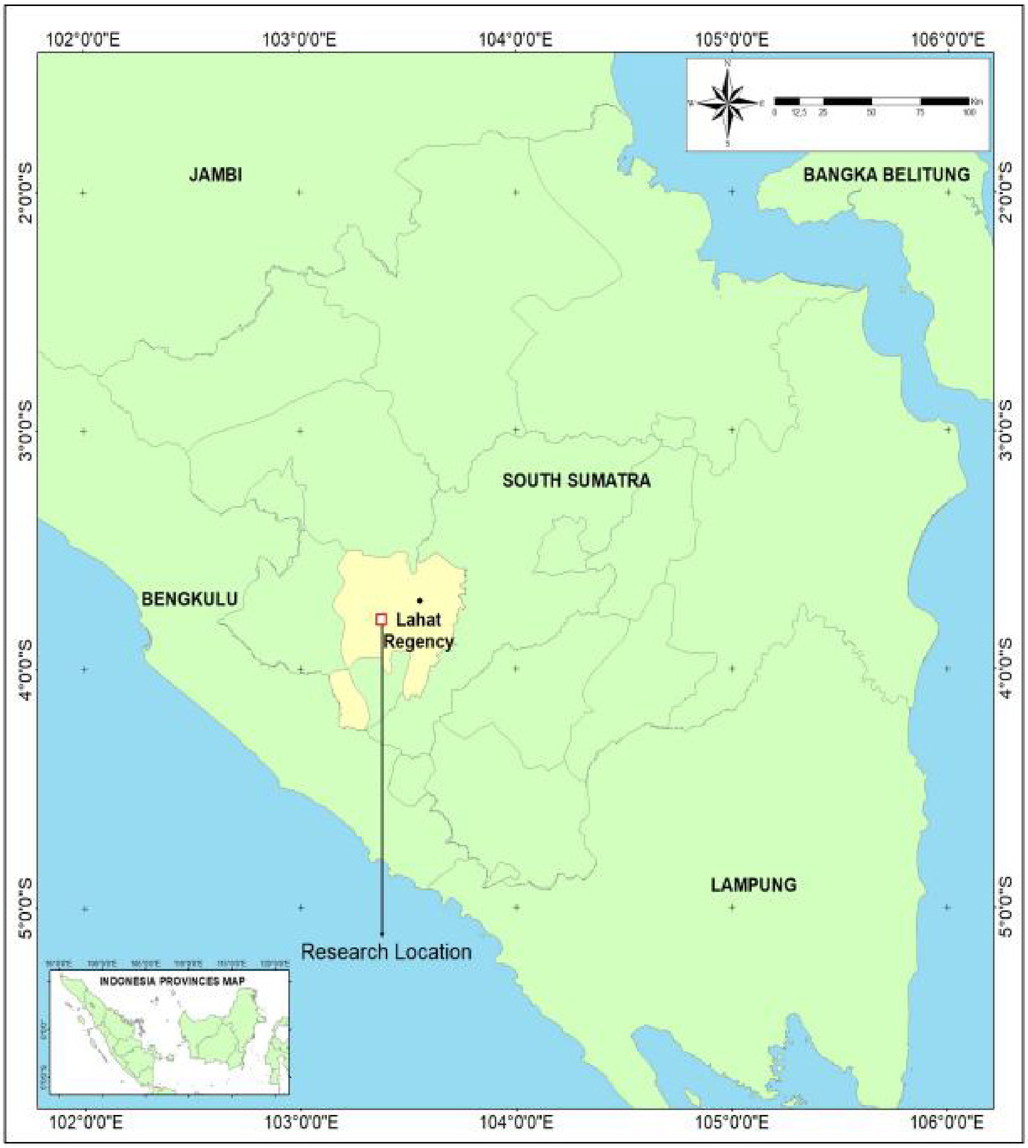


**Fig. 1. Location of the study area.**

The Lubuk Tuba village is located in the southwestern Palembang city (Figure 1), the specific coordinates are 9578000-9583000 S and 317000-322000 E UTM WGS-84 with areas of 20.05 km$^2$ (Figure 2).

### 2.1 *Geology*

Field observations were carried out to obtain a visualization of the surface geological conditions. The surface geology is necessary for lithological analysis (Appendix 1). Thus, the stratigraphy of the area is characteristic of Granodiorite (Late Cretaceous), Talangakar Formation (Late Oligocene-Early Miocene), Gumai Formation (Early-Middle Miocene), and Airbenakat Formation (Middle Miocene). Granodiorite is brittle and competent, while the other formations tend to be ductile (plastic). This is relevant when constrained by topography, as the southern part of the study area has a high topography that is quite resistant to weathering. Meanwhile, the distribution of rocks in the central and northern parts of the study area consists of incompetent rocks.

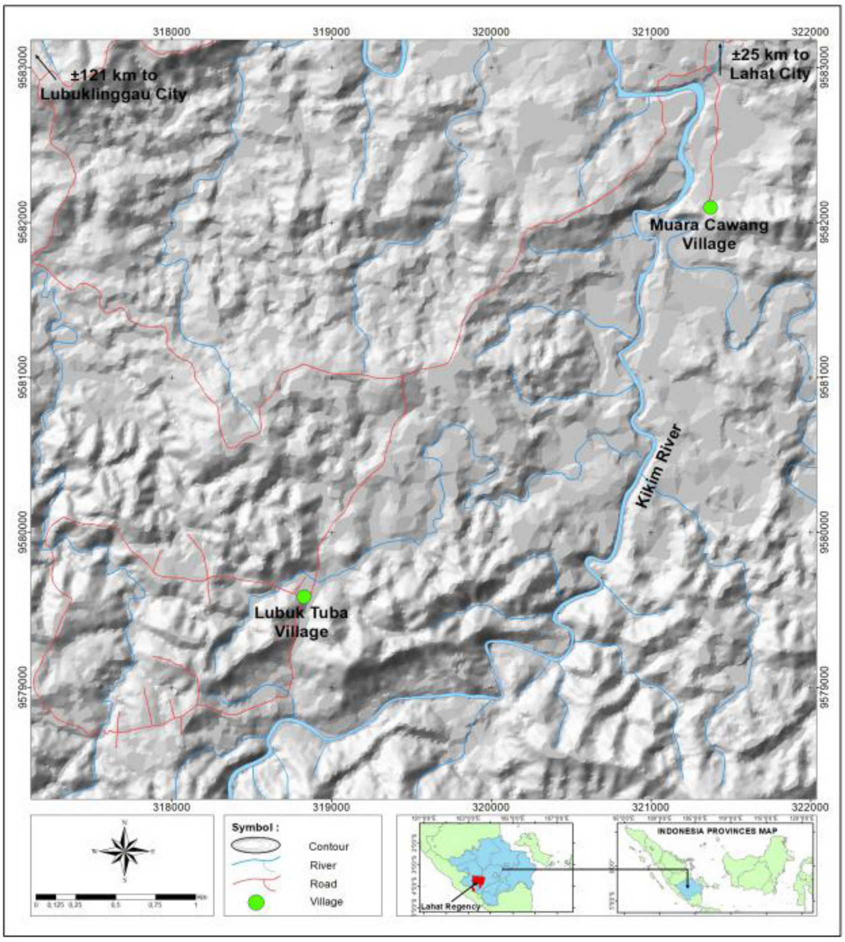


**Fig. 2. Topography view of the study area.**

### 2.2 *Morphometry*

Slope classifiers are defined in Table 1 [17]. River slope levels were mainly flat, with a few ramps present. This condition was verified by discovering sedimentary rocks with low resistance, such as claystone, siltstone, and others in the region studied (Appendix 1). Whereas in the southern region, the slope is steep and dominated by the rocks having high resistance namely granodiorite (red color in Appendix 1).

Based on the classification in Figure 2 based on Table 1 regarding the southern region of the case study, the river slope domination is moderately steep (Appendix 2). Whereas in the eastern regions, it is mainly gentle sloping and nearly flat (Appendix 2).

**Table 1. River slope classification [17].**

| Score | Elevation (m) | Land category | Slope, (%) | Classification |
|---|---|---|---|---|
| 1 | < 50 | Lowlands | 0-2 | Flat or almost flat |
| 2 | 50-200 | Low hills | 3-7 | Gently sloping |
| 3 | 200-500 | Hills | 8-13 | Sloping |
| 4 | 500-1000 | High hills | 14-20 | Moderately steep |
| 5 | > 1000 | Mountains | 21-55 | Steep |

## 3. METHOD

Three stages are involved in determining the location and technology of MHPP: acquisition (data collection by GIS), processing (analysis of morphometry parameters using AHP), and post-processing (identification of suitable technology turbine based on the condition obtained).

### *3.1 Acquisition Data by GIS*

This study employed three practical data acquisitions: river map using tanahair.indonesia.go.id/portal-web, rainfall using dataonline.bmkg.go.id, and Seamless Digital Elevation Model (DEM) using tides.big.go.id. Delineation of major alignments was interpreted using DEM [18]-[20]. The DEM analysis utilized the available shuttle radar topography mission (SRTM) 57.13 from the United States Geological Survey (USGS) web, which provided three different resolutions, *i.e.*, 1 arc-second (30 m), 3 arc-second (90 m), and 30 arc-second (1.0 km). This study applied a 30 m resolution with a set of data measured in 2014. The Geographic Information System (GIS) implementation is increasingly being used for hazard assessment [21], due to its ability to combine several parameters to obtain micro-hydro layout map.

### *3.2 Assessment of AHP Methods*

The ideal construction foundation is compact lithology due to its construction advantages, with minimal risk of landslides. The foundation was grouped into three: granodiorite, claystone, and siltstone. The highest score was the granodiorite stone, while the medium was claystone, and the lowest was siltstone [22]. The granodiorite stone is considered compact and robust as a foundation, and the influence of the geological structure is insignificant [22]. The power plant's location far from the river is not ideal due to its bulky system, which incurs a large investment cost. Therefore, the scores of the assessment based on the distance between the river and power plants were grouped into three: 3 below 100 m (< 100 m); 2 between 100 and 200 m (100 to 200 m), and 1 which reached 200 m (> 200 m). The river slope is needed as an assessment parameter, as whenever the river is dammed, flooding does not occur in the area. Therefore, the river slope scoring levels are grouped into three: 3 between 21% and 100%, 2 between 8% and 20%, and 1 between 1% and 7%. Table 2 is a summary of the leveling of lithology within the foundation (l), the distance of the river to a potential power plant location (d), and river slope (s).

**Table 2. Description of leveling of l, d, and s.**

| Score | l | d | s |
|---|---|---|---|
| 3 | Granodiorite | < 100 m | 21 – 100% |
| 2 | Claystone | 100 – 200 m | 8 – 20% |
| 1 | Carbonate siltstone | > 200 m | 1 – 7% |

***AHP procedure calculation for determine of micro-hydro potential layout***

The AHP method developed by Saaty (2018) [23] is a complex decision-making method that has been simplified, where it adopted the 32 factorial design analysis. This analysis can also be referred to as an optimization method. It implies 32 = 9, which suggests a conclusion with a maximum value of 9. Furthermore, in determining the location, three parameters were used: lithology as the foundation (l), the distance between the river and a potential power plant location (d), and river slope (s). As these three parameters are part of the geoscience aspect, they are given a value based on their influence on location determination [23]. Table 2 shows how each parameter is assessed.

The parameters of l, d, and s are calculated using a factorial design. These parameters are made into a 1 x 3 matrix or $\begin{bmatrix} l & d & s \end{bmatrix}$ called A, while B matrix is $\begin{bmatrix} 1/l & 1/d & 1/s \\ 1/l & 1/d & 1/s \\ 1/l & 1/d & 1/s \end{bmatrix}$.

The interaction between factor A and B is found in Equation 1:

$$A\times B=Y \quad (1)$$

Afterward, the treatment combination of A and B was done by Equation 2:

$$(D\times E)\times X=F \quad (2)$$

where D is $\begin{bmatrix} l \\ d \\ s \end{bmatrix}$ E is $\begin{bmatrix} 1/l & 1/d & 1/s \end{bmatrix}$, and X is $\begin{bmatrix} 1/Y_1 \\ 1/Y_2 \\ 1/Y_3 \end{bmatrix}$. The next, each F is average by times with 1/n:

$$1/n\times F=T \quad (3)$$

where n is the number of parameters of 3, the determination index value (K) and consistency index (C).

$$(D\times E)\times T=K \quad (4)$$

$$S\times K=C \quad (5)$$

where S is $\begin{bmatrix} 1/T_1 & 1/T_2 & 1/T_3 \end{bmatrix}$. For information, the $C_i \le 9$.

The $C_i$ is used to determine the location for MHPP, where its value is defined in Table 3 [23]. The $C_i$

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indicates the potential of the Kikim river. The greater the $C_i$ the more the potential.

**Table 3. Definition of $C_i$ from 1 to 9 [23].**

| Value | Explanation |
|---|---|
| 1 | Equal potential |
| 2 | Weak or slight |
| 3 | Moderate potential |
| 4 | Moderate plus |
| 5 | Strong potential |
| 6 | Strong plus |
| 7 | Very strong potential |
| 8 | Very, very strong potential |
| 9 | Extreme potential |

Furthermore, $C_i$ will be placed on the map obtained through geographic information systems (GIS) to generate an ideal area. These areas will then be represented through maps.

Appendix 3, 4, and 5 are the data used in AHP analysis. Appendix 3 and 4 involve the lithology aspect and the distance of the river from a potential power plant location, respectively. Thus, Appendix 3 and 4 are generated by the scores of Appendix 1 using Table 2. Whereas, Appendix 5 which is the river slope, is dependent on Appendix 2 using Table 2.

### *3.3 Morphometry Analysis Method*

Rivers with large water discharge cannot be said to be in an area with micro-hydro potential. Morphological aspects such as hillside, riverbed slope, and river shape influence the determination of location for the layout of the MHPP construction [24]. Furthermore, the lifetime of MHPP is influenced by terrain foundation. A good foundation criterion is a compact rock able to withstand heavy loads and equally resistant to geological influence [22]. Therefore, several morphological conditions should be considered in determining the location of MHPP: A lowland must be absent in the riverside (flood potential), to reduce the investment cost of dams; The slope of the channel to the forebay has to be nearly flat. Good lithology makes it easy to build a forebay, which is placed close to the powerhouse with a large elevation (head). This criterion matches the morphometry of the river having a steep slope. Penstock pipes placed on the steep river slope with a good lithology condition enhance the strength of the construction foundation. The distance between the powerhouse and the residential area has to be a maximum of 3 km.

Data collection for morphometric analysis was done directly to determine the layout of the dam, the position of the penstock pipe, and the powerhouse. Three aspects of morphometry were considered: river slope to ascertain the position of power plant construction, river shape in preparation for dam construction, and riverbed slope for penstock pipe installment (water elevation).

### *3.4 Determination of Micro-hydro Potential and Its Technology*

After determining the layout for the MHPP construction, the next is to estimate the available hydropower. The hydropower potential is a function of discharge (Q) and head (h) (Equation 6).

$$P = Q \times h \times g \times \rho \tag{6}$$

where g is gravity and ρ is water density.

The discharge (Q) is a function of the cross-sectional area (a) and the stream of water velocity (v). To ascertain the discharge: first, measure the width and height of the river using a scale; second, measure the velocity of water through a current meter. The measurement of the width and height of the river is necessary to determine cross-sectional areas. The river's average velocity is obtained by measurement at twelve locations spread over six sites at the top, three at the middle, and three near the riverbed. The measurement was made in May 2018 (the transition from the rainy season to dry). The schematics of the location measurement of water velocity is seen in Figure 3. Since Indonesia has two seasons (rain and dry), the discharge (Q) measurement results should be compared with the rainfall graph of local areas. This is to determine the discharge (Q) that is exploitable, and anticipate the failure of a turbine due to less power input or discharge.

The determination of turbine technology uses the head and discharge relationship graph shown in Figure 4 [13].

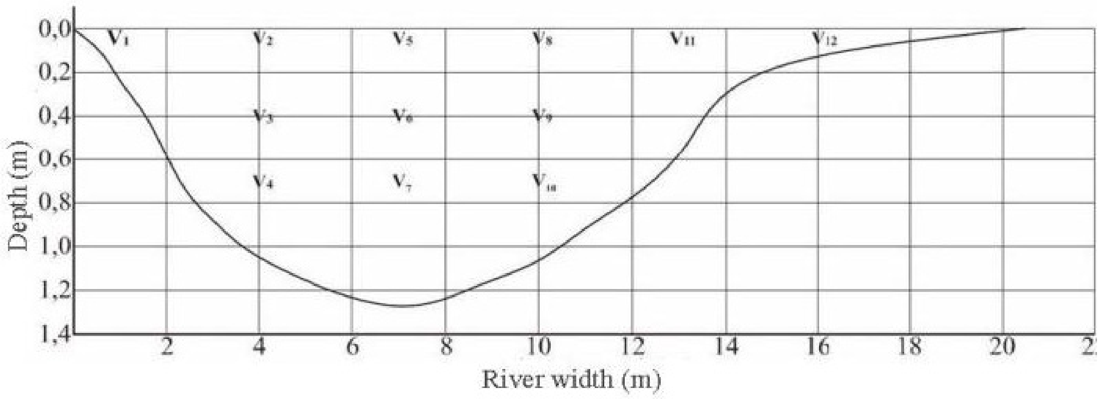



**Fig. 3. Schematic section of riverbed and water velocity measurement locations.**

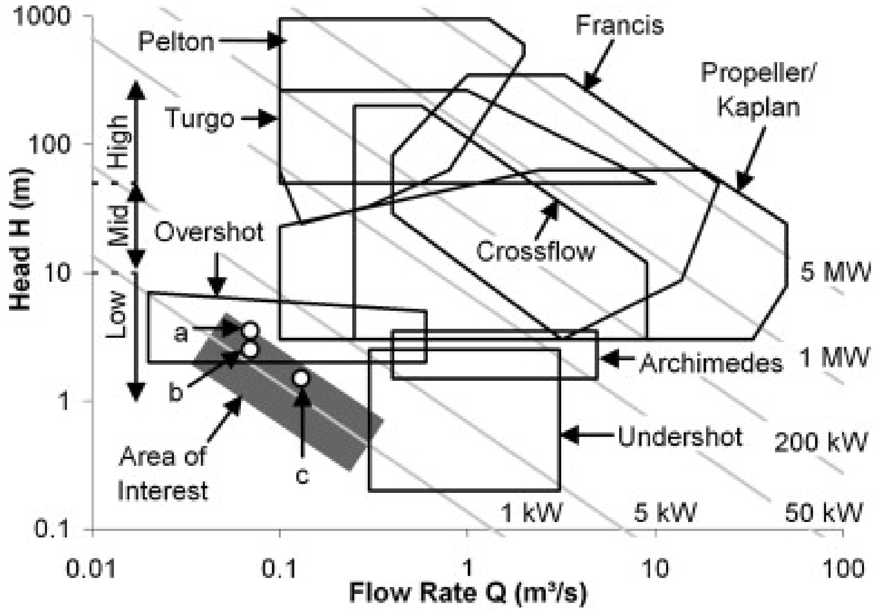



**Fig. 4. Head and discharge relationship [13].**

## 4. RESULT AND DISCUSSION

### 4.1 Lithology as a Foundation

From Appendix 3, the riverside plains in the south are dominant with claystone (yellow), while in the north, it is mainly carbonate siltstone (green). This indicates that the south is more suitable for the construction of MHPP than the north. Furthermore, the southern areas are closer to the residential area than the northern. Therefore, based on the classification of rock mass rating (RMR) using uniaxial compressive strength (UCS), the granodiorite is a hard rock, and its UCS ranges between 100 - 250 MPa, limestone between 25 - 50 MPa, and claystone 5 to 25 MPa [25]. This is in line with the results obtained by a previous study [26] where rocks with compressive strength above 100 MPa withstand both vertical and horizontal vibration. Meanwhile, rocks less than 25 MPa risk subsidence due to internal friction or swelling of clay minerals [27].

### 4.2 The Distance of the River to a Potential Power Plant Location

From Appendix 4, ArcGIS has visualized the river's distance as a potential MHPP site into three: red colour for distance < 100 m with a score of 1.32, yellow for 100-200 m with a score of 0.88, and green for above 200 m with a score of 0.44. ArcGIS visualizations have accuracy with a reading category of ± 8 m (tides.big.go.id).

### 4.3 River Slope

From Appendix 5, the river slope within the classification 21% to 100% (steep) is dominant in the south. Meanwhile, in the north, the river slope within 0 to 7% (almost flat to gently sloping) is dominant. This indicates that southern areas are more suitable for the construction of MHPP than northern. Furthermore, in southern areas, the Kikim river morphometry in several locations has steep slope angles ranging between 16 and

35°. Therefore, these conditions are suitable for the penstock pipe of MHPP, as its potential is high [28][24].

### *4.4 Results of the Assessment of AHP Methods*

Figure 5 shows the results of the assessment using the AHP method. From these results, it was found that the lowest value is 0.99 and the highest is 2.97, where the areas of a higher value are good areas for the construction of MHPP. The weighting scores between 0.99 to 2.97 are classified into three categories: 0.99 to 1.65 is not ideal (green zone); 1.66 to 2.31 is less ideal (yellow zone; and 2.32 to 2.97 is ideal (red zones).

Based on the AHP assessment, three locations with values between 2.32 and 2.97 are ideal locations for MHPP (see Figure 5-b to d). Figure 5 b-d are the results of direct observation of the location which involved AHP assessment of the river morphometry directly. From the observation, Figure 5-d is a good location due to its deep, wide river conditions, with sufficient water velocity, and a head (elevation) of 4 m. Figure 6 is a zoom-in of the location at a blue box in Figure 5-a.

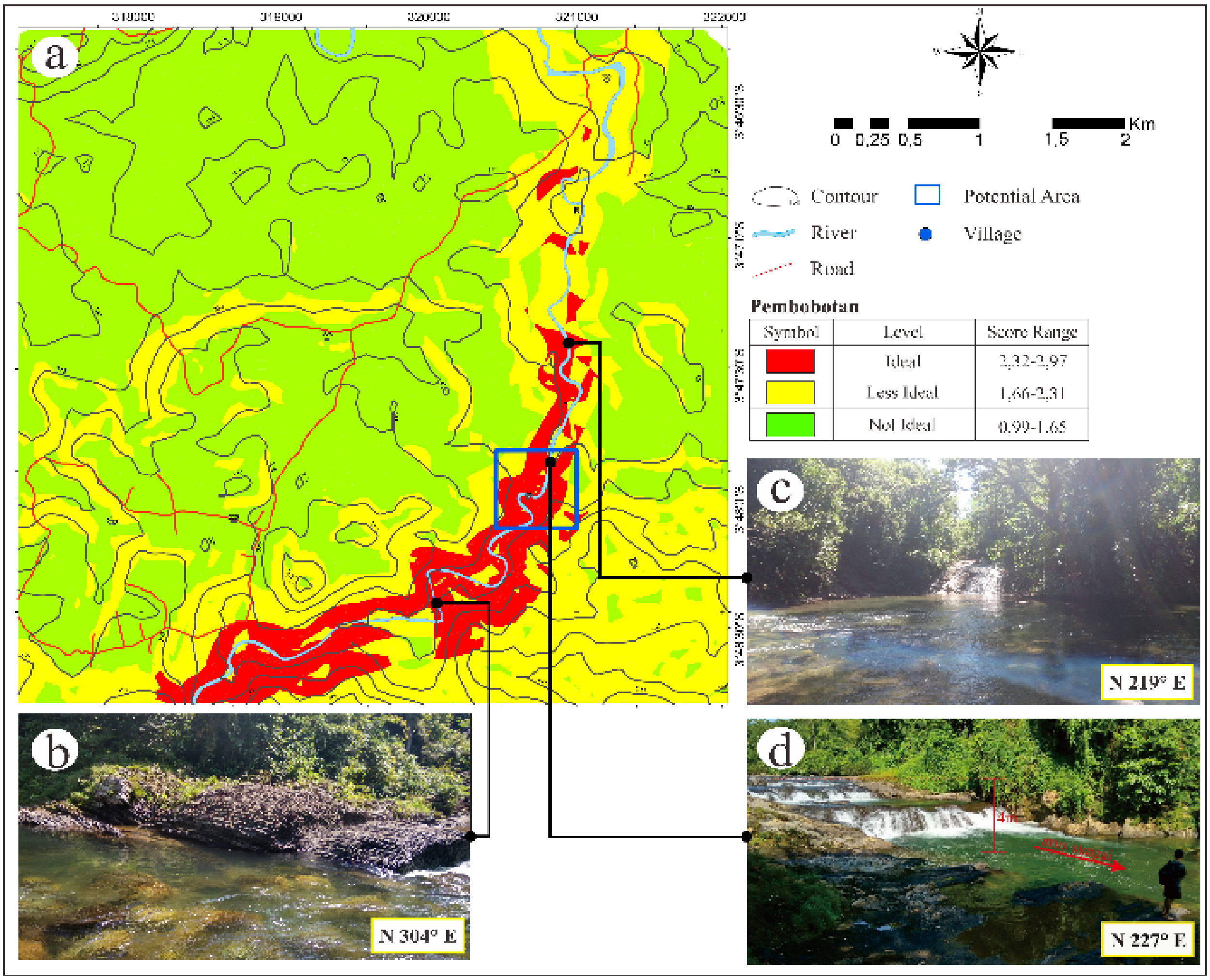



**Fig. 5. The assessment results of the location of the micro-hydro potential.**

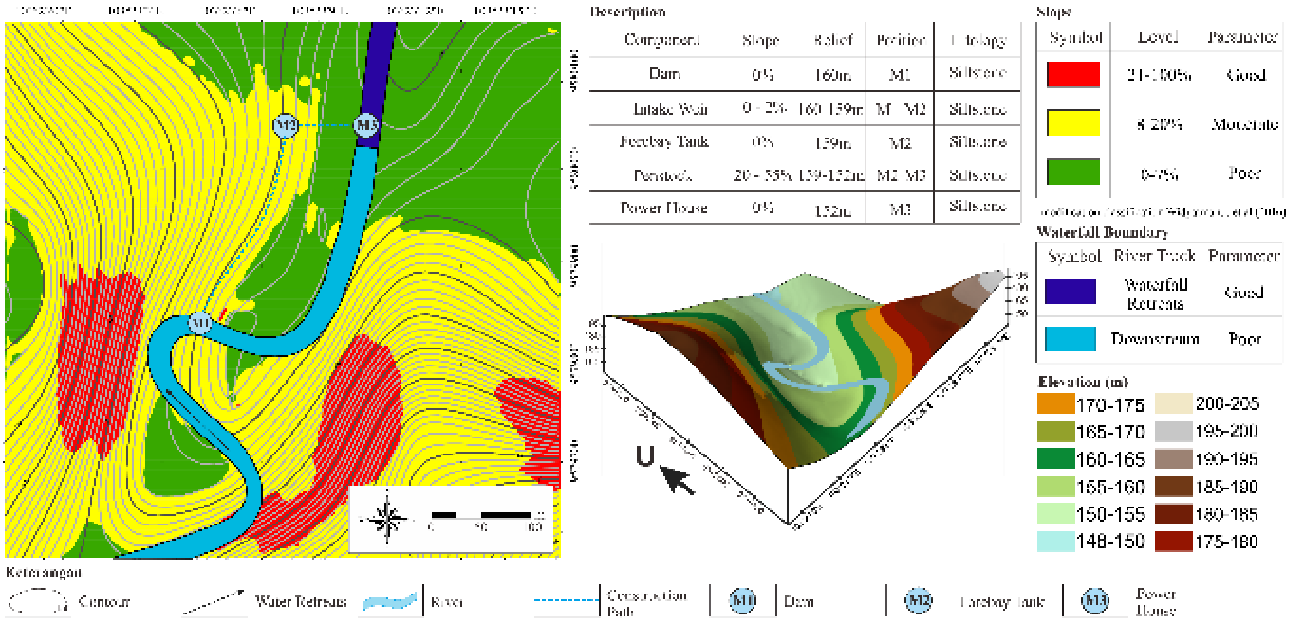



**Fig. 6. Analysis of the position of the components of MHPP.**

Based on geological analysis such as river slope and shape (elevation condition), MHPP components' layout can be adjusted (Figure 6).

The Kikim river has many small-scale waterfalls (Figure 5-d) which are favorable for MHPP implementation. From Figure 5-d, the head (elevation) of the waterfall is ± 4 m. A field measurement of the river's cross-section area is 12.91 m$^{2,}$ while the width is ± 20.5 m and an average height of ± 0.61 m (see Figure 3). Table 6 shows the average local water velocity data and the average stream velocity of ± 0.26 m/s, as seen in Table 4. Therefore, the discharge of the river is 3.19 m$^3$/s.

**Table 4. Average local water velocity at twelve locations.**

| Velocity (m/s) | Times 1 | Times 2 | Times 3 | Average |
|---|---|---|---|---|
| $v_1$ | 0.10 | 0.20 | 0.10 | 0.13 |
| $v_2$ | 0.20 | 0.20 | 0.20 | 0.20 |
| $v_3$ | 0.20 | 0.30 | 0.30 | 0.27 |
| $v_4$ | 0.20 | 0.30 | 0.30 | 0.27 |
| $v_5$ | 0.20 | 0.30 | 0.20 | 0.23 |
| $v_6$ | 0.30 | 0.40 | 0.30 | 0.33 |
| $v_7$ | 0.30 | 0.30 | 0.30 | 0.30 |
| $v_8$ | 0.30 | 0.10 | 0.30 | 0.20 |
| $v_9$ | 0.40 | 0.30 | 0.30 | 0.33 |
| $v_{10}$ | 0.20 | 0.30 | 0.30 | 0.27 |
| $v_{11}$ | 0.30 | 0.20 | 0.20 | 0.23 |
| $v_{12}$ | 0.20 | 0.20 | 0.10 | 0.17 |
| Average | | | | ± 0.26 |

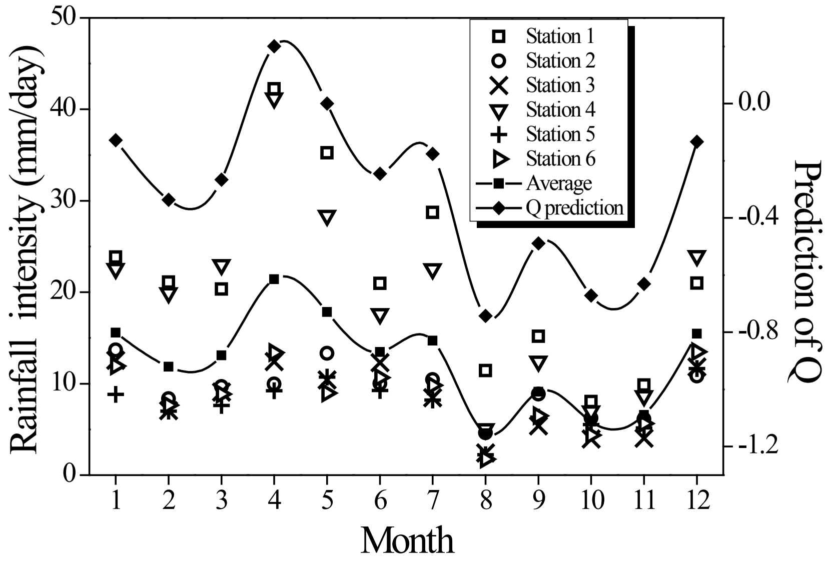



**Fig. 7. Rainfall intensity in Lubuk Tuba village.**

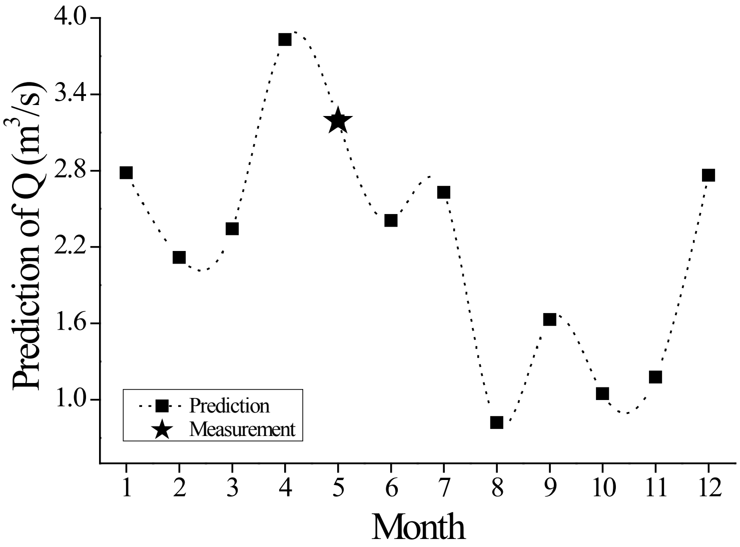



**Fig. 8. Prediction of Q in one year.**

Rainfall every month of the year in an area is certainly unstable, therefore the prediction of discharge (Q) using six data from the Meteorology Climatology and Geophysics Council (BMKG) of Republic of Indonesia (see Figure 6) [29]. In Figure 5-d and 7, the highest discharge (Q) is estimated to occur in April at 3.83 $m^3/s$ (20% from measurement results), while the lowest discharge (Q) is to be seen in August at 0.83 m3/s (74.32% from measurement results). Based on Figure 8, to anticipate the turbine not operating due to lack of input power (less discharge), the maximum exploitable discharge is 0.83 $m^3/s$. Thus, hydropower potential in the Kikim river is predicted using Equation 6 of 32.15 kW, categorized as micro-hydro.

### *4.6 Assessment of Micro-hydro Technology*

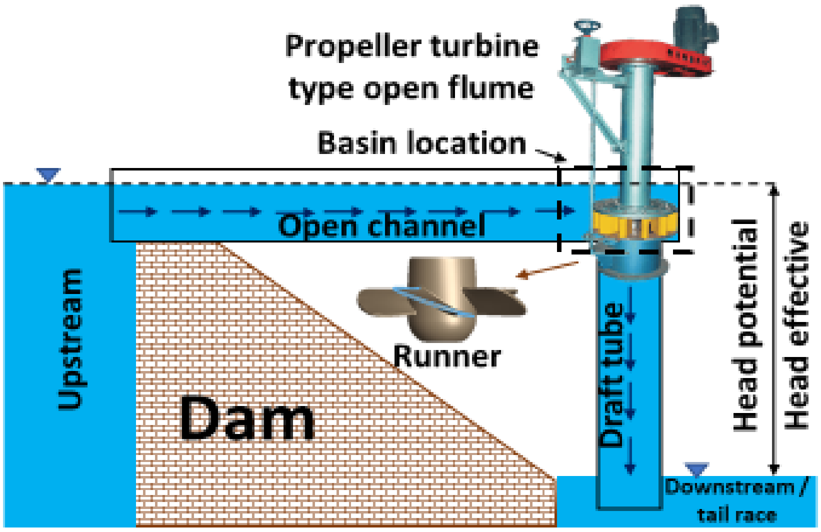
The Kikim river potential of 32.15 kW can supply electricity to 35 households with 50% efficiency and power 0.45 kW/house (0.45 kW is a minimum kWh meter owned by the National Electric Company (PT. PLN) of Indonesia). Based on Figure 3, for a discharge (Q) of 0.83 $m^3/s$ and available head (h) of 4 m, there are three suitable turbines: propeller, Kaplan, and crossflow turbine (CFT). The propeller and Kaplan turbines are similar, Kaplan turbines are usually applied to hydropower on mini scales, as its construction is more complex (has an adjustable guide vane and blade) [30][31]. Hence, in consideration of investment costs, the propeller turbines and CFT have a good agreement for micro-scale.

The propeller is a reaction turbine (it absorbs the kinetic and pressure energy of water), and has stable performance because of a wide specific speed (Ns) range of 300 to 1000 m-kW [12]. Hence these turbines are often proposed as independent power plants for remote areas in several developing countries such as

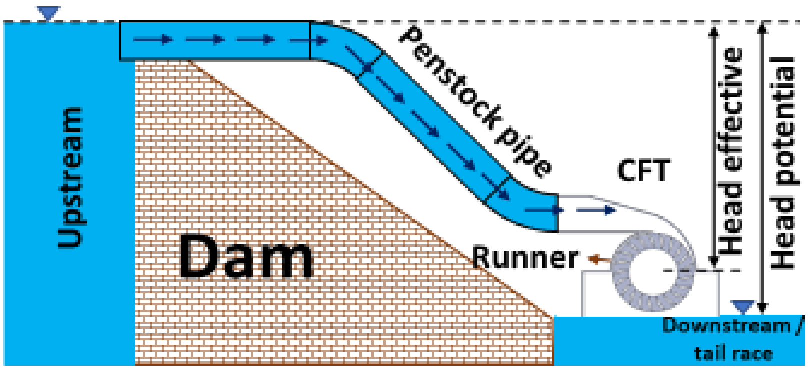
Cameroon [3], Honduras [7], Laos [5], Rwanda [6],[32], and others. The propeller turbine was recommended because the potential head is fully utilized (minimum head losses, see Figure 9-a). Since the draft tube is a device converting the kinetic energy loss of water into potential energy pressure, it increases runner torque [33]. This turbine's disadvantage is its unfriendliness to the environment, as the high runner rotation makes the aquatic biota passing through it to die. Furthermore, this turbine's maintenance is categorized as difficult and has to be maintained daily, as its rotation is sensitive to the garbage and other objects passing through it [34].

The CFT is an impulse turbine that absorbs the kinetic energy of water converted by nozzle [35]. Based on Figure 4, the CFT is effective in medium to high head (5 to 100 m) [13]. However, it is often used in remote areas due to its operation at high discharge deviation and low head condition (<5 m) [13],[36],[37]. Additionally, this turbine absorbs energy in two successions, called stage 1 and 2. The CFT is sensitive to the garbage and other objects (like propeller turbine) as they inhibit runner rotation.

This study agrees with the previous study [13] that the efficiency of the design and performance of CFT was lower compared to the propeller turbine. Since the position of the CFT has to be above the tailrace (see Figure 9-b). The advantage of using CFT lies in its civil construction is simpler than propeller turbines, where the dam can directly access the penstock pipe through the turbine system (See Figure 9-b). Unlike the propeller turbine, an open channel and basin are needed to use the turbine system. Furthermore, the CFT is rarely in demand due to the investment cost being higher than propeller turbines. In Indonesia, the per kW crossflow turbine is ± USD 4000 while the propeller is ± USD 2300, as the runner manufacturing process is difficult and lengthy due to its hand use (not mechanized).




a. The propeller turbine system.




b. The CFT system.

**Fig. 9. Schematic of micro-hydro turbine type propeller and crossflow.**

## 5. CONCLUSION

The determination of an ideal micro-hydro potential location involves the geoscience aspects of lithology, morphometry, and topography approaches, which depends on the AHP assessment method. This geoscience approach helps to visualize case study areas with accuracy and precision. The advantage is that there is no need for lengthy observations and measurements along any river, as it helps to ascertain which one is ideal. Therefore, the application of the AHP method in determining the ideal MHPP location saves cost, effort, and time.

The surface mapping and GIS results show that the ideal zone has good waterfall height (potential head) and plain with hard rock types (granodiorite). From the field observations, the waterfall or potential head (h) was 4 m, and discharge (Q) was 0.83 $m^3/s$, the hydropower potential was 32.15 kW and is categorized as a micro-scale. In consideration of energy losses and investment costs, the propeller turbines are suggested in this case. Furthermore, the potential hydropower of the Kikim river of 32.15 kW can supply electricity to 35 households with 50% efficiency and 0.45 kW/house.

## ACKNOWLEDGEMENT

The authors said thanks to Rahmat Alfath as a surveyor (collecting data), Try Saputra from PT. Sriwijaya Bara Priharum, which supports measuring instruments, and Universitas Sriwijaya for facilities software and desktop.

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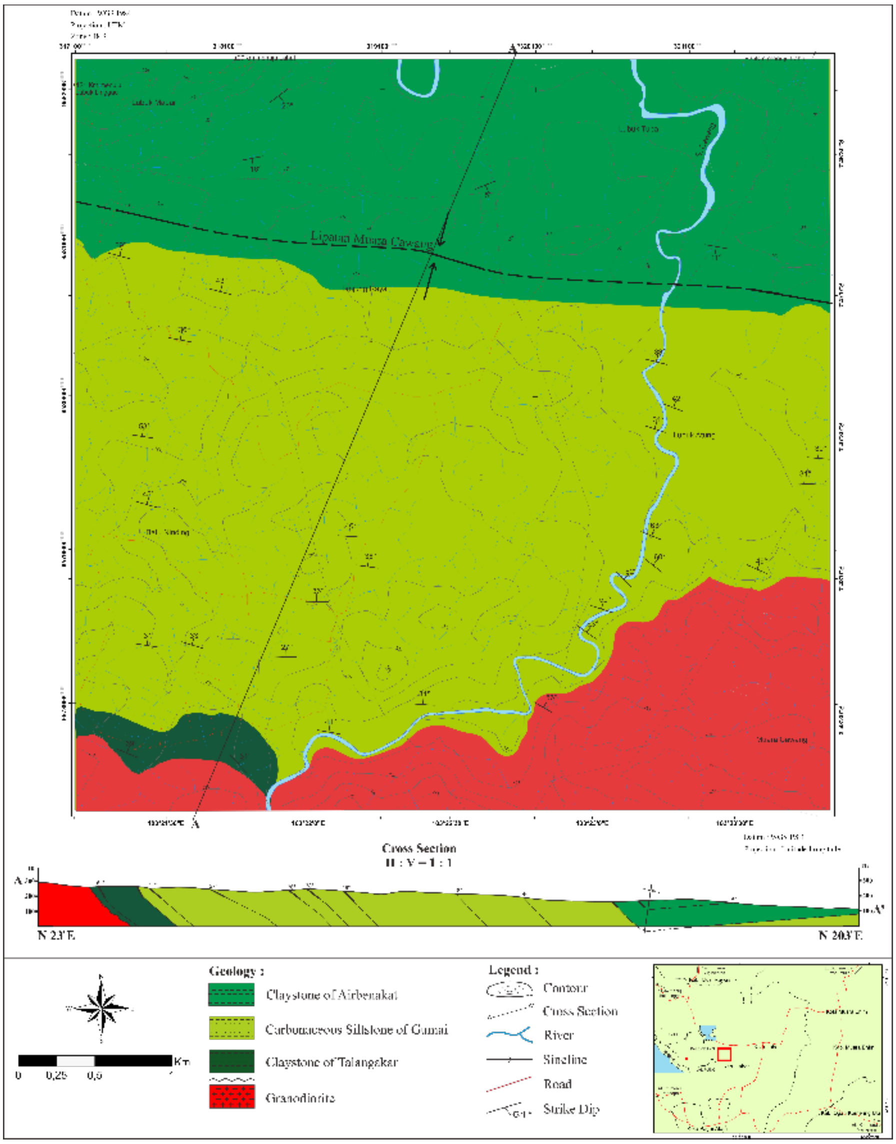
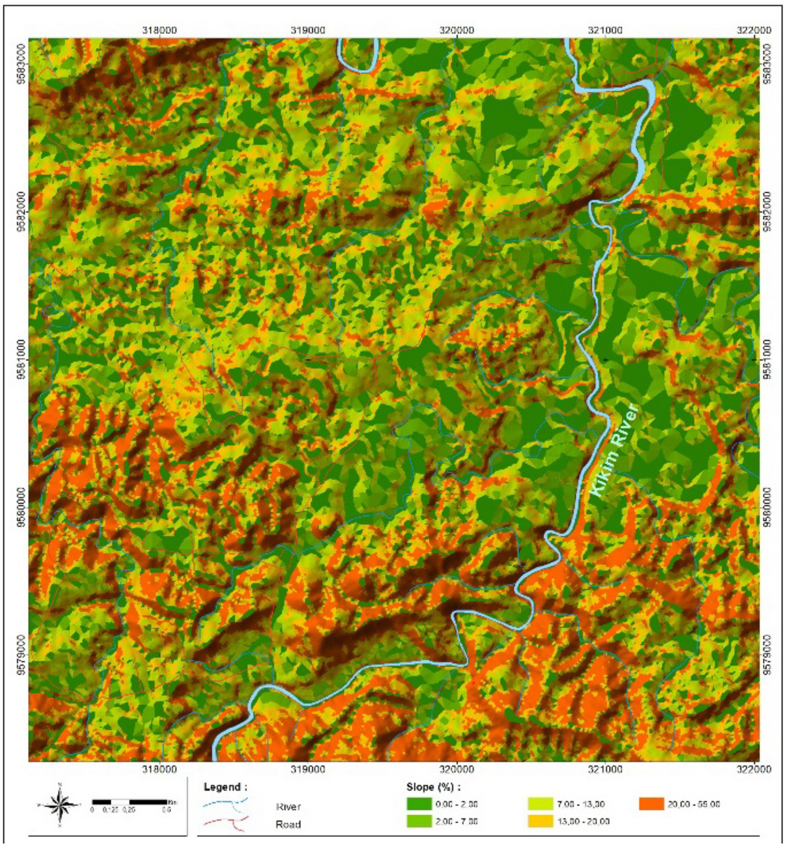
## APPENDIX

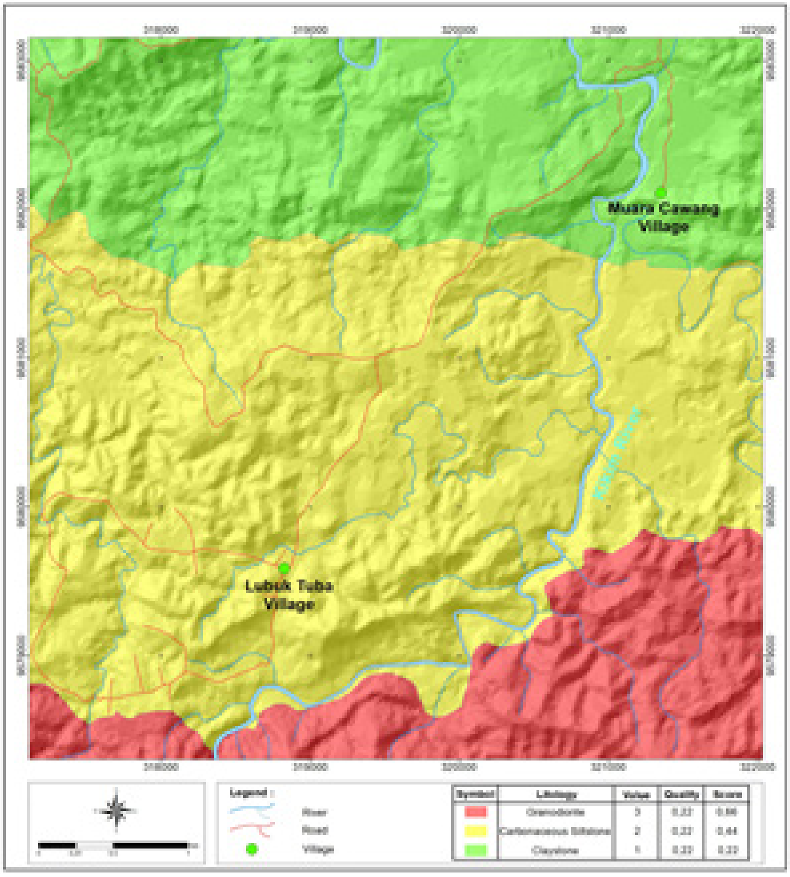
*1. Distribution of rocks in the case study area*



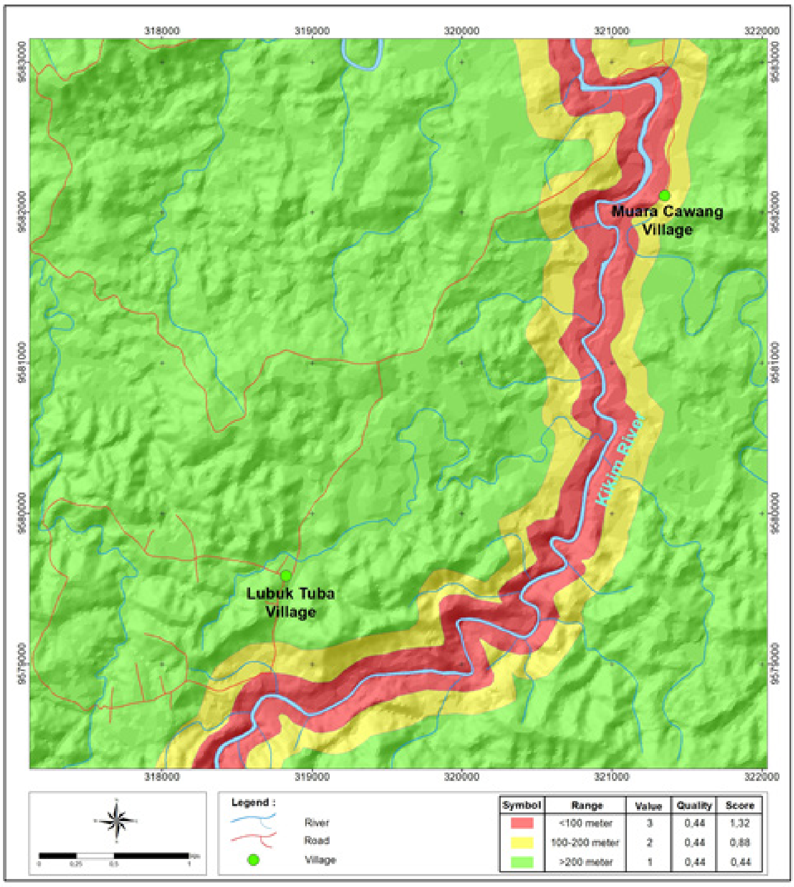
2. *Visualization of slope map in the case study area*




3. *Assessment results of lithology aspect*



4. *Assessment results of the aspect of river distance to a potential power plant location*




5. *Assessment results of river slope aspect*