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Potential for Renewable Energy Generation from Water Sources in the Batang River Area

Muhammad Hafiizh Imaaduddiin[1,*], Widya Utama[2] , Chakimoelmal Jasikur[4], Wien Lestari[3], Anissa Nur Aini[1]

[1]Department of Civil Infrastructure Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia

[2]Department of Geophysics Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia

[3]Department of Geomatics Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia

[4]Bandung Institute of Technology, Bandung 40132, Indonesia

***Corresponding author:** m_hafiizh@ce.its.ac.id

The ever-increasing use of fossil fuels causes the climate to become unbalanced due to the resulting pollution. Renewable energy is gaining widespread adoption because it is more cost-effective and eco-friendly. Using water as micro-hydro power plants or PLTMH can be a viable alternative to non-renewable fuel sources. Indonesia is one of the countries with the greatest application potential for micro-hydro power plants or PLTMH, particularly in Batang Regency, Central Java Province. This study focused on reducing the use of fossil fuels as a source of electricity in Batang Regency by utilizing water resources. Environmental approaches and hydrological analysis were employed in this study to achieve precise and optimal PLTMH planning outcomes. The results of the analysis indicated that the total discharge required to operate the PLTMH turbine is 2.22 m^3/s with an 80% mainstay discharge, while the design flood discharge is 113,679 m^3/s (Q100year). Implementing micro-hydro power plants or PLTMH in Batang Regency could be the first step in Indonesia's transition from fossil fuels to renewable energy sources.

Keywords: micro-hydro plant, renewable energy, hydroelectricity, energy consumption.

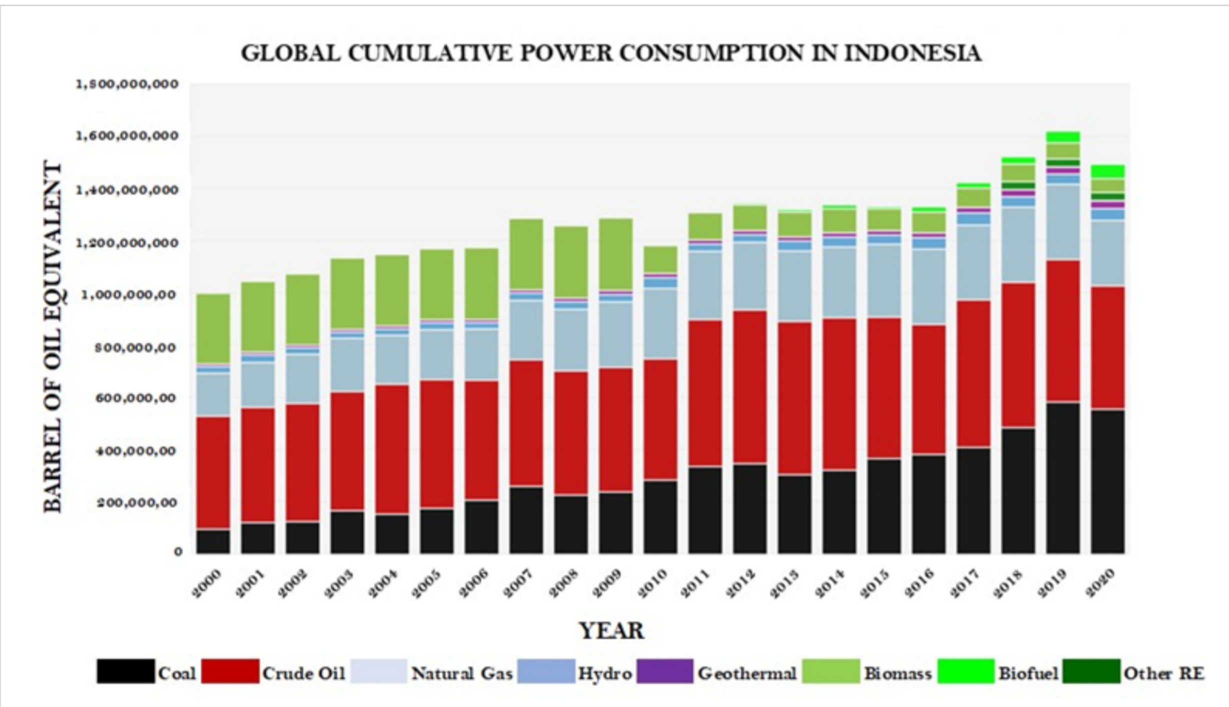
Introduction

Electricity is distributed throughout Indonesia by a single company, the State Electricity Company (PLN) (Arafah et al., 2018; Novianti, 2019). This company gets 85% of its electricity from fossil fuels (Thomas, 2020). This percentage of fossil fuel consumption continues to rise annually, but the increase is inversely proportional to the available resource supply (Menéndez et al., 2020). This increase will impact the price of fossil fuels, which is on the rise as the existing supply dwindles (Laan and Maino, 2022; Yasinta and Karuniasa, 2021). Additionally, continued reliance on fossil fuels will result in rising carbon emissions that will pollute the atmosphere and cause a significant rise in harmful gases (Tan et al., 2022). *Fig. 1* depicts the total amount of energy consumed in Indonesia. The graph demonstrates that non-renewable energy sources such as coal, crude oil, and natural gas account for the majority of energy consumption. The annual consumption of this energy will continue to increase until 2019 when it will surpass 1.4 billion. Using renewable energy, such as biomass and biofuels, gained only 107.3 million over the same time periods (Perusahaan Listrik Negara (PLN), 2021; Thomas, 2020).

With strict environmental regulations now in place, renewable energy sources are gaining ground (Yonariza et al., 2019). It is anticipated that renewable energy sources will account for more than 70% of global power generation growth (Gielen et al., 2019). Renewable energy sources, such as water, solar, geothermal, wind, and biomass, tend to produce a more environmentally-friendly energy supply (Syahputra and Soesanti, 2020; Tao et al., 2019). With the availability of renewable energy that is less harmful to the environment, it is hoped that it will supplant conventional fossil energy sources like coal and natural gas and reduce greenhouse gas emissions (Dwiyanto et al., 2016).

The water energy potential of Indonesia is approximately 75 GW, or 16.98% of the total NRE potential (Langer et al., 2021; Warjito et al., 2019). Indonesia ranks fourth in Asia in terms of its enormous hydroelectric potential, behind China, the former Soviet Union, and India (Yonariza et al., 2019). Nonetheless,

Fig. 1. *Global cumulative power consumption in Indonesia (Source: Handbook of Energy and Economic Statistics of Indonesia (HEESI) 2015–2022)*



only 5%, or 3,584.07 MW, of the country's installed electricity capacity is derived from the existing 16.98% of water energy potential (Cahyono Adi and Lasnawatin, 2021; Thomas, 2020). In Central Java, water energy potential of 75,926 kW has been realized with 69,832 kW, or 92%, of hydroelectric power plant potential (Syahputra and Soesanti, 2020). However, an additional 8% must be optimized in order for it to be fully utilized in the province of Central Java.

Batang Regency is among the regions with significant water energy potential, due to the fact that Batang Regency extends from the coast to the highlands bordering the Dieng region (Pemerintah Kabupaten Batang, n.d.). This district's average annual rainfall of 621.40 mm makes it highly suitable for the construction of a micro-hydro power plant or PLTMH (Pemerintah Kabupaten Batang, 2021). This power plant is the best option for electrification because its costs are relatively low compared to those of fossil energy. It is hoped that the construction of PLTMH in Batang Regency will improve the potential for hydroelectric power plants in Central Java province.

This study aims to provide answers to the following questions concerning the planning prospects of micro-hydro power plants in Batang Regency, Central Java, Indonesia:

a What is the potential of water resources in the Lojahan watershed as a planning location for micro-hydro power plants?

b How is the method for analyzing the power potential generated by micro-hydro power plants compared using related software analysis?

This study generally discusses the planning potential of micro-hydro power plants in the Lojahan watershed, Batang Regency, Indonesia, with the goal of obtaining great potential for the power generated as a replacement for non-renewable natural resources.

Data and Methods

Study site

This research was conducted in Batang Regency, Province of Central Java, Indonesia. Batang Regency is positioned on the northern coastline of Java Island, between 60° 51'46" and 70° 11' 47" south latitude and 109° 40' 19" and 110° 03' 06" east longitude (Pemerintah Kabupaten Batang, n.d., 2021). The Lojahan watershed, with a catchment area of 29.55 km^2, is depicted in *Fig. 2* as the location for PLTMH planning. In the study area, a location survey was conducted to gather topographic data based on the location of the pool, which was attached to a polygon point with a height difference of 10 meters drawn from the contour line. The Lojahan watershed's topographical conditions require an average slope.

Hydrological approaches

In this study, hydrological analysis calculated the monthly discharge on the Lojahan River by simply displaying rational discharge calculations and water balances to get the best results possible.

Furthermore, an analysis of flood discharge with return periods of 25, 50, and 100 years was obliged (Prastica et al., 2018). The results of the calculations were then used in simulation to determine the number of turbines needed for the PLTMH and their requirements.

Rational method

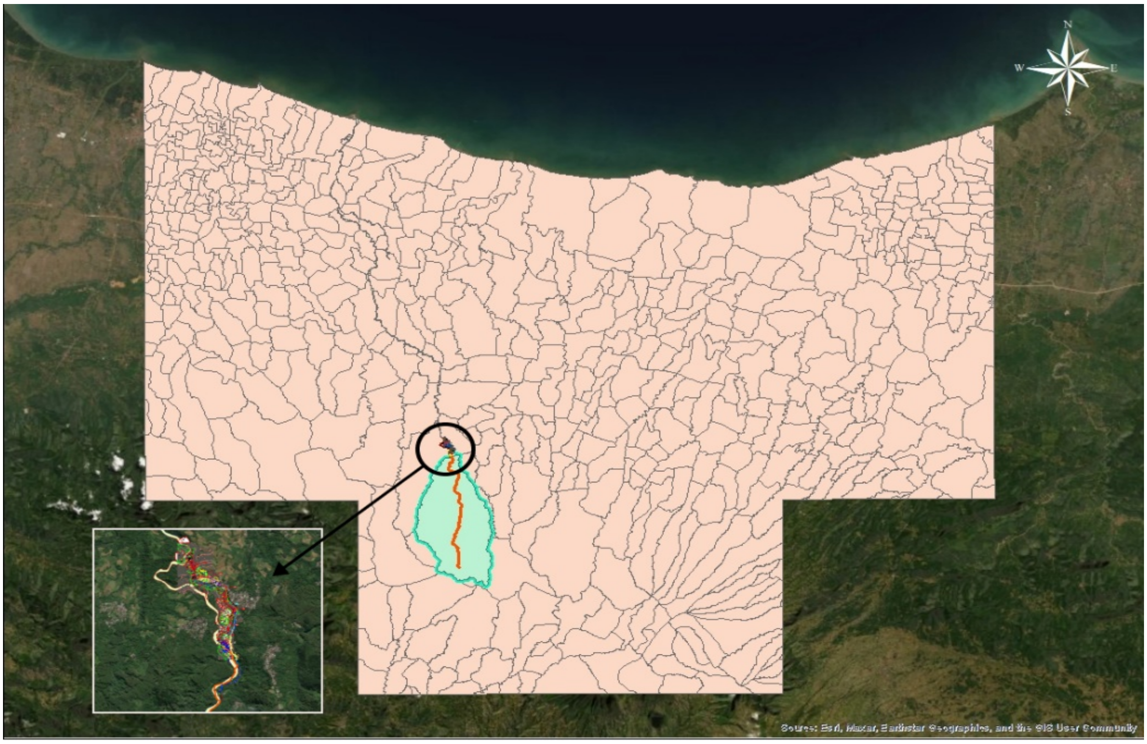
Estimating the peak discharge of Q in the watershed area is required in a planning analysis of water building facilities, and is reviewed using logical methods (Marelianda et al., 2021).

Peak discharge or Q is influenced by a number of factors, including rainfall information and a physical model of the channel's cross-section at the planning site (Utama et al., 2022). Equation 1 shows the formulation used to calculate the rational method using these parameters.

$$Q = \frac{1}{3{,}6}\, C.I.A = 0{,}278.C.I.A \qquad (1)$$

Where: Q – river discharge (m^3/s); C – coefficient runoff; I – rain intensity (mm/hour); A – catchment area (km^2).

Fig. 2. *Micro-hydro power plant location*



Water balance method

This study utilized the application of the mainstay discharge to estimate the annual discharge at the PLTMH planning site in Batang Regency. NASA's Earth Data Application for Extracting and Exploring Analysis Ready Samples provided data on the Lojahan watershed catchment's evapotranspiration (AppEEARS) (NASA, n.d.). The PLTMH planning study's location coordinates were put through the ArcGIS program to find watersheds that affect planning. The parameters were then applied to extract watersheds from the DEM Map of the State of Indonesia (Kumoro et al., 2022). The obtained results of the watershed geometry were then utilized as parameters for calculating evapotranspiration data.

The geometry of the watershed catchment was entered into AppEEARS to collect evapotranspiration data, which was then processed to obtain potential evapotranspiration values (Negm et al., 2018). The flow duration curve, or the FDC method, was used to determine the mainstay discharge using this evapotranspiration as one of the main discharges. An FDC is a cumulative frequency graph that shows historical stream variation over a specified time period with a percentage of time resolution as a gauge of how long it will take the discharge to match or exceed the historical variation (Marelianda et al., 2021). The following is Equation 2 used in this FDC:

$$x = 100\left(\frac{R}{n+1}\right) \quad (2)$$

Where: x – expedience probability; R – ranked position on the listing, starting with 1 for the considerable daily discharge value; n – number of events for the period of the record (taken as 365 in this study).

Frequency distribution of rainfall

Rainfall frequency distribution tests rainfall data with a certain re-period (Ophiyandri et al., 2021; Soehardi and Dinata, 2018). This test is used to find out which rainfall calculation methods can be applied to study planning. The re-periods calculated in this test are 25, 50, and 100 years, with the distribution methods being the Normal, Gumbel, and Log Pearson III distribution methods. The results of the three ways were then tested using the Chi-Square and Smirnov-Kolmogorov frequency distributions to obtain rainfall-compatible plans to apply to the study.

Flood discharge planned

A flood discharge design plan was required for the design of the weir tower's flood spillway and flooding at the location of the micro-hydro power plant (YoosefDoost and Lubitz, 2020). Floods are designed using Nakayasu's HSS method by estimating floods in the return period. Equation 3 shows the formulation used in this technique:

$$Q_p = \frac{C.A.R_0}{3.6\ (0.3\ T_p + T_{0.3})} \tag{3}$$

Where: Q_p – peak of flood discharge (m^3/s); C – coefficient of drainage; R_0– effective rain (mm); T_p – the period from the beginning of the rain; $T_{0.3}$ – the time required for a decreased discharge of the peak discharge (hours).

Potential power energy production

By using the topographic, geological, and hydrological data that is currently available, micro-hydro power plants can produce as much power as they are capable of. The formula used in this study's PLTMH planning to calculate the power generated is shown in equation 4:

$$P = Q.H.g.\eta_T.\eta_G.kW \tag{4}$$

Results and Discussion

The calculation results of a frequency distribution of rainfall using the Normal method, Gumbel method, and Log Pearson type III method

In each method, the theoretical requirements for passing the frequency distribution test are the values of the skewness coefficient (Cs) and the coefficient of kurtosis (Ck) (Besançon et al., 2021; Serago and Vogel, 2018). The Normal method test results showed a value of Cs = 1.3443 and a value of Ck = 0.2484, where the theoretical conditions required to pass this method are Cs = 0 and Ck = 3. The calculation results using the Gumbel method, on the other hand, showed the significance of Cs = 1.3443 and the value of Ck = 5.2184, with the theoretical conditions that must be met to pass this method having a value of Cs 1.1396 and a value of Ck 5.4002. Meanwhile, the theoretical requirements for passing the Log Pearson type III method test had flexible Cs and Ck values. Cs = 0.9015 and Ck = 4.2398 were the test results in this method. The Pearson Log type III method met the theoretical conditions of Cs and Ck values based on the Cs and Ck results on the three methods. As shown in *Table 1*, the rainfall plan applied to this study used Log Pearson type III method with return periods of 2, 5, 10, 25, 50, and 100 years.

Table 1. *Calculation of the average rainfall in Batang Regency*

Return period	Plan for rainfall (mm)
	Log Pearson III
2	107.61
5	124.84
10	136.92
25	152.84
50	165.20
100	177.96

The obtained rainfall of the plan was then used as a parameter in subsequent calculations.

Main discharge analysis

Fig. 3 depicts the flow duration curve (FDC) results. The FDC represents the relationship between discharge and confidence intervals. The application of the FDC in a specific location is critical for the distribution and characteristics of the planning site (Yonariza et al., 2019). The best mainstay discharge is used by turbines with a certain amount of intervals. According to SNI 6738-2015, the required percentage of mainstay discharge utilized in micro-power plant planning is Q80 (SNI 6738:2015, 2015). As seen in *Fig. 3*, it was found that the discharge in Q80 was 2.99 m^3/s.

Fig. 4 shows the relationship between the mainstay Q80 discharge and the average monthly rainfall. The total discharge generated was 6.99 m^3/s, with the minimum discharge in September being 0.29 m^3/s and the maximum discharge in March being 6.99 m^3/s.

Fig. 3. *Flow duration curve of mainstay discharge*

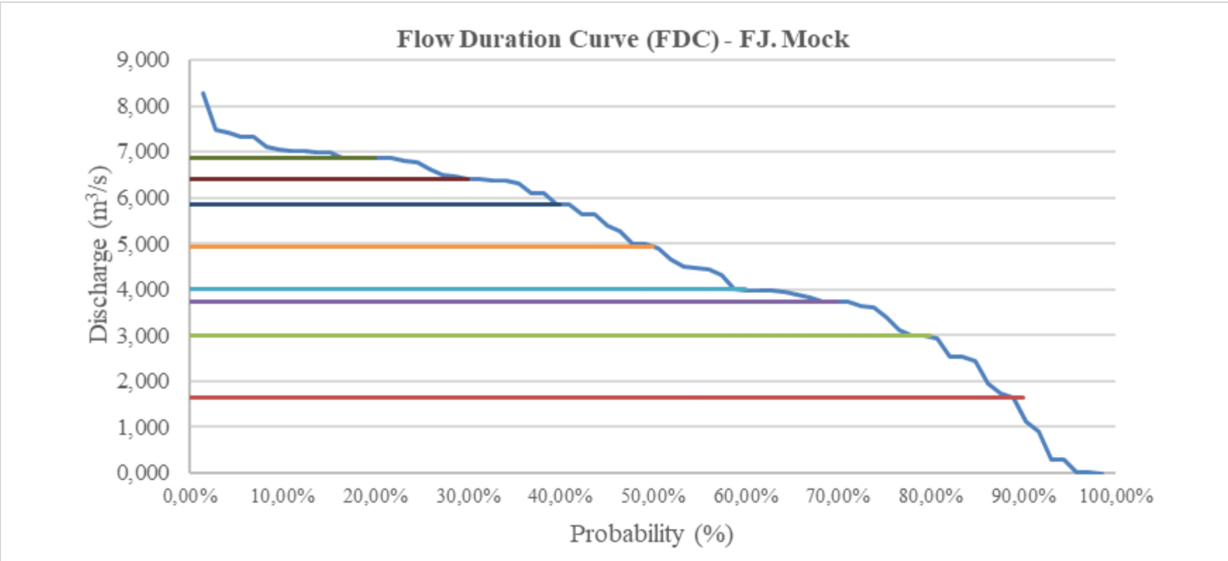
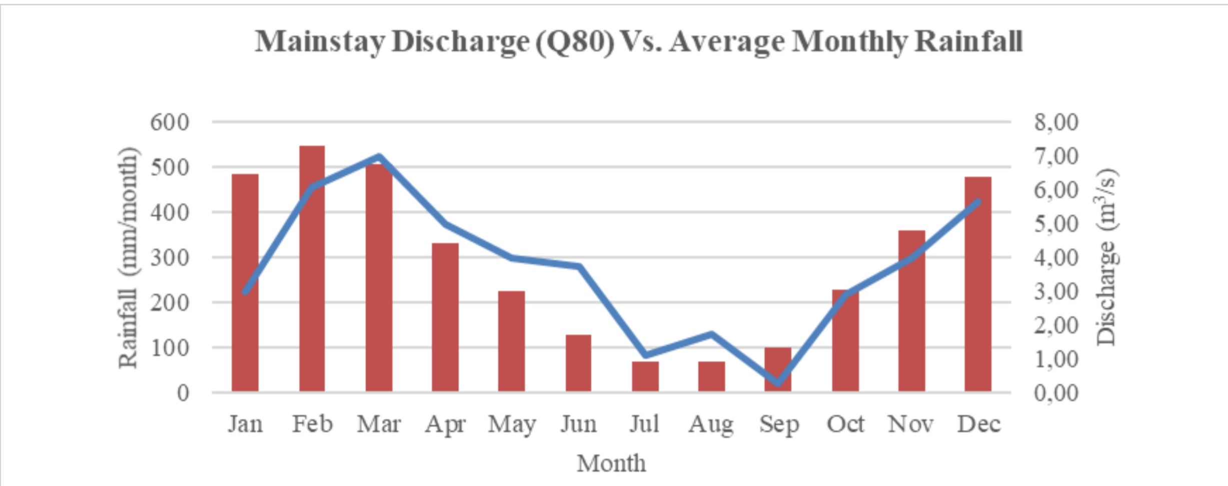


Fig. 4. *The relationship between average monthly rainfall and mainstay discharge Q80*



Discharge analysis of turbine mobilizer

The analyzed water balance method was used to determine the discharge requirement for a micro-hydro power plant's turbine to rotate and generate electricity. The result of the Q80 mainstay discharge was required to calculate the monthly accumulated volume and the turbine discharge required to generate energy. *Table 2* displays the discharge requirement based on the monthly accumulation of volume.

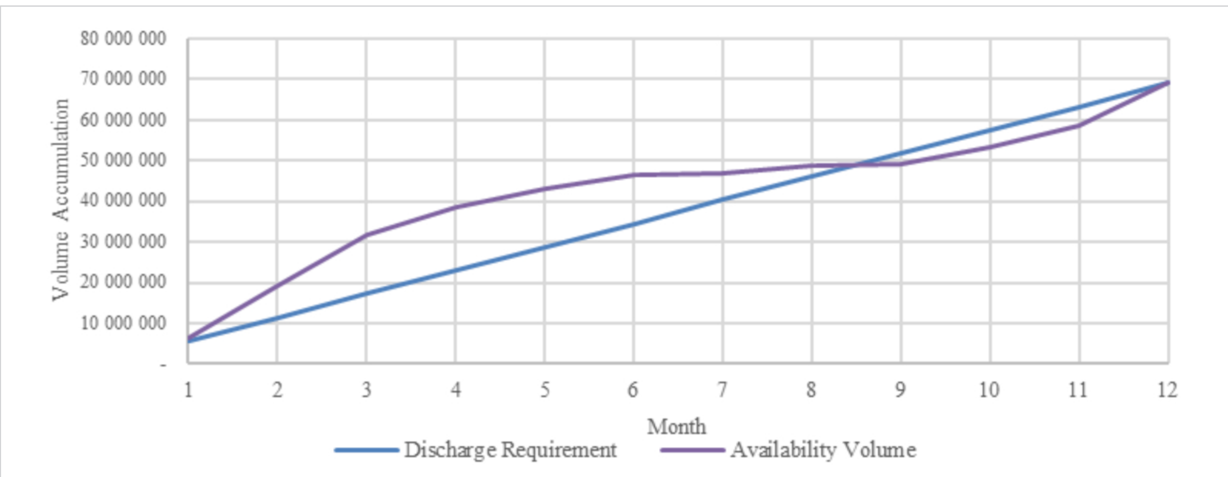
Table 2. *Calculation of turbine mobilizer discharge requirement*

Month	Q80%	Volume of accumulation	Discharge requirement
	(m^3/s)	(m^3/month)	(m^3/s)
January	2.99	6458373.152	2.22
February	6.09	19082019.64	
March	6.99	31771523.94	
April	4.98	38653931.17	
May	4.00	43141221.28	
June	3.72	46352936.7	
July	1.12	46739291.15	
August	1.73	48687651.85	
September	0.29	48985650.6	
October	2.92	53274653.93	
November	3.97	58760390.73	
December	5.64	68993511.85	
Σ Availability volume		68993511.85	

The availability volume in the Lojahan watershed was 68,993,511 m^3/month, as shown in *Table 2*. This value was determined by accumulating the monthly availability volume using the mainstay discharge Q80. The acquired availability volume was then used to calculate the discharge value of the PLTMH's power generation demands, which is 2.22 m^3/s.

Fig. 5 represents a graph of available volume versus discharge requirement. The graph represents that the need for discharge was closely related to volume availability because volume availability determined how the turbine could rotate each month. Volumes accumulated for power needs occurred from January to August, and volume shortages occurred from September to December. The graph illustrates that there was a shortage of volumes used to rotate turbines from the middle of the 8th month to the end of the 12th month, whereas the volume of needs to spin turbines was sufficient from the first month to the beginning of the middle of the 8th month. As a result, storage of water volumes from the months that produce large water volumes was carried out. From January to August, the volume overflow was stored in a pond to ensure that when the PLTMH condition lacks the volume of water to rotate the turbine, it can use the water storage in the pond. As the required volume is met, the turbine will rotate throughout the year. Using this discharge requirement, the power obtained from the potential power energy production result calculation at the planned PLTMH was 83.63 kWh with a head of 1.5 m and a turbine efficiency of 0.80.

Fig. 5. *Relationship between discharge requirement and availability volume*



Hydroelectric design analysis using HOMER software

A comparison between the calculated results and those of the software-based analysis was done to obtain a more ideal PLTMH planning design. The Hybrid Optimization Model for Electric Renewables, or HOMER, was the program used in this study. Using the software, a power plant design with more optimal power was obtained (Uddin and Joy, 2018; Yap et al., 2022). The data required for HOMER design analysis was the same as that required for previous calculations.

Fig. 6. *Batang micro-hydro powerplant schematic design using HOMER PRO*

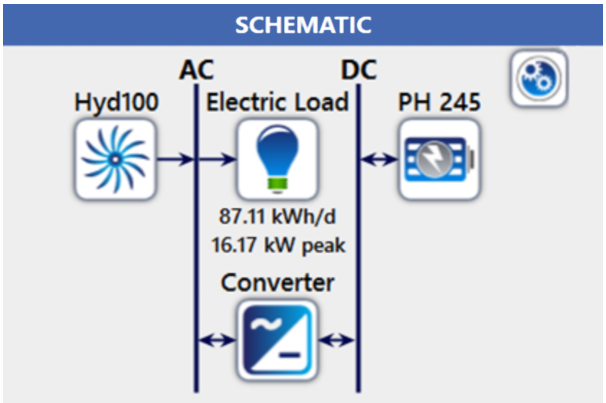


Fig. 6 depicts the hydroelectric power planning schematic design in Batang Regency created with the HOMER PRO software. *Fig. 6* shows that the Batang PLTMH scheme used a residential plan, produced 87 kWh/day, had a peak of 16 kW, and used 245 kWh of battery capacity for power storage. The graph of the total electrical load served yearly in the proposed system is presented in *Fig. 7*.

According to the chart, the average electrical load peak result from January 1 to December 31 was 16.17 kW, which did not exceed 20 kW. Meanwhile, the electrical load produced by the Batang PLTMH design was investigated through turbine analysis and inputted into the HOMER software, yielding 87.1 kWh/d of power, as shown in *Fig. 8*. The difference in power generated by the PLTMH planning was 3.47 kWh, or 3.99%, of the author's calculation result, according to the analysis using HOMER PRO results.

Fig. 7. *Annual total electrical load served*

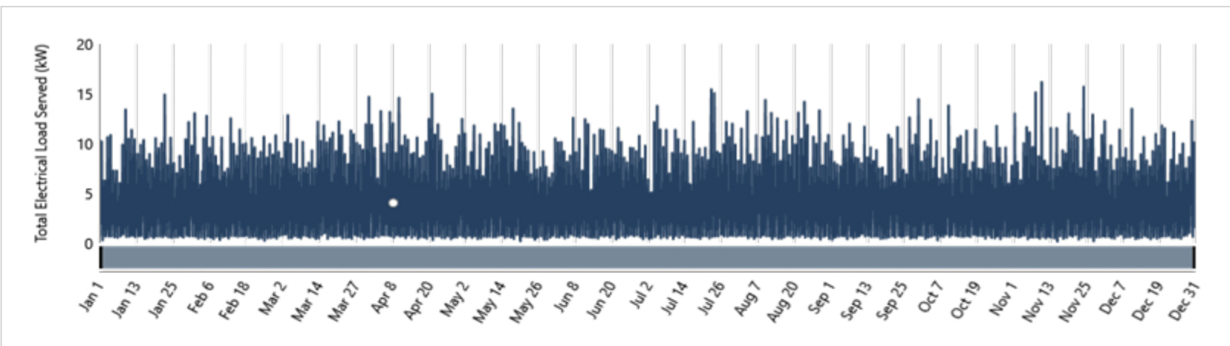
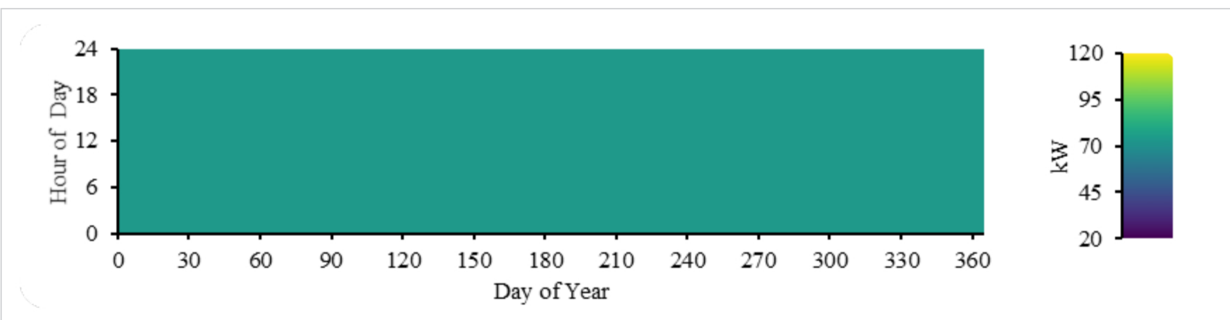


Fig. 8. *Batang micro-hydro powerplant nominal capacity*



Conclusions

Micro-hydropower plants are one of the best options for Indonesia, one of the nations with a lot of water resources, to replace non-renewable energy sources. Planning for a micro-hydro power plant could be implemented at the Lojahan watershed in Batang Regency, Central Java. The discharge available to mobilize the turbine was 2.22 m^3/s, with a power output of 83.63 kWh, according to hydrological analysis using 21 years of data. The PLTMH Batang planning design was also analyzed using HOMER software to obtain a percentage of the energy generated from the author's calculation results with the software application. The software-generated PLTMH design yielded a power output value of 87.1 kWh, which differed by 3.99% from the researcher's calculations. It is anticipated that the results of research on the potential of renewable energy from water resources in the form of hydroelectric power plants will be implemented globally by analyzing the topographic and hydrological conditions of each location with a high probability of having abundant water resources. This study can be applied to regions with abundant water resource potential by calculating and analyzing the discharge produced in a watershed that needs to be planned and the appropriate type of turbine.

It is essential to review the developments that took place at the study site for the PLTMH Planning study at the Batang Regency. One of the reasons why an assessment must be completed within a specific time frame (this study is completed every two years) is the annual existence of climate changes. The potential power produced by the micro-hydro power plant using the calculation outcomes from the topographic and hydrological data of the study location is the limitation of the PLTMH planning study. In order to achieve more ideal results, it is hoped that the scope of the subsequent study can be expanded by generating power output at the costs associated with designing a micro-hydro power plant in each study area. The community is encouraged to take part in raising the value of natural resources through PLTMH. In order for it to continue to be renewable energy on its own, there is a good balance between environmental protection and public awareness. The construction of PLTMH is anticipated to increase regional income and provide the neighborhood with electricity.

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