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River Hydrology Analysis For Micro Hydro Power Plant

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Abstract

The Micro Hydro Power Plant (PLTMH) is a generator capable of fulfilling the electrical requirements of isolated regions. PLTMH serves as an alternative means of generating electrical energy for the community. This power facility offers numerous advantages, particularly for remote areas across Indonesia. Water is a crucial energy resource due to its ability to generate electricity, a cost-effective and environmentally friendly kind of energy. The micro-hydro type PLTMH (0.5–100 kilowatts) in Aceh Province is the Lhoong PLTMH, which was built with assistance from PT. Coca-Cola in 2005. This PLTMH is located in Krueng Kala Village, Lhoong District, Aceh Besar Regency. This research aims to determine the availability of the Krueng Kala Lhoong PLTMH's flow rate and the availability of power and energy produced by the Krueng Kala Lhoong PLTMH to meet the electricity needs of Lhoong residents. It is hoped that the benefits of this research will be able to provide development and knowledge, especially in the field of pyrotechnics, and can become reference material for further study, providing information about micro hydropower plants, especially the Krueng Kala Lhoong PLTMH. The research utilizes the Pearson III Log Method to calculate maximum rainfall frequency and Fj Mock for reliable discharge calculation. The research results showed that the full rain discharge with a return period of 25 years was 1152.68 mm/hour. The total potential evapotranspiration (ET0) value occurred in March, reaching 6,649 mm/day. The mainstay discharge with a probability of 85% is Q85% = 0.24 m3/second, obtaining power of 27,914 kW and energy for a year of 20787,644 kWh. The calculation results conclude that the Krueng Kala power plant is still classified as a PLTMH, producing power below 100 kW and generating an annual energy of 20,787,644 kWh. The electricity can be distributed to Meunasah Krueng Kala Village, Baroeh Krueng Kala Village, Tunong Krueng Kala Village, and small enterprises in these three communities.

Keywords: PLTMH, Fj Mock, Power, Energy.

1. Introduction

A micro hydropower plant (PLTMH) is a device capable of fulfilling the electricity requirements of isolated and countryside regions. PLTMH serves as an alternative means of generating electrical energy for the community. Micro-hydro power plants (PLTMH) offer numerous advantages, particularly for rural areas across Indonesia [1]. Water is becoming recognized as a vital energy source due to its capacity to provide inexpensive and environmentally friendly electricity as other energy sources diminish and have adverse effects. Micro-hydro power plants are power plants that have a capacity of less than 100 kW [2].

One of the micro-hydro-type PLTMHs (0.5–100 kW) in Aceh Province is the Lhoong PLTMH, which was built with assistance from PT. Coca-Cola in 2005. This PLTMH is located in Krueng Kala Village, Lhoong District, Aceh Besar Regency. Not all the villages in Aceh Province can enjoy electricity. This is caused by the distance to villages in the interior, which cannot be reached by the State Power Plant (PLN); therefore, alternative energy sources are needed to be able to build small-scale power plants that can be applied in inland areas [3]. One way is by utilizing river or mountain water flow as an alternative energy source for propulsion energy in PLTMH. One of the uses of river or mountain water is in Krueng Kala Village, Lhoong District, Aceh Besar Regency, namely Suhom Waterfall [4]. The Ulu Masen Forest environment encompasses the Suhom Waterfall. The Ulu Masen forest habitat spans five districts: Aceh Besar, Aceh Jaya, West Aceh, Pidie Jaya, and Pidie. Abundant water that flows throughout the year serves as an alternative energy source. The Krueng Kala River is located in Lhoong District with a length of 8,258 km and a watershed area of 20.80 km2 [5].

Based on the background above, this research is about the availability of the Krueng Kala Lhoong Aceh Besar flow and the availability of power produced by the Krueng Kala Lhoong Aceh Besar PLTMH to meet the electricity needs of Lhoong residents [6]. This research aims to determine the availability of the flow rate used by the Krueng Kala Lhoong Aceh Besar PLTMH, to determine the availability of power produced by the Krueng Kala Lhoong Aceh Besar PLTMH, and to meet the electricity needs of Lhoong residents. So that in writing the final assignment, it can be focused and directed, and also for convenience in future research, the authors create a

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definition of this research problem discussing the MHP, taking into account the significant flow rate and the amount of power and energy produced in the MHP [7]. The research is located in the Krueng Kala Lhoong Aceh Besar PLTMH area, does not consider natural disaster factors so that the turbine works ideally, does not calculate building structures, and economic analysis is not discussed in this final assignment.

The research showed that rain discharge with a return period of 2 years was 602.93 mm/hour, five years was 784.99 mm/hour, 10 years was 932.79 mm/hour, and 25 years was 1152.68 mm/hour. In March, the highest recorded evapotranspiration (ET0) value was 6,649 mm/day or 206,120 mm/month. Evapotranspiration takes place when there is an adequate amount of water to fulfill the optimal requirements. The primary discharge is between 85-90% for central power generation. This indicates that out of the numerous river flow occurrences throughout the year, the discharge must fall within the 85-90% range to be harnessed as energy for electricity generation. We select the primary discharge with a probability of 85%, denoted as Q85% = 0.24 m3/sec. Based on the data collected, the power output generated with an estimated discharge of 85% is 27,914 kW, and the annual energy production amounts to 20,787,644 kWh. According to the calculation results, it can be inferred that the power output of the Krueng Kala power plant is less than 100 kW, categorizing it as a micro-hydro power plant (PLTMH). The power plant generates an annual energy output of 20787.644 kilowatt-hours (kWh). The electricity can be distributed to three villages, namely Meunasah Krueng Kala, Baroeh Krueng Kala, and Tunong Krueng Kala, and to small enterprises inside these village areas.

2. Research Methods

Research: This electricity-generating plant produced from hydropower is located in Suhom, Gampong Krueng Kala, Lhoong District, Aceh Besar Regency, and has been built since 2014. The Krueng Kala River area covers an area of 20.80 km2. The engine capacity is 40 kW, the power produced is 23 kW, and the energy produced can supply electricity to three villages around the power plant. The three settlements are Meunasah Krueng Kala, Baroeh Krueng Kala, and Tunong Krueng Kala [8].

The data collection method in this research was obtained from related agencies and taken directly from the relevant places. In this research, the data used is secondary. Secondary data is supporting data taken from affiliated agencies, which supports the calculations carried out.

1. Map of Aceh Province: This map was obtained through the Aceh Transportation Service (2022).
2. Map of Aceh Besar Regency.
3. Map of the Krueng Kala Watershed: This map of the Krueng Kala Watershed was obtained from the Sumatra River Regional Office-I (2023).
4. Longitudinal Crop Image of the Krueng Kala Watershed: This image was obtained from the Sumatra River Regional Office-I (2023).
5. Rainfall data: The rainfall data included in this study is derived from secondary sources, namely monthly maximum rainfall data (2016–2022) obtained from the Meteorology, Climatology, and Geophysics Agency, Indrapuri.
6. Hydrological Data: The required hydrological data for this research is the river flow discharge data, specifically the Krueng Kala discharge data.

The flow rate significantly influences PLTMH planning. Hydroelectric purposes utilize a flow rate of 85%. However, this figure can still change depending on the planning objectives. If the MHP serves as the primary electricity source for local residents, then increasing the discharge percentage to at least 85%–90% is necessary. Reducing the discharge percentage when the MHP provides electricity support (potential power is sold commercially) and other electricity sources can result in a more significant discharge, increasing sales profits [9].

The Pearson Log Method III for Rainfall Calculation

1. Compile rainfall data (Ri) from the most significant to the most considerable value. Lowest price.
2. Convert the number of N rainfall data points into logarithmic form.
3. Calculate the average price of the quantity.
4. Calculate the magnitude of the average deviation price from the logarithmic quantity.
5. Based on the Cs value obtained and the specified return period price (T), you can determine the Kx value using Pearson Log Table III.
6. Calculate the logarithmic value of each rainfall data point for a specific return period T.

We estimate the maximum daily rainfall for the return period T (year).

Flow Rate Calculation with F.J.Mock

The F.J. method is commonly used in this research to calculate reliable discharge and estimates of discharge availability. Mock to calculate the mainstay discharge capacity.

1. Discharge Analysis
   The MHP planning location is on a natural river where the required discharge data is unavailable, so it is necessary to carry out a discharge simulation analysis using the F.J. method. Mock to get river discharge data.

F.J.'s method, in principle, is based on the basic concept of hydrology, "water balance." This concept is based on the circulation of water on the Earth, or the hydrological cycle, where rain that falls on the surface of the Earth, in this case, the catchment area, will partly be lost as evapotranspiration and partially become direct runoff. In this calculation, the simulated cycle is an event over a monthly period. The following are the steps taken in the F.J. Water Balance calculation method. Mock

2. Calculate the water balance.
   This mock method takes into account data on rainfall, evapotranspiration, and hydrological characteristics of the river drainage area. The results of this modeling can be trusted if there is an observed discharge as a comparison. A more careful approach to hydrological parameters is necessary to ensure the simulation results can be accepted with moderate accuracy and used for further analysis. In this case, no observed discharge in the natural river is being studied for comparison.

3. Runoff
   Rainwater runoff or precipitation will take paths leading to rivers. Some will flow as surface runoff and enter the ground, then flow to the left and right to form an intermediate flow. Others will percolate deep into the soil until they reach the groundwater layer. Direct runoff often combines ground surface flow and intermediate flow to obtain runoff.

4. Mainstay Debt Analysis
   A reliable debit is sought based on the probability of each excessive discharge occurring.
   We calculate electrical power after obtaining flow discharge values from hydrological analysis on the Krueng Kala River and determining the effective waterfall height and overall PLTMH efficiency. Following are the steps in calculating electrical power.
   1. First, calculate the energy loss in the penstock by multiplying the energy loss value by the fall height value.
   2. Subtract the fall height value from the energy loss value in the penstock to calculate the practical plunge height value.
   3. Once we know the practical plunge height value, we can calculate the generated power using the calculation formula.

3. Results and Discussion

The utilized rainfall data consists of the highest monthly precipitation recorded annually at the rain gauge site. The most increased monthly precipitation recorded during six years, specifically from 2017 to 2022. We manually perform the calculations for maximum monthly rainfall. The aim of calculating maximum rainfall is to obtain the full rainwater discharge, which will later be used to calculate the monthly planned rainfall.
This calculation determines the frequency distribution. The values of Cs, Ck, CV standard deviation, and X average will be considered when calculating the basic statistical parameters.

Table 1. Average Calculation Results

No.	Year	Ri (Maximum Rainfall)	Ri-Average	$(Ri-Average)^2$	$(Ri-Average)^3$	$(Ri-Average)^4$
1	2016	1014,0	354,167	125434,028	44424551,505	15733695325
2	2017	501,0	-158,833	25228,028	-4007051,745	63645338,6
3	2018	531,0	-128,833	16598,028	-2138379,245	275494526,1
4	2019	488,0	-171,833	29526,694	-5073670,329	871825684,8
5	2020	739,0	79,167	6267,361	496166,088	39279815,3
6	2021	686,0	26,167	684,694	17916,171	468806,4823
∑		3959,000	0,000	203738,833	33719532,444	17557217543
XAverage		659,833		33956,472	-2141003,812	364704443,7

From the results of the calculation of the rainfall frequency analysis, the next step is to compare them with the values of the distribution type requirements. And here is a table for the comparison of distribution terms.

Table 2. Comparison Table of Distribution Terms

No	Distribution Type	Condition	The Calculation Results	Information
1	Normal	$Cs \approx 0,00$	$1,22 > 0,00$	Does not fulfill
		$Ck \approx 3,00$	$6,34 > 3,00$	Does not fulfill
2	Normal Logs	$Cs \approx 3\ Cv + Cv^3 = 1,12$	$0,94 > 1,12$	Does not fulfill
		$Ck \approx Cv^3 + 6\ Cv^5 + 15\ Cv^4 + 16\ Cv^2 + 3 = 5,33$	$4,62 < 5,33$	Does not fulfill
4	Pearson Log III	$Cs \neq 0,00$	$1,22 \neq 0,00$	Fulfil

5	Gumbel	Cs ≤ 1,14	1,22 > 1,114	Does not fulfill
		Ck ≥ 5,40	6,34 > 5,40	

According to the table provided, it is clear that the statistical characteristics of the data do not match with normal, log normal, and Gumbel distributions. This suggests that the data in question follows the log Pearson III distribution.

The Log Pearson type III distribution is the most suitable frequency distribution based on the computation of fundamental statistical parameters. Based on this computation, artificial rainfall will be produced throughout the selected time frame. The calculation employs the Log Pearson III methodology, utilizing the maximum rainfall data (Xi) to get the mean logarithm.

Table 3. Pearson Log Method III Calculations

No.	Xi (mm)	Log Xi	$(\text{Log X - Long Xrt})^2$	$(\text{Log X - Long Xrt})^3$
1	1014,0	3,006	0,040795	0,00824
2	501,0	2,700	0,010862	-0,00113
3	531,0	2,725	0,006236	-0,00049
4	488,0	2,688	0,013373	-0,00155
5	739,0	2,869	0,004171	0,00027
6	686,0	2,836	0,001041	0,00003
Amount		16,824	0,076	0,005
Log X average			2,804	
S log x			0,124	
Cs			1,183	

Computation of the highest amount of precipitation Personnel classified as Log-type III. The outcomes of the design rainfall computation utilizing the Log Pearson III technique for recurrence intervals of 2, 5, 10, and 25 years are as follows:

Table 4. Maximum Rainfall Calculation (Log Pearson Type III)

No.	Return Period	Log Xrt	Kt	S log x	log Xt	X.T.
1	2	2,80	-0,19	0,12	2,78	602,93
2	5	2,80	0,73	0,12	2,89	784,99
3	10	2,80	1,34	0,12	2,97	932,79
4	25	2,80	2,08	0,12	3,06	1152,68

Based on Table 4, the amount of rain discharge in the return period (T) can be seen. This table shows that the highest rain discharge occurred in the 25-year return period, reaching 1152.68 mm/hour, and the lowest occurred in the 2-year return period, namely 602.93 mm/hour.

Potential evapotranspiration refers to the collective process of water vaporization and plant transpiration on Earth's surface. The plants emit the water into the sky. Based on this reasoning, it can be inferred that potential evapotranspiration refers to the amount of energy an area receives from the sun. Moreover, transpiration is closely linked to the quantity of carbon assimilated by the plant zone, as it enables the movement of CO_2 from the atmosphere to the leaves. Before determining potential evapotranspiration, gathering specific supplementary data, including temperature, humidity, wind speed, and solar radiation data, is necessary.

After obtaining climatological data, we calculate potential evapotranspiration using the modified Penman method by utilizing this data. For more details, see Table 5.

Table 5. Calculation Results of Potential Evapotranspiration

No	Month	mm/day	mm/month
1	2	3	4
1	January	5,737	177,851
2	February	6,137	177,966
3	March	6,649	206,120
4	April	5,796	173,887
5	May	6,179	191,537
6	June	6,432	192,974
7	July	6,094	188,927
8	August	6,463	200,354

9	September	6,710	201,287
10	October	6,513	201,901
11	November	6,098	182,950
12	December	6,261	194,103

Estimating the magnitude of the mainstay discharge using the mock method involves utilizing a rainfall runoff simulation method for each catchment, soil moisture, climate conditions, and local land use vegetation. The mainstay discharge value is obtained by multiplying the river flow by the watershed area of 20.80 km2. Table 6 below shows the amount of mainstay debit.

Table 6. Results of River Mainstay Discharge Calculations

No	Year	Mainstay Discharge (m3/sec)												Max	Min
		Month													
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1	2017	0,55	0,44	0,37	0,35	0,45	0,43	0,35	0,72	0,41	0,70	0,53	0,32	0,72	0,35
2	2018	0,74	0,52	0,36	0,36	0,50	0,26	0,26	0,24	0,35	0,22	0,37	0,18	0,74	0,22
3	2019	0,52	0,48	0,37	0,42	0,33	0,29	0,44	0,44	0,19	0,31	0,23	0,23	0,52	0,19
4	2020	0,51	0,49	0,51	0,44	0,24	0,31	0,24	0,27	0,23	0,37	0,23	0,21	0,51	0,23
5	2021	0,54	0,47	0,45	0,44	0,64	0,30	0,40	0,30	0,41	0,39	0,28	0,21	0,64	0,28
6	2022	0,55	0,46	0,54	0,40	0,37	0,47	0,56	0,44	0,44	0,27	0,31	0,15	0,56	0,27
Qa m3/sec		3,42	2,85	2,59	2,42	2,54	2,06	2,24	2,40	2,03	2,27	1,96	1,30		

Table 6 shows the amount of mainstay debit obtained each month. This discharge will later meet the river's needs for the Micro Hydropower plant in Lhoong District, Aceh Besar Regency. From the mainstay debit calculation results, the following result is the mainstay debit with a probability of 85%.

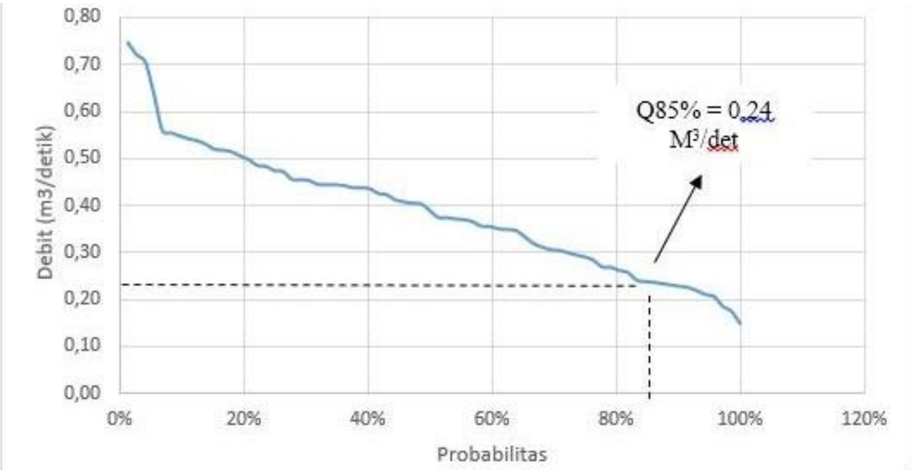

Figure 1. Mainstay Debit Graph

You can see the large amount of mainstay debt in Lhoong District. The primary discharge used for central electricity generation is 85–90%, which means that from the many river flow events throughout the year, the discharge must be 85–90%, which will be used as energy for generating electricity. Based on the data, we determine the desired probability discharge amount. The mainstay discharge with a probability of 85% is chosen namely Q85% = 0.24 m3/sec.

To determine the effective fall height, it is necessary first to calculate the amount of energy loss.

Table 7. Recapitulation of Technical Data and Calculations

Parameter	Notation	Mark	Unit
Debit	Q	0,24	M3/sec
Gross Fall Height	H gross	13,63	M
Long pipe	L	50	M
Diameter	D	1524	Mm
Thick	ẟ	7,29	Mm
Flow Speed	v	0,131	m/sec
Construction Type	-	Steel pipe	-

Connection Type	-	Weld	-

1. Primary energy losses, referred to as substantial losses, result from friction within the pipe, leading to energy dissipation.
   The presence of friction within the pipe results in the dissipation of energy.
   The data that is known to calculate the amount of energy loss due to friction along the penstock is as follows:
   Pipe material: welded steel
   Pipe length (L) = 50 m
   Net pipe diameter (D) = 1.524 m
   Flow speed = 0.131 m/sec
   Meanwhile, one parameter that is not yet known is the friction factor (f). The Moody Diagram determines the value of the friction factor. First, calculate the Reynolds number and the relative roughness number.
   Re = 1897775.66
   R = 0.0003
   Hf = 0.000430
2. Energy loss due to pipe entry
   The planned type of entry for rapid pipe entry is smooth entry. The known data required to calculate the amount of energy loss at the entry of the rapid pipe is as follows:
   Input type: fine
   Flow velocity (v) =1.566
   He = 0.00043 m
3. Energy loss due to output
   Energy loss due to the output or outlet of the penstock pipe.
   Ho = 0.00087 m
4. Total Energy Loss (Hgross)
   Based on the calculations in 1 to 3, we can conclude the total energy loss from the upstream of the rapid pipe to the pipe outlet as follows:
   Hlosses = 0.00173 m
   From the results of these calculations, the amount of energy loss that occurs is 0.000173, which is still less than the maximum energy loss, namely 0.00173. So, the calculation is acceptable. The obtained effective fall height is:
   Net H = 13.628 m.
   So, based on the data from the calculations and analyses that have been carried out, the amount of power capacity and energy produced can be calculated, namely as follows:
   Power generated
   P = 27.914 kW
   The annual energy production is:
   E = 20787.644 kWh.

The analysis found that the energy produced during the year was 20787.644 kWh.

Table 8. Classification of Hydro Power Plants

No	Type	Power / Capacity
1	PLTA	> 5 M.W. (5000 kW)
2	PLTM	100 kW - 5000 kW
3	PLTMH	0 - 100 kW

The classification of types of power plants based on their power and capacity may be observed in Table 8. Based on the analysis of Krueng Kala in Lhoong District, Aceh Besar Regency, the power generated is 27,914 kW, below 100 kW. Therefore, Krueng Kala is categorized as a micro hydropower plant. Additionally, the total energy produced throughout the year amounts to 20,787,644 kWh. The power can be directed towards three villages: Meunasah Krueng Kala, Baroeh Krueng Kala, Tunong Krueng Kala, and small enterprises.

4. Conclusion

After conducting a thorough analysis and discussion in this study, numerous conclusions can be drawn: By utilizing the Fj. Using a mock approach and analyzing evapotranspiration and rainfall data for the Krueng Kala Watershed in Lhoong District, Aceh Besar Regency, a dependable discharge of Q (85%) is derived. The consistent flow rate of Q (85%) is 0.24 m3/second. The power plant can harness the energy from a vertical drop of 13.63 meters. Based on the data collected, the power output of the Krueng Kala power plant was 27,914 kW, assuming an 85% discharge. Therefore, according to the results of the analysis, the Krueng Kala power plant is still categorized as a PLTMH (small-scale hydroelectric power plant), as its power production is below 100 kW. The investigation findings reveal that the power plant generates an annual energy production of 20787.644 kilowatt-hours (kWh). The energy can be directed towards supplying power to three specific villages: Meunasah Krueng Kala Village, Baroeh Krueng Kala Village, and Tunong Krueng Kala Village. It can also be utilized by small enterprises operating inside these village regions.

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