Integration of Hydrology and Topography in Mini Hidro Energy Potential Estimation

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Abstract

The increasing demand for renewable energy sources is driven by population growth, rising national energy consumption, and government commitments to reducing carbon emissions. Mini hydro power plants (MHPPs) represent an environmentally friendly renewable energy solution with significant development potential, particularly in regions with sustainable river flows. This study aims to analyze the potential of the Padee River in Tenguwe Village, West Kalimantan, as a source of hydroelectric energy for MHPP development through a technical approach that includes hydrological, hydraulic, topographic, and system efficiency aspects. The analysis includes dependable flow estimation based on climatic data and watershed characteristics. Results show that the Padee River provides a sufficient and reliable discharge with stable year-round flow conditions and optimal site topography to support the construction of mini-hydro power infrastructure. The results show that the site has enough water flow to be used for generating renewable energy. This study serves as a reference for early-stage site selection and technical planning in similar river-based MHPP developments.

Keywords: Mini-Hydro Power Plant, Hydrological Potential, Dependable Flow, Padee River, Renewable Energy, Site Feasibility

1. INTRODUCTION

Water resources are essential for development across multiple sectors, including energy supply (1). One strategic use of water is for hydropower plants, which takes advantage of the energy from flowing water to produce electricity (2). On a smaller scale, Mini Hydro Power Plants (MHPPs) are a practical and renewable energy solution, especially in areas where access to electricity is still limited (3).

Indonesia has a large potential for hydropower, with a total technical capacity of more than 94 GW, although only a small part of it has been utilized so far (4). This situation highlights the need to develop small-scale power plants like MHPPs. The Padee River in Tenguwe Village is one of the potential sites, with flow and topographic conditions that are suitable for a run-of-river system. This study aims to analyze the hydrological and technical feasibility of developing an MHPP on the Padee River by estimating the dependable flow and the potential electrical output.

1.1. Concept of Mini-Hydro Power Plants

The basic working principle of a Mini Hydro Power Plant (MHPP) is to convert the potential energy of water into mechanical energy through a turbine, which is then transformed into electrical energy (5). The process begins by diverting river water into a penstock, where it flows downward following a specific elevation drop (head). As the water descends, its potential energy increases due to the height difference. This energy is then converted into kinetic energy as the water accelerates through the penstock toward the turbine. The force of the high-speed water flow rotates the turbine, generating mechanical motion that is subsequently converted into electricity (6).

Most Mini Hydro Power Plant (MHPP) systems adopt a run-of-river design, which utilizes the natural flow of a river without the need for large-scale water storage or dam structures. This approach is considered efficient and environmentally sustainable, as it minimizes disruption to the river ecosystem and can operate continuously in regions where river discharge remains relatively stable throughout the year (7).

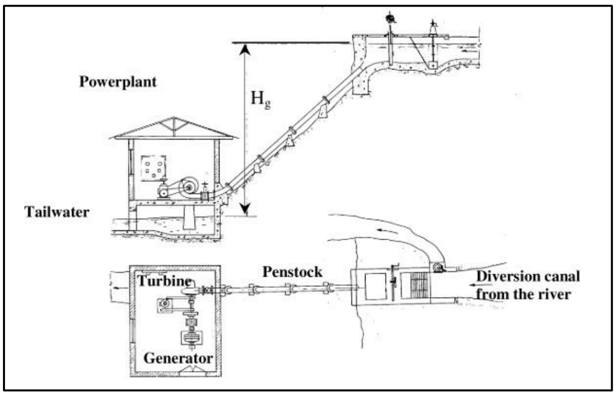


Figure 1. Mini Hydro Power Plant Scheme (7)

1.2. Dependable Flow

Dependable flow refers to the minimum river discharge expected to be available at a certain probability level, typically 80% or 90% of the time. Ideally, this flow is determined using long-term observed streamflow data. However, in cases where such data is unavailable, river discharge can be estimated using hydrological simulation methods. One widely used approach is the F.J. Mock method, which calculates water balance based on rainfall, evapotranspiration, and watershed characteristics (13).

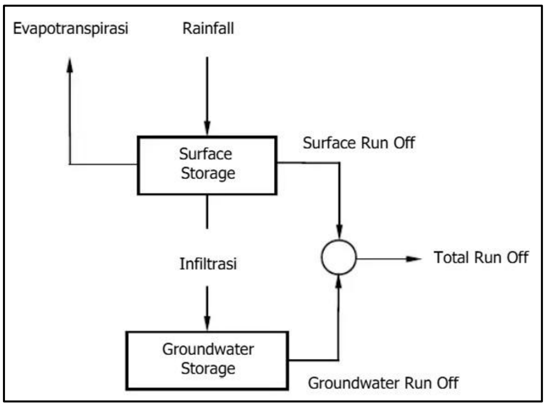


Figure 2. Rainfall-Runoff Model (13)

The dependable flow generated from the F.J. Mock simulation can be presented as a Flow Duration Curve (FDC), which illustrates the percentage of time a specific discharge is equaled or exceeded within a one-year period. The FDC serves as a fundamental reference in determining turbine capacity, as it reflects the consistency and reliability of river flow over time (8).

1.3. Head

The water head refers to the elevation difference between the highest and lowest points of the water flow utilized to drive the turbine. This parameter plays a critical role in determining the amount of potential energy available for conversion. A higher head value corresponds to greater potential energy, which can be more effectively transformed into mechanical and electrical energy (7).

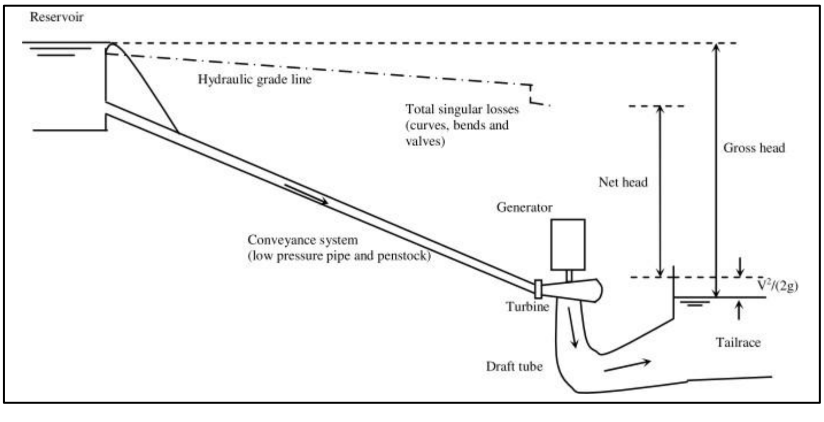


Figure 3. Head Scheme (7)

In head calculations, it is essential to account for energy losses (headloss) caused by friction, constrictions, and flow obstructions along the channel (11). According to Bernoulli's principle, the total energy of the flow remains constant; however, it can decrease due to frictional forces and changes in flow geometry. These energy losses are generally categorized into two types: friction losses that occur along the length of the conduit, and minor losses resulting from flow direction changes, bends, or contractions (10).

$$h_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g} \quad \text{................................ (1)}$$

$$h_m = K \cdot \frac{v^2}{2g} \quad \text{................................ (2)}$$

$$h_{\text{loss}} = h_f + \sum h_m \quad \text{................................ (3)}$$

Where:

h_f = Major head loss (m);
h_m = Minor head loss (m);
h_{loss} = Total head loss (m);
L = Length of the pipe (m);
v = Flow velocity (m/s);
g = Acceleration due to gravity (m/s^2);
f = Darcy–Weisbach friction factor (dimensionless);
K = Minor loss coefficient (dimensionless);
D = Diameter of the pipe (m).

The net head is calculated using the following equation

$$Hnet = Hgross - hloss \quad \text{................................ (4)}$$

Where:

Hnet = Net head (m), the effective height available for power plants;
Hgross = Gross head (m);
Hloss = Total head loss (m).

1.4. Power Generation Estimation

The performance of a hydro power plant is determined by the annual electrical energy output, which depends on the flow discharge, net head, and overall system efficiency. It can be expressed using the following equation (12):

$$P = \rho_{water}\ x\ g\ x\ H_{net} x\ Q\ x\ \eta \quad \text{................................ (5)}$$

Where:

P = Power output (Watt)
η = Overall system efficiency (turbine, generator, transmission)
ρ = Density of water (typically 1000 kg/m^3)
g = Acceleration due to gravity (9.81 m/s^2)
Q = Average flow rate (m^3/s)
Hnet = Net head (m)

According to the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 12 of 2017, hydro power plants with an installed capacity of up to 10 MW are required to maintain a minimum capacity factor of 65%. For plants with capacities exceeding 10 MW, the capacity factor is determined based on the requirements of the electricity system. The regulation also provides the formula for calculating the capacity factor of a Mini Hydro Power Plant (MHPP), which is expressed as follows:

$$Capacity\ Factor(\%) = \frac{Annual\ Average\ Energy}{(365\ Day)x(24\ Hour)x(Power)} \quad \text{................................ (6)}$$

2. METHOD

This study aims to analyze the potential of the Padee River for the development of a Mini Hydro Power Plant (MHPP). A quantitative approach with descriptive-analytical methods was employed to assess the feasibility of MHPP development along the river. The methodology includes the analysis of climatological and hydrological data based on rainfall records and watershed characteristics, which were processed to estimate the dependable flow. In addition, a topographic contour model was developed using elevation data to determine the effective head (net head) for power plants.

2.1. Research Object

The object of this study is the Padee River, located in Tenguwe Village, Landak Regency, West Kalimantan. This river was selected based on its hydrological and topographical characteristics, which indicate significant potential for utilization as an energy source in a Mini Hydro Power Plant (MHPP) system. The research focuses on the analysis of dependable flow as the basis for estimating potential electrical energy output, as well as the calculation of the net head, which is a key factor in determining the plant's power capacity. The aim of this study is to assess the development potential of the Padee River for MHPP implementation as a renewable energy solution in villages areas.

Figure 4. Research Object

2.2. Research Stage

This research was conducted through a series of systematic stages. The initial stage involved the collection of rainfall data, land use information, topographic data, and technical specifications of the power plants system. These datasets were analyzed using hydrological methods, including the Mock method, to estimate the dependable flow, which reflects year-round water availability.

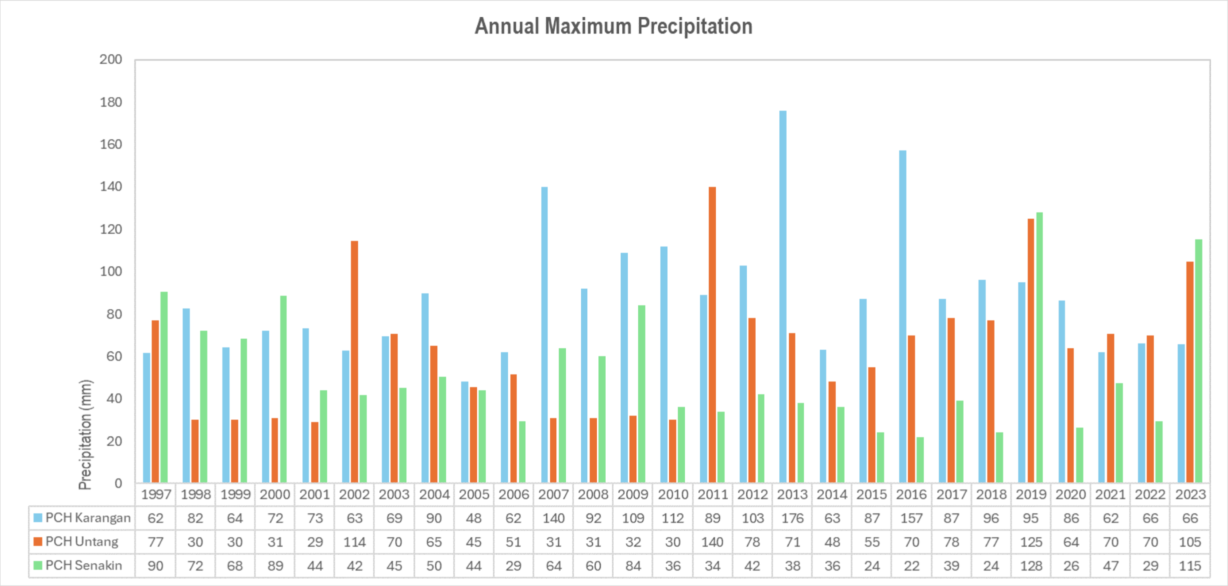
Topographic analysis was then carried out to determine the effective head (net head), taking into account energy losses along the flow path. Based on the calculated flow and head, the potential electrical power output was estimated, along with the projected annual capacity factor. The final stage involved evaluating the technical feasibility of the proposed MHPP system, which serves as the foundation for considering renewable energy development in the study area.

2.3. Data Inventory

The hydrological and climatological data used in this study were obtained through a combination of ground-based observations and satellite-derived datasets. Surface data were collected from the nearest rainfall and streamflow monitoring stations, while satellite data were sourced from the Modern-Era Retrospective Analysis for Research and Applications (MERRA), which provides global climate variables such as precipitation, temperature, humidity, and evapotranspiration. The use of MERRA data aimed to supplement the limited field observations and enhance the accuracy of dependable flow analysis and water balance calculations within the watershed.

Table 1. Location Rainfall Station

Rainfall Station	Coordinate	Available Data
Karangan	0 33' 30" LU-109 22' 34" BT	27 Year
Untang	0 42' 49" LU-109 30' 31" BT	27 Year
Senakin	0 22' 22" LU-109 34' 02" BT	27 Year



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
PCH Karangan	62	82	64	72	73	63	69	90	48	62	140	92	109	112	89	103	176	63	87	157	87	96	95	86	62	66	66
PCH Untang	77	30	30	31	29	114	70	65	45	51	31	31	32	30	140	78	71	48	55	70	78	77	125	64	70	70	105
PCH Senakin	90	72	68	89	44	42	45	50	44	29	64	60	84	36	34	42	38	36	24	22	39	24	128	26	47	29	115

Figure 5. Hydrological Data from Rainfall Stations

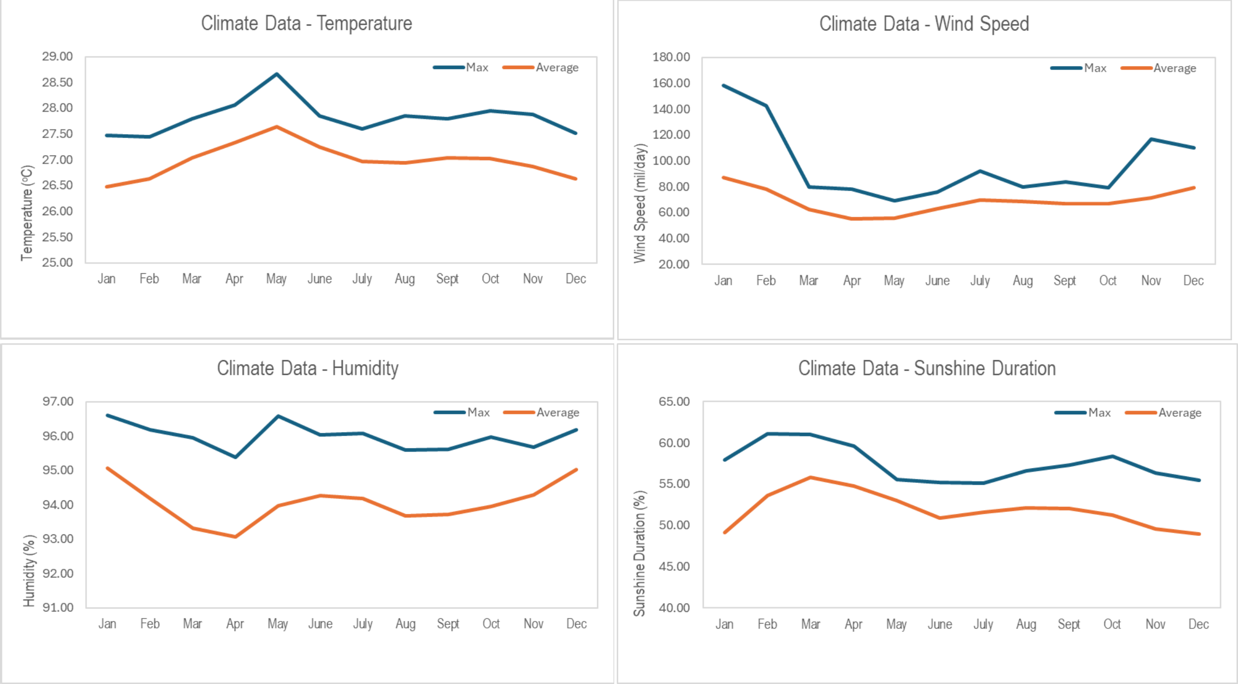


Figure 6. Climate Data

3. RESULTS AND DISCUSSION

3.1. Dependable Flow Analysis

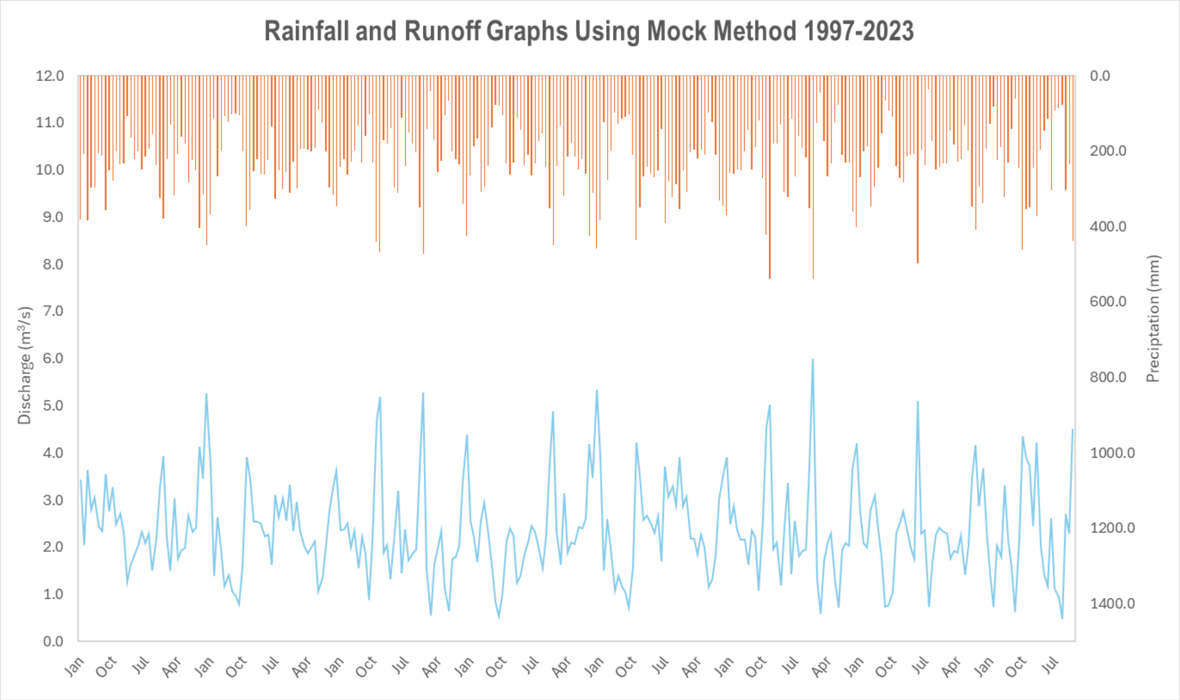
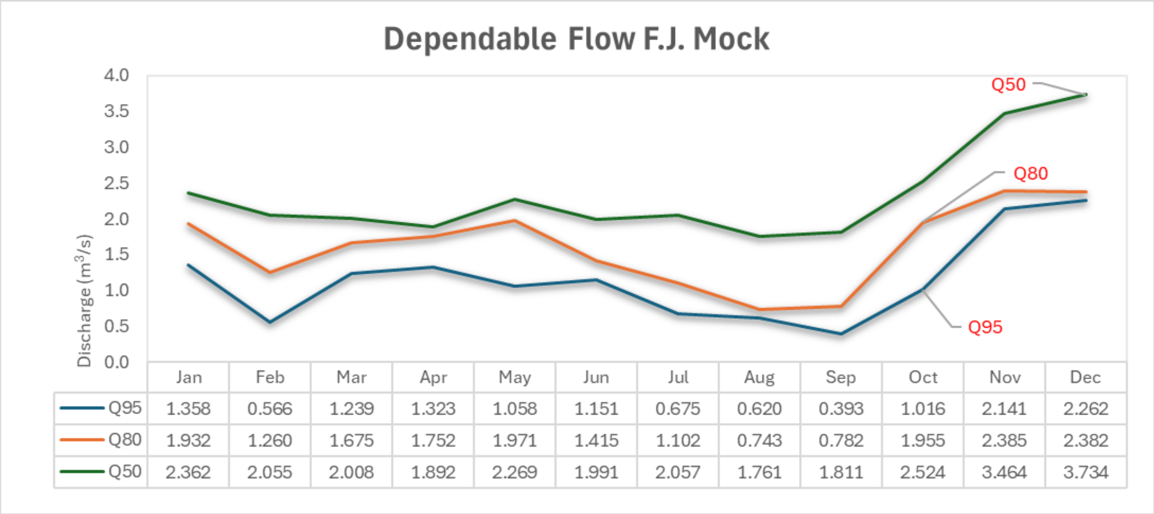


Figure 7. Simulation of F.J Mock Dependable Flow vs Rainfall

The river flow shows a clear seasonal pattern, where peak discharge usually follows periods of heavy rainfall. However, the time between rainfall and peak flow varies, suggesting that certain processes, like soil storage and infiltration, are influencing how water moves through the watershed.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q95	1.358	0.566	1.239	1.323	1.058	1.151	0.675	0.620	0.393	1.016	2.141	2.262
Q80	1.932	1.260	1.675	1.752	1.971	1.415	1.102	0.743	0.782	1.955	2.385	2.382
Q50	2.362	2.055	2.008	1.892	2.269	1.991	2.057	1.761	1.811	2.524	3.464	3.734

Figure 8. Results of F.J. Mock's Reliable Discharge Modeling

The analysis results show that Q50 discharge, which represents the average annual flow, reaches its highest value in December and its lowest in September. Q80, the dependable minimum flow available 80% of the year, displays a fluctuating trend-lower during the dry season (August–September) and higher during the rainy season (November–December). Meanwhile, Q95 reflects the extreme minimum flow conditions and represents the lowest possible discharge throughout the year. Among these, Q80 is considered the most appropriate basis for MHPP system design, as it offers a balance between water supply reliability and power generation efficiency. It is a conservative yet practical choice to ensure continuous plant operation throughout the year.

3.2. Flow Duration Curve

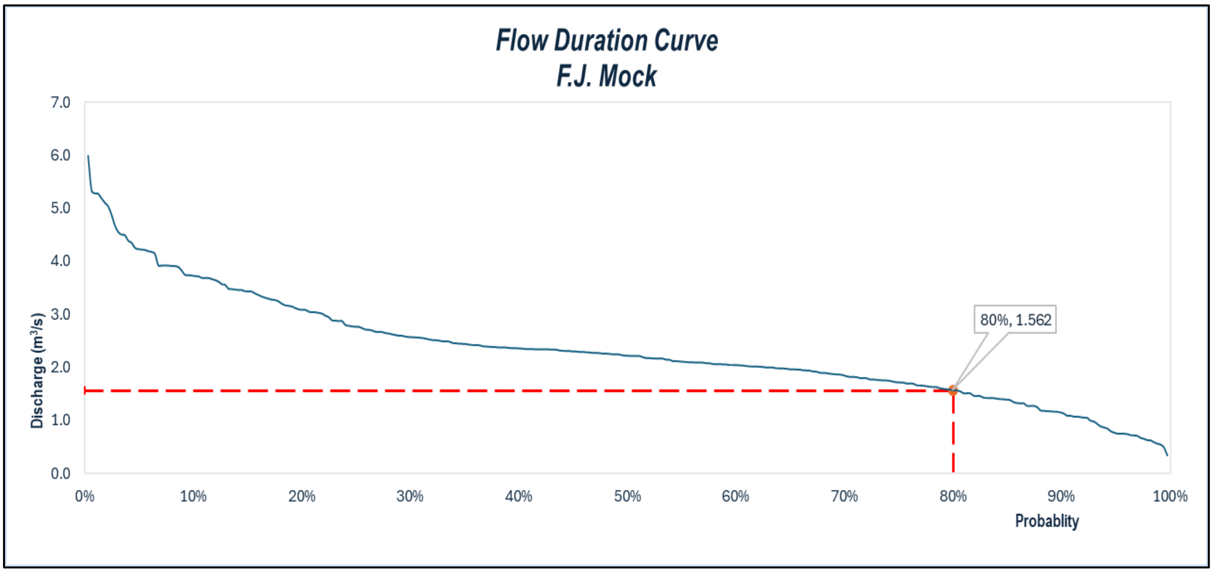


Figure 9. Flow Duartion Curve

The Flow Duration Curve (FDC) generated from the Mock Method simulation illustrates the distribution of streamflow based on its frequency of occurrence during the 1997–2023 period. The graph indicates that high flows (>4 m³/s) occurred in less than 10% of the time, while moderate flows (2–3 m³/s) dominated 30% to 60% of the observed period. Low flows (<1.5 m³/s) appeared 20% to nearly 100% of the time, reflecting typical dry season conditions.

The Q80 discharge, recorded at 1.562 m³/s and marked on the graph, was selected as the dependable flow since it is available 80% of the time throughout the year. This value is considered ideal for Micro Hydro Power Plant (MHPP) planning, as it ensures continuous operation, reliable water supply, and efficient energy generation year-round.

3.3. Net Head

The calculation of energy loss (headloss) in this study focuses only on the primary components that significantly affect the net head within the penstock system. Based on the system configuration and site conditions, the headloss estimation is limited to major elements that contribute substantially to the reduction of fluid energy. The results of the headloss analysis are presented as follows:

Table 2. Headloss

No	Remark	Elevation
A	Forebay	122.46 m
B	PowerHouse	106.65 m
C	Head Static Gross	15.81 m
D	Headloss	
	1 Losses due to flow friction in pipes $H_{friction}$	0.299 m
	2 Head loss due to flow friction through Trashrack H_{tr}	0.049 m
	3 Head loss at intake/ Entrance Losses H_c	0.008 m
	4 Head loss at penstock bend H_b	0.207 m
	5 Head loss in penstock valve H_v	0.126 m
	6 Head loss at the branch H_{br}	0.050 m
	7 Headloss at the Nozzle H_{nz}	2.115 m
	Total Headloss	2.854 m
Head Static Nett		**12.956 m**

The gross static head is determined from the elevation difference between the forebay and the powerhouse, which is 15.81 meters (122.46 m – 106.65 m). After accounting for the total headloss, the resulting net static head is 12.956 meters. This net head value is used as the basis for power generation calculations.

3.4. Potential Power Generation

The net power output is obtained by multiplying the theoretical power by the overall system efficiency, which combines both turbine and generator efficiencies. The electrical power generated by each turbine is calculated using Equation (5), which accounts for energy losses during the conversion process from water potential energy to electrical energy, as shown below:

Table 3. Calculation of Total Power and Energy

Dependable Flow	Design Flow Rate	Flow Rate per Turbine		Residual Flow	Install Capacity			Annual Energy Production	
		Turbine 1	Turbine 2		Turbin 1	Turbin 2	Total	Turbin 1	Turbin 2
%	m^3/s	m^3/s	m^3/s	m^3/s	kW	kW	kW	kWh	kWh
5%	4.23	0.78	0.78	2.66	84.36	84.36	168.72	36948.71	36948.71
10%	3.72	0.78	0.78	2.16	84.36	84.36	168.72	36948.71	36948.71
15%	3.43	0.78	0.78	1.87	84.36	84.36	168.72	36948.71	36948.71
20%	3.08	0.78	0.78	1.52	84.36	84.36	168.72	36948.71	36948.71
25%	2.76	0.78	0.78	1.20	84.36	84.36	168.72	36948.71	36948.71
30%	2.57	0.78	0.78	1.00	84.36	84.36	168.72	36948.71	36948.71
35%	2.44	0.78	0.78	0.88	84.36	84.36	168.72	36948.71	36948.71
40%	2.35	0.78	0.78	0.79	84.36	84.36	168.72	36948.71	36948.71
45%	2.29	0.78	0.78	0.73	84.36	84.36	168.72	36948.71	36948.71
50%	2.21	0.78	0.78	0.65	84.36	84.36	168.72	36948.71	36948.71
55%	2.10	0.78	0.78	0.54	84.36	84.36	168.72	36948.71	36948.71
60%	2.04	0.78	0.78	0.48	84.36	84.36	168.72	36948.71	36948.71
65%	1.96	0.78	0.78	0.40	84.36	84.36	168.72	36948.71	36948.71
70%	1.84	0.78	0.78	0.28	84.36	84.36	168.72	36948.71	36948.71
75%	1.71	0.78	0.78	0.15	84.36	84.36	168.72	36948.71	36948.71
80%	1.56	0.78	0.78	0.00	84.36	84.36	168.72	36948.71	36948.71
85%	1.38	0.78	0.60	0.00	84.36	65.10	149.46	36948.71	28514.57
90%	1.14	0.78	0.35	0.00	84.36	38.30	122.66	36948.71	16775.23
95%	0.75	0.31	0.31	0.13	33.74	33.74	67.49	14779.48	14779.48
							Total	679856.30	651248.67
					Total/Year		kWh	1331104.97	
							GWh	1.33	
					Capacity Factor			**90.1%**	

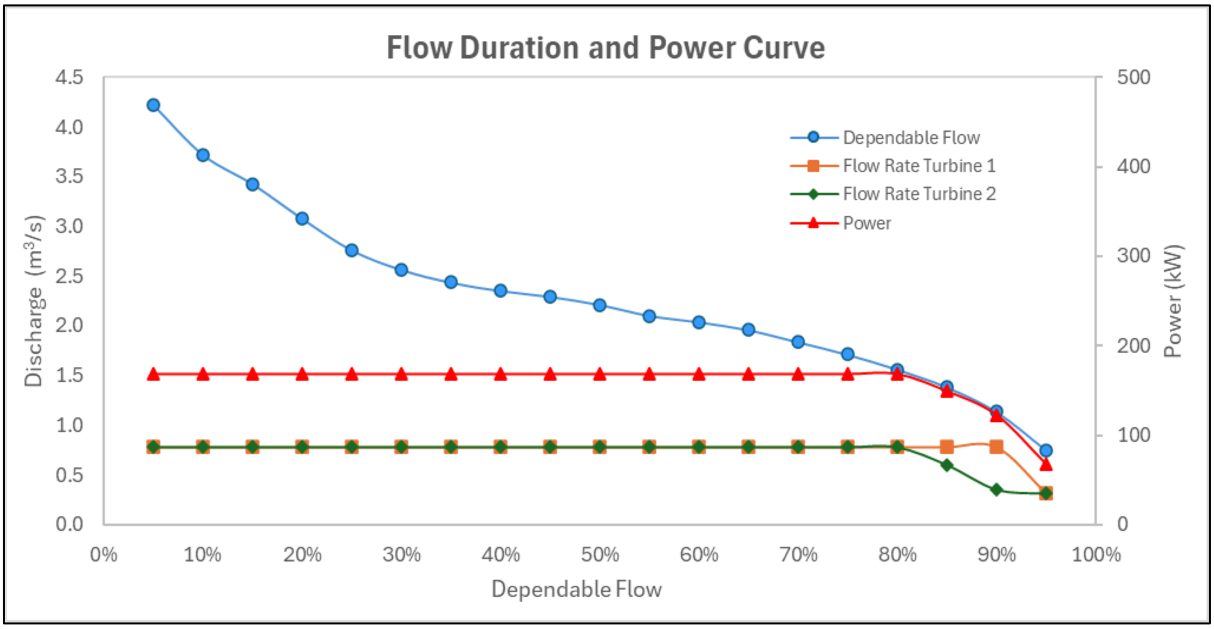


Figure 10. Graphic Flow Rate and Power Based on Probability

Based on the calculation results, a capacity factor of 90.06% was obtained, indicating that the power plant is capable of operating consistently near its maximum capacity throughout the year. This value is considered very high, both technically and in terms of regulatory standards. This achievement demonstrates that the MHPP system design has successfully optimized flow utilization and energy conversion efficiency, enabling the system to operate reliably and sustainably.

4. CONCLUSIONS

This study has demonstrated the hydrological and technical feasibility of developing a Micro Hydro Power Plant (MHPP) on the Padee River in Tenguwe Village, West Kalimantan. The following key conclusions highlight the study's main contributions:

1. The application of the F.J. Mock method successfully provided a dependable flow estimate that supports the viability of a run-of-river MHPP system. This confirms that hydrological modeling can be effectively used in regions with limited streamflow observation data to support energy planning.
2. The integration of topographical analysis and hydraulic loss evaluation led to an accurate determination of the net head, which is critical for realistic power output estimation. This approach strengthens design reliability for small-scale hydropower in rural areas.
3. The resulting capacity factor of over 90% and projected annual energy output exceeding 1.3 GWh highlight the strong performance potential of the planned MHPP system. This shows that well-planned micro-hydro systems have the potential to deliver stable, sustainable, and affordable electricity to isolated communities.

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REFERENCES

1. Cech T. Principles of water resources: History, development, management, and policy. New Jersey: John Wiley & Sons; 2005.
2. Bhuiyan MA. Micro hydro power: promising renewable energy for the future—case study in Malaysian context. Energy Procedia. 2011;1081–7.
3. Isa MA, Sudjono P, Sato T, Onda N, Endo I, Takada A, et al. Assessing The Sustainable Development of Micro-Hydro Power Plants in an Isolated Traditional Village West Java, Indonesia. Energies (Basel). 2021 Oct 2;14(20).
4. Sudjarwadi. Pengembangan Sumber Daya Air. 2021.
5. Harrison GP. Micro-Hydro Design and Operation for the Sustainable Development of Rural Communities. Journal of Renewable Energy Development. 2020;789–801.
6. Nasir BA. Design of Micro-Hydro-Electric Power Station [Internet]. International Journal of Engineering and Advanced Technology (IJEAT). 2014. Available from: www.ijeat.org
7. Ramos H, Betâmio De Almeida A, Portela MM, Pires De Almeida H. Title: Guideline for Design of Small Hydropower Plants A. Carvalho Quintela. 2000.
8. Kwakye SO, Bárdossy A. Quantification of the hydrological consequences of climate change in a typical West African catchment using flow duration curves. Journal of Water and Climate Change. 2022 Jan 1;13(1):26–42.
9. Firmansyah R. 1652841737_Perancangan Pembangkit Listrik Tenaga Mikrohidro Gunung Sawur unit 3 Lumajang. 2018;
10. Layman's. A handbook prepared under contract for the Commission of the European Communities, Directorate-General for Energy by European Small Hydropower Association (ESHA). 2004.
11. Nurharyanto RT, Gunawan I. Studi Kelayakan Teknis Potensi Energi Terbarukan Mini Hydro Di Desa Goal Kecamatan Sahu Timur Kabupaten Halmahera Barat. IRA Jurnal Teknik Mesin dan Aplikasinya (IRAJTMA). 2023 Dec 16;2(3):44–54.
12. Paish O. Small hydro power: technology and current status. Renewable and Sustainable Energy Reviews. 2002;6(6):537–56.
13. Mock, F. J. (1973). Climate Data Manual for the Water Balance Model. Water Management Technical Report, United Nations – Economic and Social Commission for Asia and the Pacific (ESCAP