

Solar-Powered Peat Water Treatment Model for Achieving Sustainable Clean Water Independence at Nurul Jadid Islamic Boarding School, Kubu Raya RegencyIka Muthya Anggraini^{1*}, Ivan Andri Gunawan², Shandra Andina Rahsia³^{1,2,3} Study Program of Infrastructure and Environmental Engineering, Faculty of Engineering, Universitas Panca Bhakti Pontianak, IndonesiaEmail: ikamuthya.a@upb.ac.id*, Ivan.andriGunawan@upb.ac.id, Shandra.andina@upb.ac.id*Corresponding Author: ikamuthya.a@upb.ac.id**Abstract**

Nurul Jadid Islamic Boarding School in Kubu Raya Regency is a social educational institution that provides free education for orphans and underprivileged children. Its location within a peatland area presents significant challenges for clean water provision, as the groundwater is acidic, dark in color, rich in organic matter, and bacterially contaminated. Limited electricity access further increases operational costs, highlighting the need for an efficient, economical, and renewable-energy-based treatment system. This study aims to design a solar-powered clean water treatment plant (WTP) tailored to peat water characteristics and to prepare a cost estimation (RAB) for technical and financial planning. A quantitative approach was employed, including water demand analysis, raw water quality testing in accordance with Ministry of Health Regulation No. 2 of 2023, design of treatment units in compliance with SNI 6774:2008, and estimation of investment and operational costs. The findings show that the pesantren's water demand is 1.62 L/s (139,968 L/day). The treated water complied with drinking water standards, with turbidity reduced from 107 NTU to 2.4 NTU, color from 545 TCU to 5.12 TCU, iron concentration from 5.71 mg/L to 0.23 mg/L, and pH increased from 6.2 to 6.86. E. coli and Coliform were completely eliminated (0 CFU/100 mL). From the energy perspective, a 3.2 kWp solar panel system (eight 400 Wp units) generated 9 kWh/day with a 12–15 kWh battery reserve, sufficient to meet the WTP's 1.5 kW demand. The initial investment of IDR 178.1 million and a monthly operational cost of IDR 1.2 million confirm the technical and economic feasibility of sustainably providing clean water at the pesantren.

Keywords: Islamic Boarding School; Clean Water; Peatland; Solar Panel; SDGs**1. Introduction**

Pesantren Nurul Jadid in Kubu Raya Regency faces considerable challenges in ensuring access to clean water. Its location within a peatland area results in groundwater that is acidic, dark in color, and rich in organic matter, rendering it unsuitable for direct use without prior treatment (1-3). The primary water sources currently relied upon are rainwater and wells; however, their availability is limited, particularly during the dry season (4). This situation is further compounded by restricted access to electricity, while the operational costs of conventional power remain relatively high (5).

As a social institution providing free education for orphans and underprivileged children, the pesantren operates under strict financial constraints. Consequently, an efficient and sustainable alternative energy solution is essential. Solar panels represent a promising option, as they reduce reliance on fossil fuels while offering environmental benefits (6-7). Solar-powered water pumping systems have been proven effective, whereby electricity generated by solar cells is stored in batteries and later converted into alternating current (AC) via an inverter to operate the pump (8).

In addition to energy provision, water treatment technologies appropriate for peatland conditions are required. Slow sand filtration has been shown to effectively reduce organic matter content, while solar-powered distillation can further improve water quality (9-10). Nevertheless, implementation of such systems still faces challenges, including high initial investment costs, routine maintenance requirements, and limited human resources. To address these challenges, this study proposes the development of a renewable energy-based clean water supply system specifically designed to adapt to the characteristics of peat water at Pesantren Nurul Jadid. A systematic approach is employed, involving three stages: (i) analysis of water demand and raw water quality compared against Indonesian Ministry of Health Regulation No. 2 of 2023 (11); (ii) design of a solar-powered clean water treatment system with a battery bank to ensure energy availability under cloudy conditions and at night (12-13); and (iii) comprehensive cost estimation that accounts for initial investment, operational expenses, and long-term maintenance to guarantee sustainable operation.

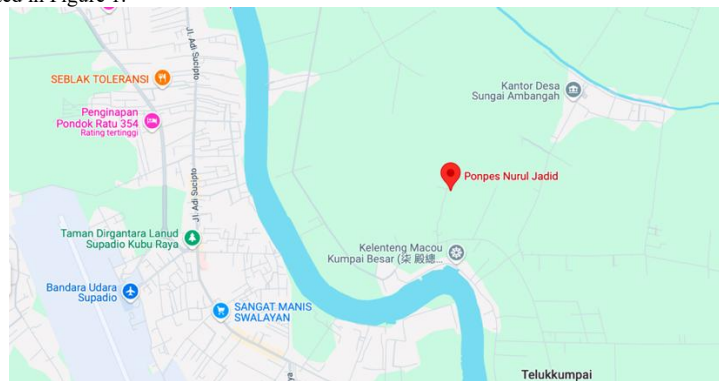
1.1 Research Objectives

This study aims to:

1. Design a renewable energy-based clean water supply system that is adaptive to the specific characteristics of peat water at Pesantren Nurul Jadid.
2. Develop an efficient and realistic cost estimation (RAB) to ensure the sustainability and long-term operability of the proposed system.

2. Method : This study adopted a **quantitative research design** to develop a Clean Water Treatment Plant for Pesantren Nurul Jadid. The design process followed a data-driven approach, referring to national clean water quality standards, particularly the Indonesian Ministry of Health Regulation No. 2 of 2023 on drinking water quality requirements.

2.1 Research Site: The research was carried out at Pesantren Nurul Jadid, located in Sungai Ambangah Village, Sungai Raya District, Kubu Raya Regency. The geographical location of the site is presented in Figure 1.

**Fig 1. Research Site**

2.2 Data Collection: Two types of data were used:

- a) Primary data: water quality parameters (physical, chemical, and biological), water demand estimation, raw water sources, and solar radiation intensity.
- b) Secondary data: technical specifications of treatment units based on SNI 6774:2023, available land area, number of water users, market prices, and geographical as well as climatological data of the region.

2.3 Research Procedure: The methodology comprised four stages:

- i. Water demand analysis – estimation of clean water requirements based on user numbers and projected demand.
- ii. Raw water quality analysis – comparison of raw water parameters with the Indonesian Ministry of Health Regulation No. 2 of 2023 to determine appropriate treatment.
- iii. System design – specification of treatment units (sedimentation, filtration, solar-powered pumping, and disinfection). The design followed SNI 6774:2023 and considered flow rate, raw water quality, land use, and solar integration with battery storage (14).
- iv. Cost estimation (RAB) – preparation of investment, operation, and maintenance costs based on current market prices.

3. Result

3.1 Clean Water Demand Analysis: The water demand at Pondok Pesantren Nurul Jadid was calculated based on the number of users, in accordance with SNI 8153:2015, which pertains to Plumbing Systems in Buildings (15). This standard provides guidelines for determining the daily water consumption per person for various building types, including educational facilities and dormitories. Based on this reference, the total daily demand was estimated at 66,600 liters per day, as

shown in Table 1. Subsequently, the peak demand calculation considered a Peak Hour Factor (PHF) of 1.75 in accordance with the Ministry of Public Works and Housing Regulation No. 27/PRT/M/2016 on the Implementation of Drinking Water Supply Systems (16). This regulation stipulates that fluctuations in water consumption during peak hours must be accounted for by applying a correction factor. Additionally, a water loss factor of 1.2 was applied to account for network leakage, distribution inefficiency, and unmeasured consumption, as mandated by the same regulation. Taking these two factors into account, the average clean water demand at the study site is 1.62 liters per second, equivalent to 139,968 liters per day. This value forms the basis for the design capacity of the clean water treatment system to be developed at Pondok Pesantren Nurul Jadid.

Table 1. Clean Water Demand

No	User Category	Number of Users	Average Consumption (L/person/day)	Water Demand (L/day))	Demand	Average Consumption (L/person/day)
1	Students	513	120	61560	-	-
2	Teachers	40	120	4800	-	-
3	Kitchen Staff	2	120	240	-	-
	Total			66600		66.60 m ³ /day
4	Water Loss (20%)	-		-		79.92 m ³ /day
5	Peak Hour Demand	-		-		139.86 m ³ /day
6	Average Demand	-		-		1.62 L/s (5,827.5 L/hr)

3.2 Clean Water Treatment Planning Based on Solar Irradiance and Raw Water Quality: Pondok Pesantren Nurul Jadid relies on peat water from open channels as the primary source for bathing, washing, and sanitation (MCK). The direct use of untreated peat water not only creates aesthetic issues such as odor and discoloration but also poses serious health risks, including waterborne diseases. The limited access to clean water and adequate sanitation reflects the substantial challenges faced by the pesantren in fostering a healthy environment and supporting daily educational activities.



Fig 2. Types of Water and Sanitation Activities (MCK) at Pondok Pesantren Nurul Jadid

To determine the appropriate treatment method, the raw water quality was analyzed using physical, chemical, and microbiological parameters, in accordance with Ministry of Health Regulation No. 2 of 2023 on Drinking Water Quality Standards (12). Laboratory test results served as the basis for selecting a treatment technology that complies with health requirements. Subsequently, the clean water treatment unit was designed with reference to SNI 6774:2008 to ensure that the treated water meets quality standards (17). The system is further supported by renewable energy through the integration of solar panels as the primary power source. The planned design of the clean water treatment plant (WTP) is illustrated in Figure 3.

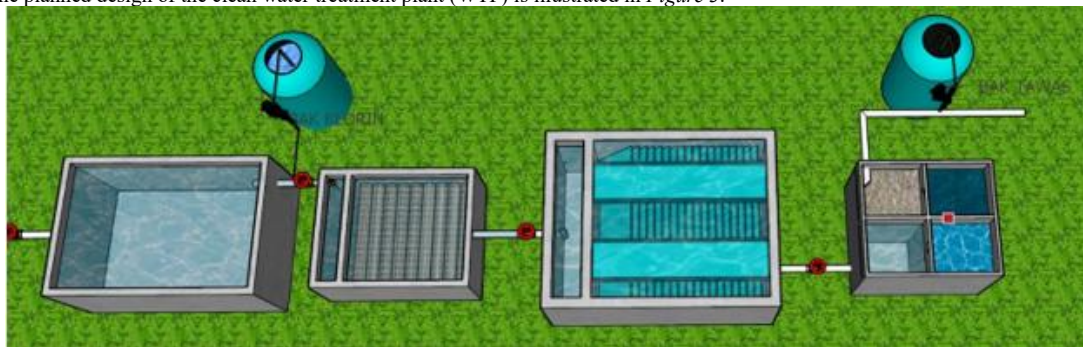


Fig 3. Design of the Water Treatment Plant

To ensure performance and reliability, a small-scale model was developed as an initial trial phase. This pilot testing aimed to evaluate the effectiveness of each treatment process, including coagulation, flocculation, sedimentation, filtration, and disinfection, before full-scale implementation. The small-scale trials generated data on turbidity reduction efficiency, chemical dosing requirements, and the operational stability of pumps and solar panels.



Fig 4. Simulation of Water Treatment Using Solar Panels

1). Power Requirements

a. Raw Water Pum

Flow Rate: $Q = 0,00162 \text{ m}^3/\text{s}$

- Estimated Pump Head: $H = 10 \text{ m}$
- Hydraulic Power:
- $P_h = \rho \times g \times Q \times H$ (1)
- $= 1000 \times 9,81 \times 0,00162 \times 10 = 158,9 \text{ W}$
- Motor Power:
- $P_{\text{motor}} = P_h / (\eta_p \times \eta_m)$
- $= 158,9 / (0,65 \times 0,85) = 287 \text{ W}$

The selected pump has a capacity of 0.5 HP with an electrical power rating of 370 W.

b. Alum Dosing Pump

Alum Dosage = $4,536 \text{ mg/s} = 4,536 \times 3600 = 16,3 \text{ g/hr}$
 with a 10% solution (100 g/L):

$V = 16,3 / 100 = 0,163 \text{ L/h} = 163 \text{ mL/h} = 2,7 \text{ mL/min}$

A mini dosing pump with a capacity of approximately 3 mL/min and a power consumption of 50 W was selected.

c. Aerator (Hydraulic Coagulation)

Estimated Aeration Energy demand = $0,03 \text{ kW per m}^3 \text{ of water}$

$P = 0,03 \times 5,83 = 0,175 \text{ kW} = 175 \text{ W}$

A small aerator rated at 200 W was chosen.

d. Chlorine Dosing Pump

- Dosis kaporit = $0,81 \text{ mg/s}$

$= 0,81 \times 3600 = 2916 \text{ mg/h} = 2,92 \text{ g/h}$

- With a 5% solution (50 g/L):

$V = 2,92 / 50 = 0,058 \text{ L/h} = 58 \text{ mL/h} = 0,97 \text{ mL/min}$

A mini dosing pump of approximately 1 mL/min with 30 W power was sufficient.

e. Reservoir/Distribution Pump

Flow rate: $Q = 0,00162 \text{ m}^3/\text{s}$

Reservoir Head: $H = 15 \text{ m}$

- Hydraulic Power:
- $P_h = 1000 \times 9,81 \times 0,00162 \times 15 = 238 \text{ W}$
- Motor Power:
- $P_{\text{motor}} = 238 / (0,65 \times 0,85) = 432 \text{ W}$

A 0.75 HP pump with a power rating of 550 W was selected.

The total electrical demand for the water treatment units was calculated at 894 W ($\approx 0.9 \text{ kW}$). By applying a 20% safety factor, the required capacity increases to 1.2 kW. To ensure stable and continuous operation, a minimum power supply of 1.5 kW ($\approx 2 \text{ HP}$) is required.

2). Solar Irradiance: Solar irradiance was measured over one week from 8–14 August 2025 at one-hour intervals between 08:00 and 17:00 using a Solar Power Meter. During the measurement period, weather conditions were generally cloudy to partly cloudy. The results are presented in Table 2.

Table 2. Average Hourly Solar Irradiance Over One Week

Time	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Irradiance (W/m ²)	94,2	130,7	136,3	181,2	204,9	255,3	291,5	224,7	92,4	45,2

The measurement results indicate that solar irradiance generally increases from the morning hours, reaching its peak between 13:00 and 14:00 with an average of approximately 255–291 W/m². After this period, irradiance gradually decreases until late afternoon. These findings demonstrate that the optimal potential for solar energy occurs between 11:00 and 14:00, which can be effectively utilized in the design of solar panel systems for the water treatment unit.

3). Solar Panel Capacity Requirements

Design Data:

- Total electrical load: 974 W
- Selected load (with 20% safety factor): $1,200 \text{ W} \approx 1.2 \text{ kW}$
- Stable operating power: 1.5 kW
- Average operating duration: 6 hours/day
- Average daytime irradiance: 200–250 W/m²
- Peak irradiance (11:00–14:00): 291–350 W/m²
- Effective Peak Sun Hours (PSH): 4 hours/day
- System efficiency (panel + inverter + cabling): 75%
- Polycrystalline solar panel, rated at 400 Wp

a. Daily Energy Demand

$E = P \times t = E = 1,5 \text{ kW} \times 6 \text{ h} = 9 \text{ kWh/day}$

b. Energy Output per Solar Panel

$E_{\text{panel}} = P_{\text{panel}} \times \text{PSH} \times \eta = 0,4 \text{ kW} \times 4 \text{ h} \times 0,75 = 1,2 \text{ kWh/day}$

A single 400 Wp panel can generate approximately 1.2 kWh/day.

c. Required Number of Panels

$N = E_{\text{total}} / E_{\text{panel}} = N = 9 / 1,2 = 7,5 \approx 8 \text{ panel}$

d. Total System Capacity

$P_{\text{total}} = N \times P_{\text{panel}}$

$P_{\text{total}} = 8 \times 0,4 = 3,2 \text{ kWp}$

The total installed solar panel capacity = 3,2 kWp

e. Panel Area Requirement

The area of one panel is approximately 1.8 m².

Luas 1 panel = $\pm 1,8 \text{ m}^2, A = 8 \times 1,8 = 14,4 \text{ m}^2$

Thus, an unshaded rooftop or land area of approximately 15 m² is required.

f. Battery Capacity (Off-Grid Configuration)

- Daily energy demand: 9 kWh
- Energy reserve (autonomy) for one day: 9 kWh
- With a Depth of Discharge (DoD) of 80%: $C_{bat} = 9 / 0,8 = 11,25 \text{ kWh}$

Therefore, the selected battery capacity ranges from 12–15 kWh (e.g., three LiFePO₄ units rated at 48V–100Ah, equivalent to 14.4 kWh).

To support the performance of the solar PV system with an installed capacity of 3.2 kWp (eight units of 400 Wp panels) designed to meet the electricity demand of the water treatment unit at 1.5 kW (~9 kWh/day), an inverter with a minimum capacity of 2 kW is required. For operational flexibility, a 2.5 kW inverter is recommended. Additionally, an MPPT charge controller rated at 80–100 A is necessary to ensure optimal power conversion and regulation. When equipped with a 12–15 kWh battery bank, the unit can operate fully off-grid. In a grid-tied configuration, the number of batteries can be reduced, thereby lowering investment costs without compromising system reliability. Water quality testing was carried out at Mutu International Laboratory, which is accredited by the National Accreditation Committee (KAN). Sampling was conducted twice, before and after treatment through the water purification unit. The laboratory test results are presented below.

Table 3. Laboratory Test Result

No	Parameter	Quality Standard (QS) – Ministry of Health Regulation No. 2/2023	Before Treatment	After Treatment	Unit
Microbiology					
1	Escherichia coli	0	96	0	CFU/100 mL
2	Total Coliform	0	870	0	CFU/100 mL
Physical					
3	Ambient Temperature (in situ)	± 3 °C of ambient air	31.7	21.0	°C
	Water Temperature (in situ)	-	30.0	20.0	°C
4	Total Dissolved Solids (TDS)	< 300	322	271	mg/L
5	Turbidity	< 3	107	2.4	NTU
6	Color	10	545	5.12	TCU
7	Odor	Odorless	Odorous	Odorless	-
Chemical					
8	pH (in situ)	6.5 – 8.5	6.2	6.86	-
9	Nitrate (NO ₃ ⁻ , dissolved)	20	4.30	1.32	mg/L
10	Nitrite (NO ₂ ⁻ , dissolved)	3	0.039	0.018	mg/L
11	Hexavalent Chromium (Cr ⁶⁺ , dissolved)	0.01	0.11	0.007	mg/L
12	Iron (Fe, dissolved)	0.2	5.71	0.23	mg/L

From a microbiological perspective, the raw water quality indicated severe contamination, with Escherichia coli at 96 CFU/100 mL and Total Coliform at 870 CFU/100 mL—far exceeding the permissible limit of 0 CFU/100 mL set by Ministry of Health Regulation No. 2/2023. Such levels pose a high risk of waterborne diseases. However, after treatment, both parameters decreased to undetectable levels (0 CFU/100 mL), demonstrating that the disinfection and filtration processes successfully eliminated fecal contamination, thereby rendering the water safe for use. In terms of physical and chemical quality, the raw water, which was initially of very poor condition, showed substantial improvements. Turbidity was reduced from 107 NTU to 2.4 NTU, color from 545 TCU to 5.12 TCU, while the treated water TDS level of 271 mg/L remained well below the threshold of 500 mg/L. The treated water was also odorless, and the pH increased from an acidic level of 6.2 to 6.86, aligning with the regulatory standard. Furthermore, the concentration of hexavalent chromium (Cr⁶⁺) was reduced to 0.007 mg/L, below the maximum limit of 0.01 mg/L. These findings indicate that the treatment process not only improved aesthetic parameters but also effectively mitigated health-related risks, ensuring that the treated water is safe for daily use. The contamination present in the raw water posed serious risks to public health and environmental quality. Fecal contamination increases the likelihood of waterborne diseases such as diarrhea, dysentery, and cholera (18-19), thereby necessitating effective disinfection through chlorination or advanced technologies such as graphene-based electro-disinfection (20). Elevated turbidity and color reduce visual quality and indicate the presence of organic matter, which requires treatment through coagulation-flocculation, sedimentation, and multistage filtration (21-22). The presence of Cr⁶⁺, known to be toxic, mutagenic, and carcinogenic, as well as excessive iron, could cause aesthetic problems, metallic taste, and biofilm formation within distribution pipelines (18).

3.3 Technical Design of the Clean Water Treatment Unit

3.3.1 Coagulation–Flocculation Unit: The coagulation unit in this water treatment system employs alum as the coagulant, as it is more cost-effective compared to commercially available polyaluminum chloride (PAC), making it more suitable for application in the pesantren. In terms of water quality, alum tends to lower pH, rendering the water more acidic. Ike et al. (2021) reported that alum hydrolysis significantly decreases the final pH of treated water; therefore, a filtration medium is provided at the final stage to adjust the pH (24). Jar test results indicated that the optimum alum dosage was 2.8 ppm, resulting in turbidity of 4.70 NTU, color of 5 ACU, and pH of 4.8. For a field flow rate of 1.62 L/s, the required coagulant dosage was calculated to be 4.536 mg/s, equivalent to 272.2 mg/min, 16.33 g/h, or approximately 392 g/day.

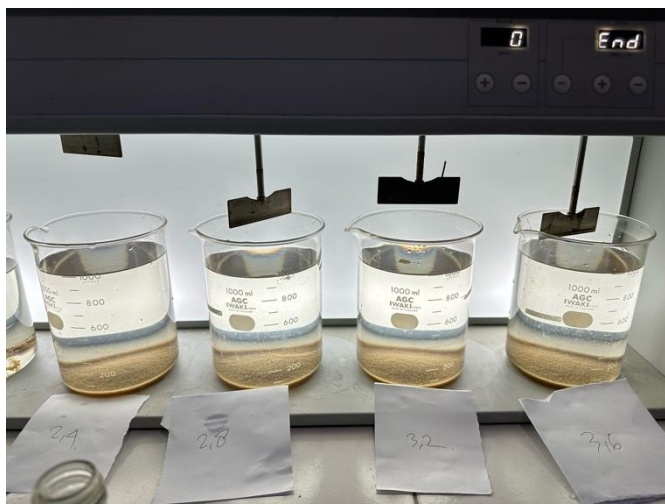


Fig 5. Determination of Optimum Alum Dosage Using Jar Test

The coagulation basin is equipped with an aeration system, which enhances the mixing of the coagulant while simultaneously facilitating particle collisions. Water passes through a series of zigzag-shaped pipes that create natural turbulence. This design eliminates the need for a mechanical mixer, thereby reducing energy consumption while maintaining effective mixing performance.



Fig 6. Coagulation–Flocculation Basin

The selected type for the coagulation–flocculation unit is hydraulic mixing. The number of planned basins is four, with the following design criteria.

Table 4. Coagulation–Flocculation Unit

Component	Parameter	Value / Dimension	Compliance with SNI 6774:2008
General	Flow rate (Q)	1.62 L/s (0.00162 m³/s)	Compliant (≤ 100 L/s for small scale)
General	Number of basins	4 units	Consistent with common practice
Coagulation Pipe	Diameter (D)	0.0481 m (Ø 2 in)	Compliant
	Length (L)	2.0 m	-
	Volume (V)	$3.63 \times 10^{-3} \text{ m}^3$	-
	Detention time (Td)	2.24 s	Compliant (> 2 s)
	Velocity gradient (G)	800 s^{-1}	Compliant
	G · Td	1792	Compliant
	Head loss	0.146 m	Compliant (< 0.5 m)
Coagulation Basin	Retention time (t _i)	60 s	Compliant (30–120 s)
	Volume (V)	0.0972 m³	-
	Dimensions (L × W × H)	0.36 × 0.18 × 1.50 m	Compliant (ratio 2:1–3:1)
Flocculation Basin I	Retention time (t _z)	600 s	Compliant (10–30 min)
	G	60 s^{-1}	Compliant (20–80 s ⁻¹)
	Head loss	0.22 m	Compliant (< 0.3 m)
	Dimensions (L × W × H)	1.14 × 0.57 × 1.50 m	Compliant
Flocculation Basin II	G	40 s^{-1}	Compliant
	Head loss	0.10 m	Compliant
Flocculation Basin III	G	30 s^{-1}	Compliant
	Head loss	0.055 m	Compliant
Total Flocculation Head Loss	-	0.375 m	Compliant (< 0.5 m)

3.3.2 Sedimentation Unit. The sedimentation unit was designed based on the following criteria: a detention time of 1.5 hours, a basin cross-sectional area of 5.832 m², and a basin depth of 2.5 m. Inclined plate settlers were adopted to enhance surface overflow performance, with a plate spacing of 7.5 cm (0.075 m), an effective plate height of 1.5 m, and an inclined plate length of 1.73 m at a 60° angle. The detailed design parameters are summarized in Table 5.

Table 5. Design Criteria for The Sedimentation Unit

Component	Parameter	Value / Dimension	Description	Compliance with SNI 6447:2008
General	Detention time (t)	1.5 h	Basin residence time	Compliant (1–3 h)
	Basin surface area (A)	3.499 m²	Calculated from V/h	-
	Basin depth (H)	2.5 m	Effective depth	Compliant (2–4 m)
Hydraulics	Flow rate (Q)	5.832 m³/h (≈ 1.62 L/s)	Design flow rate	-
	Surface Loading Rate (SLR)	1.67 m³/m²·h	Q/A	Compliant (0.8–2.5)
	Weir Loading Rate (WLR)	6.98 m³/m·h	Q/W	Compliant (< 11)
Geometry	L:W ratio	≈ 5:1	Longitudinal design	Compliant (3:1–6:1)
	Basin dimensions (L × W × H)	4.18 × 0.84 × 2.5 m	Calculated dimensions	Compliant
Plate Settler	Plate angle (θ)	60°	Inclined plate	Compliant (55–60°)
	Plate spacing (w)	0.075 m (7.5 cm)	Plate separation	Compliant (5–10 cm)
	Inclined plate length	1.73 m	Inclined plate	Compliant
	Number of plates (N)	≈ 23 units	hp / w	-
	Horizontal projection area	3.49 m²	W × L	-
	Effective surface area	≈ 40.1 m²	$N \times A_{\text{proyeksi}} \times \cos 60^\circ$	-
	Effective SLR (with plates)	≈ 0.145 m³/m²·h	Q / A_{efektif}	Compliant
Flow Pattern	Plate settling path length	2.0 m	hp / sin θ	-
	Horizontal velocity (v)	$7.75 \times 10^{-4} \text{ m/s}$	Q / (W × H)	-
	Reynolds number (Re)	≈ 1938	vH/v	Compliant (Re < 2000, laminar)
	Froude number (Fr)	≈ $1,56 \times 10^{-4}$	$N_{fr} = v / \sqrt{gH}$	Compliant (low Fr, stable flow)

The sedimentation unit was designed with a plate settler system to enhance the efficiency of floc particle settling following the coagulation–flocculation process. This design utilizes a series of inclined plates arranged in parallel at a 60° angle, thereby shortening the settling path and increasing the effective contact area. Kasenene et al. (2021) demonstrated that inclined plate settlers are highly effective for treating high-turbidity water while maintaining cost efficiency.



Fig 7. Sedimentation Basin

3.3.3 Filtration Unit

The filtration unit employs locally available and cost-effective media, namely coarse silica sand, fine silica sand, and shell sand. Coarse silica sand functions to retain larger particles, whereas fine silica sand is effective in reducing turbidity. The use of shell sand was selected due to its abundant availability in Kubu Raya, West Kalimantan, as well as its ability to release calcium carbonate, which increases water pH. Hata (2024) demonstrated that shell-based materials have the potential to improve water quality through disinfection and neutralization (25), while Nurhayati et al. (2021) emphasized the role of calcium carbonate in stabilizing pH and maintaining the quality of treated water (26). To ensure process stability, the filtration unit is equipped with a float regulator to maintain a consistent flow rate in accordance with the media capacity. The technical design is presented in Table 6.

Table 6. Filtration

Component	Parameter	Value / Dimension	Description	Compliance with SNI 6774:2008
General	Filtration flow rate (Q)	1.62 L/s (5.83 m ³ /h)	Design flow rate	–
	Basin total height	1.50 m	–	Compliant (≥ 1.2 m)
	Filtration velocity (Vf)	6 m/h	Standard filtration rate	Compliant (5–10 m/h)
Basin Dimensions	Cross-sectional area (A)	0.97 m ²	Q/Vf	–
	Basin size (L × W × H)	1.39 × 0.70 × 1.50 m	L:W ratio = 2:1	Compliant
Filter Media	Fine silica sand	0.40 m (d = 0.20–0.35 mm)	Filtration layer	Compliant
	Coarse silica sand	0.30 m (d = 0.50–1.00 mm)	Filtration layer	Compliant
	Shell sand	0.30 m (d = 1.0–2.0 mm)	pH adjustment	Compliant
	Free backwash space	0.50 m	Allowance for expansion	Compliant
Headloss	Filter media	0.21 m	Carman–Kozeny calculation	Compliant (< 0.3 m)
	Total (incl. nozzles)	0.22 m	Media + nozzles	Compliant
Media Expansion	Fine sand	ΔL = 0,26 m	Vs ≈ 0,020 m/s	–
	Coarse sand	ΔL = 0,11 m	Vs ≈ 0,035 m/s	–
	Shell sand	ΔL = 0,08 m	Vs ≈ 0,050 m/s	–
	Total expansion	0,45 m (45%)	Within safe limits	Compliant (15–50%)
Nozzle	Number	14 buah	Q nozzle = 0,00012 m ³ /s	Compliant
	Actual velocity	0,193 m/detik	–	Compliant (0.15–0.30 m/s)
	Head loss	0,0015 m	Very low	Compliant



Fig 8. Filtration Unit and Filter Media

3.3.4 Disinfection (Chlorination) The disinfection process in the clean water treatment system is carried out by adding calcium hypochlorite (Ca(ClO)₂) into the raw water stream through a gravity-fed system. Calcium hypochlorite is used as a disinfectant to ensure drinking water quality by eliminating pathogenic microorganisms and maintaining residual chlorine levels in accordance with health standards. The gravity system allows the chlorine solution to flow in a controlled manner to the distribution unit, ensuring that the applied dosage remains stable, effective, and consistent with operational requirements. This approach is considered simple, efficient, and energy-free, making it suitable for small- to medium-scale water treatment facilities.

The raw water flow rate (Q) was recorded at 1.62 L/s (0.00162 m³/s), with a target chlorine residual of 0.35 mg/L (as Cl₂). Based on the calculation, the chlorine demand as Cl₂ (MCl₂) is:

$$MCl_2 = C_{\text{target}} \times Q = 0,35 \text{ mg/L} \times 1,62 \text{ L/s} = 0,567 \text{ mg/s}$$

$$M_{\text{Ca(ClO)}_2, 70\%} = \frac{MCl_2}{0,70} = 0,567 / 0,70 = 0,81 \text{ mg/s}$$

From these results, the daily chlorine demand can be converted as follows:

- Per hour: 0,81 × 3600 = 2916 mg/h ≈ 2,92 g/h
- Per day: 2,92 × 24 = 70,0 g/day

3.3.5 Cost Estimation

The cost estimation was prepared to provide a comprehensive overview of the financial requirements for constructing the solar-powered clean water treatment system at the pesantren. The preparation of cost estimation ensures that every component, including both the energy installation and water treatment units, is calculated in detail according to its specific function and operational needs in the field.

Table 7. Cost Estimation

A. Solar Panel Installation					
No	Description	Volume	Unit	Unit Price (IDR)	Total Cost (IDR)
1	Electric Power Generation 2000 W/h				
1	Solar Panel 400 Wp Mono	8.00	bh	Rp2,912,500.00	Rp23,300,000.00
2	Power Inverter 2500 W Pure Sine Wave DC to AC (12V/24V/48V to 220V)	1.00	bh	Rp1,812,500.00	Rp1,812,500.00
3	MPPT 100A 12V/24V/36V/48V Solar Charge Controller	1.00	bh	Rp3,850,000.00	Rp3,850,000.00
4	LiFePO ₄ Battery 48V 100Ah	3.00	bh	Rp9,111,250.00	Rp27,333,750.00
5	Battery Rack	1.00	bh	Rp785,000.00	Rp785,000.00
6	Solar Panel Mounting Structure	1.00	ls	Rp2,500,000.00	Rp2,500,000.00
7	NY Y Cable 2×10 mm	30.00	m	Rp83,500.00	Rp2,505,000.00
8	Supporting Materials	1.00	ls	Rp500,000.00	Rp500,000.00
9	Assembly and Installation Services	1.00	ls	Rp7,510,350.00	Rp7,510,350.00
Total					Rp70,096,600.00
Rounded					Rp70,100,000.00
B. Water Treatment Instalation					
No	Description	Volume	Unit	Unit Price (IDR)	Total Cost (IDR)

1	Coagulation–Flocculation Basin	unit	4	Rp2,750,000.00	Rp11,000,000.00
2	Sedimentation Basin (Plate Settler)	unit	1	Rp25,000,000.00	Rp25,000,000.00
3	Filtration Basin	unit	1	Rp15,000,000.00	Rp15,000,000.00
4	Silica Sand	kg	150	Rp15,000.00	Rp2,250,000.00
5	Shell Sand	kg	150	Rp2,500.00	Rp375,000.00
6	Dosing Pump (Alum)	unit	1	Rp3,250,000.00	Rp3,250,000.00
7	Alum Tank 500 L	unit	1	Rp1,750,000.00	Rp1,750,000.00
8	Dosing Pump (Chlorine)	unit	1	Rp3,250,000.00	Rp3,250,000.00
9	Chlorine Tank 500 L	unit	1	Rp1,750,000.00	Rp1,750,000.00
10	Raw Water Pump (HITACHI Booster Pump, 230 W, 23 L/min, 10 m head)	unit	2	Rp5,375,000.00	Rp10,750,000.00
11	Reservoir Pump (HITACHI Booster Pump, 250 W, 45 L/min, 20 m head)	unit	2	Rp9,937,500.00	Rp19,875,000.00
12	Coagulation Aerator	unit	1	Rp4,750,000.00	Rp4,750,000.00
13	Supporting Materials and Pipe Accessories	lot	1	Rp4,500,000.00	Rp4,500,000.00
14	Pipe Assembly and Installation Services	lot	1	Rp2,500,000.00	Rp2,500,000.00
15	Electrical Installation	lot	1	Rp2,000,000.00	Rp2,000,000.00
Total					Rp108,000,000.00
C. Operational Cost					
No	Description	Volume	Unit	Unit Price (IDR)	Total Cost (IDR)
1	Procurement of Coagulant Chemicals (Alum)	kg	15	Rp30,000.00	Rp450,000.00
2	Procurement of Chlorine Chemicals (Calcium Hypochlorite)	kg	5	Rp50,000.00	Rp250,000.00
3	Filter Operation Costs	month	1	Rp500,000.00	Rp500,000.00
Total					Rp1,200,000.00

Based on the above results, the daily chlorine demand can be calculated as follows. The application of a 2000 W/h solar panel system integrated with a clean water treatment unit comprising coagulation–flocculation, sedimentation, filtration, and disinfection processes demonstrates both technical feasibility and social relevance in the context of pesantren with limited financial resources. The total initial investment amounted to IDR 178,100,000, consisting of IDR 70,100,000 for the solar panel installation and IDR 108,000,000 for the water treatment unit. This system is capable of operating independently without reliance on the conventional electricity grid. The design was developed in accordance with Ministry of Health Regulation No. 2 of 2023 concerning drinking water quality requirements, thereby ensuring that the treated water consistently meets health standards. From an economic perspective, the system provides significant efficiency for pesantren operations. The monthly operational cost is approximately IDR 1,200,000, covering chemical requirements (alum and chlorine) and filter media maintenance, which is relatively low compared to conventional schemes dependent on PLN electricity. This efficiency is crucial given that pesantren generally operate with limited budgets, enabling the sustainable provision of clean water without imposing a financial burden on the institution.

4. Conclusion

This study confirms the technical and economic feasibility of a solar-powered clean water treatment system for Pesantren Nurul Jadid. The integration of coagulation–flocculation, sedimentation, filtration, and chlorination effectively improved peat water quality, achieving full compliance with Indonesian Ministry of Health standards by reducing turbidity, color, and iron concentrations and eliminating *Escherichia coli* and Coliform. Supported by a 3.2 kWp solar panel system with 12–15 kWh battery storage, the plant reliably supplied its 1.5 kW energy demand in off-grid conditions. With an initial investment of IDR 178.1 million and a monthly operating cost of IDR 1.2 million, the system offers a sustainable and replicable model for clean water provision in resource-constrained educational institutions, contributing to Sustainable Development Goal (SDG) 6: Clean Water and Sanitation and SDG 7: Affordable and Clean Energy.

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