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SHIELD: SHIELD (Solar-powered Hydraulic Infrastructure for Enhanced Lighting and Disinfection) in Sitio Camachile, Nabuclod, Floridablanca, Pampanga

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ABSTRACT

The project SHIELD (Solar-Powered Hydraulic Infrastructure for Enhanced Lighting and Disinfection) project was developed to enhance water safety and accessibility in Sitio Camachile, Nabuclod, Floridablanca, Pampanga. The existing hydraulic ram pump system provides filtered water but failed to meet microbial safety standards as it was assessed containing high levels of Total Coliform and the presence of Escherichia coli. This study aimed to integrate ultraviolet (UV) disinfection and solar-powered lighting into the existing water infrastructure. The design involved calculating energy requirements, system efficiency, installing a photovoltaic system, and utilizing UV lights to neutralize waterborne pathogens. More so, various laboratory tests were conducted before and after the installation which showed that microbial levels dropped within the acceptable range for drinking water. Post-experiment water tests showed significant improvements, E. coli levels dropped from >8.0 MPN/100mL to 2.6 MPN/100mL. Total Coliform was reduced to <1.1 MPN/100mL, meeting potable water standards. A 240W solar panel successfully powered the 750 Wh/day energy load for both UV Light and Street Light. The project demonstrates a sustainable model for clean water access and supports multiple SDGs including clean water, energy, innovation, and equality. It is recommended to expand the SHIELD system to other stations and add battery storage to improve resilience during low sunlight and support long-term, community-based maintenance.

Keywords: Disinfection; Microbial Contamination; Solar Energy; Sustainable Development; Ultraviolet Treatment; Water Purification; Rural Infrastructure; Photovoltaic System; Waterborne Pathogens; Public Health; Clean Water Access; Renewable Energy.

1. Introduction

Access to quality food and clean water is essential for survival and aligns with Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 10 (Reduced Inequalities). In the Philippines, many remote areas, including Aeta communities, continue to face challenges in accessing potable water. Sitio Camachile in Barangay Nabuclod, Floridablanca, Pampanga—home to 280 Aeta families—struggles due to limited infrastructure. A hydraulic ram pump design could help meet the community's daily water need of approximately 9,540 liters [1].

The SHIELD project enhances the existing hydraulic ram pump (Hydram) system by incorporating solar-powered UV disinfection and lighting. Solar panels will power UV lights to disinfect water and a lamp post to illuminate the water station for six years. UV disinfection, endorsed by the World Health Organization, is effective against waterborne pathogens [2]. UV radiation at 254–265 nm efficiently killed E. coli, achieving 100% mortality at a dose of 1.17 log mJ/cm² [3]. By providing lighting, the system ensures safe, continuous water filtration day and night. Integrating solar panels supports sustainability and energy efficiency by converting solar energy into electricity to power the UV [4]. Battery storage allows uninterrupted operation during low sunlight or night time, ensuring access to clean water.

As different studies have shown, using solar energy combined with UV disinfection technology is a practical and sustainable way to address water quality problems in far-flung communities. Researchers like Sampaio and

Gonzalez [4] and Hayat et al. [5] pointed out that solar power is not only renewable but also widely available and environmentally friendly—making it an ideal energy source for rural setups.

UV disinfection offers distinct advantages over other methods to disinfect water such as chlorination and ozonation technologies. Chlorination is one of many methods that can be used to disinfect water, it adds chlorine to kill pathogens but may leave harmful chemicals like trihalomethanes (THMs) [7]. Containers, weigh scales, chlorinator, injectors, switchover modules, vacuum lines, booster pumps, solution lines, diffusers, and a flow meter are the equipment of chlorination. Safety requirements are passive ventilation, mechanical ventilation, warning alarms and devices, showers, panic hardware for doors, and eye washes. A separate air tight room for chlorination equipment is mandatory [8]. It produces hazardous disinfection by-products (DBPs) such as trihalomethanes (THMs), which pose long-term health risks including cancer and reproductive disorders [9]. UV light kills a wider range of microorganisms without harmful chemicals or by-products ensuring safe drinking water without changing its taste. The doses of UV light necessary for a 99.9% inactivation of the cultured vegetative bacteria, total Coliforms, and standard plate count microorganisms were comparable [10].

Ozonation is a long-established water treatment method that uses ozone (O_3), a powerful oxidant, to disinfect and oxidize contaminants. The system uses a high-voltage electric discharge in the presence of oxygen to generate ozone, which is then used for water disinfection. Oxygen flows through a dielectric gap between electrodes, where the electric field breaks down oxygen molecules to form ozone [11]. While effective, it is costly, energy-intensive, and relies on complex systems [12]. UV lights are simpler, cheaper, and more energy-efficient. They do not need continuous ozone generation. UV lights are divided by development engineers near-ultraviolet (NUV) and deep-ultraviolet (DUV) lights, emitting in the range of 300–400 and 200–300 nm, respectively [13].

UV disinfection technology was selected not only for its proven effectiveness but also for its compatibility with the existing hydraulic infrastructure. Its integration required minimal modification, making it a practical and scalable enhancement to the current Hydram water system [14].

Access to clean water remains a challenge for remote communities such as Sitio Camachile in Floridablanca, Pampanga. While the existing Hydram project provides sustainable and free water, it is not yet potable due to microbial contamination, specifically the presence of E. coli [1]. This study proposes enhancing the system by integrating solar-powered UV disinfection technology to eliminate pathogens and ensure water safety.

1.1. Study Objectives

The objectives of this study are as follows:

(1) To compute the total energy consumption of the UV lights and LED lighting system per day, measured in (Wh/day) as the basis for designing the components of the solar PV system to meet the energy requirement.

(2) To develop a solar-powered UV disinfection and lighting, adhering to energy efficiency/scalability standards.

(3) To assess how the addition of UV lights can affect pathogen levels to meet acceptable standards including: (a) Total Coliform levels after the disinfection (MPN/100mL), (b) Presence or absence of E. coli after the disinfection.

2. Methods

2.1. Conceptual Framework

The conceptual framework illustrates the development and implementation of the SHIELD (Solar-powered Hydraulic Infrastructure for Enhanced Lighting and Disinfection) system through a cyclical process composed of four main components: Input, Process, Output, and Feedback & Maintenance. It begins with identifying essential inputs, such as the existing hydraulic ram pump system, the off-grid nature of the community, specific needs for potable water and night-time lighting, and baseline water quality data indicating microbial contamination. These inputs guide the system design and component sizing, followed by the physical assembly of the SHIELD system. Laboratory and field testing without full site installation is conducted to evaluate performance, particularly in terms of energy efficiency and water quality improvement. The process yields a fully functional prototype that meets microbial safety standards and demonstrates verified solar power and lighting effectiveness, making it ready for actual deployment and future scaling.

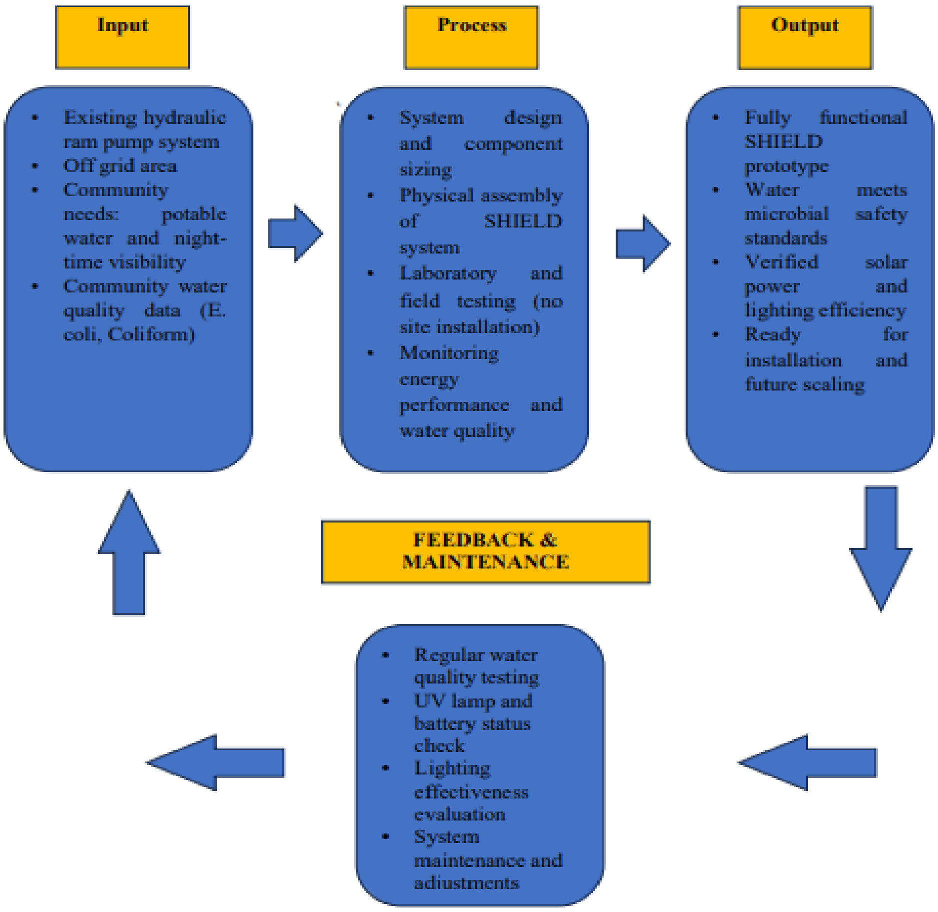

Figure 1. Conceptual Framework

To ensure sustainability, a feedback and maintenance loop is integrated, involving regular water testing, UV lamp and battery checks, lighting evaluations, and necessary system adjustments. This loop feeds back into the initial inputs and processes, creating a sustainable and adaptive approach to delivering clean water and lighting to off-grid communities.

2.2. Research Design

The study used quantitative data to evaluate the effectiveness and efficiency of the SHIELD system, focusing on solar energy generation, system performance, and overall efficiency.

2.3. Research Locale

The study was conducted in Sitio Camachile, Nabuclod, Floridablanca, Pampanga, a remote community of 280 Aeta families. The area was chosen due to its existing Hydram water filtration system, which lacked adequate lighting and effective disinfection.

2.4. System Design

Prototype designs were developed to visualize the physical layout and integration of the system's components.

2.4.1. One Line Diagram

The Diagram shows a solar-powered system that uses a 240W solar panel to charge a 150Ah lead-acid battery through a Pulse Width Modulation (PWM) charge controller. Safety is ensured with circuit breakers and a DC watt-amp meter. A 12V/100A relay protects the battery by managing voltage levels. A 1500W inverter converts the stored energy to AC power, supplying a 3-gang outlet connected to a 50W LED light and two 15W UV lights for night lighting and water disinfection.

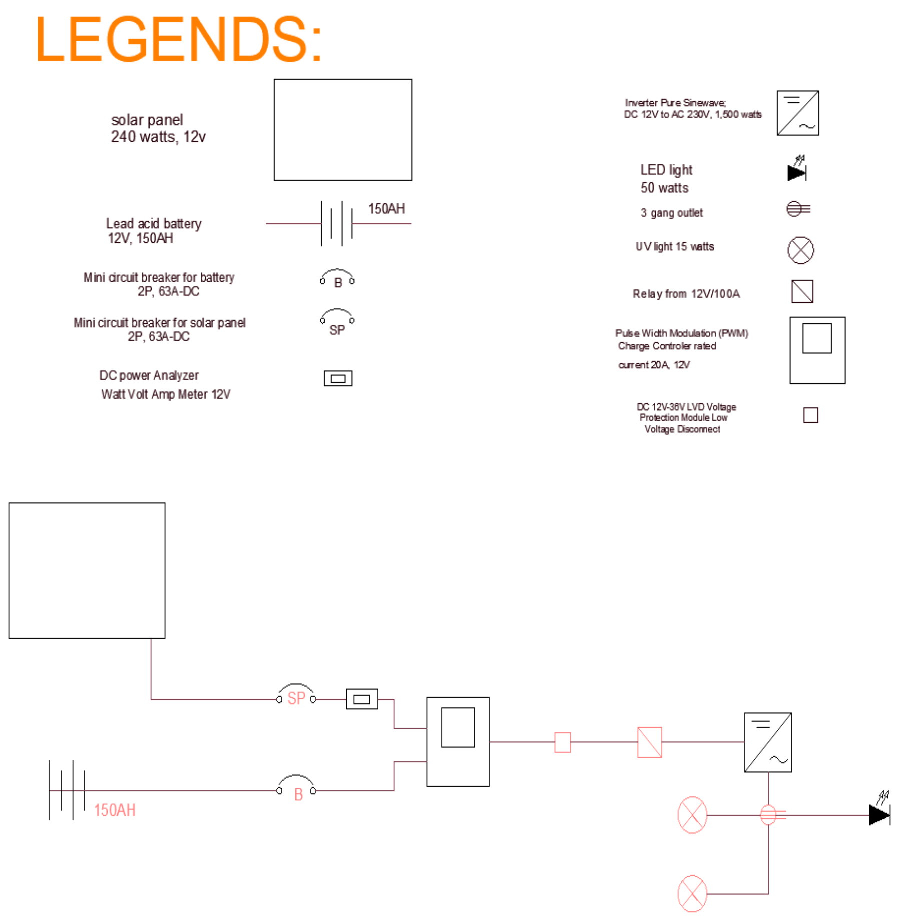

Figure 2. One Line Diagram

Asian Journal of Basic Science & Research
Volume 7, Issue 3, Pages 39-57, July-September 2025

2.4.2. Design and Sizes

The Figure 3 illustrates a solar-powered UV water disinfection system designed for off-grid use. A 21-gallon water tank, measuring 608.52 mm in height and 26 mm in diameter, houses a UV light that emits at 254 nm—an effective wavelength for killing harmful bacteria and viruses [14], [15]. The UV lamp, which is 545 mm tall with a 406.4 mm diameter, is securely installed using a 3-inch GI steel coupling, a PVC male adaptor, and a reducer. A 1-inch PVC tube runs from the tank to a raised platform that holds the battery and controller unit, which manage power delivery to the UV light. The controller is mounted on a support structure 1000 mm tall, with a 500 mm by 280 mm top platform [16]. This design ensures safe and efficient operation of the UV system using solar-charged energy, making it a practical solution for clean water access in remote areas.

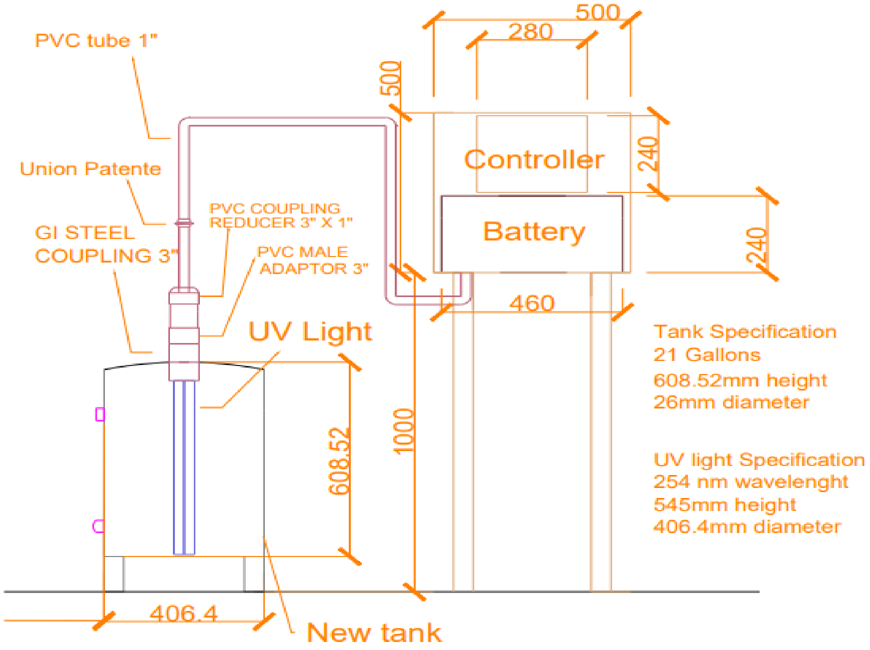

Figure 3. Prototype Design

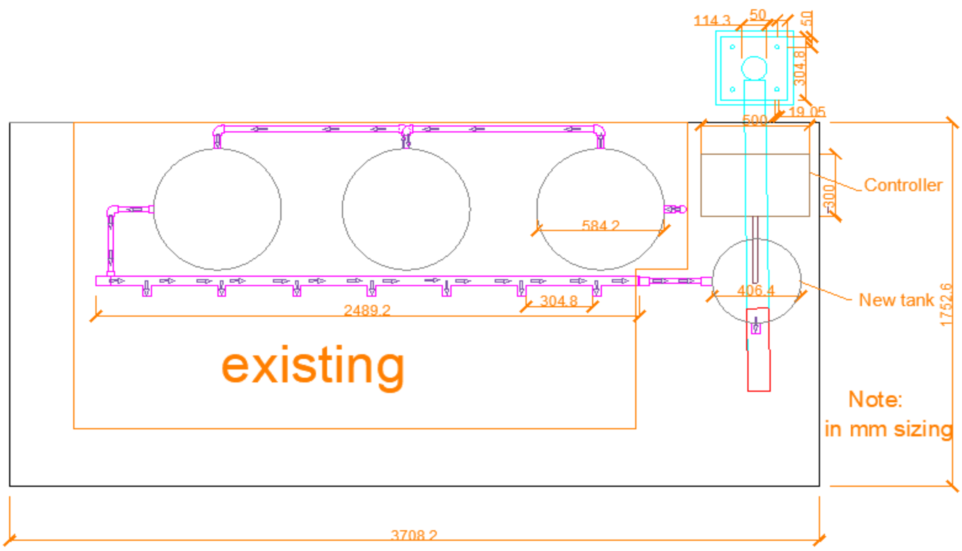

Figure 4. Elevation Top View with Existing Hydram Filtration

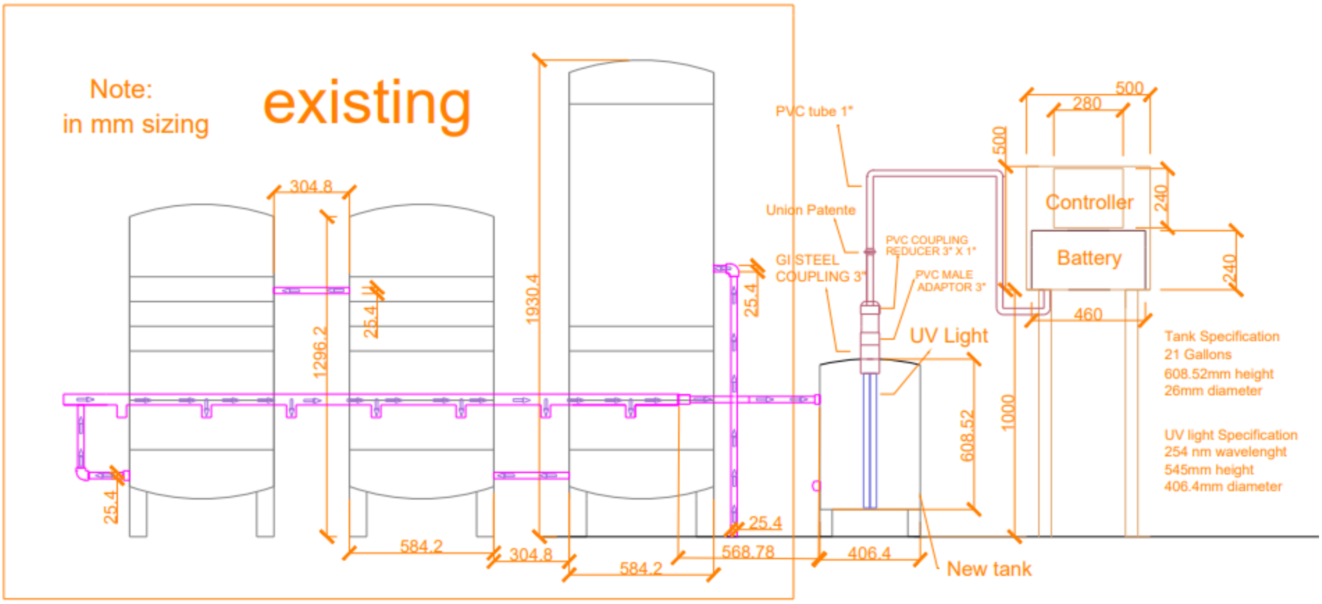

Figure 5. Elevation Front View with the Existing Hydram Filtration

The Figure 4 and 5 presents a detailed millimeter-based layout of a water filtration and storage system, comprising three existing tanks and a new tank setup connected by a PVC piping network. Key features include a 254 nm UV disinfection unit [6], [7], a controller battery, and standard fittings like ¾” GI steel couplings and 1” PVC pipes. The tanks, each with a 21-gallon (79.5 Liters) capacity and industry-standard dimensions [16], ensure efficient flow and water treatment. The system is well-designed, accurately sized, and integrates components in line with engineering best practices, making it both effective and reliable [14-16].

Figure 6 provides a front-view 3D rendering of the proposed SHIELD infrastructure layout.

Figure 6. 3D Rendered Perspective (Front View)

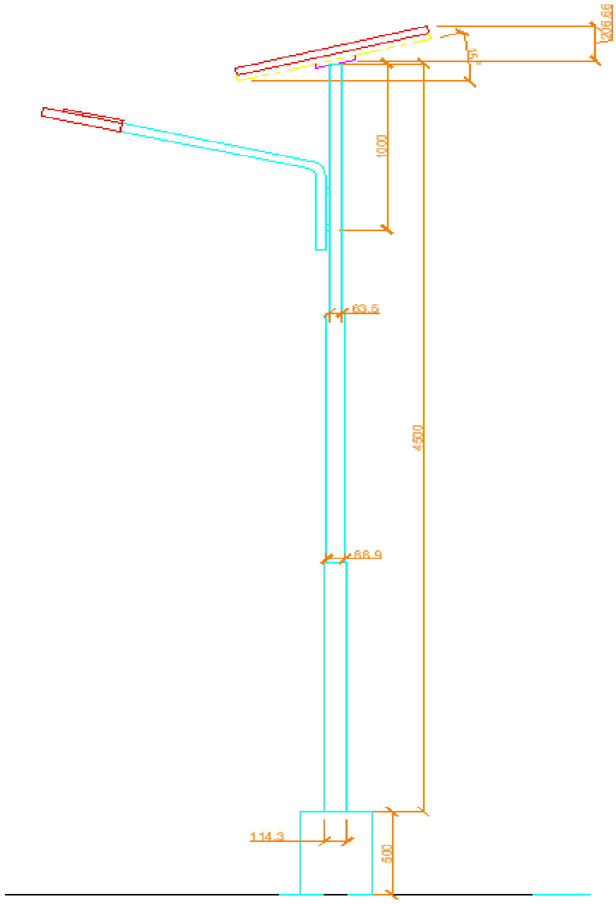

Figure 7. Post Sizing of Solar Street Lighting System

The Figure 7 presents a side elevation view of a solar-powered street lighting system, with measurements in millimeters. The structure includes a vertical pole, an arm extending outward to hold the LED lamp, and a solar panel mounted at the top. The total height of the pole is approximately 4500mm (4.5 meters), with structural reinforcements and accurate spacing for mounting components. The lamp arm extends diagonally and is fixed at a height of 4500 mm from the base, while the solar panel is installed above it at an inclined angle to optimize sunlight capture, with the panel's base starting at 5000 mm from the ground. The base of the pole shows a foundation embedment depth of 500 mm with a base width of 114.3 mm, which helps anchor the system securely. This design is both safe and effective, supported by multiple industry standards and safety guidelines. Solar street lights should be installed with proper structural integrity, embedment depth, and tilt angle to withstand environmental stresses like wind and seismic activity [17]. A pole height between 4–6 meters is typical for residential and local road lighting, ensuring effective illumination without over-lighting or glare.

2.5. Formula and Computations

2.5.1. Total Power

P = P1 + P2…. Pn …(1)

Where: P = Power

2.5.2. Daily Energy Consumption

Energy consumption and solar sizing follow standard electrical engineering methods, guided by the *Solar Electric Handbook* (SEI) and Institute of Electrical and Electronics Engineers (IEEE) 3001.2 standards for energy audits [18].

$$\text{Daily Energy Consumption} = \frac{\sum \text{Power of Device x Operating Time}}{\text{Day}} \qquad \ldots(2)$$

2.5.3. Size of PV Panel

The estimated peak sun hours for Sitio Camachile, Nabuclod, Floridablanca, Pampanga is approximately 5.18 hours per day and for experimental setup (Porac, Pampanga) is approximately 5.14 hours [20].

$$\text{Total PV Power} = \frac{\text{Total Daily Energy Consumption}}{\text{Sun Hours per Day}} \qquad \ldots(3)$$

2.5.4. Number of PV Panel

$$\text{Number of Panels} = \frac{\text{Total PV Power}}{\text{Wattage Per Panel}} \qquad \ldots(4)$$

2.5.5. Battery Sizing

To determine the appropriate battery size, start by calculating the total watt-hours used by appliances per day. Then, divide this value by 0.85 to account for battery losses, and divide the result by 0.6 to consider the depth of discharge. Next, divide the outcome by the battery's nominal voltage. Finally, multiply this result by the number of days of autonomy the days the system must operate without solar input to get the required ampere-hour capacity of the deep cycle battery [21].

$$\text{Battery Capacity} = \frac{\text{Total Watts per day used x Days of autonomy}}{(\text{Efficiency of Lead Acid Battery})(\text{DoD})(\text{N})} \qquad \ldots(5)$$

2.5.6. Inverter Capacity

The inverter capacity for a solar PV system can be determined using this formula: [21]

$$\text{Inverter Size} = \text{Total Load x } (1 + \text{Safety Margin}) \qquad \ldots(6)$$

2.5.7. Solar Charge Controller Size

When selecting a solar charge controller, it is important to match it with the voltage of the PV array and batteries, and choose the appropriate type based on your application. The controller must also have sufficient capacity to handle the current from the PV array. For series-type charge controllers, sizing depends on the total input current from the PV panels and their configuration—whether in series or parallel. As a standard practice, the recommended method for sizing is to take the short circuit current (Isc) of the PV array and multiply it by 1.3 to ensure the controller can safely handle the current load [21].

Table 1. PV Panel Specification

PV Panel Specification	**Pm**	**Im**	**Isc**	**Vm**	**Voc**
	240 Wp	8.01 A	8.60 A	30 V	36.8 V

Asian Journal of Basic Science & Research
Volume 7, Issue 3, Pages 39-57, July-September 2025

$$\text{Controller Current Rating} = (\text{Number of Strings x Isc}) \text{ x Safety Factor} \qquad \ldots(7)$$

Where:

Pm = Maximum power

Im = Current at maximum power

Isc = Short-circuit current of one PV module

Vm = Voltage at Maximum power

Voc = Open Circuit Voltage

Number of Strings = Number of parallel PV module groups

2.5.8. Full Tank Disinfection Time

While water near the lamp is disinfected almost instantaneously, full tank sterilization depends on how efficiently the water circulates around the UV source. The Hydram project provides water to the upland Aeta community with an average water discharge of 22 liters per minute [22].

$$\text{Time} = \frac{\text{Tank Volume}}{\text{Flow Rate}} \qquad \ldots(8)$$

2.5.9. UV light Computation

Two submersible 15-watt UV-C lamps are installed in a 21-gallon galvanized water tank with a drinking water faucet to disinfect contaminated water. Each lamp emits 57 μW/cm² of UV radiation at a 1-meter distance, with a peak wavelength of 254 nm ideal for germicidal action. Unlike external UV systems, the submersion design allows direct exposure to water, improving disinfection efficiency. This setup targets harmful waterborne bacteria, specifically E. coli and Coliform, which are present in the Hydram project's water and make it unsafe for drinking.

Escherichia coli (E. coli): a fecal indicator bacterium, commonly used as a measure of microbial water quality. It typically requires a UV dose of 30,000 μW·s/cm² for 99.9% inactivation [15].

$$\text{I} = \text{Io} \times \left(\frac{\text{do}}{\text{d}}\right)^2 \qquad \ldots(9)$$

I = Intensity

Io = Original Intensity

d_0 = the original distance from the light source where the intensity Io is measured

d = the new distance to calculate the intensity

t = time of disinfection for 5cm distance from UV light

2.5.10. UV Exposure time

$$\text{Time(seconds)} = \frac{\text{Required Dose (mj/cm}^2)}{\text{UV Intensity (mW/cm}^2)} \qquad \ldots(10)$$

2.5.11. Lumen Output

$$\text{Lumens} = \text{wattage} \times \text{Luminous Efficacy} \qquad \ldots(11)$$

Residential streets typically require between **3,000 and 6,000 lumens** per street light to ensure pedestrian safety and security while minimizing light pollution [23].

2.6. Ethical Consideration

The SHIELD project upheld ethical standards by ensuring the rights and welfare of the Aeta community in Sitio Camachile, Nabuclod, Floridablanca. Participation was voluntary, with individuals given the right to refuse and informed consent obtained through proper briefing before any interviews or activities.

2.7. Assembly Procedure of Solar Power System Components

The SHIELD system features a fully integrated water treatment station with power generation, storage, and disinfection components. It uses a 240W solar panel as the power source, paired with a 1500W pure sine wave inverter, 12V 20A charge controller, and a 12V 150Ah lead-acid battery. Key components include two 15W UV submersible lights (254 nm), a 50W LED lamp, a 12V/100A DC relay, DC circuit breakers, a 3-gang AC outlet, monitoring meters, and necessary wiring and mounting materials.

2.8. Pre Installation Setup

A site survey was conducted in the target community to assess sunlight exposure, the existing water filtration structure, and ease of community access. All electrical components and mounting tools were prepared, and a layout was designed for the placement of solar panels, battery housing, and lighting fixtures.

2.9. Solar Panel Installation

The 240W solar panel was installed on a metal post facing south at a 15–20° tilt to optimize sunlight exposure. Its output was connected to a circuit breaker, then to a watt meter, and finally to the input terminal of the solar charge controller.

2.10. Battery Bank Installation

The 12V, 150Ah lead acid battery were connected to a circuit breaker, and from there, to the input terminal of the solar charge controller.

2.11. Controller's Terminal

The solar charge controller was linked to the battery breaker, watt meter, DC relay, and monitoring devices for automation and performance tracking.

2.12. Inverter and AC Load Setup

Thick-gauge wires connected the battery to the inverter, which powered two 15W UV lights inside the water tank and a 50W LED light for nighttime use. The LED was mounted on a metal post near the filtration system for effective lighting.

2.13. Experimental setup test

Field testing was conducted over five days in Calzadang Bayu, Porac, Pampanga, monitoring battery cycles, UV exposure time, and water quality. The UV lamps ran for about 5 hours daily, while the LED lights provided 12 hours of nighttime illumination. Power usage was tracked using an AC watt meter.

2.14. System Operation Procedure

The solar-powered system was designed for safe and efficient operation using components like a 1500W inverter, solar charge controller, DC breakers, and a voltage-controlled relay. It includes automatic battery protection through low-voltage disconnect and reconnect settings.

2.15. Operating Procedure

The SHIELD project's operating procedure starts with inspecting all wire connections for tightness and correct polarity, ensuring no load is connected to the inverter during startup. The sequence begins by turning on the battery circuit breaker, activating the charge controller and relay module. The solar panel breaker is then turned on to start charging the battery. The relay module automatically protects the battery by disconnecting the inverter at 10.5V and reconnecting it at 12.0V. Once reconnected, AC loads can be used, as long as they don’t exceed the inverter's 1500W capacity.

2.16. Shut Down Procedure

To safely shut down the system, unplug all AC appliances, then turn off the solar panel breaker, followed by the battery breaker.

2.17. Voltage Protection Summary

Table 2. Voltage Protection Summary

Protection Feature	Voltage Threshold
Low-Voltage Disconnect	10.5 V
Reconnect After Charging	12.0 V
Maximum Charge	13.7 V

2.18. UV Light Maintenance Procedure

Regular maintenance is essential for keeping the UV light effective and ensuring clean water. When the UV lamp reaches the end of its service life, it should be replaced by trained personnel. Before starting, the system must be completely powered off. The process involves disconnecting the union patente and power connector, then carefully removing the old UV lamp from the tank. A new 15W, 254nm UV light is prepared, connected to the existing power wires, and reinserted into the tank. The adapter and connectors are resecured, and the system is sealed and powered back on for operation.

2.19. Procedure Experiment using UVC light

An experiment was conducted to test the effectiveness of UVC light in reducing Coliform and E. coli. Water samples were collected using official 100 ml bottles from the Eminent Water Laboratory. UVC light was

Asian Journal of Basic Science & Research
Volume 7, Issue 3, Pages 39-57, July-September 2025

submerged in contaminated water for 20 minutes, after which a sample was taken and kept cold during transport to the lab. If results are unsatisfactory, further testing with 10, 20, and 30-minute UVC exposure intervals will be performed.

3. Results and Discussion

3.1. Daily Energy Consumption of UV light and LED Lightning with Battery Voltage Monitoring (Days)

Table 3. Daily Energy Consumption of UV light and LED Lightning with Battery Voltage Monitoring (3 Days)

Day	Time	Battery Voltage (V)	Energy Consumption (Wh)	Solar Charging	UV Status	LED Status
1	7:00–9:00 AM	13.7 → 13.6	60	Yes	ON	OFF
1	9:00–10:00 AM	13.6 → 13.7	30	Yes	ON	OFF
1	10:00–11:00 AM	13.7 → 13.7	0	Yes	OFF	OFF
1	11:00 AM–1:00 PM	13.7 → 13.7	0	Yes	OFF	OFF
1	1:00–3:00 PM	13.7 → 13.6	61	Yes	ON	OFF
1	3:00–5:00 PM	13.6 → 13.7	0	Yes	OFF	OFF
1	5:00–6:00 PM	13.7 → 13.7	0	Yes	OFF	OFF
1	6:00–8:00 PM	13.7 → 13.5	104	No	OFF	ON
1	8:00–10:00 PM	13.5 → 13.3	103	No	OFF	ON
1	10:00 PM–12:00 AM	13.3 → 13.1	103	No	OFF	ON
2	12:00–2:00 AM	13.1 → 12.9	102	No	OFF	ON
2	2:00–4:00 AM	12.9 → 12.6	104	No	OFF	ON
2	4:00–6:00 AM	12.6 → 12.4	101	No	OFF	ON
2	6:00–7:00 AM	12.4 → 12.4	0	Yes	OFF	OFF
2	7:00–9:00 AM	12.4 → 12.5	61	Yes	ON	OFF
2	9:00–10:00 AM	12.5 → 12.6	30	Yes	ON	OFF
2	10:00–11:00 AM	12.6 → 12.8	0	Yes	OFF	OFF
2	11:00 AM–1:00 PM	12.8 → 13.1	0	Yes	OFF	OFF
2	1:00–3:00 PM	13.1 → 13.0	60	Yes	ON	OFF
2	3:00–5:00 PM	13.0 → 13.1	0	Yes	OFF	OFF
2	5:00–6:00 PM	13.1 → 13.1	0	Yes	OFF	OFF
2	6:00–8:00 PM	13.1 → 13.0	104	No	OFF	ON
2	8:00–10:00 PM	13.0 → 12.8	102	No	OFF	ON
2	10:00 PM–12:00 AM	12.8 → 12.6	103	No	OFF	ON
3	12:00–2:00 AM	12.6→ 12.3	105	No	OFF	ON
3	2:00–4:00 AM	12.3 → 12.1	102	No	OFF	ON
3	4:00–6:00 AM	12.1 → 11.9	102	No	OFF	ON
3	6:00–7:00 AM	11.9 → 12.0	0.	Yes	OFF	OFF
3	7:00–9:00 AM	12.0 → 12.2	60	Yes	ON	OFF
3	9:00–10:00 AM	12.2 → 12.3	30	Yes	ON	OFF

3	10:00–11:00 AM	12.3 → 12.5	0	Yes	OFF	OFF
3	11:00 AM–1:00 PM	12.5 → 12.9	0	Yes	OFF	OFF
3	1:00–3:00 PM	12.9 → 13.1	61	Yes	ON	OFF
3	3:00–5:00 PM	13.1 → 13.2	0	Yes	OFF	OFF
2	5:00–6:00 PM	13.2 → 13.3	0	Yes	OFF	OFF
3	6:00–8:00 PM	13.3 → 13.1	103	No	OFF	ON
3	8:00–10:00 PM	13.1 → 12.9	101	No	OFF	ON
3	10:00 PM–12:00 AM	12.9 → 12.8	104	No	OFF	ON
4	12:00–2:00 AM	12.8 → 12.6	103	No	OFF	ON
4	2:00–4:00 AM	12.6 → 12.3	103	No	OFF	ON
4	4:00–6:00 AM	12.3 → 12.2	102	No	OFF	ON

From April 26 to 28, 2025, energy use followed a clear pattern. UV lights consumed around 150 Wh/day, while the LED light used 600 Wh over 12 hours. Minimal energy was used during standby periods, likely including the solar charge controller's background load. Solar charging kept battery voltage within a healthy range (11.9V to 13.7V). However, cloudy weather on Day 2 led to insufficient charging, resulting in Day 3 starting at a lower voltage of 11.9V.

3.2. Daily Energy Consumption of UV light and LED Lightning with Battery Voltage Monitoring (5 Days)

Table 4. Daily Energy Consumption of UV light and LED Lightning with Battery Voltage Monitoring (5 Days)

Day	Time	Load State	Solar Charging	Battery Voltage (V)	Notes
1	7:00 AM	No Load	Yes	13.7	Fully Charged Battery
1	3:00 PM	UV Light	Yes	13.6	Sustained performance
2	7:00 AM	After LED use	Yes	12.4	Discharged overnight, includes controller load
2	3:00 PM	UV Light	Yes	13.0	Low recovery
3	7:00 AM	After LED use	Yes	12.0	Discharged overnight, includes controller load
3	3:00 PM	UV Light	Yes	13.1	Recovered normally
4	7:00 AM	After LED use	Yes	12.2	Discharged overnight, includes controller load
4	3:00 PM	UV Light	Yes	13.2	Sustained performance
5	7:00 AM	After LED use	Yes	12.3	Discharged overnight, includes controller load
5	3:00 PM	UV Light	Yes	13.4	Sustained performance

Table 4 shows consistent charging and discharging over five days. Each night, LED use lowers the battery voltage but keeps it safely above 10.5V. By early afternoon, solar charging restores it to around 13.25V, indicating the 240W PV modules are sufficient for daily recharging. With a total daily load of about 767W, the system maintains stable battery performance and effective energy recovery, confirming it is well-matched to the load and reliably meets energy demands.

Asian Journal of Basic Science & Research
Volume 7, Issue 3, Pages 39-57, July-September 2025

3.3. System Overview and Design Criteria

The complete specifications and performance benchmarks are summarized in Table 5.

Table 5. System Overview and Design Criteria

Component	Picture	Specification	Energy Efficiency/Storage Contribution
Solar Panel		240W monocrystalline	High-efficiency conversion 15-20%, and can reach up to 23% in the most advanced designs. suited for limited sunlight hours
UVC Light		Qty. 2 x 15W submersible, 254 nm	Targeted wavelength ensures rapid pathogen kill, minimizing energy use
LED Street Light		50W Street Light LED	75% less energy, and last up to 25 times longer, than incandescent lighting.High lumens per watt; optimized for wide coverage and lower power consumption
Battery		1 lead acid battery, 12 V, 150Ah	Deep cycle, 70–80% energy efficiency, coulombic efficiency of 85% to 95%, reliable for moderate off-grid applications
Inverter		Pure sinewave, 12V–220V, 1,500W	Converts DC to clean AC output; reduces conversion losses and protects electronics

Charge Controller		PWM, 12V 20A	Prevents overcharging, manages charging cycles for longer battery life
Relay		Relay Panels 12V, 100A	Relay panels can contribute to both energy efficiency and energy storage, particularly in industrial and building automation contexts. They can be used to automate energy-efficient switching, reduce standby power consumption

3.4. Water Quality Improvement

Experiment 1: Water Quality Improvement

Using water from a dirty, unused faucet in Bacolor, Pampanga, researchers tested the effectiveness of a 20W UV-C light (wavelength unspecified) in reducing Total Coliform and E. coli levels. The UV-C light was submerged in a water drum for 20 minutes. The treated sample was submitted for analysis, with results available after seven working days.

Table 6. Experiment 1: Water Quality Improvement

Experiment 1 (Results)	PNSDW Limit	Total Coliform	*E. Coli*
Raw Water	Less than 1.1 MPN/100ml	Greater than 8.0 MPN/100ml	Greater than 8.0 MPN/100ml
After Procedure (20 mins using UVC light)	Less than 1.1 MPN/100ml	Greater than 8.0 MPN/100ml	2.6 MPN/100ml

Experiment 2: Water Quality Improvement

Water from an old, unused deep well in Porac, Pampanga was treated using two 15W UV-C lights (254 nm) powered by solar energy. The lights were installed inside a galvanized tank and submerged for 10, 20, and 30 minutes to assess the optimal exposure time for reducing Total Coliform and E. coli levels. Treated samples were submitted for analysis, with results available after seven working days.

Table 7. Experiment 2: Water Quality Improvement

Experiment 2 (Results)	PNSDW Limit	Total Coliform	*E. Coli*
Raw Water	Less than 1.1 MPN/100ml	Greater than 8.0 MPN/100ml	Less than 1.1 MPN/100ml
After Procedure (10 mins using UVC light)	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml
After Procedure (20 mins using UVC light)	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml
After Procedure (30 mins using UVC light)	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml	Less than 1.1 MPN/100ml

3.5. Comparison with Traditional System

Table 8. Comparison with Traditional System

Aspect	Traditional Systems	SHIELD System
Power Source	Electricity from the grid or diesel generators	Solar panels with energy storage
Lighting	Streetlights powered by the grid, often limited in rural areas	LED streetlights powered by solar, independent of grid infrastructure
Water Disinfection	Chlorination or boiling, costly and time-consuming	UV-C disinfection powered by solar energy, chemical-free
Infrastructure Cost	High due to wiring, poles, fuel, or chemicals	Moderate initial cost, minimal operating cost
Maintenance	Frequent maintenance for electrical lines and chlorination	Minimal maintenance, mostly cleaning and checks
Environmental Impact	CO_2 emissions or chemical waste	Eco-friendly, clean energy, no harmful byproducts
Resilience to Power Outages	Prone to failure during blackouts	Operates independently from the grid

4. Conclusion

The SHIELD (Solar-Powered Hydraulic Infrastructure for Enhanced Lighting and Disinfection) project successfully addressed water quality and accessibility issues in Sitio Camachile, Nabuclod, Floridablanca by integrating a solar-powered UV disinfection system and LED lighting. Laboratory tests confirmed that the system effectively eliminated microbial contaminants, making the water safe to drink. The 240W solar setup demonstrated the feasibility of off-grid solutions, and lighting significantly improved night-time accessibility and safety. To fully realize the system's benefits, it is recommended that the SHIELD system be installed in the actual community once the damaged Hydram water source is restored. For future improvements, replacing lead-acid batteries with lithium-ion alternatives is advised to enhance sustainability and efficiency. The project should also be expanded to other water stations in the area to ensure equal access to safe drinking water. Enhancing system resilience through added battery storage, automating UV and water tank operations, and establishing routine monitoring and maintenance are critical for long-term functionality. Collaboration with Local Government Units (LGUs), Non-Governmental Organizations (NGOs), and private sectors is encouraged for funding and scalability. Lastly, future research should focus on advanced renewable energy and disinfection technologies to optimize system performance and extend its application to other underserved communities.

5. Future Recommendations

1. Use Lithium-Ion Battery Systems – Replace lead-acid batteries with lithium-ion alternatives for higher efficiency, longer lifespan, and reduced maintenance.

2. Incorporate Automated UV Operation – Automate UV light activation using water flow sensors to optimize energy use and extend lamp life.

3. Standardize SHIELD Kits – Develop preconfigured kits for fast replication across rural or disaster-prone communities.

4. Implement Motion-Sensor Street Lights – Add motion-detection features to conserve energy when no activity is detected near water stations.

5. Conduct Regular Community Training – Offer community-based training on system maintenance and water safety to promote local ownership and sustainability.

Declarations

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Competing Interests Statement

The authors declare that they have no competing interests related to this work.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

Availability of data and materials

Authors are willing to share data and material on request.

Institutional Review Board Statement

This study was approved by the Institutional Review Board of Don Honorio Ventura State University, Philippines.

Informed Consent

Informed consent was obtained through proper briefing before any interviews or activities.

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