Water-Lifting System to Improve Water Access and Livelihoods for Gabsongkeg Village

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Abstract: This paper presents a comprehensive approach to collecting and analyzing data to select the components for a solar-powered water pumping system in Papua New Guinea (PNG). The aim is to enhance access to clean water in rural and urban areas. Despite the abundance of water in PNG, limited access due to technological constraints has been a significant challenge. While studies have underscored the need for proper water access, it needs to receive more attention. The primary constraints in delivering water services include the need for appropriate policies and budget mechanisms to monitor rural and urban water expenditures.

Furthermore, the country's water supply is heavily reliant on electricity, and the high cost of electricity and rugged terrain inhibit water access in rural areas. Nevertheless, PNG has the potential to harness renewable energy and provide affordable electricity to rural areas, thus improving water supply. Solar power, particularly photovoltaic technology, is feasible due to its cost-effectiveness and sustainability. Despite initial installation costs, the long-term benefits outweigh the setup expenses. A 200W PV panel array is employed to power a 160W pump designed to satisfy the domestic water requirements of a single household and store up to 2000L of water.

Keywords: *Development, Gabsongkeg, Renewable Energy, Technology, Solar, Water-Lifting.*

1. Introduction

The necessity for primary water sources and adequate sanitation facilities remains a pressing issue in Papua New Guinea. A study conducted in 2010 revealed that 61% of the population is either partially served or needs access to safe drinking water, and 58% need improved sanitation solutions (SDA, 2013, PNGMDP, 2010). The subsequent decades have seen a stark rise in the populace alongside a decrease in the provision of essential government services, resulting in a substantial increase in the percentage of individuals lacking access to water and sanitation, now at 79% and 67%, respectively. Furthermore, less than 10% of Papua New Guinea's 8.6 million residents are connected to the national power grid (NRCS, 2010). The grid's electricity is predominantly produced through diesel, hydro, and thermal. However, this supply needs to be improved, leading to frequent disruptions nationwide. The geographical terrain further complicates the extension of electrification to remote locations, exacerbating the water scarcity issue due to the energy deficit. Despite these formidable challenges, Papua New Guinea has a significant opportunity to leverage renewable energy sources to alleviate these issues by providing cost-effective and sustainable electricity, especially to disenfranchised rural communities. This could facilitate the operation of water supply systems.

In rural sectors, the prevalent methods of water procurement involve the collection of rainwater and extraction from creeks, springs, and wells. While water is plentiful in PNG, the ease of access and risk of contamination pose substantial challenges (Bettina, 2022). Individuals often undergo lengthy journeys to procure clean water, relying on rudimentary rope-and-pulley systems to extract water from wells, a process fraught with health and safety risks, particularly for women and children tasked with water collection. During arid periods, the reliance on rainwater tanks and surface water from creeks and rivers is untenable. Groundwater extraction via wells becomes a critical resource during these times. Although solar water pumping systems are well-established in developed nations, they are a relatively novel concept in Papua New Guinea. They warrant further exploration and substantial investment for widespread implementation and public awareness initiatives. Utilizing renewable energy for rural water supply is an academic suggestion awaiting governmental or external support for actualization.

This paper proposes adopting a solar-powered water pumping system as a viable solution to the rural water supply issue in Papua New Guinea (Tinglin, 2014; Subrata, 2023). The analysis, centered on a single household, explores the system's feasibility for broader application, potentially at a village scale. The broader attention towards harnessing renewable energy within the country could play a pivotal role in achieving the Sustainable Development Goals and realizing Papua New Guinea's Vision 2050.

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The project aims to design a solar-powered water lifting system in Gabsongkeg village, located in the Markham district of Morobe province. Its goal is to introduce affordable and sustainable water-lifting technology and use the easily accessible underground water in the area to enhance livelihoods.

2. Method and Materials

The system was carefully designed to pump water from the well into a storage tank, considering the expected number of people using the water for activities such as laundry and bathing. Detailed calculations determined the right size for the pump and solar panel components. Soil tests were carried out to ensure optimal functioning and to understand how quickly the well fills up on rainy days and how much water the soil can hold on sunny days. Furthermore, extensive testing was done to evaluate the quality and safety of the water for human consumption.

2.1. System Design and Setup

The survey conducted at the project site revealed a daily water requirement of 400 liters. Based on this data, the pump design flow rate was calculated to be 1.13 liters per minute, and the total dynamic head was found to be 2.4673 bar. The flow rate and total dynamic head are crucial factors in selecting the appropriate pump. Consequently, a 160W (0.2146HP) centrifugal pump was chosen using a pump performance curve to meet a single household's anticipated daily water requirement. Centrifugal pumps offer advantages such as higher operating speeds, lifting viscous liquids such as muddy water, and a higher discharge rate.

The system is best suited for a centrifugal pump due to its head, ease of design, high efficiency, smooth flow rate, ease of operation, and wide range of capacity. Utilizing the design parameters determined above, the selected pump was designed using SolidWorks (Figure 1). The rotating impeller creates suction, drawing water through the pump inlet. The rotary motion applies centrifugal force to the water, forcing it out of the pump outlet. The impeller is rotated by a motor driven by solar power as shown in Figure 1.

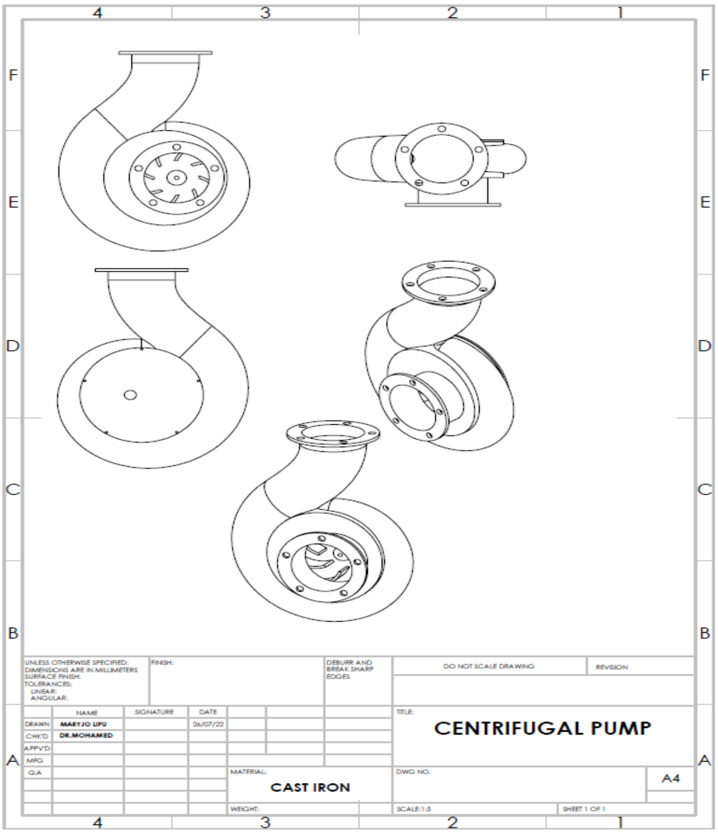

Fig. 1. Centrifugal pump design.

Table 1: PV Electrical Characteristics

Characteristics	Value	Units
Peak Power	117	Watt (Pw)
Power Tolerance	±5	Percentage%
Max Power Voltage	35.5	Volts (V)
Max Power Current	3.3	Amps (A)
Open Circuit Voltage	40.0	Volts (V)
Short Circuit Current	3.5	Amps (A)

The power rating of the pump was used to calculate that 200 watts of power from PV solar panels were needed to power the system sufficiently (Fraenkel, 1986; Chandel, 2015). According to the solar data, the panels were sized to provide 200W of power and tilted at a 6° angle, which is the optimum tilt angle for Gabsongkeg village. The size of the PV panels was determined from the Table 1. Multiple panels are connected in series to produce a steady current, with the total voltage output being the sum of each panel's voltage output. Parallel connections add up the current of each panel while the voltage remains fixed (Fraenkel, 1986; Chandel, 2015)

. The total output power of the PV array is calculated using a specific formula as shown in Equation (1):

$$P_{total} = I_{output} \times V_{output} \qquad (1)$$

Given the 200W power requirement for this system, the PV panels can be sized and selected. Since each panel has a peak power rating of 117W at 35.5V and 3.3A (Table 1), the system will use two panels to provide 117 × 2 = 234W to cater to the pump's power requirement as shown in Equations (2), (3) and (4). The panels will be connected in series, as verified below:

$$Voltage\ output = 35.5 + 35.5 = 71V \qquad (2)$$

$$Current\ output = 3.3A \qquad (3)$$

$$Total\ power\ output = 3.3\ \times 71 = 234.3W \qquad (4)$$

The calculations indicate that when the PV panels are connected in series, the power output is slightly higher than the panel's rating, providing enough energy to meet the pump's 200W power requirement. It's important to note that the parallel configuration of the panels would yield similar results to the series configuration, but the series configuration is chosen for ease of installation.

When setting up the system, the installation location must be carefully considered, considering factors such as solar shading, electric modules, wire runs, and sizes, conduit runs, trenching, controller accessibility, tank location, and pump head, among others, when designing the system layout as shown in Figure 2. For example, even a tiny shaded portion of the panel can reduce the output of the entire array, potentially stopping the pump's production. The solar PV panels convert sunlight to electrical energy, which then passes through the solar pump controller, stabilizing the voltage and creating a three-phase output to drive the pump's electric motor. Batteries are included in the system to store energy for use during periods without sunlight or at night, and the controller is responsible for charging the batteries. The pump is manually controlled to prevent the well from running dry and to avoid water overflow in the tank. The system Setup as indicated in Figure 2.

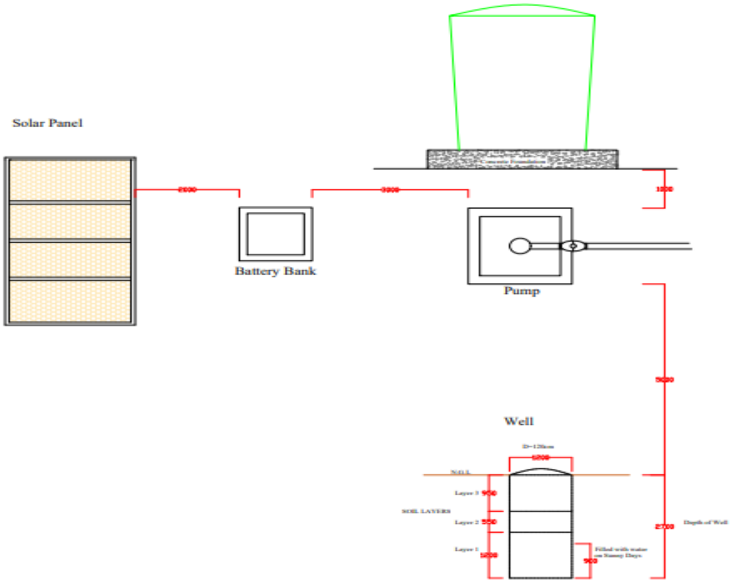

Fig. 2. System Setup Schematic.

2.2. Particle Size Distribution Test

The Particle Size Distribution Test (PSD) is conducted to determine the sizes of soil particles in a given material as shown in Figure 3. This is achieved by passing the soil sample through sieves of varying mesh sizes. The PSD is valuable for assessing the porosity and other properties of the material. The process involves weighing the sample and then oven-drying it for twenty-four hours. After drying, the sample is mixed with water to saturate the particles before sieving. Seven sieve sizes ranging from 2.36mm to 75µm are used. The soil is poured into a stack of sieves clamped to a mechanical shaker and shaken for three minutes as shown in Figure 3. The mass retained in each sieve is weighed to calculate the percentage retained and passing through each sieve.

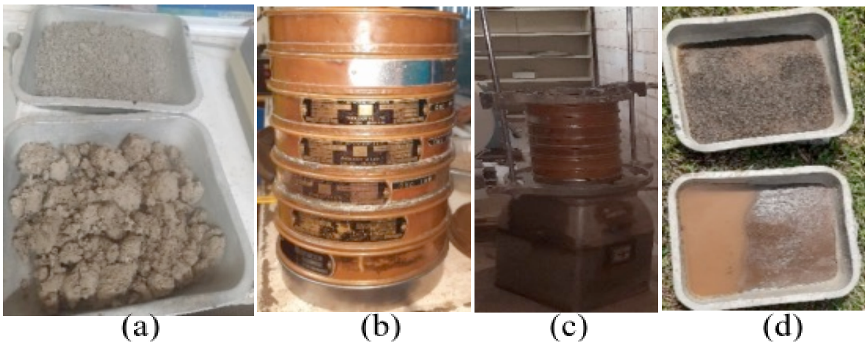

Fig. 3. (a) Samples dried in the oven; (b) arrangement of sieves; (c) mechanical shaker; (d) samples dried in the sun.

2.3. Atterberg test

The Atterberg test is used to determine the type of soil present in a soil sample by monitoring the moisture content of the soil. The consistency and behavior of soil is directly influenced by its moisture content. Increase in moisture content causes the transition of silty and clay between four phases: solid, semi-solid, plastic and liquid phase. Atterberg test defines the liquid, plastic and shrinkage limits by carefully controlling the moisture content while monitoring the physical changes.

The steps in the Atterberg test for the liquid limit are as follow: the soil sample is first mixed with water to form a paste and cured for twenty-four hours. A portion of the paste is then spread in the brass cup of the liquid limit machine which is set to a 10mm height. The paste is divided from the center of the cup to the edge using a grooving tool. The crank is then turned and the number of blows counted. The liquid limit is reached when the two halves of the paste meet and close at any point within the groove.

To test for the plastic limit, a small portion of the paste is rolled into 1/8-inch thread on paper towel till it crumbles. The rolled pieces are then weighed in weighing cups before drying on a hotplate for twenty-four hours. The dried sample is weighed again to find the moisture content, which will determine the plastic limit at which the rolled thread crumbled as shown in Figure 4.

The shrinkage limit test is conducted by molding the soil paste into a shrinkage mold and air-drying for twenty-four hours to determine if the soil will shrink. The amount of shrinkage measured will determine the plastic limit and indicate the type of soil as shown in Figure 4.

Fig. 4. (a) Casagrande cup containing soil for the liquid limit test (b) shrinkage mold containing soil for shrinkage limit test.

2.4. Water testing

The main reason for testing a water sample is to assess its quality and determine if it's safe for drinking and another household uses. The testing process follows standard procedures, including tests for hardness, turbidity, total solids, pH, total and fecal coliform, color, nitrate, calcium, and fluoride. The test focuses on the total coliform and fecal coliform, as they indicate the presence of bacteria in the water (Bettina, 2022; Tinglin, 2014A; Cong, 2011).

3. Result and Discussion

The results from soil tests carried out on the samples as shown in Figure 5.

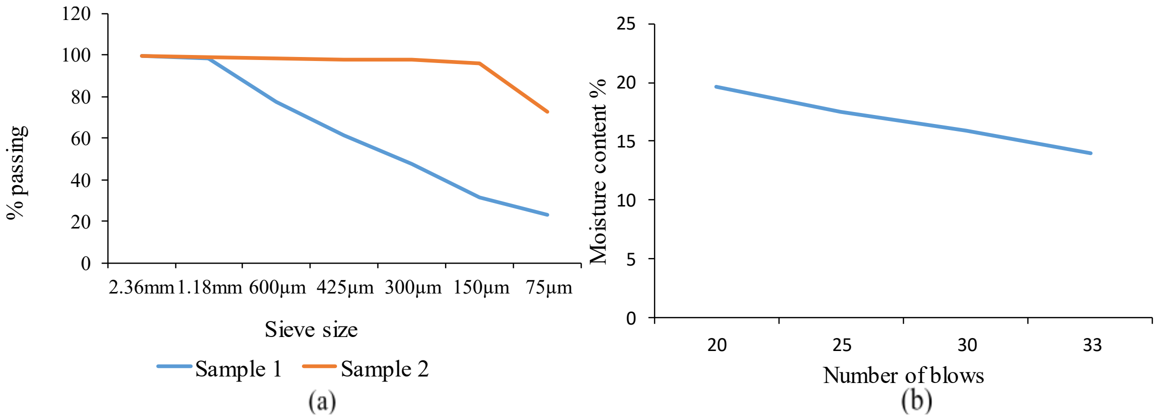

Fig. 5. (a) Percentage passing vs. Sieve size, (b) Atterberg liquid limit graph.

In Figure 5(a), the results of two soil layers are plotted on the same axis. The graphed data of mass percentage passing at various sieve sizes shows that as sieve size decreases, passing mass also decreases. This holds for both samples. From the characteristic behavior of each sample, it can be evaluated that sample one is of silty sand composition and sample two is clay. The clay sample indicates a much lower percentage of passing than silty sand through a 75µm sieve. A low percentage passing means better retention, indicating higher water holding capacity.

The Atterberg test confirmed these results in Figure 4(b), showing that silt sand is a non-plastic material while clay is a plastic material. Clay undergoes shrinkage due to its composition, which allows for better water retention. When the water evaporates, the material shrinks. On the other hand, silty sand does not contain binders in its composition, which helps retain water and thus has no shrinkage. In determining the liquid limit of the clay material, it is seen that the higher moisture content of the material results in fewer blows and vice versa.

The identified soil type and characteristics are of great significance for the health of the water source as they show how the well will be able to retain water (Table 2). Silty sand is found at the bottom of the well, and clay is in the layer above it. The higher percentage passing of silty sand allows the healthy water to be replenished from the underground reservoirs. At the same time, the layer of clay ensures water is not rapidly depleted or evaporated, particularly in dry seasons of little rainfall.

Table 2 showing the water sample was tested, and the results are below World Health Organization (WHO) standards.

Table 2: The results of the water test that was conducted are listed in the table.

Analysis	Analysis Result	Standard Minimum Concentration	Standard Maximum Concentration
Coliforms, Faecal	0 colonies/100ml	Not acceptable	Not acceptable
Coliforms, Total	2200 colonies/100ml	Not acceptable	Not acceptable
Color, Apparent	75 Hazen	5	15
Total Solids	710 mg/L	500	2000
Turbidity	22 N.T. U	1	5

It can be seen that the above test results deviate from the standard acceptable limits.

For the total coliform test, both the fecal and total coliform tests are carried out. Fecal coliform refers to the coliform bacteria found in human and animal feces, while total coliform covers all types of coliform bacteria. The test results show (as shown in Table 2) that the well water sample contains 2200 colonies/100 ml. because of this, the water is not fit for drinking and must be disinfected before it can be consumed [8].

Color of water is at 75 Hazen when the limit value is 15 Hazen. This shows from the apparent color that the water is not physically clean, due to high turbidity, which is shown to be 22 NTU. Hence the water required filtration to remove the suspended solids and impurities and the filtered water must be tested again to ensure all results as per standards, so that it can be deemed fit for consumption.

From the test results discussed above, it is clear the soil type determined is appropriate a well water system to be used for domestic purposes except consumption. The project is well suited for rural household applications and is estimated to cost K8463.00 for all components and setup.

4. Conclusion

This project aims to evaluate using solar energy to power a water pump to lift water from a well into a storage tank. Solar energy eliminates traditional electricity, making this project suitable for rural areas. The selection and sizing of system components are based on a review of relevant literature and prior research. Soil analysis is also crucial for this project. Soil tests are essential for identifying the soil type in the region and determining its water-holding capacity, which is necessary for estimating the well's service life. Being environmentally friendly, cost-effective, and renewable, solar energy presents a superior alternative to diesel-generated electricity. Implementing a solar-powered water pumping system is a valuable solution to the challenge of water lifting in rural areas lacking access to the power grid.

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