DEVELOPMENT OF A SOLAR-POWERED WASTEWATER PURIFYING MACHINE FOR DOMESTIC PURPOSE USING AUTOMATED FILTERING PROCESS

O. E. OGUNDAHUNSI[1*], S. O. TENIOLA[2], J. ADEOYE[3], D. O. OLADEPO[4], Z. B. SANUSI[5], I. O. AJAGBE[6], O. A. ADEAGA[7]

[1]*Department of Agricultural Engineering, Abiola Ajimobi Technical University, Ibadan, Nigeria.*
[2,4,5,6,7]*Department of Mechanical Engineering, Abiola Ajimobi Technical University, Ibadan, Nigeria.*
[3]*Department of Mechatronics Engineering, Abiola Ajimobi Technical University, Ibadan, Nigeria.*

Corresponding Author: femi.ogundahunsi@tech-u.edu.ng

Abstract
Access to safe drinking-water remains a major challenge in many developing regions, where inadequate infrastructure and unreliable electricity supply make water availability difficult. To address this, a solar-powered household water purification system was designed and tested. The system is effective, affordable, and sustainable, particularly for off-grid communities. Water samples collected from different areas of a school compound were analyzed before and after purification according to World Health Organization (WHO) standards. The untreated samples showed high turbidity, slight odor, and acidic pH levels, making them unfit for drinking. After purification, turbidity was reduced below 2 NTU, pH decrease within the recommended 6.5–8.5 range, and both total dissolved solids (TDS) and odor were significantly minimized. The system uses a solar energy setup with a panel and battery powering 12 V DC pump, ensuring continuous water flow. It incorporates three stages of filtration: a ceramic filter, an activated carbon filter, and a tap filter. For automation, an Arduino Uno, microcontroller, relay module, and water level sensor are integrated to control the system. Overall, this solar-driven purification system not only provides potable water but also promotes the use of renewable energy, contributing to better public health and reduced environmental impact.

Keywords
Solar water purification, DC water pump, Solar charge controller, Battery, Automation, Water level sensor

1. INTRODUCTION

One of the biggest problems of the twenty-first century is the worldwide water crisis, which has significant consequences for environmental sustainability, economic development, and public health [1]. Despite being a basic human right, a sizable section of the world's population still lacks access to clean, safe drinking water. The World Health Organization (WHO) estimates that 2.3 billion people lack basic sanitation facilities and 844 million people lack access to better water sources globally [2]. The widespread spread of waterborne illnesses, which continue to kill thousands of people each year, especially in rural and low-income communities, is one of the primary effects of this scarcity [3].
Despite their widespread use, traditional water purifying techniques have drawbacks. Many of these systems are highly dependent on electricity produced from fossil fuels, which are expensive and detrimental to the environment [4]. Such dependence leads to long-term environmental damage, greenhouse gas emissions, and chemical pollution from disinfection byproducts. The environmental effects of water treatment technologies must be carefully studied, as Ali [5] highlights that there is an increasing need for sustainable and effective solutions.
More emphasis has been paid to solar-powered water filtration systems as a workable and eco-friendly solution to these challenges. Solar energy is an ideal resource for powering water purification equipment since it is abundant, renewable, and available in most regions of the world, especially in remote and underserved places. These systems eliminate the need for energy from fossil fuels by utilizing solar energy to power procedures including reverse osmosis, distillation, and ultraviolet (UV) disinfection. By doing this, they simultaneously solve issues with water quality, lower waste output, promote energy independence, and significantly reduce operational expenses. However, these existing systems share common shortcomings: they do not incorporate automated pump control to stop filtration once the storage tank is full, leading to energy wastage and potential

overflow; they often lack real-time automation through integrated microcontrollers; and few are optimized for ease of use by households with no technical expertise. The current study addresses these gaps.

The effectiveness, versatility, and sustainability of solar-powered purifying technologies are highlighted by recent studies. Alharbi et al. [6] showed how solar energy might be successfully integrated with sophisticated filtering techniques to increase water quality and system efficiency. In a similar vein, Kumar [7] emphasized the significance of guaranteeing that everyone has access to clean drinking water as a crucial factor in determining human health, dignity, and socioeconomic well-being. These results corroborate the growing body of evidence showing solar-powered water purification reduces the environmental effects of traditional treatment techniques while providing a scalable solution to water scarcity.

Despite these developments, research has mostly concentrated on the environmental advantages or technical performance of solar-powered systems, frequently ignoring their scalability, affordability, and adaptation to various socioeconomic circumstances. Additionally, little research has been done on their long-term operating viability in actual environments, especially in rural off-grid populations where water scarcity is most severe. To fully establish solar-powered water filtration as a viable and sustainable solution for the world's water problems, these gaps must be filled.

By creating an automated solar-powered water purifying system with a water level sensor, the current study advances this subject. By automatically stopping the purification and pumping process when the pure water storage tank is full, the sensor maintains effective functioning. This design prolongs the life of the system, conserves solar energy, and avoids overflow and water waste. The study illustrates a low-maintenance, ecological, and community-friendly method of providing safe water in off-grid settings by combining automation with renewable energy.

2. MATERIALS AND METHOD

The following instruments were used to test raw water samples collected from three points within the school compound:

- pH: calibrated digital pH meter (range 0–14, accuracy ±0.01) and litmus paper.
- Turbidity: portable turbidimeter (NTU).
- TDS: digital TDS meter (mg/L).
- Odour and appearance: sensory assessment and Whatman No. 1 filter paper for visible suspended matter.

2.1. Design Consideration

The design of the solar-powered purification system was guided by several key considerations to ensure functionality, affordability, and suitability for the target user group (rural and peri-urban households without grid electricity access).

Energy source: Solar energy was selected as the sole power input because Nigeria, like much of West Africa, receives abundant solar irradiance (approximately 3.5–7.0 kWh/m²/day), making photovoltaic power highly reliable. Polycrystalline panels were preferred over monocrystalline due to their lower unit cost while maintaining acceptable efficiency (~14–17%) for small-scale applications.

Structural frame: Mild steel hollow sections were chosen for the support frame due to their high strength-to-weight ratio, weldability, local availability, and low cost. The frame was painted with an anti-rust primer and enamel topcoat to prevent corrosion from prolonged exposure to water and outdoor conditions. PVC pipes and fittings were used for all water-carrying connections due to their chemical inertness, flexibility, and resistance to corrosion.

Filtration media selection: A three-stage filtration sequence was adopted to balance cost with purification effectiveness. The sediment filter (5 µm polypropylene) removes gross particles; the activated carbon block filter adsorbs chlorine, organic compounds, and taste/odour-causing substances; and the ceramic tap (mineral) filter provides final micro-filtration (down to 0.5–1 µm) to remove residual bacteria and suspended fine solids. This sequence protects each downstream filter from early clogging, extending service life.

Automation and energy conservation: A float switch water level sensor was integrated in preference to more expensive capacitive or ultrasonic sensors, as it provides reliable binary switching (full/not full) adequate for this application at minimal cost. When the tank is full, the Arduino-relay circuit interrupts pump power, preventing energy wastage and tank overflow, a key novelty that distinguishes this system from similar published designs.

Scalability: The modular design allows future upgrading: a larger solar panel and battery, an additional filtration stage (e.g., ultraviolet sterilizer or reverse osmosis membrane), or a larger storage tank can be integrated without redesigning the core frame.

2.2. Block Diagram

The system functions through a modular structure that contains three essential components: the solar power unit, the water purification unit along the pumping and storage system. The solar power unit operates with photovoltaic panels alongside an available battery storage system that uses sunlight to produce electricity. The generated energy enables the operation of the water purification unit that battery, or filtration to purify water from its source. The portion of the system consisting of reservoirs and pumps enables water transportation into the purification cycle as well as provides ready access to treated water. The interconnecting network of these subsystems operating efficiently represents the overall objective of water supply systems across different environmental conditions. The system flow and movement of energy and water is depicted in the simplified block diagram shown in Figure 1. Solar-powered filtration units accept water at their inlet to generate clean water which gets stored in the tank. The design chooses simplicity alongside scaling features so it becomes adaptable to various home space needs and water quality requirements. The overview sets the base for sequential component selection procedures along with development methods which ensure complete comprehension of operational principles and system architecture.

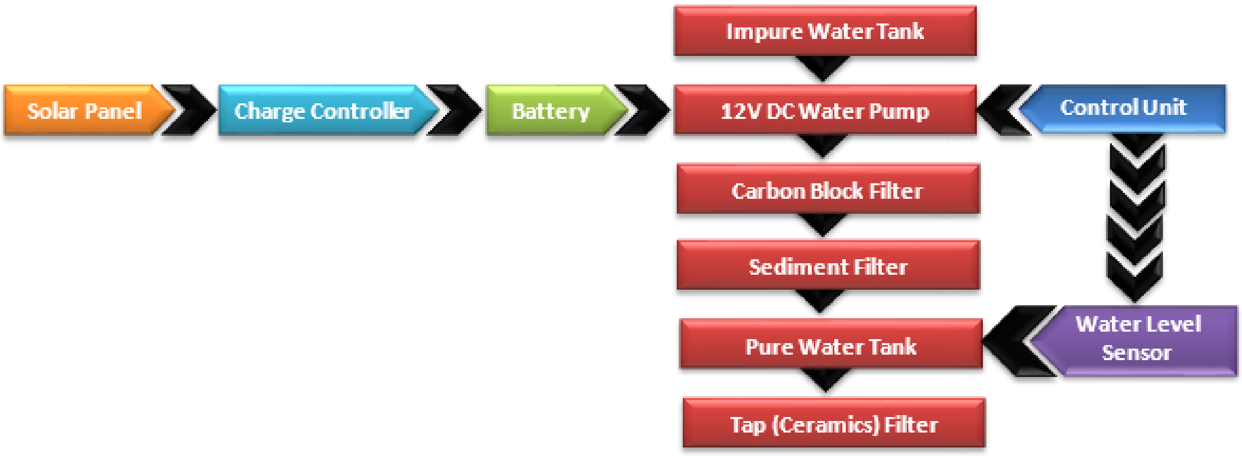


Fig. 1: Block Diagram of Solar Powered Water Purification System

2.3. Components Specification

The setup includes a polycrystalline solar panel (30W) which features sufficient power generation together with portability to be mounted onto residential roofs or temporary structures. A basic charge controller (10A rating) is selected to regulate battery charging and prevent over discharge, compatible with the 30W panel and 12V battery. For this system we are using a 12V 7.2Ah battery. The battery will ensure continuous operation during low sunlight conditions (e.g., nighttime or cloudy periods). The battery is being charged by the solar panel through the charge controller to prevent it from overcharging. The pumping mechanism enables water to move across purification stages before becoming available for household consumption. The 12V DC pump functions perfectly with solar power and delivers enough force to push through the filters. The purification unit comprises three key stages: Carbon block filter: Remove chlorine, organic compounds and unpleasant odors, improving taste and reducing chemical contaminants. Sediment Filter: captures particles such as sand, silt, and rust, preventing clogging of Subsequent filters. Tap (ceramic) filter: provides fine micro-filtration to remove bacteria and suspended solids, serving as the final purification stage before water consumption (Adeniran, et al., 2021). The sediment filter used in this system is a standard polypropylene spun fibre cartridge housed in a transparent polypropylene casing. The filter medium is manufactured from melt-blown thermoplastic polypropylene (PP) fibres densely wound around a rigid PP core to form a gradient-density structure. The gradient density (with pore sizes ranging from approximately 30 µm at the outer surface to 5 µm at the inner core) enables progressive particle capture of sand, silt, rust flakes, clay, and other fine particulates. The control unit automates the system's operation. An Arduino Uno microcontroller processes input from a water-level sensor installed in the pure water tank. When the tank reaches full capacity, the relay module cuts power to the pump. This design ensures energy efficiency, prevents overflows, and reduces the need for manual intervention.

2.4. Reverse Osmosis (RO) and Membrane Filtration

In contrast to conventional filtration methods that use a mesh or filter to eliminate particles, reverse osmosis (RO), shown in Figure, 2 is a pressure-driven separation technique utilizing a semi-permeable membrane alongside cross-flow filtration concepts. Reverse osmosis water purification delivers the highest degree of filtration [8]. The reverse osmosis membrane functions as a blockade against all salts and inorganic substances, in addition to organic compounds with a molecular weight exceedingly roughly 100 [8].

The process works by applying high pressure to force water through the membrane while filtering out harmful substances [9].

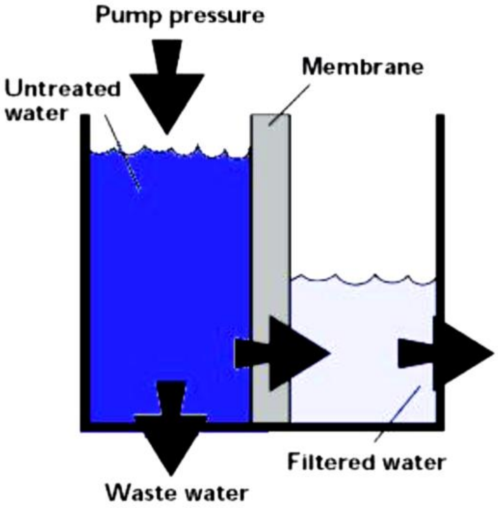


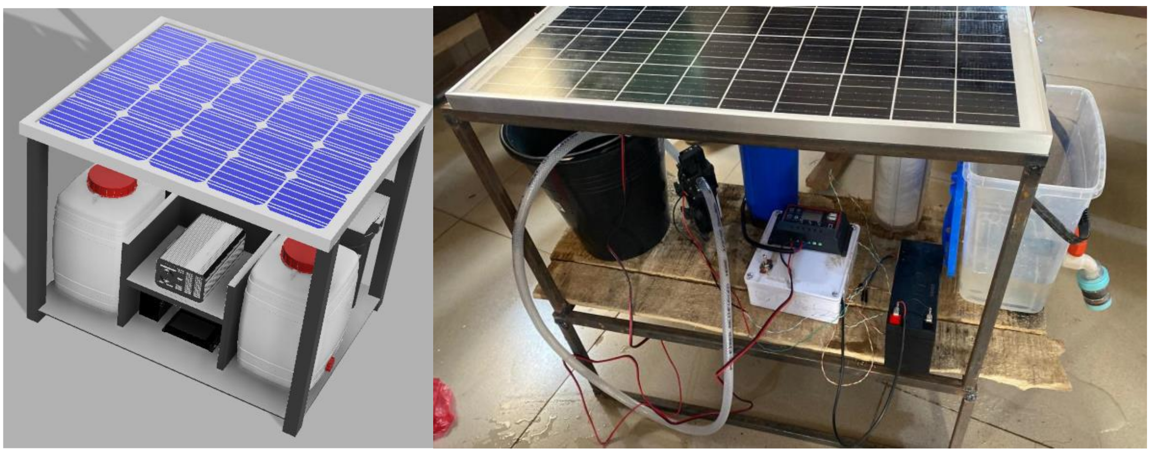
Fig. 2: RO process [9]

3. RESULTS AND DISCUSSION

This project has successfully designed a solar-powered domestic water purification system that would help in the provision of clean drinking water in a sustainable and cost-effective way. The system, as shown Figure 3, which was designed and fabricated, incorporates renewable solar energy with a three stage filtration system comprising a sediment filter, an activated carbon filter and a ceramic tap filter. A solar panel and a battery were used to power a 12 V DC pump, an Arduino Uno, a relay module, a water level sensor and the system was designed that way so as to work automatically.

Laboratory analysis on raw water samples taken at various points in the school indicated that the water condition prior to purification was of a low level based on the standards of the WHO with respect to turbidity, odor, and pH. The water used after purification had much better quality with the pH of the water within the WHO guidelines, the turbidity within 2NTU, and the TDS almost half, and the odor was removed. The evaluation of the performance also indicated that the solar powered system could easily keep the pump and automation unit powered up, even in off-grid settings**.**

At full load, the prototype system operates with a flow rate of approximately 2–3 L/min, as determined by the specification of the 12 V DC pump used in the system. The system incorporates a 10-litre storage tank, which can be filled within 3–5 minutes under normal operating conditions. Although the prototype utilizes a reduced power supply (30 W solar panel and 12 V battery), the selected pump is capable of maintaining this flow rate efficiently. However, due to head losses and resistance across the filtration media, the effective filtration rate is slightly reduced to approximately 1.5–2.5 L/min. This ensures a practical and steady supply of purified water suitable for household use.



(a) (b)

Fig. 4: (a) CAD drawing of Solar Water Purification System, (b) Developed Solar Water Purification Svstem

Table 1: Pre-purification results

Parameter	WHO Standard	Sample A	Sample B	Sample C	Observation
pH	6.5–8.5	6.1	5.9	6.3	Below WHO minimum of 6.5
Turbidity (NTU)	< 5 NTU	8.5	10.2	7.8	56–104% above limit
TDS (mg/L)	< 500	420	465	390	Within limit but elevated
Odour	Odourless	Slight	Noticeable	Slight	Detectable — unacceptable
Appearance	Clear	Cloudy	Cloudy	Slightly cloudy	Visually unacceptable

pH values of 5.9–6.3 fell below the WHO minimum of 6.5 across all three samples. Turbidity readings of 7.8–10.2 NTU exceeded the WHO guideline of < 5 NTU by 56–104%. Odour was detectable in all samples. These results confirm the raw water was unfit for drinking under WHO Guidelines for Drinking Water Quality.

Table 2: Post-purification results

Parameter	WHO Standard	Sample A	Sample B	Sample C	Observation
pH	6.5–8.5	7.0	6.9	7.2	Within WHO range
Turbidity (NTU)	< 5 NTU	1.8	2.1	1.5	Acceptable
TDS (mg/L)	< 500	210	230	190	~50% reduction
Odour	Odourless	Odourless	Odourless	Odourless	Acceptable

4. CONCLUSION

The results of the project verify that the constructed solar-based purifying unit can be successfully applied to household use as it is affordable and environmentally sustainable. The use of solar energy minimizes dependence on the national grid and the three-stage filtering disposal system is able to remove physical, chemical, and microbial contaminants in water. That is why the system is especially advantageous in rural and peri-urban locations where sources of clean water and electricity are scarce.

REFERENCES

[1] Ogundahunsi, O. E., Olaoye, I. O., and Fabunmi, P. A. (2024a). Determination of Thermal Efficiency and Fuel Consumption Rate of a Pressure Cooker Fueled with Blends of Waste Vegetable Oil and Kerosene. *Turkish Journal of Agriculture - Food Science and Technology*, 12(6): 1033-1038. DOI: https://doi.org/10.24925/turjaf.v12i6.1033-1038.6319

[2] World Health Organization (2019). Progress on household drinking water, sanitation and hygiene 2000-2017: Special focus on inequalities. World health Organization (WHO) and the United Nations Children's Fund (UNICEF).

[3] Adeniran, K. A., Babafemi, O. P., and Ogundahunsi O. E. (2021). Relative Coagulation Effectiveness of Baobab (Adansonia digitata L.) Seeds and Aluminium Sulphate in the Purification of Domestic Sewage. *International Journal of Scientific and Engineering Research* 12(11): 1172-1188

[4] Ogundahunsi, O. E., Akpan, G. E., Shittu, T. D., and Umani, K. C. (2024b). Biofuel production from cassava processing by-products and processing wastes. In Plant Biology, sustainability and climate change, Sustainable Cassava. *Academic Press*, Pages 311-328. https://doi.org/10.1016/B978-0-443-21747-0.00017-5.

[5] Ali, H. (2019). Evaluating the environmental footprint of water treatment technologies. *Journal of Environmental Engineering*, 12(3), 201-210.

[6] Alharbi, A., Smith, J., and Zhao, L. (2023). Integration of solar energy with advanced filtration technologies for efficient water purification. *Journal of Sustainable Water Treatment*, 15(2), 123-135.

[7] Kumar, V. (2020). Ensuring universal access to safe drinking water. A human rights perspective. *International Journal of Water Security*, 4(1), 45-57.

[8] Yang, J., Zhang, Y., and Li, H. (2019). Reverse osmosis for safe drinking water; Principles and applications. *Environmental Science and Pollution Research*, 26(14), 14256 -14268.

[9] Prakash, P., Singh, R., and Mehra, A. (2018). Advances in reverse osmosis technology for water purification: A review *Journal of Water Process Engineering*, 25(3), 125-132.