Design and Development of a Solar-powered Water Purifier Prototype

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ABSTRACT

Access to safe drinking water remains a persistent public health concern, particularly in educational institutions where students rely on shared water sources for daily consumption. Despite existing water management practices, microbial contamination and water quality issues continue to be reported, indicating the need for sustainable and accessible treatment systems. This study presents the design and development of a solar-powered water purifier prototype and evaluates its effectiveness in improving selected water quality indicators at Mindanao State University–Maigo College of Education, Science and Technology (MSU–MCEST).

An experimental-developmental research design was used. The prototype consisted of a solar panel, charge controller, rechargeable battery, power inverter, and a five-stage ultrafiltration system integrated with ultraviolet (UV) sterilization. Water samples were collected from four campus locations—the Senior High School (SHS) Building, Junior High School (JHS) Building, Administration Building, and Peace Park—and were subjected to pre-treatment and post-treatment analyses. Water quality assessment included selected heavy metal indicators using heavy metal test strips and microbiological analysis using bacterial testing kits.

Post-treatment results showed reductions in both microbiological contamination and selected chemical indicators. Cadmium (Cd), detected in several untreated samples, was not detected after treatment. Zinc (Zn) remained detectable in one post-treatment sample, indicating limited removal of certain dissolved constituents. All untreated samples tested positive for bacterial contamination, while all treated samples tested negative. These results indicate effective reduction of detectable bacterial contamination, attributed to the ultraviolet (UV) sterilization component under the conditions of the study.

Overall, the findings indicate improved microbiological and partial chemical water quality following treatment. However, limitations related to field-based testing methods, sample size, and duration constrain generalization. Further studies using laboratory-based analyses, expanded sampling, and long-term performance evaluation are recommended.

Keywords: solar-powered water purifier, water purification, bacterial contamination, solar energy, water safety

INTRODUCTION

Access to safe drinking water is essential for health, learning, and daily functioning. However, water quality from shared campus water sources cannot always be guaranteed. The World Health Organization (WHO, 2023) reported that contaminated drinking water remains a major cause of preventable disease, particularly in settings with inconsistent monitoring and maintenance systems. The United Nations (2025) identified access to safe water and sanitation as a global priority under Sustainable Development Goal 6. Similarly, Prüss-Ustün et al. (2019) identified unsafe water, sanitation, and hygiene as major contributors to global disease burden.

In the Philippines, microbial contamination, including coliform bacteria and *Escherichia coli*, has been detected in community water sources and refilling stations, indicating variability in water safety (Cambarihan et al.,

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2022; Cuenca et al., 2021). Waterborne diseases have been associated with reduced academic performance due to absenteeism and decreased concentration (Healing Waters International, 2024). Broader public health and productivity impacts of unsafe drinking water have also been documented (Tetteh & Tettey, 2025). UNICEF (2019) emphasized that access to safe drinking water and sanitation in schools is necessary to protect student health and support learning outcomes.

In response, solar-powered water purification technologies have been developed as alternative approaches to improving water quality. Methods such as Solar Water Disinfection (SODIS), ultraviolet (UV) sterilization, and solar distillation have been shown to reduce microbial contamination while utilizing renewable energy (García-Gil et al., 2021; Ahmad et al., 2024). Integration of UV-based systems into solar-powered designs has been reported to improve disinfection efficiency while maintaining energy efficiency and sustainability (Bharathi et al., 2021). In addition, solar integration reduces dependence on conventional electricity and supports improved access to clean water (Dey et al., 2024).

Empirical evidence supports the effectiveness of solar-powered purification systems. Decentralized systems have been shown to reduce bacterial contamination in community settings (Hendrickson et al., 2020). The integration of Internet-of-Things (IoT) monitoring with solar purification systems has been reported to improve operational efficiency and water quality monitoring (Ahmed et al., 2024). Solar-based purification technologies have also been identified as suitable for resource-limited settings due to their ability to support potable water production in areas with limited infrastructure (Gürsu, 2024). Ultraviolet sterilization has been confirmed as an effective method for reducing bacterial contamination in drinking water systems (Kim et al., 2022).

In the Philippine context, solar-powered water treatment systems have been reported to improve water quality and achieve community acceptance, particularly in areas with limited access to electricity (Yu Jeco et al., 2019). The Department of Science and Technology (DOST, 2021) has prioritized the development of sustainable water resource technologies. The International Renewable Energy Agency (IRENA, 2023) further emphasized that renewable energy integration supports environmental sustainability and reduces dependence on conventional energy sources.

Theoretical foundations in sustainability and public health support the development of renewable energy-based water treatment systems. Sustainable Development Theory emphasizes the balance between environmental protection, social well-being, and resource sustainability (Brundtland Commission, 1987). The United Nations Sustainable Development Goals, particularly SDG 3, SDG 6, and SDG 7, support initiatives related to health, clean water, and affordable clean energy (United Nations, 2015). The Health Belief Model also suggests that health-related behaviors are influenced by perceived risks and awareness of preventive measures (Rosenstock, 1974).

Despite increasing research on solar-powered water purification systems, limited studies have examined their application in academic institutions where students rely on shared drinking water sources. This study addresses this gap by developing and evaluating a solar-powered water purifier prototype for campus-based use and examining its performance under field conditions. It contributes to the literature by assessing the feasibility of integrating renewable energy and water treatment technologies within an educational setting.

METHODOLOGY

This study employed an experimental-developmental research design to develop a functional solar-powered water purifier prototype and evaluate its performance in improving selected water quality indicators under campus conditions. The developmental phase involved the design and construction of the prototype, while the experimental phase assessed its effectiveness in improving selected water quality parameters.

The research instrument consisted of the solar-powered water purifier prototype developed by the researchers. The system was composed of a solar panel, charge controller, rechargeable battery, power inverter, and a water purification unit equipped with ultraviolet (UV) sterilization technology.

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Water samples were collected from four locations within the MSU–MCEST campus, namely the Senior High School (SHS) Building, Junior High School (JHS) Building, Administration Building, and Peace Park, using sterile containers. Pre-treatment samples were collected to establish baseline water quality conditions and were analyzed using bacterial testing kits and heavy metal test strips to determine initial contamination levels.

The collected samples were subsequently processed through the solar-powered water purifier prototype. Post-treatment samples were then obtained and subjected to the same testing procedures to assess changes in water quality following purification.

Data were analyzed using comparative descriptive analysis. Pre-treatment and post-treatment results were compared to determine changes in bacterial contamination and selected heavy metal indicators. To improve consistency, multiple measurements using heavy metal test strips were conducted for selected samples.

Bacterial testing required a 48-hour incubation period as specified by the testing kit; thus, tests were conducted twice to ensure result consistency. Given the use of field-based testing kits and a limited number of samples, the results were interpreted as preliminary indicators of prototype performance rather than definitive measurements of water safety.

RESULTS AND DISCUSSION

The solar-powered water purifier prototype integrates solar energy with a multi-stage water purification system. Solar energy serves as the primary power source. The prototype consists of a solar panel, charge controller, rechargeable battery, power inverter, and a water purification unit equipped with ultraviolet (UV) sterilization technology.

Table 1. Technical Specifications of the Solar-Powered Water Purifier Prototype

Component	Specification
Water Purification Unit	Five-Level Universal Ultrafiltration System
Filtration Technology	Ultrafiltration (UF) with UV Sterilization
Maximum Flow Rate	250 L/h
Operating Pressure	0.1–0.3 MPa
Energy Source	Solar Energy
Solar Battery	12V Rechargeable Battery
Power Conversion	Solar Panel, Charge Controller, and Power Inverter
Construction Materials	Food-grade PP Plastic, Coated Steel, Painted Metal
Application	Small-scale Drinking Water Purification

The system was designed as an integrated unit combining solar energy generation, five-stage ultrafiltration, and UV sterilization. Its primary function is to enable water treatment independent of conventional electrical power sources. The integration of renewable energy supports sustainability while providing a practical approach to small-scale water purification in educational settings.

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Table 2. Materials and Components of the Solar-Powered Water Purifier Prototype

Materials/Components	Function
Water Purifier with UV Sterilizer	Purifies and disinfects water using ultraviolet technology
Solar Battery (12V)	Stores electrical energy produced by the solar panel
Solar Panel with Charge Controller and Power Inverter	Converts solar energy into electrical energy and regulates power supply
Bacteria Testing Kit	Detects bacterial contamination in water samples
Heavy Metal Test Strips	Detects selected heavy metal indicators in water

The components were selected based on availability, cost-effectiveness, and suitability for small-scale water treatment applications.

Table 3. Heavy Metal Test Results Before and After Treatment Using the Solar-Powered Water Purifier Prototype

Sample Location	Treatment Condition	Cadmium (Cd) (mg/L)	Zinc (Zn) (mg/L)	Magnesium (Mg) (mg/L)	Calcium (Ca) (mg/L)
SHS Building	Pre-Treatment (Trial 1)	5	ND	250	250
SHS Building	Pre-Treatment (Trial 2)	30	5	250	250
SHS Building	Post-Treatment (Trial 1)	ND	5	250	250
SHS Building	Post-Treatment (Trial 2)	ND	ND	250	250
JHS Building	Pre-Treatment (Trial 1)	ND	ND	425	250
JHS Building	Pre-Treatment (Trial 2)	ND	ND	425	250
JHS Building	Post-Treatment (Trial 1)	ND	ND	425	250
JHS Building	Post-Treatment (Trial 2)	ND	ND	425	250
Administration Building	Pre-Treatment (Trial 1)	5	ND	250	250
Administration Building	Pre-Treatment (Trial 2)	15	ND	250	250
Administration Building	Post-Treatment (Trial 1)	ND	ND	250	250

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Administration Building	Post-Treatment (Trial 2)	ND	ND	250	250
Peace Park	Pre-Treatment (Trial 1)	ND	ND	100	250
Peace Park	Pre-Treatment (Trial 2)	15	ND	100	120
Peace Park	Post-Treatment (Trial 1)	ND	ND	250	250
Peace Park	Post-Treatment (Trial 2)	ND	ND	250	250

Note. ND = Not Detected.

Table 3 presents the concentrations of selected heavy metals in water samples collected from different campus locations before and after treatment. Cadmium (Cd) was detected in several untreated samples from the SHS Building, Administration Building, and Peace Park. No cadmium or zinc was detected in both pre-treatment and post-treatment samples from the JHS Building. Following treatment, cadmium was not detected in any sample across all locations.

Zinc (Zn) was detected in one untreated sample and remained detectable in one post-treatment sample, indicating limited removal of certain dissolved constituents. Magnesium (Mg) and calcium (Ca) levels remained relatively consistent across most samples. Variations observed in Peace Park samples may be attributed to limitations of field-based test strip sensitivity or natural variability in source water composition rather than treatment effects. These findings highlight limitations associated with semi-quantitative field-testing methods.

Table 4. Bacterial Test Results Before and After Treatment Using the Solar-Powered Water Purifier Prototype

Sample Location	**Before Treatment**	**After Treatment**
SHS Building	Positive	Negative
JHS Building	Positive	Negative
Administration Building	Positive	Negative
Peace Park	Positive	Negative

Note. Bacterial testing was conducted on two separate occasions due to the 48-hour incubation period required by the testing kit. Results were consistent across both testing periods. Positive indicates detectable bacterial contamination, while Negative indicates no detectable bacterial contamination based on the testing kit used.

All untreated samples tested positive for bacterial contamination, while all post-treatment samples tested negative. Bacterial testing was conducted twice due to the 48-hour incubation requirement, with consistent results across both trials. This consistency indicates a uniform reduction in detectable bacterial contamination following treatment.

The results indicate reductions in microbiological contamination and partial improvement in selected chemical parameters. The absence of detectable bacteria in post-treatment samples suggests that the ultraviolet (UV) sterilization component contributed significantly to disinfection. This is consistent with Kim et al. (2022), who reported the effectiveness of UV-based systems in reducing bacterial contamination in drinking water.

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The persistence of zinc in one post-treatment sample indicates limited removal efficiency for certain dissolved heavy metals. This limitation is consistent with the functional scope of UV disinfection and physical filtration systems, which are generally more effective against microorganisms than dissolved inorganic substances.

Given the limited number of sampling sites and reliance on field-based test kits, the results should be interpreted as preliminary performance indicators rather than definitive measures of water safety. García-Gil et al. (2021) similarly reported that solar-powered disinfection systems effectively reduce microbial contamination while maintaining energy efficiency. Overall, the findings support the feasibility of integrating solar energy with water purification systems for improved water quality in educational settings.

Limitations of the Study

This study was limited by the small number of sampling locations and the short duration of testing. Water quality assessment was conducted using field-based bacterial testing kits and heavy metal test strips rather than laboratory-grade analytical methods. Consequently, the results are based on semi-quantitative and qualitative measurements rather than precise quantitative analyses.

The scope of analysis was limited to selected heavy metal indicators and the presence or absence of bacterial contamination. It did not include identification of specific bacterial species or measurement of exact contaminant concentrations.

Bacterial testing was restricted to two testing periods due to the 48-hour incubation requirement of the testing kit, which limited the number of repeated trials within the study timeframe. This reduced the extent of replication that could have strengthened result reliability.

In addition, the study did not assess long-term operational performance, maintenance requirements, energy efficiency, treatment cost, or system scalability under continuous-use conditions. Therefore, the findings primarily reflect short-term performance under controlled experimental conditions.

CONCLUSION

This study developed a functional solar-powered water purifier prototype integrating renewable energy with a multi-stage water treatment system. Test results indicated reductions in microbiological contamination, with no detectable bacterial presence in treated samples. Improvements were also observed in selected chemical parameters, particularly the non-detection of cadmium after treatment.

However, zinc remained detectable in one treated sample, indicating limited removal efficiency for certain dissolved substances. Interpretation of the findings is constrained by the small sample size, short testing period, and use of field-based testing methods instead of laboratory-grade analyses.

Overall, the results indicate improved water quality following treatment, particularly in terms of microbiological parameters. The findings support further investigation of solar-powered purification systems for application in educational settings. Future research should involve larger sample sizes, laboratory-based analyses, extended operational testing, and comparative evaluation with established water treatment systems.

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