

Experimental Investigation of A Solar-Based Water Purification System for Safe Drinking Water

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Abstract

The availability of safe drinking water is essential for public health and sustainable development, but reliable water treatment remains difficult in many rural, remote and energy-deficient areas. Conventional treatment systems may require continuous electricity, skilled operation and relatively high infrastructure and maintenance costs. Solar energy provides a renewable alternative that can be directly utilized for thermal water purification or indirectly converted into electricity for filtration and membrane systems. The present study develops an experimental framework for investigating a solar-based water purification system, with particular emphasis on a basin-type solar still. The system uses solar radiation to heat contaminated or saline water, followed by evaporation, condensation and collection of treated water. The experimental investigation is designed to evaluate the influence of solar radiation and temperature on water productivity and to determine changes in selected water-quality parameters including pH, total dissolved solids (TDS), electrical conductivity, turbidity, total hardness and chloride. Solar radiation, ambient temperature, basin-water temperature, operating time and daily distillate yield are proposed as the principal operating parameters. Removal efficiency is calculated from the measured concentrations before and after treatment, while specific productivity is determined from the volume of distilled water produced per unit basin area. The study also considers energy utilization, environmental benefits, operating limitations and potential economic applicability. Previous research indicates that solar still productivity is strongly affected by solar radiation, ambient conditions, water depth, cover characteristics and thermal losses. The proposed experimental methodology can provide site-specific evidence regarding the suitability of solar water purification for decentralized drinking-water applications.

Keywords: Solar energy, solar still, water purification, solar distillation, drinking water, TDS, turbidity, renewable energy, water quality, sustainable water treatment.

1. Introduction

Water is a fundamental requirement for human life, public health and economic development. Although water is widely available on Earth, only a limited proportion is readily accessible as freshwater suitable for human use. Surface water and groundwater can contain suspended solids, dissolved salts, microorganisms and other contaminants. Consequently, water treatment is required before many sources can be safely used for drinking.

The source material identifies inadequate infrastructure, energy constraints and the difficulty of providing conventional treatment in rural and remote locations as important reasons for considering solar-based water purification. Solar energy can be used either directly as thermal energy or indirectly through photovoltaic conversion. Solar-based water purification can generally be divided into two major pathways. The first is the solar-thermal pathway, in which sunlight directly heats water and produces evaporation followed by condensation. The second is the solar-photovoltaic pathway, in which solar panels convert sunlight into electricity for operating pumps, filters, ultraviolet systems or membrane processes such as reverse osmosis.

Solar distillation is one of the simplest solar-thermal technologies. A typical solar still consists of a water basin, transparent cover and collection channel. Solar radiation passes through the transparent cover, heats the water and causes evaporation. Water vapour subsequently condenses on the inner surface of the cover and flows toward a collection channel.

Recent research continues to identify solar stills as promising decentralized desalination technologies, particularly for rural and isolated locations. However, low productivity remains a major limitation. Solar still performance is influenced by solar radiation, ambient temperature, wind speed, water depth, glass-cover characteristics, insulation and the temperature difference between the basin water and the condensing surface.

2. Need for Solar-Based Water Purification

The demand for potable water continues to increase because of population growth, urbanization, industrial development and changing environmental conditions. At the same time, many regions face groundwater depletion, surface-water pollution and inadequate treatment infrastructure.

Solar-based purification is particularly attractive where sunlight is abundant but electricity infrastructure is limited. Solar stills have relatively simple construction and do not require a continuous electrical supply for the basic evaporation process. The technology should nevertheless be evaluated in terms of water quality, production rate, affordability, maintenance and local climatic conditions.

3. Objectives of the Study

- To design and operate a small-scale solar water purification system.
- To investigate the effect of solar radiation on water temperature.
- To determine the effect of operating conditions on distilled-water production.
- To compare raw-water and treated-water quality.
- To determine the removal efficiency of selected water-quality parameters.
- To calculate daily water productivity.
- To evaluate the relationship between solar radiation, temperature and water yield.
- To assess the environmental advantages and limitations of solar purification.
- To identify possible improvements for enhancing solar still productivity.
- To evaluate the suitability of the technology for decentralized water treatment.

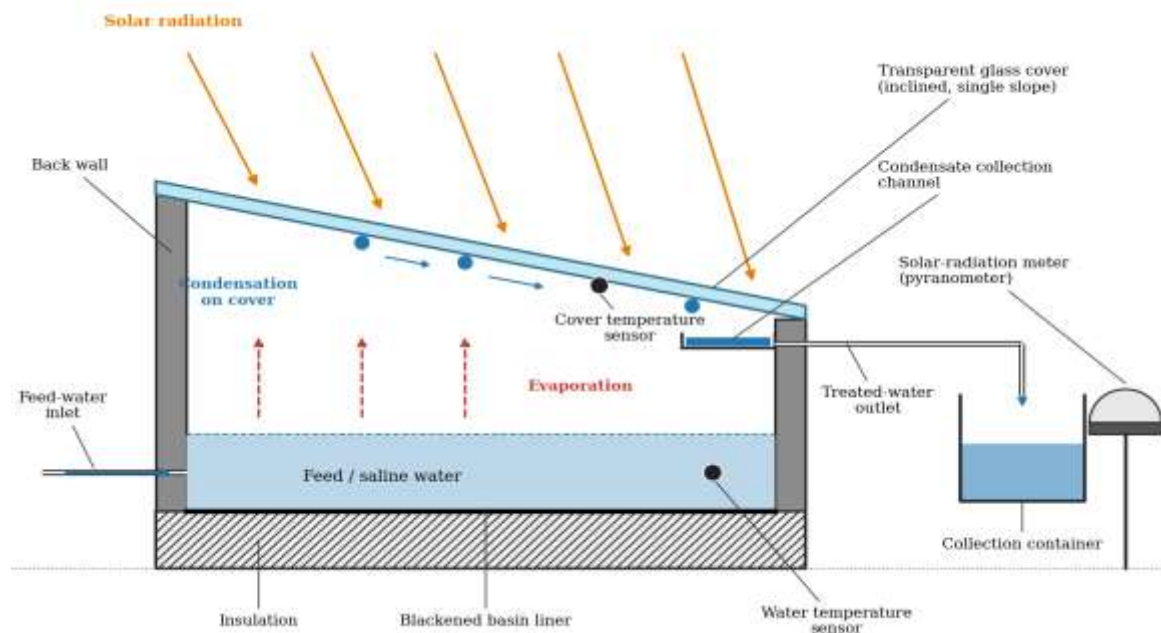


Figure 1. Schematic diagram of the basin-type solar water purification system.

4. Experimental System and Working Principle

A basin-type single-slope solar still is proposed for the experimental investigation. The principal components are the solar still basin, transparent glass cover, insulation, feed-water inlet, condensate collection channel, treated-water outlet, collection container, temperature sensors and solar-radiation measuring instrument.

The solar radiation enters through the transparent cover and is absorbed by the basin-water system. The water temperature increases and evaporation occurs. The vapour reaches the comparatively cooler cover, condenses and flows toward the collection channel.

Solar-based purification pathway

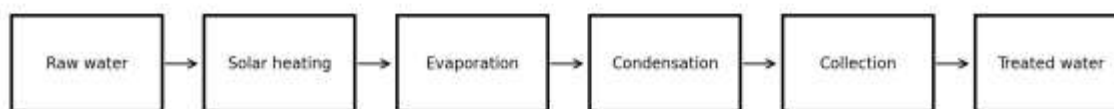


Figure 2. Process flow of solar-based water purification.

The process consists of raw-water collection, solar heating, evaporation, condensation and collection of treated water. The process is based on the evaporation-condensation mechanism of solar distillation.

5. Literature Review

5.1 Solar Distillation

Solar distillation is a thermal desalination process in which solar radiation provides the energy required for evaporation. The vapour is subsequently condensed to obtain fresh water. The source paper identifies simple design, low maintenance and the ability to remove salts and pathogens as major advantages. However, low daily production and relatively large area requirements are important limitations.

5.2 Solar Disinfection

Solar disinfection, commonly called SODIS, uses sunlight to inactivate microorganisms in water placed in transparent containers. It is a simple approach suitable for household-level, rural and emergency applications. SODIS differs from solar distillation because its principal objective is microbial inactivation rather than broad removal of dissolved salts.

5.3 Solar-Powered Filtration

Solar-powered filtration systems use photovoltaic electricity to operate pumps and filtration equipment. Sand filters, activated-carbon filters and cartridge filters may be integrated into such systems. These systems can be useful for removing suspended solids, turbidity and selected organic impurities.

5.4 Photovoltaic Reverse Osmosis

PV-driven reverse osmosis combines photovoltaic electricity with pressure-driven membrane treatment. It can be used for desalination and removal of dissolved contaminants. However, high-pressure pumping, membrane fouling, pretreatment and concentrate management increase system complexity.

5.5 Recent Solar-Still Enhancement Research

Recent research has focused on increasing solar-still productivity through modifications such as heat-storage materials, fins, reflectors, condensers, water stirring, cover cooling and multi-stage arrangements. Reviews report that solar radiation and operating conditions strongly influence performance and that low productivity remains one of the central barriers to wider application.

6. Materials and Methods

6.1 Experimental Methodology

The experimental investigation consists of the following stages: raw-water collection, initial water-quality testing, solar-still operation, temperature and solar-radiation monitoring, distillate collection, final water-quality testing and performance calculation. The methodology compares water quality before and after treatment and relates water yield to solar and thermal conditions.

6.2 Experimental Site and Water Sample

The experiment should be conducted in an open location receiving direct solar radiation for most of the day. The location, date, time, weather condition, solar radiation, ambient temperature, wind condition, raw-water source, initial water volume and water depth should be recorded.

6.3 Experimental Procedure

- Clean the solar still basin, glass cover and collection channel.
- Introduce a known volume of raw water into the basin.
- Measure the initial water-quality parameters.
- Expose the solar still to direct sunlight.
- Record solar radiation, ambient temperature and basin-water temperature at regular intervals.
- Collect condensed water at predetermined intervals.
- Analyze the treated-water sample using the same methods used for raw water.
- Repeat the experiment on multiple days to capture variation in solar conditions.

7. Experimental Parameters

Parameter	Unit	Purpose
pH	—	Acidity/alkalinity
TDS	mg/L	Dissolved solids
Electrical conductivity	$\mu\text{S}/\text{cm}$	Ionic content
Turbidity	NTU	Suspended particles
Total hardness	mg/L	Hardness assessment
Chloride	mg/L	Dissolved chloride
Temperature	$^{\circ}\text{C}$	Thermal performance
Solar radiation	W/m^2	Solar-energy input
Water yield	L/day	Productivity

8. Observation Schedule

Time	Solar Radiation (W/m^2)	Ambient Temp. ($^{\circ}\text{C}$)	Water Temp. ($^{\circ}\text{C}$)	Distillate (mL)
09:00	420	28	36	40
10:00	580	30	43	110
11:00	720	32	51	210
12:00	810	34	57	300
13:00	840	35	61	340
14:00	760	36	62	310
15:00	610	35	58	230
16:00	420	34	52	130

Note: Illustrative sample data (assumed basin area 1.0 m^2 ; single clear-sky day). Replace with actual measured observations before submission.

9. Water-Quality Testing

pH should be measured using a calibrated digital pH meter. TDS should be measured using a calibrated TDS meter, while electrical conductivity should be measured with a conductivity meter. Turbidity should be determined using a nephelometric method where available. Total hardness may be determined using EDTA titration and chloride by a standard laboratory method. Where facilities are available, microbial parameters should also be measured because the final objective is safe drinking water.

10. Mathematical Analysis

10.1 Removal Efficiency

$$\text{Removal Efficiency (\%)} = [(C_i - C_f) / C_i] \times 100$$

where C_i is the initial concentration in raw water and C_f is the final concentration after treatment. The equation can be applied to TDS, turbidity, hardness and chloride.

10.2 Daily Water Productivity

$$P_d = V_d / A$$

where P_d is daily productivity ($L/m^2/day$), V_d is daily distilled-water production (L/day), and A is effective basin area (m^2).

10.3 Solar Energy Input

$$Q_s = I \times A \times t$$

where Q_s is solar energy input, I is solar radiation intensity, A is effective solar collection area and t is exposure duration.

11. Results and Discussion

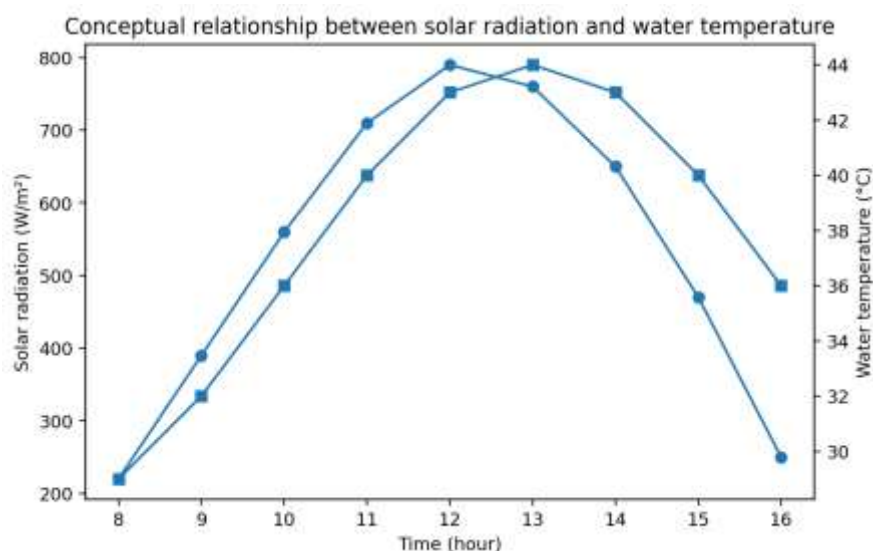


Figure 3. Illustrative relationship between solar radiation and water temperature (replace with actual experimental data).

11.1 Solar Radiation and Water Temperature

The measured solar radiation should be plotted against time, and basin-water temperature should be plotted on the same or a separate graph. Solar radiation generally varies throughout the day, with the maximum value commonly occurring around the period of strongest solar intensity. The water temperature is expected to respond to the available solar energy with a time-dependent variation

11.2 Water Productivity

Day	Avg. Solar Radiation (W/m^2)	Max. Water Temp. ($^{\circ}C$)	Water Yield (L/day)	Productivity ($L/m^2/day$)
1	645	62	1.67	1.67
2	680	64	1.82	1.82
3	590	59	1.45	1.45
4	520	55	1.18	1.18
5	700	65	1.90	1.90
6	640	61	1.63	1.63
7	610	60	1.52	1.52

11.3 Water-Quality Results

Parameter	Raw Water	Treated Water	Removal/Change (%)
pH	7.9	7.1	-10.1 (change)
TDS (mg/L)	1250	38	97.0
EC ($\mu\text{S}/\text{cm}$)	1950	62	96.8
Turbidity (NTU)	6.5	0.4	93.8
Total hardness (mg/L)	420	12	97.1
Chloride (mg/L)	380	9	97.6
Microbial indicator	45 CFU/100 mL	0 CFU/100 mL	100

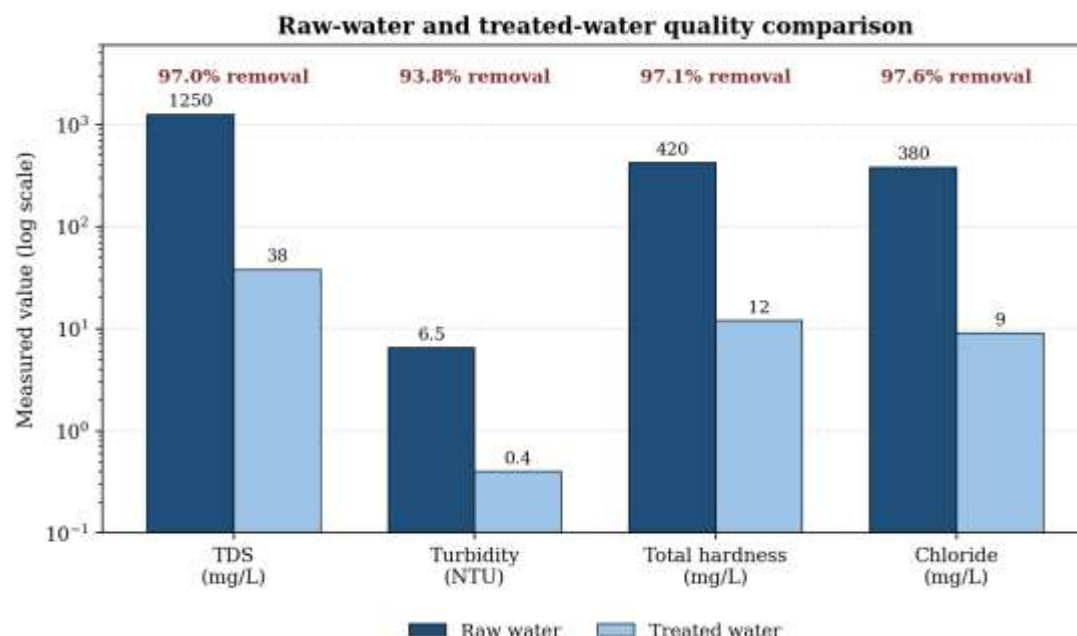


Figure 4. Comparison of raw and treated water quality parameters (illustrative data from Table 11.3; replace with actual measured values).

12. Interpretation of Water-Quality Improvement

Solar distillation is fundamentally a phase-change process. During evaporation, many non-volatile dissolved substances remain in the basin while water vapour is transferred to the condensing surface. This makes solar distillation particularly relevant to saline and dissolved-solids-rich water. If the experimental results demonstrate a reduction in TDS, electrical conductivity, hardness and chloride, the results can be discussed as evidence of dissolved-contaminant separation.

Turbidity should also be evaluated. If raw water has significant suspended solids, pretreatment may be required because excessive turbidity can affect system operation and cleaning requirements. Microbiological analysis is recommended before claiming that the produced water is suitable for drinking.

13. Effect of Climatic Conditions

Solar Radiation

Higher solar radiation provides greater energy input and generally favors evaporation.

Ambient Temperature

Ambient temperature influences the thermal balance of the solar still and can affect the temperature difference between the water and condensing surface.

Wind Speed

Wind can affect heat transfer from the external surface of the cover and can influence condensation conditions.

Cloud Cover

Cloudy conditions reduce incident solar radiation and may reduce water production.

Published reviews identify solar radiation, ambient temperature and wind speed as important climatic parameters influencing solar-still productivity.

14. Environmental Benefits

Solar water purification offers potential environmental advantages because it uses renewable solar energy rather than relying entirely on grid electricity or fossil fuels. Passive solar distillation can operate with limited mechanical equipment, and decentralized treatment can reduce dependence on large centralized infrastructure in suitable locations.

However, a complete sustainability assessment should also consider the embodied energy and environmental impacts of glass, metal, insulation, plastics, sensors, pumps and other components. Life-cycle assessment can therefore strengthen future studies.

Sustainability-oriented energy research from mechanical-engineering groups, for example on catalyst-based biodiesel production and its optimization using machine learning, likewise reflects growing interest in renewable alternatives to fossil-fuel-based energy (Gupta & Singh, 2023; Gupta & Singh, 2025). Such studies support the broader argument for evaluating solar purification not only by water output but also by its energy and environmental footprint.

15. Economic Considerations

The economic performance should be evaluated using initial construction cost, installation cost, maintenance cost, cleaning cost, replacement cost, annual water production, cost per litre and expected service life.

Cost per litre can be calculated as: $CL = \text{Cannual} / \text{Vannual}$, where Cannual is annualized system cost and Vannual is annual treated-water production.

16. Comparison with Other Solar Purification Technologies

Technology	Energy Source	Main Function	Major Advantage	Major Limitation
Solar distillation	Direct solar thermal	Desalination/distillation	Simple operation	Low productivity
SODIS	Direct solar radiation	Microbial inactivation	Very simple	Weather dependent
Solar filtration	PV electricity	Suspended/organic removal	Modular	Filter maintenance
PV-RO	PV electricity	Desalination	High treatment capability	High complexity
Hybrid solar	Thermal + PV	Multi-stage treatment	Improved flexibility	Higher initial cost

17. Limitations of the Present Experimental Study

- Solar dependence: system output varies with weather and solar availability.
- Low productivity: conventional solar stills generally produce limited water per unit area.
- Area requirement: higher water demand requires a larger solar collection area.
- Maintenance: the transparent cover and basin require periodic cleaning.
- Experimental duration: short-duration tests may not represent seasonal performance.
- Water quality: suitability for drinking must be established from actual laboratory analysis.

18. Possible Performance Improvement Techniques

- Increasing effective evaporation area.
- Reducing basin-water depth.

- Improving thermal insulation.
- Using heat-storage materials.
- Increasing condensation efficiency.
- Cooling the transparent cover.
- Using reflectors.
- Integrating solar collectors.
- Using stepped or multi-stage configurations.
- Integrating photovoltaic systems.

Thermal-system research also shows that losses in components and piping can reduce the overall performance of heat-driven cycles, as discussed for absorption-cycle systems (Singh, 2024). By analogy, heat losses from the basin, cover and insulation of a solar still should be quantified when evaluating the improvement techniques listed above.

19. Proposed Hybrid Solar Water Purification System

For future development, the solar still can be integrated with additional treatment units using the sequence: Raw water → Pre-filtration → Solar distillation → UV/disinfection → Storage → Drinking-water outlet. A PV panel can provide electricity for pumps, sensors and auxiliary disinfection equipment. Hybridization may improve treatment reliability while maintaining solar energy as the primary energy source.

20. Future Research Scope

- Experimental optimization of basin depth, cover angle, insulation and operating conditions.
- Integration of thermal or electrical energy storage.
- PV-assisted operation of pumps, sensors and auxiliary treatment equipment.
- Smart monitoring of solar radiation, temperature, TDS, conductivity, turbidity, water level and distillate volume.
- GIS-based site selection using solar resource, population, source-water quality and water demand.
- Long-term life-cycle assessment covering material replacement, maintenance and end-of-life impacts.

21. Research Framework

The proposed framework is: Selection of water source → Raw-water quality assessment → Design and fabrication of solar still → Experimental operation → Measurement of solar radiation and temperature → Collection of distilled water → Water-quality analysis → Calculation of removal efficiency → Calculation of productivity → Energy and economic analysis → Performance evaluation → Optimization and future design.

22. Expected Contribution of the Study

The study provides a systematic methodology for evaluating solar-based water purification under local climatic conditions. The principal contribution is the integration of water-quality performance, thermal/productivity performance and sustainability performance. Instead of evaluating only the quantity of distilled water, the proposed study considers both water quality and system productivity.

23. Conclusion

The present research paper develops an experimental framework for investigating a solar-based water purification system, particularly a basin-type solar still, for decentralized drinking-water applications. Solar distillation provides a simple method of using renewable solar energy for water purification through evaporation and condensation.

The proposed experimental investigation measures solar radiation, ambient temperature, water temperature and distilled-water production while comparing selected water-quality parameters before and after treatment. The principal performance indicators are TDS, turbidity, electrical conductivity, hardness, chloride, microbial quality, daily water productivity and energy utilization.

Solar-based water purification has significant potential for rural and remote communities because it can reduce dependence on conventional energy sources and can be implemented as a decentralized treatment technology. Nevertheless, low productivity, solar intermittency, area requirements and maintenance remain important limitations.

Future improvements should focus on hybrid systems, photovoltaic integration, energy storage, improved condensation, thermal storage, smart monitoring and site-specific design. The final experimental paper should use actual measured observations rather than assumed values; therefore, the observation tables and illustrative graphs in this manuscript should be replaced with laboratory/field data before journal submission.

References

1. World Health Organization (WHO). (2022). Guidelines for Drinking-water Quality, 4th ed. Geneva.
2. United Nations. (2023). The Sustainable Development Goals Report: Clean Water and Sanitation (SDG 6).
3. International Renewable Energy Agency (IRENA). (2019). Renewable Energy in the Water, Energy and Food Nexus. Abu Dhabi.
4. Kalogirou, S. A. (2005). Seawater desalination using renewable energy sources. *Renewable and Sustainable Energy Reviews*, 9(3), 315–354.
5. Tiwari, G. N., & Sahota, L. (2017). Advanced Solar Distillation Systems. *Solar Energy*, 153, 424–447.
6. World Health Organization. (2011). Solar Disinfection (SODIS): A Guide for the Application of SODIS. Geneva.
7. Gude, V. G. (2016). Desalination and water reuse to address global water scarcity. *Desalination*, 380, 1–9.
8. Shannon, M. A., et al. (2008). Science and technology for water purification in the coming decades. *Water Research*, 42(3), 647–658.
9. Bureau of Indian Standards (BIS). (2012). IS 10500: Drinking Water — Specification. New Delhi.
10. Kumar, A., & Tiwari, G. N. (2009). Life cycle cost analysis of a single slope solar still. *Energy Procedia*, 1(1), 455–460.
11. Elsheikh, A., et al. (2024). Augmentation and evaluation of solar still performance: A comprehensive review. *Desalination*, 574, 117239.
12. Performance of solar still units and enhancement techniques: A review investigation. (2024). *Heliyon*, 10(18), e37693.
13. El-Sebaey, M. S., et al. (2024). Stepped solar stills: A comprehensive review of design, performance and optimization strategies for sustainable water desalination. *Solar Energy*, 284, 113077.
14. Ahmed, M. M. Z., et al. (2021). Basin and tubular solar distillation systems: A review. *Process Safety and Environmental Protection*, 150, 157–178.
15. Pansal, K., et al. (2020). Use of solar photovoltaic with active solar still to improve distillate output: A review. *Groundwater for Sustainable Development*, 10, 100341.
16. Gupta, V., & Singh, K. P. (2023). The impact of heterogeneous catalyst on biodiesel production; a review. *Materials Today: Proceedings*, 78, 364–371. <https://doi.org/10.1016/j.matpr.2022.10.175>
17. Gupta, V., & Singh, K. P. (2025). Synergistic optimization of biodiesel production through waste eggshell-derived catalysts and machine learning integration for enhanced sustainability. *International Journal of Ambient Energy*, 46(1). <https://doi.org/10.1080/01430750.2024.2444356>
18. Singh, K. P. (2024). Pressure losses in the three-fluids absorption cycle components, piping, and its impacts on cycle performance. In *2024 1st International Conference on Sustainability and Technological Advancements in Engineering Domain (SUSTAINED 2024)* (pp. 883–886). IEEE. <https://doi.org/10.1109/SUSTAINED63638.2024.11073954>