Proceedings of the Indian National Science Academy (2026) 92:1070–1079
https://doi.org/10.1007/s43538-025-00464-5

RESEARCH PAPER

Performance analysis of solar desalination system with thermal storage material at various water depths

Mukesh Kumar[1] · Suresh Kumar Patel[2] · Vinay Mishra[1] · Balendu Shekher Giri[3] · Dhananjay Singh[1]

Received: 29 January 2025 / Accepted: 16 May 2025 / Published online: 5 June 2025
© Indian National Science Academy 2025

Abstract
The availability of reliable sources of potable water is a challenge for most people around the world. Solar desalination is an economic and sustainable technology for potable water production, as it uses abundantly available solar energy. However, the performance of solar stills is yet to match with existing conventional desalination techniques. The current study focuses on experimental investigation and performance improvement of solar desalination system with thermal storage material (pebbles) at different basin water depth varying from 0.5 cm to 2.5 cm. The solar desalination unit having a basin area of 3600 cm^2 is used for this research work. The thickness of tilted glass cover is 4 mm, making an angle of 20° with the horizontal surface. The highest productivity is obtained at 1.5 cm water depth with pebbles. Economic analysis has also been conducted for service lives of 15, 20 and 25 years.

Keywords Solar still · Solar energy · Potable water · Pebbles · Performance

Introduction

Water is very essential element on the earth crust and every living organism on the earth depends on water for his/her survival. About 70% of the earth's surface is covered with water, of which less than 1% is found in lakes, rivers, and marshes, 30% is found underground, and 69% is found in glaciers (Yadav et al. 2013; Arora et al. 2017; Bytyc et al. 2018; Alagan et al. 2023). Due to continuously rising global population, the need for drinking water is increasing day by day. Various needs of community development like industrialization, farming exercise for food are more dependent on water (Venkatesh et al. 1989; Kumar et al. 2012; Elsaid et al. 2020). Now the concept of recycling and reuse has been tremendously increasing during last few years. Recycling and reuse technique has been used in order to save every single drop of water for human mankind (Pal et al. 2017; Pal et al. 2018; Chauque et al. 2021).

According to UN Water progress report 2021, new technology needs to be developed for fresh water production. Recently, government of India issued a gazetted notification that we can drop the treated water into water bodies which will make a great benefit for the meeting the demand of human kind in terms of industrial, agricultural and domestic needs (Saadat et al. 2018; Chandanshive et al. 2018; Pratap et al. 2023; Srivastava et al. 2022). In developing nations, inexpensive natural wastewater treatment methods are highly beneficial (Hoff et al. 2019; Wang et al. 2019a, b). The cost of treatment is under the manageable condition of those families who have very less source of income for their survival (Zhu et al. 2019). The low cost technologies are also useful as they can be run without technical staff and need limited financial support. Unconventional low-cost wastewater treatment technologies are needed specially for rural communities. (Nafey et al. 2002; Kaviti et al. 2018; Rawat et al. 2018).

Distillation is a separation process involving phase change from liquid to vapour (evaporation) with the help of a suitable heat source followed by phase change from vapour to liquid (Condensation) (Kushwaha et al. 2011). The performance of the solar still strongly depends upon climatic conditions like wind velocity, relative humidity, water basin depth, solar intensity. Relative humidity has an

✉ Balendu Shekher Giri
balendushekher23@gmail.com

[1] Department of Chemical Engineering, Institute of Engineering & Technology, Lucknow 226021, India

[2] Department of Chemical Engineering, Government Polytechnic, Lakhimpur-Kheri 262701, India

[3] Sustainability Cluster, University of Petroleum & Energy Studies, Dehradun 248007, India

inverse relationship with the performance of solar stills. The yield of the solar still is marginally increased by wind speed. A solar still requires no electricity for evaporation and no moving part is involved (Nazemi et al. 2018; Bagheri et al. 2021). Water is the basic requirement for the survival of human life, without which, human life is supposed to be not possible even for 3–5 days. Humans can live without food for a month, but they cannot live without fresh water for a week. Hence, water is a fundamental necessity for human life (Kabeel et al. 2012; Hocaoglu et al. 2019; Wang et al. 2019a, b; Sen et al. 2023). Every country in this world need potable water for their development as it is the basic need of industries, schools, hospitals etc. (Garg et al. 2000; Compain 2012; WHO 2017; Gracia-Lor et al. 2012; Hejna et al. 2020; Malik et al. 2024).

Almost everything like daily food, washing clothes cannot be done without use of water and the scarcity of water affects the economic growth of any country adversely and also degrades the quality of life (Glatzmaier et al.1990; Jose et al. 2008; Manokar et al. 2014; Dawn et al. 2021). A lot of research is going across the world for the production of freshwater and use of solar still in the process of desalination is a step forward activity for this. There are several materials like nano-fluids, reflectors, water heating system, heat storage materials that are used to enhance the productivity of solar still (Abed et al. 2017; Zhanget al. 2018; Nigam et al. 2019). Several thermal storage materials e.g. pebble, sand, gravel, bricks, marble have been used in the past to increase the productivity of the solar still (Qureshimatva et al. 2015; Singh and Dwivedi 2017; Li et al. 2021). This technology is innovative as it uses solar energy to separate impurity from water. Human health may suffer if contaminated drinking water is consumed (Chen et al. 2021a; Chenet al. 2021b; Chithra et al. 2022). Thus, the drinking water crisis can be resolved with this low-cost sustainable method. Using various thermal storage materials with different conductivities has greatly increased the solar distillation unit's production.

The novelty of current study is to investigate the performance enhancement of a single slope passive type solar still with basin surface area as 0.6×0.6 cm^2. Due to its simple construction, economical, low maintenance and smooth operation, it might be proved especially useful for desert area, where access to suitable and sufficient fresh water is lacking. It generates potable water in an environment friendly manner. A passive solar still with a single slope was designed and fabricated for the current study. The solar still's performance is investigated for consecutive five days. This work is especially interesting as the performance enhancement of solar distillation system with thermal storage material (pebbles) is evaluated. The pebbles absorb solar heat during sun shine and this stored heat is released during off-shine hours, enhancing the evaporation rate inside the still and hence solar still's performance has been increased. Further, the yield of solar still was also investigated for different water basin depths. The solar still's economic analysis has also been carried out and comparison with similar works is also provided.

Materials and procedures

Setup for an experiment

A passive type solar still (single slope) was constructed on the rooftop of Chemical Engineering Department, IET Lucknow, U.P. (Latitude 26°51' N and longitude 80° 56' E) using galvanized iron sheet available in the local market (Fig. 1). The solar still side walls and basin are fabricated of 1.5 mm thick galvanized iron (GI) sheet with its thermal conductivity and density as 50 W/(m–K) and 7800 g/cm^3 respectively. The operating areas of solar still are considered like total basin area, effective condensing area and effective evaporative area are 0.6×0.6 m^2, 0.6×0.64 m^2 and 0.6×0.6 m^2 respectively. The height of north and south walls of solar still from the basin surface was taken as 0.37 m and 0.15 m respectively. However, to increase the solar absorption, complete internal area of the basin has been painted with a black dye so as to enhance the thermal performance of the experimental setup (Pal et al. 2017; Shakya et al. 2018). The setup has been covered with 4 mm thick toughened glass, which maintains its superb optical qualities to ensure that the saline water in the water basin receives the maximum amount of solar heat exposure. The cover glass's inclination angle was set to 20 degrees to maximize the system's exposure to solar radiation, which is considered as an optimal angle and its thermal conductivity and density as 1.3 W/

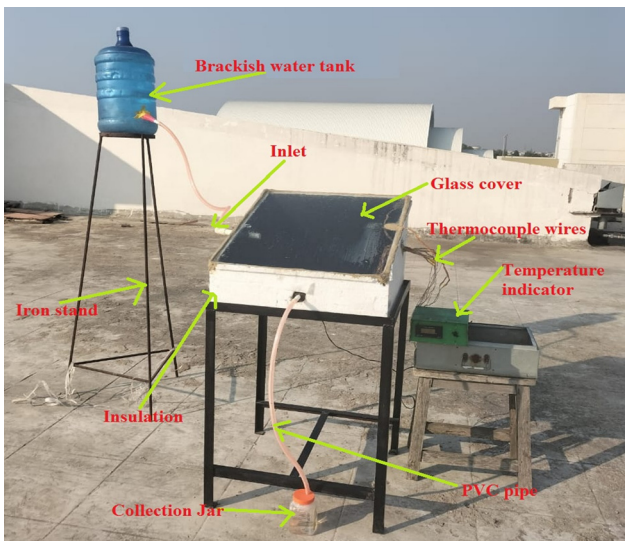


Fig. 1 Setup for an experiment

(m–K) and 2.52 g/cm^3 respectively. At this inclination angle, condensate film on inner surface of the cover glass ensures to flow smoothly (Patel et al. 2020a, b, c). The set-up has been made air tight with the help of silicon sealant. Thermocol has been used to insulate solar still because it has a low thermal conductivity of 0.035 W/(m–K) and the density of 10 g/cm^3. Feed water has been put in a 20 L water bottle which flows out through action of siphoning. The whole chamber has been made air tight so that there is no leakage from the system.

Experimental procedure

The experimental investigation has been performed from 25 to 29th February, 2024 with pebbles, at different water depth between 0.5 cm and 2.5 cm (with an increment of 0.5 cm). All the readings were taken in triplicate (Kumar et al. 2025). The basin water depth was determined to be 1.5 cm corresponding to maximum yield output.

The temperatures of basin, inner and outer glass surface, ambient temperature along with wind velocity have been measured on hourly basis from 7:00 h to 19:00 h, during the experiment.

Size and quantity of thermal storage materials

The experimental investigation has been performed by using the thermal storage material (pebbles) with fabricated single slope solar still at different basin water depths. For the experiment, 2.0 kg of pebbles with an average size of 30–40 mm are used. The smaller diameter pebbles yield more in comparison to larger diameter pebbles. Thermal energy can be effectively stored by pebbles due to its higher thermal conductivity. Pebbles increase the solar still's efficiency by expanding the surface area that is accessible for heat transfer. The following formula $Q = mc_p\Delta T$ can be used to calculate the amount of energy stored in the thermal storage material. Where, Q = heat stored in the material (J), m = mass of storage material (kg), C_p = specific heat capacity of material (J/kg.K), and ΔT = temperature difference (K). The measurement of solar radiation is made using solarimeter. Various stages of experiment using pebbles are shown in Fig. 2.

Operating principle of solar still

In solar desalination process, the solar still's basin is charged with feed water. Solar radiations enter the still through the top of the glasscover surface. Due to greenhouse effect created by the glass surface, the temperature of brackish water rises. The solar still is insulated with thermocol from all sides to minimze heat loss. The water gets evaporated by absorbing solar thermal energy and water vapours are created. The molecules of the vapour near the walls collide with it through molecular collisions and adhere to it in order to release heat and undergo a phase transition from vapor to liquid during the condensation process.The condensate makes a thin layer on the inside surface of the glass as it flows downward due to the cover glass's slope. Since the glass cover's slope is optimized, condensate could adhere to the surface and flow easily. Finally, the condensate is received with the help of collection pipe in a measuring jar. This is illustrated below in Fig. 3 (Subramani et al. 2015; Zarzoum et al. 2017; Patel et al. 2020a, b, c; Khan et al. 2022).



Fig. 2 **a** Pebbles, **b** pebbles in still, **c** operating still with pebbles, **d** solar power meter

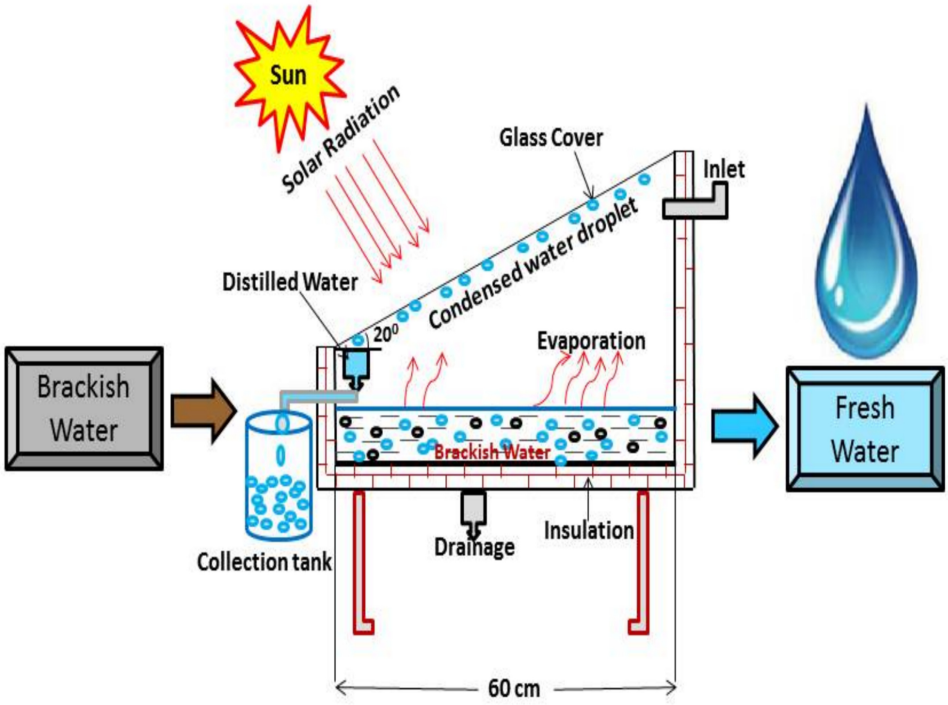


Fig. 3 Schematic of single slope solar still

Uncertainty analysis

Uncertainty refers to the range, within which, the true value of any measurand may lie. Each measurement includes some uncertainty. Therefore, it becomes necessary to carry out uncertainty analysis for experimental works (Farrance et al., 2012). It may broadly be classified as internal and external uncertainty. Internal uncertainty refers to the uncertainty associated with the measurement process while external uncertainty is due to other reasons including instrumental uncertainty.

The internal uncertainty for the experimental work is estimated using the following expression (Patel et al. 2020a, b, c)

$$U_i = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \cdots + \sigma_n^2}}{N} \tag{1}$$

$$\sigma = \frac{\sqrt{\sum \left(X_i - \overline{X}\right)^2}}{N_o} \tag{2}$$

$$\%Internal\ Uncertainty = \frac{U_i}{Mean\ of\ total\ observation\ \left(\overline{X}\right)} \tag{3}$$

where, U_i is the internal uncertainty, σ is the standard deviation, N is the number of sets, $X_i - \overline{X}$ is the mean deviation, and N_o is the number of observations.

The external uncertainty is mostly caused by the measurement devices employed during the experiment. As a rule of thumb, the uncertainty of a measuring device should be within 20% of the least count (Son et al. 2020).

The accuracy of measurement results can be affected by instrument uncertainty. Thermocouples, temperature indicator, anemometers, and measuring cylinder are some of the instruments used to measure various parameters during the experiment. The temperatures at different location within the still are measured using thermocouples (type-T, Copper/Constantan). A summary of the instruments' technical specs is listed in Table 1 (Petersen et al. 2019).

Thermal efficiency of solar still

The solar system's overall thermal efficiency still is defined as the ratio of the total distillate output (total heat transfer rate) to the total heat input (the total amount of heat incident as solar thermal radiation) into the solar still (Garg et al. 2015; Sharron 2015). It is represented as follows:

$$\eta_0 = \frac{\sum \dot{m}_{ew} \times L_{vap}}{\sum (I(t) \times A_{ss} \times 3600)} \tag{4}$$

Similarly, the single slope solar still's overall thermal efficiency can be expressed as follows:

Table 1 Technical specifications of instrument used

S. No	Instrument	Accuracy	Range
1	Solar power meter (Tenmars,TM-206)	±1 W/m^2	0–1200 W/m^2
2	Calibrated thermocouple (T type)	±1 °C	0–250 °C
3	Digital temperature indicator (12 channels)	±5 °C	− 20–450 °C
4	Anemometer (AVM-01, MATRAVI)	±5%	0–30 m/s
5	Humidity (HD-303) & Temperature (HTC) meter	Temp±1 °C RH±5%	Temp (10–60 °C) RH (0–100%)
6	Measuring cylinder	±5 mL	0–500 mL

$$\eta_0 = \frac{\sum_{i=1}^{i=12} \dot{m}_{ew} \times L_{vap}}{\sum_{i=1}^{i=12} I(t)_{input} \times dt} \times 100 \quad (5)$$

The values of I(t)input and I(t) are considered as zero when there is no sunshine, where I(t) and $I(t)_{input}$ are the solar intensities (W/m^2), m_{ew} is the mass of evaporated water (kg/m^2), L_{vap} is the latent heat of vaporization (kJ/kg), and η_0 is the overall thermal efficiency (Pratap et al. 2013; Awasthi et al. 2018; Singh et al. 2023).

The following formula can be used to determine the latent heat (heat of vaporization):

$$L_{vap} = 3.1615 \times 10^6 \left[1 - \left(7.616 \times 10^{-4} \times T_v\right)\right] for\, T_v > 70°C \quad (6)$$

$$L_{vap} = 2.4935 \times 10^6 \begin{bmatrix} 1 - \left(9.4779 \times 10^{-4} \times T_v\right) \\ +\left(1.3132 \times 10^{-4} \times T_v^2\right) \\ -\left(4.7974 \times 10^{-9} \times T_v^3\right) \end{bmatrix} for\, T_v < 70°C \quad (7)$$

Result and discussions

The performance of passive type solar still has been studied based on operational parameters such as thermal storage material (pebbles) and water basin depth. The pebbles absorb solar energy during sun shine. The stored energy is released during off-shine hours enhancing evaporation rate inside the solar still and hence, the solar still's performance has been increased. The different water depth used in this experiment varies from 0.5 cm to 2.5 cm with an increment of 0.5 cm daily. Hourly readings are taken from 7:00 h to 19:00 h, during the experiment.

Figure 4 depicts the variation (hourly) of solar radiation during 25–29 February, 2024. The solar radiation progressively rises until mid-day (noon time) and after that it falls till evening. The maximum amount of solar radiation was observed to be 840 W/m^2 at 14:00 h on 29 February, 2024.

Figure 5 shows the variation (hourly) of ambient temperature during 25–29 February, 2024 and the maximum ambient temperature was observed to be 28 °C at 14:00 h on 29 February, 2024. Figure 6 represents the variation (hourly)

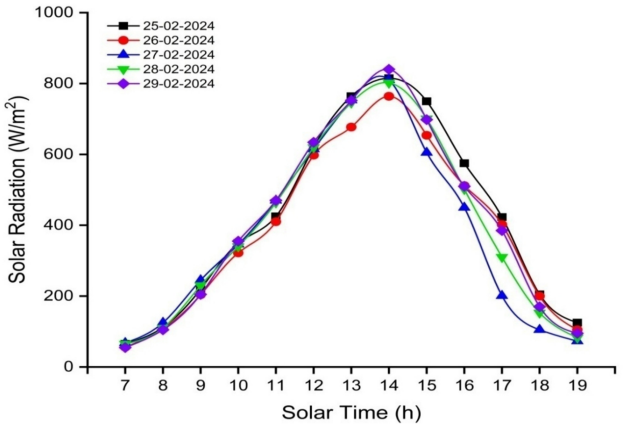


Fig. 4 Hourly variation of solar radiation with solar time

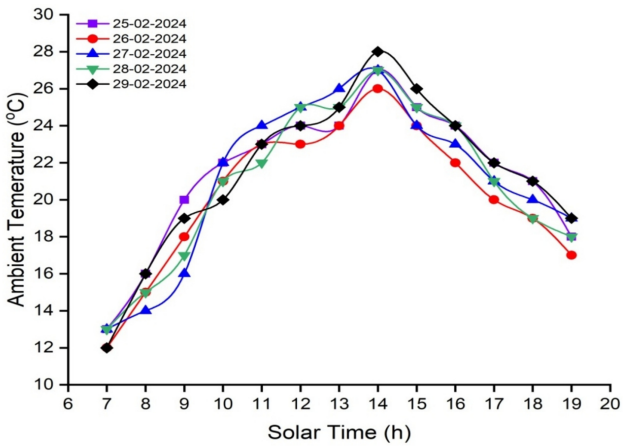


Fig. 5 Hourly variation of ambient temperature with solar time

of temperatures (basin, water, and vapour) inside the still. The maximum basin, water and vapour temperatures were recorded to be 38.7 °C, 36.5 °C, and 37.2 °C at 13:00 h on 27 February, 2024, respectively. At first, the temperature in the basin surface is lower than the ambient temperature. The temperature of basin surface rises quickly as the ambient temperature rises due to the greenhouse effect. The glass cover's surface and the black paint or dye's ability to absorb

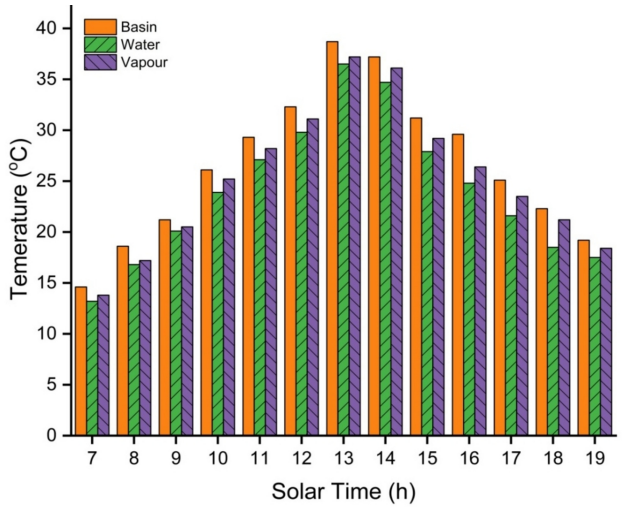


Fig. 6 Hourly variation of basin, water & vapour temperatures on 27.02.2024 with solar time

solar heat combine to provide a greenhouse effect. The basin water begins to heat up and evaporate because of the rising temperature in the basin. The vapour temperature is found to be higher than that of water temperature because it contains latent heat of vaporization. The water vapours condense upon contact with the inner surface of glass cover as the inside temperature (glass cover) is significantly lower than the vapours. The entire process is driven by the temperature differential between the water and inner glass cover surface.

The variation (hourly) of outer glass cover and inner glass cover temperature are represented in Fig. 7. The maximum amount of glass cover temperature at inner and outer surface was recorded to be 37.2 °C, and 34.9 °C at 13:00 h respectively.

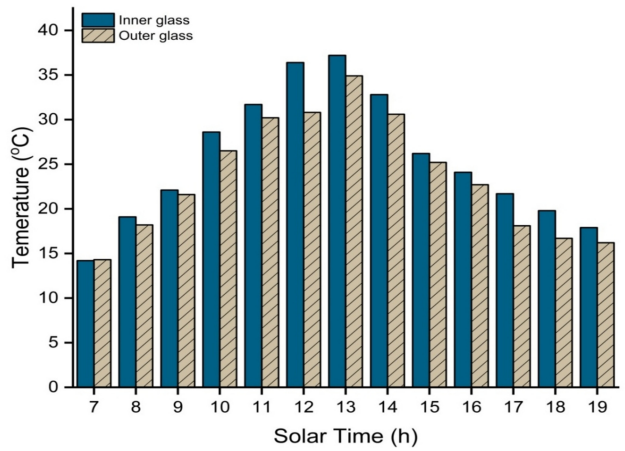


Fig. 7 Hourly variation of inner and outer glass surface temperature with solar time

Thermocol, an insulating substance, prevents heat loses from the solar still in atmosphere. The yield of the solar still (hourly variation) with the effect of thermal storage material (pebbles) is shown in Fig. 8. The variation (hourly) of yield is found to follow the solar radiation exposure. It is found that the hourly variation in yield follows the solar radiation. The maximum hourly yield was recorded to be 152 mL/h at 13:00 h on 25 February, 2024. In order to improve the evaporation rate inside the still and enhance its performance, the pebbles absorb solar heat during the sun-shine and release it during the off-shine. Pebbles improve the properties of heat transfer, which increases the rate at which basin water evaporation occurs.

This can be majorly attributed to excellent thermal properties of pebbles. Pebbles improve the rate of heat transfer of basin water by efficiently absorbing solar heat. Consequently, the evaporation rate rises, increasing the solar output even further. The variation of cumulative yield of the solar still is shown in Fig. 9.

The experiments were conducted at IET, Lucknow at five different basin water depths (0.5, 1.0, 1.5, 2.0 and 2.5 cm). The yield of solar still is significantly influenced by the basin water depth. The maximum cumulative production was found as 932 mL at a water depth of 1.5 cm in the basin. The yield evaluated at the lower water depth (1.0 cm) was as 7.19% lower than the results obtained at the 1.5 cm basin water depth. At the higher water depth (2.0 cm), it was as 6.9% lower than the results obtained at the 1.5 cm basin water depth. Yield comparison with relevant earlier works is furnished in Table 2.

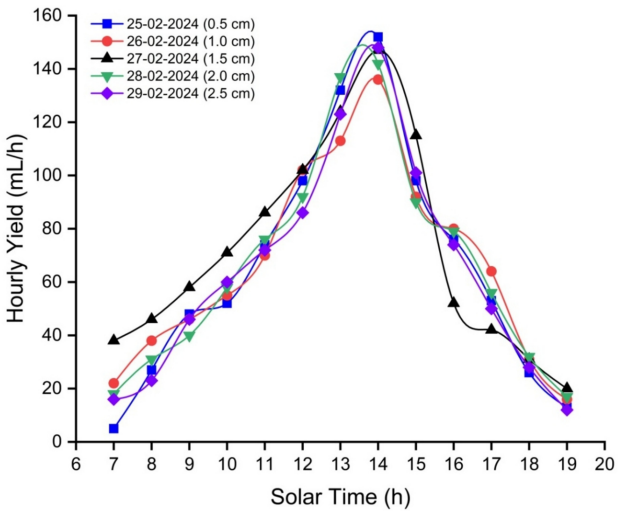


Fig. 8 Hourly yield variation of solar still with solar time

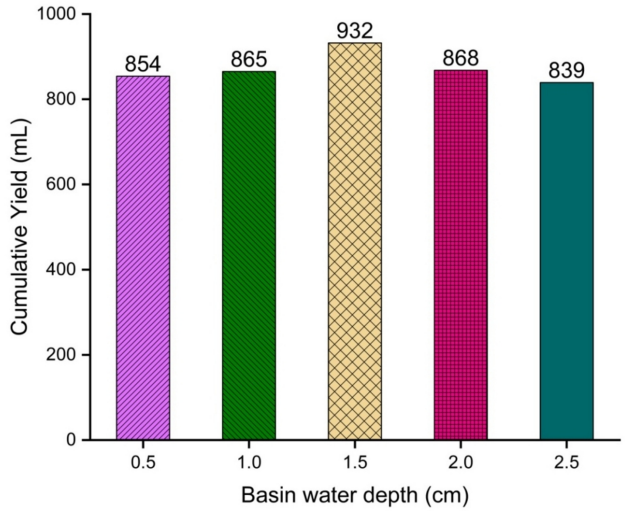


Fig. 9 Variation of cumulative yield of solar still with basin water depth

Table 2 Yield comparison with earlier works

Material Used	Yield (L/m^2)	References
Pebble	1.30	Balaji et al. (2019)
Sandstone	1.80	
Basalt	1.75	
Basalt	1.07	Mohamed et al. (2019)
Pebbles	2.80	Arunkumar et al. (2020)
Clay ball	2.87	Prasad et al. (2024)
Black painted clay ball	3.43	
Pebbles	2.58	Present study

Economic analysis

Economic analysis is a crucial factor in order to assess the setup's feasibility in terms of the total cost of labour and materials, which includes maintenance cost and operating costs, as shown in Table 3. In Table 4, the economic analysis is represented. The capital cost of the solar still is Rs. 5200 (P_{cost} = 5200/−). Annual maintenance is calculated as 12% of capital cost, while interest is calculated as 15% of capital cost. The market price per litre for drinking water is considered to be Rs 20/. In this research, 320 days that is considered as clear days because it is anticipated that solar energy will produce yields on these days. The remaining forty-five days are considered as completely or partially cloudy, meaning that incident solar energy is non-productive (Yadav 2017; Pal et al. 2017; Patel et al. 2021).

Based on the following equations, the parameters that were used in the economic analysis are determined:

(i) Capital recovery factor (CRF) is calculated by:

Table 3 Cost of materials fabrication for a single-slope solar still

Components	(R_s)
Galvanized iron sheet (2 mm thick)	1100
Iron stand (Basin)	1800
Insulation material (Thermocol)	220
Glass putty	130
PVC pipes	430
Glass cover (4 mm)	2 × 600 = 1200
Thermocouples (type-T)	200
Pebbles cost (2.0 kg)	120
Total cost (P_{cost})	5200/−

*Above costs are based as per local market rate

Table 4 Economic analysis of the solar still

Type of cost	Cost (R_s)		
Solar still's life (n)	15-years	20-Years	25-years
Principle cost (P_{cost})	5200	5200	5200
Capital recovery factor (CRF)	0.15	0.134	0.127
Sinking fund factor (SFF)	0.03	0.03	0.03
Salvage value (SV)	624.00	624.00	624.00
Initial annual cost (IAC)	764.40	691.60	660.40
Annual salvage value (ASV)	140.40	67.41	39.00
Annual maintenance cost (AMC)	114.66	103.74	99.06
Total annual cost (TAC)	265.92	262.06	259.37
Annually yield (AY)	464.00	464.00	464.00
Annually useful energy (AUE)	290.92	290.92	290.92
Annually fresh water (ACFW)cost/lit	1.65	1.49	1.42
Annually fresh water cost / KWh	2.63	2.38	2.27
Net profit (NP)	6195.60	8588.40	9500.20
Payback period (PP)	268.58	193.75	175.15

$$CRF = i(1+i)^n / \{(1+i)^n - 1\} \tag{8}$$

where n = solar still's life service and i = annual interest rate.

(ii) Initial annual cost (IAC):

$$AFC = (CRF) \times P_{cost} \tag{9}$$

(iii) To calculate annual salvage value (ASV):
For each system, Sinking fund factor (SFF):

$$SFF = i / \{(1+i)^n - 1\} \tag{10}$$

Thus, (ASV) is as follows:

$$ASV = (SFF) \times P_{cost} \tag{11}$$

Since maintenance is required for the solar distillation system, the following formula should also be used to calculate the annual maintenance cost (AMC):

$$AMC = 0.15 \times AFC\,(15\%of\ the\ annual\ firstcost) \quad (12)$$

$$Net\ Profit(NP) = AY \times (IMCDW - ACFW) \quad (13)$$

$$Payback\ Period\ (PP) = P_{cost}/NP \times Operational\ days\ in\ a\ year\ (320days) \quad (14)$$

(a) Total annual cost (TAC) per m^2 = (IAC + AMC − ASV).

(b) Annually yield (AY) = (320 days × daily average yield)

(c) Annually useful energy (AUE) = (latent heat of vaporization × AY)

(d) Annual distilled water cost/lit = (IAC/AY)

(e) Annual distilled water cost/kWh = (IAC/AUE)

Implications and limitations

The performance of a small size single slope solar still is investigated and optimized w.r.t. basin water height using thermal storage materials. The outcome of the work is useful for scale up of this sustainable solar desalination method. Instrumental uncertainty and exclusion of wind velocity and humidity constitutes the major limitations of the work. Wind velocity and humidity are considered to be redundant variables as their variation is insignificant during the investigation period for the geographical location of Lucknow, UP, India.

Conclusions

This study of a passive type solar still with single slope that is made of galvanized iron (GI) sheet at IET Lucknow in February 2024. Thermal storage material (pebbles) was used to improve the performance of the fabricated solar still. Experiments were conducted with various water basin depths, ranging from 0.5 cm to 2.5 cm. The maximum global radiation was found as 840 W/m^2 on 29 February at 14:00 h. This maximum radiation indicates the abundance of solar energy used for the solar desalination process. The maximum ambient, basin, water and vapour temperatures were found as 27 °C, 25 °C, 27 °C and 28 °C respectively. The maximum hourly yield is observed to be 152 mL/h with 0.5 cm basin water depth. However, the maximum cumulative yield was found 932 mL/day at 1.5 cm water basin depth. The payback period is calculated as 269, 194, and 175 days for a 15-year, 20-year, and 25-year life, respectively.

These results highlight the promising future of small-scale, affordable solar still systems. Further performance enhancement can be investigated by using other suitable methods.

Acknowledgements The authors would like to thank the Institute of Engineering & Technology Lucknow for providing the analytical facility needed during the research.

Data availability Not applicable.

References

Abed, F.M., Kassim, M.S., Rahi, M.R.: Performance improvement of a passive solar still in a water desalination. Int. J. Environ. Sci. Tech. **14**, 1277–1284 (2017)

Alagan, M., Kishor, S.C., Perumal, S., Manoj, D., Raji, A., Kumar, R.S., Almansour, A.I., Lee, Y.R.: Narrative of hazardous chemicals in water: Its potential removal approach and health effects. Chemosph. **335**, 139178 (2023)

Arora, R., Joshi, H.C., Pandey, I.P., Tewari, V.K.: Assessment of water quality of bhagirathi from gangotri to rishikesh using RS and GIS techniques. Rasayan J. Chem. **10**, 1167–1183 (2017)

Arunkumar, T., Wang, J., Rufuss, D.D.W., Denkenberger, D., Kabeel, A.E.: Sensible desalting: investigation of sensible thermal storage materials in solar stills. J. Energy Storage **32**, 101824 (2020)

Awasthi, A., Kumari, K., Panchal, H., Sathyamurthy, R.: Passive solar still: recent advancements in design and related performance. Environ. Tech. Revi. **7**, 235–261 (2018)

Bagheri, A., Esfandiari, N., Honarvar, B.: Experimental investigation of the effect of using the cylindrical parabolic collector, different solar panels and their cooling on seawater desalination in double-slope solar still. Energy Sources Part A Recov. Utiliza. Environ. Effects **47**, 1–14 (2021)

Balaji, R., Aravindh, V., Baburangan, J., Koushik, S., Mahendran, P.: Performance analysis of single slope solar still using sensible heat storage material. App. Innov. Res. **1**, 120–127 (2019)

Bytyci, P.S., Cadraku, H.S., Etemi, F.N.Z., Ismaili, M.A., Fetoshi, O.B., Shalaabazi, A.M.: The assessment of surface water quality in the Lepenc river basin using water quality index (WQI) methodology. Rasayan J. Chem. **11**, 653–660 (2018)

Chandanshive, V.V., Kadam, S.K., Khandare, R.V., Kurade, M.B., Jeon, B.H., Jadhav, J.P., Govindwar, S.P.: In situ phytoremediation of dyes from textile wastewater using garden ornamental plants, effect on soil quality and plant growth. Chemosphere **210**, 968–976 (2018)

Chauque, B.J.M., Rott, M.B.: Solar disinfection (SODIS) technologies as alternative for large-scale public drinking water supply: advances and challenges. Chemosphere **281**, 130754 (2021)

Chen, L., Deng, Y., Dong, S., Wang, H., Li, P., Zhang, H., Chu, W.: The occurrence and control of waterborne viruses in drinking water treatment: a review. Chemosphere **281**, 130728 (2021a)

Chen, L., Xu, P., Kota, K., Kuravi, S., Wang, H.: Solar distillation of highly saline produced water using low-cost and high-performance carbon black and airlaid paper-based evaporator (CAPER). Chemosphere **269**, 129372 (2021b)

Chithra, A., Sekar, R., Senthil, K.P., Padmalaya, G.: A review on removal strategies of microorganisms from water environment using nanomaterials and their behavioural characteristics. Chemosphere **295**, 133915 (2022)

Compain, P.: Solar energy for water desalination. Procedia Eng. **46**, 220–227 (2012)

Dawn, S.S., Vishwakarma, V.: Recovery and recycle of wastewater contaminated with heavy metals using adsorbents incorporated from waste resources and nanomaterials—a review. Chemosphere **273**, 129677 (2021)

Elsaid, K., Sayed, E.T., Abdelkareem, M.A., Mahmoud, M.S., Ramadan, M., Olabi, A.: Environmental impact of emerging desalination technologies: a preliminary evaluation. J. Environ. Chem. Eng. **8**(5), 1–38 (2020)

Farrance, I., Frenkel, R.: Uncertainty of measurement: a review of the rules for calculating uncertainty components through functional relationships. Clin. Biochem. Rev. **33**(2), 49–75 (2012)

Garg, M.C., Joshi, H.: A review on PV-RO process: solution to drinking water scarcity due to high salinity in non-electrified rural areas. Sep. Sci. Tech. **50**, 1270–1283 (2015)

Garg, H.P., Prakash, J.: Solar energy: fundamental and applications, pp. 176–190. Tata McGraw-Hill Publications Company Limited, New Delhi (2000)

Glatzmaier, G.C., Nix, R.G., Mehos, M.S.: Solar destruction of hazaedous chemicals. J. Environ. Sci. Health Part A Environ. Sci. Eng. Toxico. **25**, 571–581 (1990)

Gracia-Lor, E., Sancho, J.V., Serrano, R., Hernandez, F.: Occurrence and removal of pharmaceuticals in wastewater treatment plants at the Spanish Mediterranean area of Valencia. Chemosphere **87**, 453–462 (2012)

Hejna, M., Moscatelli, A., Stroppa, N., Onelli, E., Pilu, S., Baldi, A., Rossi, L.: Bioaccumulation of heavy metals from wastewater through a *Typha latifolia* and *Thelypteris palustris* phytoremediation system. Chemosphere **241**, 125018 (2020)

Hocaoglu, S.M., Wakui, Y., Suzuki, T.M.: Separation of arsenic (V) by composite adsorbents of metal oxide nanoparticles immobilized on silica flakes and use of adsorbent coated alumina tubes as an alternative method. J. Water Process Eng. **27**, 134–142 (2019)

Hoff, R., Echeverria, A.D., Hoff, G.D., Kneip, R.C., Jank, L., Arsand, J., Goncalves, F.F.: Efficiency of a low-cost pyramid-shaped solar still for pesticide removal from highly contaminated water. Chemosphere **234**, 427–437 (2019)

Jose, S., Paggi, J., Collins, P., Collins, J., Bernal, G.: Water quality and zooplankton composition in a receiving pond of the stormwater runoff from an urban catchment. J. Environ. Biology **29**, 693–700 (2008)

Kaviti, A.K., Yadav, A., Shukla, A.: Inclined solar still designs: a review. Renew. Sustain. Energy Rev. **54**, 429–451 (2018)

Kabeel, A.E., Khalil, A., Omara, Z.M., Younes, M.M.: Theoretical and experimental parametric study of modified stepped solar still. Desalination **289**, 12–20 (2012)

Khan, S.A.R., Ponce, P., Yu, Z., Golpira, H., Mathew, M.: Environmental technology and wastewater treatment: strategies to achieve environmental sustainability. Chemosphere **286**(1), 131532 (2022)

Kumar, A.T., Jayaprakash, R., Ahsan, A.: A comparative experimental testing in enhancement of the efficiency of pyramid solar still and hemispherical solar still. Interna. J. Renew. Energy **7**, 1–7 (2012)

Kumar, M., Patel, S.K., Mishra, V., Singh, D., Giri, B.S., Singh, D.: Performance analysis of modified solar still with parabolic reflector and nanofluids. J. Taiwan Inst. Chemi. Engin. **166**(2), 105651 (2025)

Kushwaha, J.P., Srivastava, V.C., Mall, I.D.: An overview of various technologies for the treatment of dairy wastewaters. Critical Revi. Food Sci. Nutrition **151**, 442–452 (2011)

Malik, A., Katyal, D.: Geospatial evaluation of groundwater quality in an industrialized district of Haryana, India, using an integrated approach. Proc. Indian Natl. Sci. Acad. **90**, 997–1014 (2024)

Manokar, A.M., Kalidasa, M., Esakkimuthu, G.: Different parameters affecting the rate of evaporation and condensation on passive solar still-a review. Renew. Sustain. Energy Rev. **38**, 309–322 (2014)

Mohamed, A.F., Hegazi, A.A., Sultan, G.I., El-Said, E.M.: Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: experimental study and thermo-economic analysis. Sol. Energy Mater. Sol. Cells **200**, 109958 (2019)

Li, D., Zhang, X., Zhang, S., Wang, D., Wang, Z., Liu, Y., Yu, X., Zhao, Q., Xing, B.: A flexible and salt-rejecting electrospun film-based solar evaporator for economic, stable and efficient solar desalination and wastewater treatment. Chemosphere **267**, 128916 (2021)

Nafey, A.S., Abdelkader, M., Abdelmotalip, A., Mabrouk, A.A.: Enhancement of solar still productivity using floating perforated black plate. Energy Conver. Managt. **43**, 937–946 (2002)

Nazemi, K., Salari, S., Eskandani, M.A.: Assessment of the *Escherichia coli* pollution in drinking water and water sources in Sistan. Iran. J. Water Reuse Desalin. **8**, 386–392 (2018)

Nigam, M., Rajoriya, S., Singh, S.R., Kumar, P.: Adsorption of Cr (VI) ion from tannery wastewater on tea waste: kinetics, equilibrium and thermodynamics studies. J. Environ. Chem. Eng. **7**, 1–9 (2019)

Pal, P., Yadav, P., Dev, R., Singh, D.: Performance analysis of modified basin type double slope multi-wick solar still. Desalination **422**, 68–82 (2017)

Pal, P., Nayak, A.K., Dev, R.: A modified double slope basin type solar distiller: experimental and enviro-economic study. Evergreen **5**, 52–61 (2018)

Patel, S.K., Singh, D., Kumar, B., Singh, D.: Solar desalination technology: physicochemical parameters estimation of contaminated & treated water of Gomti River Lucknow (UP). India. Int. J. Recent Tech. Eng. **8**, 86–692 (2020)

Patel, S.K., Singh, D., Dev, R.: Removal of arsenic contamination from Gomti river water by using activated charcoal absorbent integrated with solar distillation unit. Asian J. Chem. **32**(3), 550–554 (2020b)

Patel, S.K., Kumar, B., Pal, P., Dev, R., Singh, D.: Production of potable water from Gomti river by using modified double slope solar still with external mounted reflectors. Sol. Energy **209**(1), 576–589 (2020c)

Patel, S.K., Singh, D., Devnani, G.L., Sinha, S., Singh, D.: Potable water production via desalination technique using solar still integrated with partial cooling coil condenser. Sustaina. Energy Tech. Assess. **43**(1), 1–10 (2021)

Petersen, K.L., Heck, N., Reguero, B.G., Potts, D., Hovagimian, A., Paytan, A.: Biologicaland physical effects of brine discharge from the Carlsbad desalination plant and implications for future desalination plant constructions. Water **11**(2), 1–21 (2019)

Prasad, R.A., Eldin, M.H.A., Elhadi, A.M., Kalaivani, S.: Comparative study of solar still with low-cost energy storage materials: energy and exergy study. Iran. J. Chem. Chem. Eng. **43**(3), 1241–1251 (2024)

Pratap, D., Singh, D.: Impact of fluoride on environment & human health. Int. J. Sci. Res. Business Tech. **1**, 56–61 (2013)

Pratap, B., Kumar, S., Nand, S., Azad, I., Bharagava, R.N., Ferreira, R.F.N., Dutta, V.: Wastewater generation and treatment by various eco-friendly technologies: possible health hazards and further reuse for environmental safety. Chemosphere **313**(1), 137547 (2023)

Qureshimatva, Q., Maurya, R.R.: Determination of physicochemical parameters and water quality index (Wqi) of Chandlodia Lake, Ahmedabad, Gujarat. India. J. Enviorn. Anal. Toxicol. **5**(4), 1–6 (2015)

Rawat, B.S., Negi, P., Pant, P.C., Joshi, G.C.: Evaluation of energy yield ratio (EYR), energy payback period (EPBP) and GHG-emission mitigation of solar home lighting PV-systems of 37Wp modules in India. Int. J. Renew. Energy Res. **8**(1), 459–465 (2018)

Saadat, A.H.M., Islam, M.S., Parvin, F., Sultana, A.: Desalination technologies for developing countries: a review. J. Sci. Res. **10**(1), 77–97 (2018)

Sen, P., Mehta, R., Mehta, P.: Water quality assessment of Banas River, eastern-south region of Rajasthan, using water quality index. Proc. Indian Natl. Sci. Acad. **89**, 134–142 (2023)

Sharon, H., Reddy, K.S.: A review of solar energy driven desalination technologies. Renew. Sustain. Energy Revi. **41**, 1080–1118 (2015)

Shakya, A.K., Ghosh, P.K.: Simultaneous removal of arsenic and nitrate in absence of iron in an attached growth bioreactor to meet drinking water standards: importance of sulphate and empty bed contact time. J. Clean. Product **186**(10), 304–312 (2018)

Singh, S.K., Dwivedi, V.K.: Evaluating thermal performance of a basin type modified active solar still. Desalin. Water Treat. **72**(1), 100–111 (2017)

Singh, D., Singh, D., Mishra, M., Kushwaha, J., Dev, R., Patel, S.K., Shankar, R., Giri, B.S.: Sustainability issues of solar desalination hybrid systems integrated with heat exchangers for the production of drinking water: a review. Desalination **566**(1), 1–14 (2023)

Subramani, A., Jacangelo, J.G.: Emerging desalination technologies for water treatment: a critical review. Water Res. **75**(1), 164–187 (2015)

Son, H.S., Shahzad, M.W., Ghaffour, N., Ng, K.C.: Pilot studies on synergetic impacts of energy utilization in hybrid desalination system: multi-effect distillation and adsorption cycle (MED-AD). Desalination **477**(1), 114266 (2020)

Srivastava, A., Kumari, M., Prasad, K.S.: Fluoride occurrence, health issues, and removal using adsorption process. Proc. Indian Natl. Sci. Academy **88**, 129–141 (2022)

Venkatesh, A., Chaturvedi, A.K.: Experimental observations on a portable solar still. Solar Energy Socity. India **3**, 9–13 (1989)

Wang, Y., Gao, B., Li, S., Jin, B., Yue, Q., Wang, Z.: Cerium oxide doped nanocomposite membranes for reverse osmosis desalination. Chemosphere **218**(1), 974–983 (2019a)

Wang, H., Xu, G., Qiu, Z., Zhou, Y., Liu, Y.: NOB suppression in pilot-scale mainstream nitritation–denitritation system coupled with MBR for municipal wastewater treatment. Chemosphere **216**(1), 633–639 (2019b)

WHO: Progress on drinking water, sanitation and hygiene: update and SDG Baselines, Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) (2017)

Yadav, A., Mukherji, S., Garg, A.: Removal of COD and color from simulated textile wastewater using a combination of chemical/physicochemical processes. Indus. Eng. Chem. Res. **52**(30), 10063–10071 (2013)

Yadav, M.C.: Water desalination system using solar heat: a review. Renew. Sustain. Energy Revi. **67**(1), 1308–1330 (2017)

Zarzoum, K., Zhani, K.H.B.: Experimental validation of optimized solar still using solar energy. J. of Fundamental Renew. Energy Appl. **7**(6), 7–16 (2017)

Zhang, Y., Liu, L., Li, K., Hou, D., Wang, J.: Enhancement of energy utilization using nanofluid in solar powered membrane distillation. Chemosphere **212**, 554–562 (2018)

Zhu, S., Mostafaei, A., Luo, W., Jia, B., Dai, J.: Assessing water quality for urban tributaries of the Three Gorges Reservoir, China. J. Water Reuse Desalin. **9**(1), 105–114 (2019)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.