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# Design and implementation of an advanced solar water distillation system for the efficient purification of contaminated water into clean drinking water

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## Abstract

Solar energy is abundant in Sri Lanka, but there is currently no efficient method to use solar energy to purify polluted water into fresh water. This study aimed to address this issue by introducing an advanced solar water distillation system. The basin size of the prototype unit was 0.48 $m^2$ and its performance was tested using different setups: a basin only (T1), a basin with a flat-plate solar collector (T2), a basin on a sand layer (T3), a basin with sponge cubes (T4), and a basin with all components together (T5). Data were collected at 30-minute intervals from 6.00 am to 6.00 pm for each treatment. The results showed that T5 performed significantly better than the other treatments ($p<0.05$). The maximum temperature recorded for the basin water was 59°C when the ambient air was at 64°C in T5. The flat-plate solar collector, sand layer, and sponge cubes contributed to increase the distilled volume by 73.0%, 20.5%, and

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48.2% respectively. The new solar water distillation system with all the features (T5) can improve the distillation productivity by 138% compared to the conventional type (T1) by giving 4143 ml/m$^2$/day of average production. The new distillation system is an effective solution for addressing the drinking water issue in agricultural areas, as it consistently demonstrates satisfactory quality in terms of pH, EC, TDS, and concentrations of As and Cd.

**Keywords*:*** Distilled volume, Distilled water, Flat-plate solar collector, Solar energy, Solar water distillation

## Introduction

Drinking water is one of the basic needs of human beings for their survival and good health. Guaranteeing the availability and sustainable management of water is identified as one of the Sustainable Development Goals (United Nations, 2020). According to Modi & Modi, 2019, in spite of having 1.4 billion km$^3$ of water on the earth, only 2.5% of it is fresh while the rest 97.5% is sea water. According to the World Health Organization (WHO), nearly 2.1 billion people do not have access to safe drinking water while 3.4 million people die each year due to water related issues (WHO, 2022). Contaminated drinking water causes a major burden on human health and there is the greatest risk of waterborne diseases among infants and young children, attenuated people and the elderly, especially when living under unhygienic conditions (Gorchev and Ozolins, 2011).

The lack of access to clean water is a major problem in Sri Lanka, particularly in coastal areas and dry zones (Jayasekara, 2017). The dry zones are crucial for rice production in the country, and farmers in these areas often rely on chemical fertilizers and agrochemicals to boost their yields. Unfortunately, this has led to a high concentration of heavy metal ions, such as As, Cd, Cu, and Zn, in the groundwater (Jayalal, 2015; Jayasumana et al., 2015). As a result, there is a prevalent and severe health issue known as chronic kidney disease of unknown etiology (CKDu) in the North Central Province of Sri Lanka. The presence of elevated levels of As (Jayasumana et al., 2015) and Cd (Jayalal, 2015), in the water has been identified as the main cause of CKD. Dharma-wardana et al., 2015 have shown that high ionicity of ground water polluted by agrochemicals used for cooking and drinking is the cause for kidney failures. Therefore, it is crucial to purify both the hard and contaminated water to meet the demand for safe drinking water in the dry zones, where there is a scarcity of clean water.

Solar water distillation is a viable and cost-effective method for purifying water in Sri Lanka's dry zone due to the abundance of solar radiation throughout the year (Jayasekara, 2017) . The annual average solar radiation is in the range of 4.2 to 5.6 $kWhm^{-2}d^{-1}$ and available throughout the year with low seasonal variations in Sri Lanka (Renné, George, Marion, Heimiller and Gueymard, 2003). Unlike other methods such as Reverse Osmosis and Vapour Compression, which require high initial investments, solar water distillation units are simple to use, require minimal maintenance, and have low energy consumption (Tabwere, 2019). Additionally, solar energy is a free and sustainable source of power, eliminating the need for fuel costs. The only drawback of solar energy is that it requires more space for the collection of sunlight (Sebaey, 2013). Nonetheless, this method remains a great alternative for obtaining fresh water from hard water sources in the country.

A conventional solar water distillation system consists of various components, including a solar still, a glass top with a single or double slope, a water supply unit to cool the glass top, and an outlet for collecting distilled water. In the solar still, the greenhouse effect allows the absorption of solar heat, causing the top layer of water in the basin to absorb heat energy and evaporate. As a result, the evaporated water condenses on the glass top and is collected as distilled water through a pipe. The basic architecture and working principle of this system are illustrated in Figure 1.

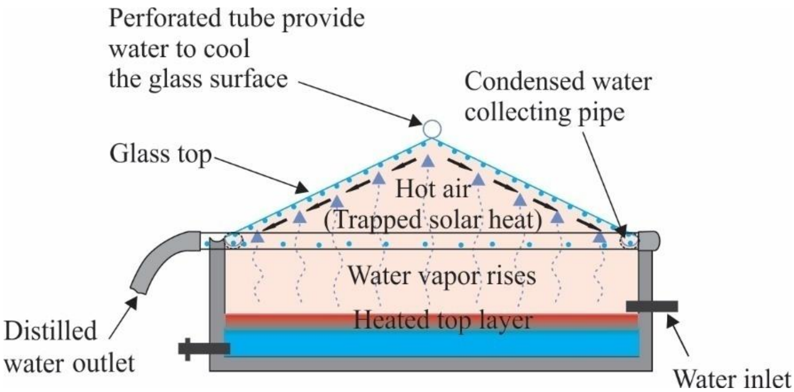


**Figure 1.** Illustration of the basic architecture and working principle of a conventional solar water distillation system

Numerous studies have been conducted to enhance the distillation efficiency in conventional types and developed in several ways. Experiments have demonstrated that the use of solar concentrators (plain mirrors and parabolic reflectors) both internally and externally can enhance evaporation in solar stills (Dev, Abdul-Wahab and Tiwari, 2011). Various phase change materials such as paraffin wax and nano particle enhanced paraffin are capable of storing additional heat as latent heat to improve the distillation efficiency (Kabeel and Abdelgaied, 2016). Sensible heat storage materials such as fins, sand, sponges, marbles, pebbles, iron scrap, wick, charcoal, corrugated absorbers, black cotton, jute, clay, mild steel, and black gravel granite can also be employed in solar stills to enhance the productivity (Arunkumar et al., 2019). Heat-absorbing materials like PV panels, black cotton, and jute can be utilized as high-heat-gaining materials in solar stills to achieve more efficient distillation (Pal et al., 2017; Manokar et al., 2018). Several studies have shown that the use of nano-fluids in solar stills can increase evaporation. Mixing nano-particles of $Al_2O_3$ and $Cu_2O$ in the wastewater within the still has shown significant improvements in distillation capacity (Omara, Kabeel & Essa, 2015). Some studies have focused on modifying the design of solar stills to enhance productivity. Stepped-type solar stills have been found to increase absorbing area and improve distillation output (Abdullah, 2013). Joy, Antony, and Anderson (2018) have suggested that using air blowers to create a bubbling effect in the still can increase the evaporation rate by distributing heat energy evenly throughout the basin. Condensers can be installed to improve the condensation process and accelerate distillation. A common approach involves using a bank of tubes immersed in flowing fresh water as the condenser in solar stills (Refalo, Ghirlando & Abela, 2016). Combining solar water distillation systems with IoT technology enables continuous real time monitoring and remote operation of the system to get hot water for domestic use (Kahandage, Seyar, Noguchi and Ahamed, 2023).

Despite various advancements in solar water distillation techniques, the usage of this method in Sri Lanka is still limited to the conventional type. Therefore, the objective of this research was to develop a prototype active solar water distillation unit with a double slope design that incorporates novel features such as utilizing a flat-plate solar collector to preheat water, incorporating a layer of sand beneath the solar still to retain heat, and placing sponge cubes inside the basin to enhance evaporation surface area and reduce surface tension of water. These modifications were made with the aim of improving the capacity and efficiency of solar distillation, and ultimately promoting the adoption of solar water distillation as a solution for the drinking water issue in the dry zones and coastal areas of Sri Lanka.

## Materials and Methods

### Designing and fabrication

The solar water distillation unit was designed with several systems such as double sloped solar still to store and evaporate water, cooling system for condensation of distilled water, flat plate solar collector to pre-heat the water, and frame to carry all the components together. All the fabrication work were carried out at the engineering workshop of Faculty of Agriculture, Rajarata University of Sri Lanka. Figure 2 shows the major components of the designed solar water distillation unit. Materials were selected for the fabrication of each component considering simplicity, reliability and stability.

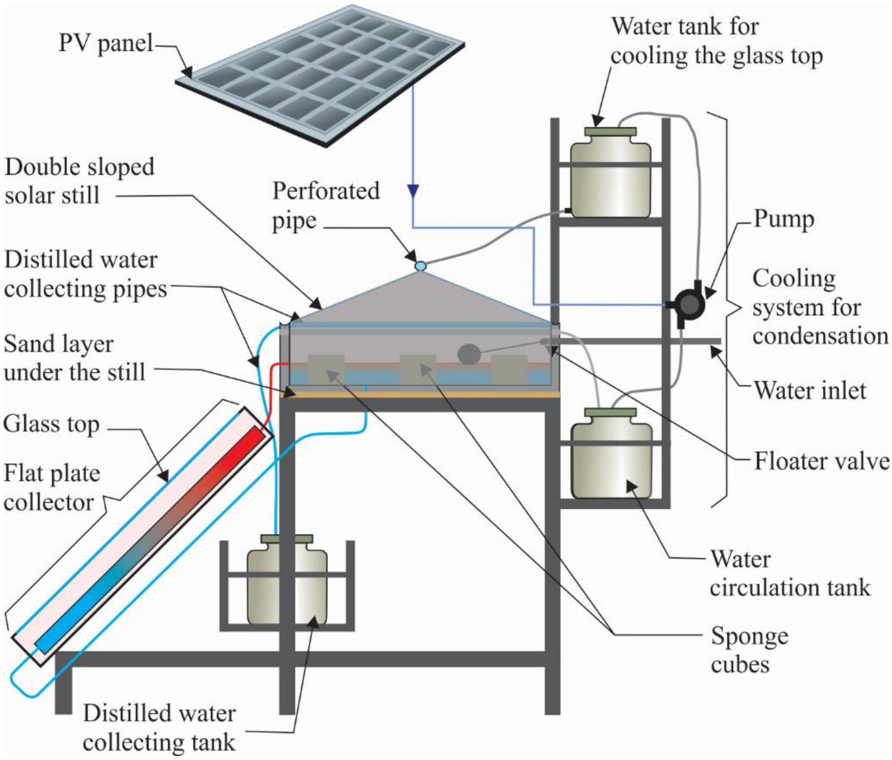


**Figure 2.** Major components of the designed solar water distillation system

### *Double sloped solar still*

The solar still consists of a double sloped glass top, a basin, and a water supplying pipe with a floater valve to maintain the desired water depth. The floater valve was used for the main water supply to keep the water level constantly at 2 cm level as 2 cm depth is more effective for solar distillation (Badran and Al-Tahaineh, 2005). The glass top is made of a 5 mm thick transparent glass sheet inclined at 35° on both sides (Akash, Mohsen and Nayfeh, 2000). Two shallow plastic troughs are fixed beneath the inside edges of both sides of the glass top to collect the condensed distilled water. To prevent corrosion, the basin is constructed using stainless steel sheets (gauge 20). The dimensions of the basin are 0.8 m in length, 0.6 m in width and 0.15 m in height, providing an effective evaporation area of 0.48 $m^2$. All surfaces of the basin are black painted to enhance absorption of solar radiation and minimize solar energy transmissivity. The basin is placed on a sand layer (2 cm) to store the additional heat and insulated with 5 cm thick polystyrene to reduce heat losses (Senavirathna, Weerasinghe, Maier and Rosemann, 2011). Additionally, fifteen sponge cubes (6 cm× 6 cm× 3 cm) are placed in the basin to increase the wet surface area and decrease the surface tension of water (Abu-Hijleh and Rababa, 2003; Diabil, 2022). Figure 3 illustrates the arrangement of the solar still.

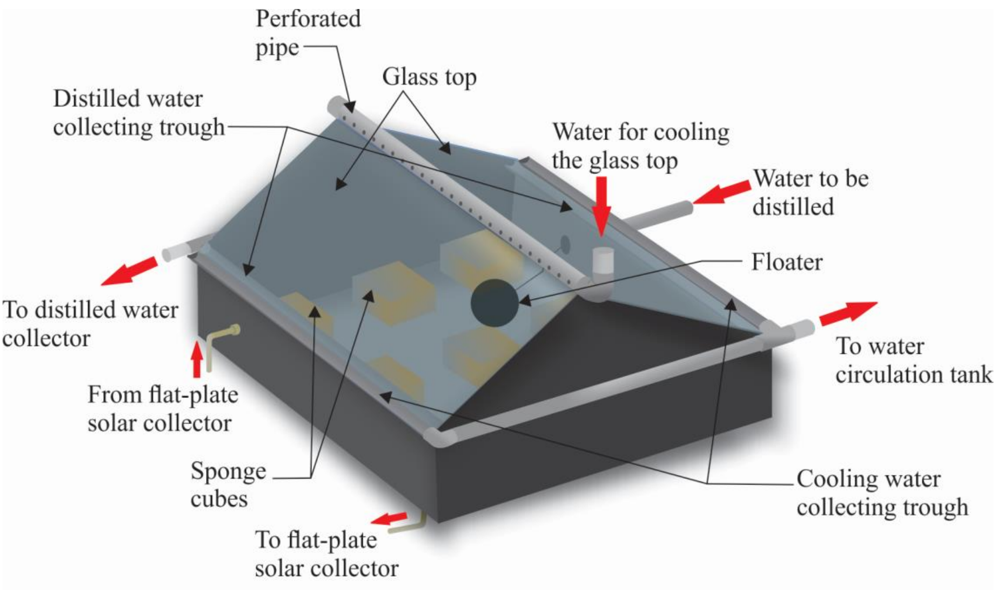


**Figure 3.** 3D illustration of the arrangement of components of the solar still

***Flat-plate solar collector***

The purpose of the flat-plate solar collector was to raise the temperature of the water in the basin, thereby increasing the rate of distillation. The solar collector is positioned at an angle of 45º to the horizontal, facing east. It was made up of a frame composed of mild steel, with an outer cover made of plywood, an inner cover made of black painted sheet metal, a polystyrene insulation layer in between inner and outer covers, and a copper tube (7 mm in diameter and 10m in length) in a unique serpentine configuration for efficient heat transfer and prevention of airlocks. A 5mm thick transparent glass plate was used as the top of the collector to create a greenhouse effect, raising the internal air temperature. The lower end of the copper tube was connected to the bottom of the solar still, allowing cool water from the basin to flow into the collector due to gravity. The heated water was then directed to the solar still at the upper end of the collector, following the pressure gradient. Because heated water has a lower density than cold water, it naturally flowed upward through the copper tube, causing the upper layer of the basin water to contain heated water. This led to a rapid evaporation of the basin water.

### *Cooling system for still top*

Distilled output of a solar water distillation system can be increased with a cooling system on the still top by creating a temperature difference between the glass cover and the water surface to increase the condensing process (Abu-Hijleh & Mousa, 1997). Therefore, a perforated PVC pipe was installed on the top of the solar still to ease splashing and cooling both slopes of the glass cover. The cooling water is collected by plastic troughs fixed beneath both sides of the glass top and circulated using a solar powered small pump (0.4 hp). The use of solar power for the pump aligns with efforts to reduce carbon emissions and mitigate the impact of global warming (Kahandage, Piyathissa et al., 2023).

## Performance evaluation of the solar water distillation unit

The performance of the solar water distillation system was assessed using five different treatments to quantify the impact of newly introduced features separately. These treatments included a basin without any additional features (T1), a basin with a flat-plate solar collector (T2), a basin placed on a sand layer (T3), a basin with sponge cubes (T4), and a basin with all the features combined (T5) in the Faculty of Agriculture, Rajarata University of Sri Lanka (8°22'20.63"N 80°25' 3.79"E). To ensure maximum solar radiation throughout the day, the system was positioned in a north-south orientation. Three replications of each treatment were conducted from 6.00 am to 6.00 pm. Measurements were taken every 30 minutes for ambient temperature, distilled output, basin water temperature, and air temperature using a mercury thermometer and measuring cylinder. Distilled output of all the treatments were analyzed using Analysis of Variance (ANOVA) with general lineal model procedure (GLM) developed by Statistical Analysis System 9.0 (SAS). Mean separation was done using Least Significant Difference (LSD). Meteorological data, including ambient air temperature, wind velocity, sunshine duration, solar radiation, and rainfall, were collected at the same intervals from the meteorological station at the Faculty of Agriculture, Rajarata University of Sri Lanka. Water quality parameters such as pH, EC (Electrical conductivity), and TDS (Total dissolved solids) were measured using multi- parameter analyzer (HATCH, Sension 156), and concentrations of Na, Mg, K, Ca, As, and Cd were measured using Inductivity Couple Plasma Optical Emission Spectrophotometer (ICP-OES) in the analytical service laboratory, RUSL for samples collected from the newly introduced solar water distillation unit, laboratory distilled water, and water supplied by the National Water Board. The treatments considered in performance evaluation are represented by Figures 4, 5, 6, 7, and 8.

**Figure.4** The distillation unit only with the basin (T1)

**Figure 5.** The distillation unit only with flat-plate solar collector (T2)

**Figure 6.** The distillation unit only with a sand layer (T3)

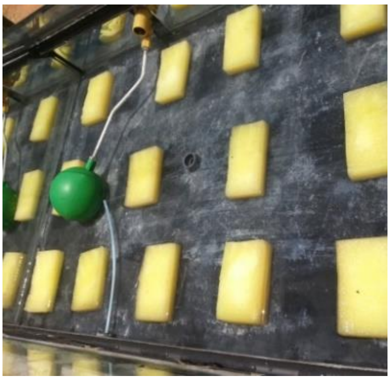

**Figure 7.** The distillation unit only with sponge cubes (T4)

**Figure 8.** The distillation unit with all the features (T5)

## Results and Discussion

### Performance of solar water distillation methods

The average distilled output, maximum and average temperature values of basin water and air, and improvement percentage of each treatment compared to the control (T1) are demonstrated in Table 1.

**Table 1.** Temperatures of basin water and air, distilled output, and improvement.

| Treatment | Basin water temperature ($^{0}$C) | | Basin air temperature ($^{0}$C) | | Total Average distilled output (mL/ $m^2$/ day) | Improvement compared to the control (T1) (%) |
|---|---|---|---|---|---|---|
| | Maximum | Average | Maximum | Average | | |
| **T1** | 49.2 | 38.8 | 51.6 | 40.8 | 1738.5 | - |
| **T2** | 58.8 | 45.5 | 61.6 | 48.1 | 3006.9 | 72.98 |
| **T3** | 52.6 | 41.1 | 54.0 | 41.4 | 2095.0 | 20.5 |
| **T4** | 49.5 | 46.6 | 55.3 | 42.2 | 2576.3 | 48.2 |
| **T5** | 58.3 | 43.6 | 64.3 | 46.3 | 4143.0 | 138.3 |

Table 1 provides insights into the effectiveness of each treatment condition. Comparing the other treatments to treatment T1 (basin only), the improvement in each parameter can be observed. Treatment T2 (basin only with the flat-plate solar collector) showed the highest maximum water temperature and highest average air temperature compared to other treatments. That is due to the extraction of solar heat from flat-plate solar collector and transferring to water. The distillation improvement of treatment T2 compared to treatment T1 is 72.9%. Rajaseenivasan, Nelson Raja & Srithar, (2014), have shown that coupling with a flat-plate solar collector can improve the distillation capacity by 60% compared to a same-size basin without a flat-plate collector. Badran & Al-Tahaineh (2005) have found in their study that flat-plate solar collectors can increase the distillation by 36% compared to the conventional type.

Treatment T3 (basin only with the sand layer) had the lowest improvement in distilled output of 20.5% compared to treatment T1. At the same time, it can be observed that the average basin water temperature and average basin air temperature were slightly higher than treatment T1 and lower than other treatments. The sand layer beneath the basin is supposed to absorb additional heat from the basin and provide it again when the ambient temperature goes down. Therefore, the performance of the sand layer depends on the extra heat in the basin. Senavirathna et al. (2011) have revealed that the distillation capacity can be improved by 29.6% when a 2 cm river sand layer is incorporated beneath the basin.

Treatment T4 (basin only with sponge cubes) showed a 48.2% distillation improvement compared to treatment T1. The sponge cubes present in the water basin serve as a sensible heating material and promote evaporation by lessening the water's surface tension through capillary forces by their structure. Additionally, they aid in expanding the evaporative space within the basin. Abu-Hijleh and RababaÕh (2003) have shown that with 20% sponge-to-water volume ratio and 7 cm water depth can improve distillation by 273%. The reason for the lesser improvement in the present study may be the low sponge-to-water ratio.

Treatment T5 (basin with all the features) had the highest distillation improvement of 138.3% compared to treatment T1. The overall improvement percentage is approximately the same as the summation of individual contribution of all the new features tested in this study. Figure 9 represents the variation of the distilled output of each tested treatment with ambient temperature, basin air temperature, and basin water temperature.

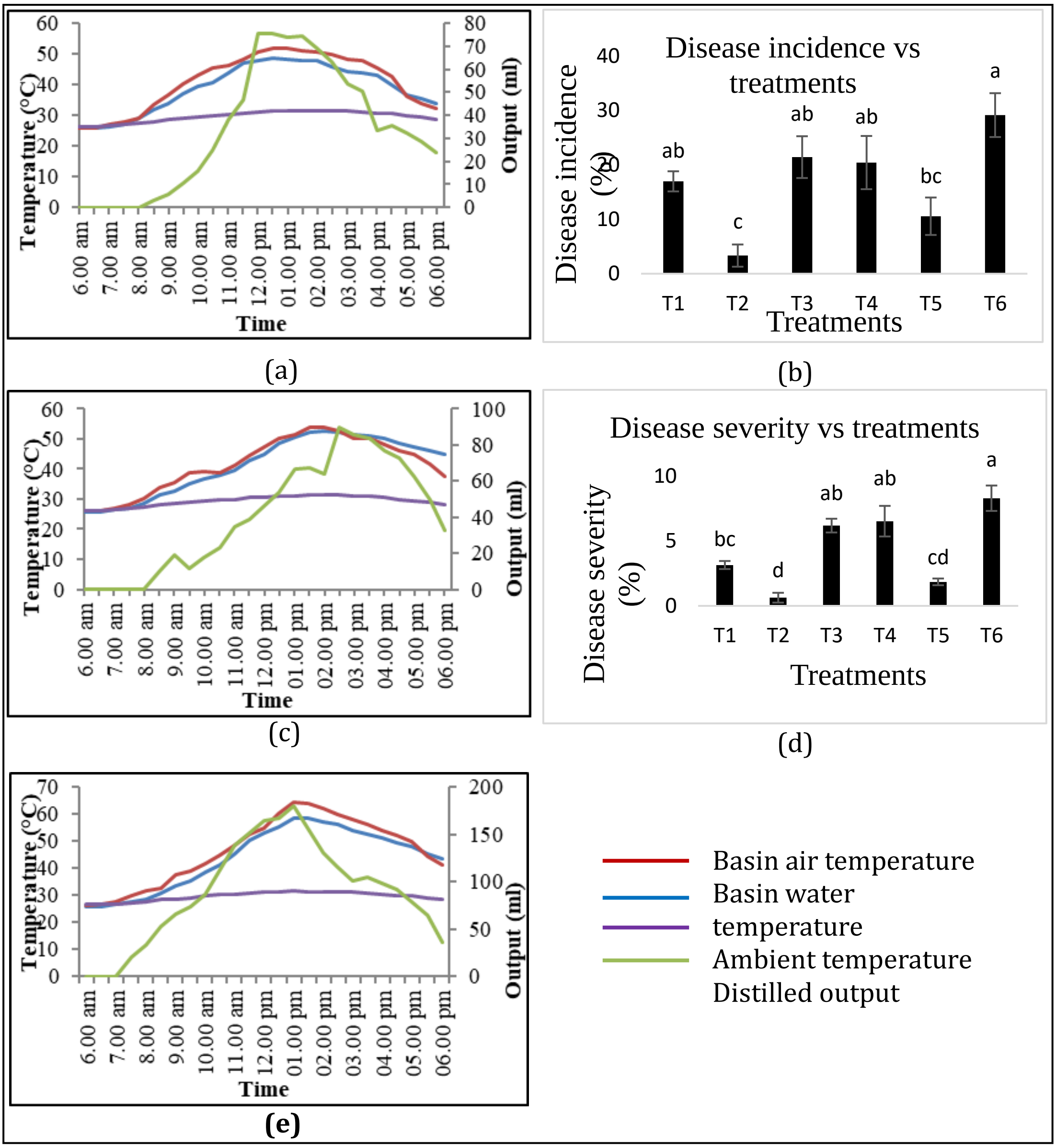


**Figure 9.** Variations of the distilled output of (a) T1, (b) T2, (c) T3, (d) T4, and (e) T5 with basin air temperature, basin water temperature, and ambient temperature.

Based on Figure 9, the ambient temperature in each treatment showed a similar variation throughout the duration of the experiment. All the graphs clearly indicate that the amounts of distilled output have increased during the morning period, even when air and water temperatures in the basin are low. The highest increase in both basin air and basin water temperatures occurred just after noon, as the absorption of heat was greater than the losses to the atmosphere. In the early morning hours, the difference in temperature between the glass and water was smaller, resulting in lower productivity. This was because the water absorbed less energy during this time. This indicates that changes in ambient air temperature directly affect the intensity of solar radiation, and the distilled output is also directly proportional to the ambient temperature. A study conducted by Kusumadewi, Notodarmodjo and Helmy (2018) on the desalination of seawater and brackish water in Indonesia confirmed these findings.

With the effect of all the features introduced, treatment T5 starts the distillation earlier than other treatments and continues with the highest distillation capacity. The pattern of distillation output suggests that the flat-plate solar collector is more efficient than other features. The flat plate solar collector effectively absorbs heat, resulting in significantly increased basin water temperature (19.5%) and higher production when used to preheat the water in the basin.

In the case of treatment T3, where a sand bed was incorporated under the metal basin, heat energy was absorbed from the basin water. This led to a decrease in both the temperature of the basin water and the basin air, resulting in lower production during the morning period. However, the sand bed retained more heat energy due to its high thermal capacity during the afternoon period. Consequently, the distilled output, as well as the temperature of the basin air and water, increased more noticeably in the afternoon compared to the morning. Table 2 shows the comparison of total distilled output and output during morning and afternoon of each treatment.

**Table 2.** Comparison of the total distilled output and output during morning and afternoon of each treatment.

| Treatment | Average distilled output (mL) | | |
|---|---|---|---|
| | (6.00 am – 12.00 noon) | (12.00 noon – 6.00 pm) | Total output (6.00 am – 6.00 pm) |
| **T1** | 302.4$^{C}$ | 1436.1$^{D}$ | 1738.5$^{E}$ |
| **T2** | 826.4$^{B}$ | 2180.6$^{B}$ | 3006.9$^{B}$ |
| **T3** | 322.5$^{C}$ | 1772.5$^{C}$ | 2095.0$^{D}$ |
| **T4** | 806.9$^{B}$ | 1769.4$^{C}$ | 2576.3$^{C}$ |
| **T5** | 1527.8$^{A}$ | 2615.2$^{A}$ | 4143.0$^{A}$ |

*Means with the same letter in same column are not significantly different ($P \geq 0.05$).*

During the morning session, treatment T5 had the highest mean value of 1527.8 ml/m$^2$/day. However, there were no significant differences between treatments T2 and T4 ($P \geq 0.05$). Although the control treatment T1 had the lowest output of 302.4 ml/m$^2$/day in the morning, there were no significant differences between the control and treatment T3 (322.5 ml/m$^2$/day) ($P \geq 0.05$).

During the afternoon session, treatment T5 had the highest distilled output, accounting for 63.0% of the total output. As distillation in treatment T5 starts earlier (Figure 9 (E)), the percentage of output during the afternoon is comparatively lower. Conversely, treatment T1 had the lowest output, representing 82.6% of the total distillation. There were no significant differences between the distillation outputs of treatments T3 and T4 in the afternoon ($P \geq 0.05$). However, the afternoon output of treatment T3 accounted for 84.6% of its total output, while it was 68.7% for treatment T4. The reason for the highest portion of the output of treatment T3 during the afternoon is the retention heat of the sand layer. According to Figure 9 (C), due to this retention heat, the basin water temperature in T3 is higher even in the afternoon compared to other treatments.

The results clearly indicated that there were significant differences in the total distilled output among the treatments ($P \geq 0.05$). The treatment T5 has recorded the highest distilled output and it is 4143 ml/m2/day. According to a study carried out in Mapalana, Sri Lanka, a modified solar water distillation system has been found to produce an average distilled output of 2017.5 ml/m2/day and the conventional solar distillation system manufactured by NERD center, Sri Lanka, produces an average of 1557.0 ml/m2/day when operating in the Mapalana area (Senavirathna et al., 2011). Therefore, the output of the distillation unit introduced by this study is more than double that of the existing solar water distillation systems in Sri Lanka. However, by adopting more new technologies, efficiency and productivity can be improved further.

**Water quality parameters**

Table 3 shows the measured physico-chemical parameters (pH, EC, TDS, $Na^+$, $Mg^{2+}$, $Ca^{2+}$, $K^+$, As, and Cd) values of the samples collected by the newly introduced solar water distillation system (NSD), laboratory distilled water (LDW), and drinking water supplied by National Water Board (NWB), Sri Lanka.

**Table 3.** Physico-chemical parameters for water quality of water samples from different sources with WHO standards for permissible levels

| Parameter | Source of water sample | | | WHO standards |
|---|---|---|---|---|
| | NSD | LDW | NWB | |
| **pH** | 7.21± 0.06 | 7.66 | 7.38 | 6.5-8.5 |
| **EC (µS/ cm)** | 7.01±0.86 | 1.41 | 431 | <1000 |
| **TDS (mg/L)** | 3.19± 0.57 | 0.61 | 207.9 | <1000 |
| **Na (mg/L)** | 0.7951± 0.023 | 0.2697 | 18.2392 | <200 |
| **Mg (mg/L)** | 0.7691± 0.034 | 0.0009 | 7.8910 | <35 |
| **Ca (mg/L)** | 0.8291± 0.132 | 0 | 8.4903 | <75 |
| **K (mg/L)** | 1.1087± 0.201 | 0.3896 | 2.8967 | <12 |
| **As (mg/L)** | 0.00124±0.0001 | 0.00105 | 0.0017 | <0.01 |
| **Cd (mg/L)** | 0.00013± 0.00002 | 0.0003 | 0.0029 | <0.003 |

(Perveen & Amar-Ul-Haque, 2023; Rahman et al., 2023)

According to the results, the measured physico-chemical water quality parameters in every sample did not exceed the upper permissible limits recommended by WHO guidelines.

Extreme pH levels can have negative effects on the usability of water. A high pH can result in a bitter taste, while low pH levels can cause corrosion of distributing pipes. The electrical conductivity (EC) of water can be used to determine the concentration of dissolved salts or ions in the water. Total Dissolved Solids (TDS) in water is one of the major factors affecting the taste of drinking water. Water with a TDS level below approximately 600 mg/l is generally considered to taste good, while water with a TDS level above around 1000 mg/l is significantly less pleasant to drink (WHO, 2017). The lowest EC and TDS values were recorded in the water sample from the laboratory distillation system. Sodium, Calcium, Magnesium, and Potassium are crucial for maintaining human health and play essential roles in metabolism. However, when water contains elevated amounts of Calcium and Magnesium, it becomes hard and less enjoyable to drink. In some cases, excessive mineral levels can also have negative impacts on human health. Specifically, elevated levels of Calcium and Magnesium in drinking water can be harmful to human health (Sengupta, 2013).

In Sri Lanka, heavy metals like Arsenic and Cadmium are highly dangerous even in small quantities and have been linked to CKDu (Jayasumana et al., 2015). The World Health Organization (WHO) has established the acceptable levels for Arsenic and Cadmium at 0.01 ppm, and 0.003 mg/l, respectively. The levels of Arsenic and Cadmium found in the distilled water obtained from the newly introduced solar water distillation system in this study were below the maximum permissible levels, as well as the levels found in the water distributed for drinking by the National Water Board, Sri Lanka. Therefore, the use of water distillation systems can be recommended to effectively clean agricultural polluted water in the dry zone and resolve the drinking water issue.

The lowest concentrations of all the measured minerals were recorded by the laboratory distilled water. Therefore, the distilled water from the new solar water distillation system cannot be recommended for laboratory purposes. However, compared to the drinking water provided by the National Water Board in Sri Lanka, the concentration levels of $Na^{+}$, $Ca^{2+}$, and $Mg^{2+}$ in the distilled water obtained from the new distillation system are very low. Therefore, to maintain the familiar taste of water, a mixture of salts should be added to match the preferences of customers. In the European market, the concentrations of $Ca^{2+}$, $Na^{+}$, and $Mg^{2+}$ in drinking water are 459-575 mg/l, 0.1-2.0 mg/l, and 0.1-128 mg/l, respectively (Martínez-Ferrer, Peris, Reyes & Guañabens, 2008). In the market today, a variety of trace mineral mixtures are readily accessible. These mixtures are designed to enhance the taste of distilled water, allowing individuals to effortlessly make it drinkable in the comfort of their own homes by simply following the manufacturer's instructions. Many methods such **as** adding trace mineral drops, using an alkalizing water filter, or by adding pink salt to the water can be easily used to re-mineralize distilled water (Byrd, 2023).

## Conclusions

The present study tested three solar water distillation efficiency improvement methods such as coupling the solar still with a flat-plate solar collector, adding a sand layer beneath the solar still, and using sponge cubes in the basin to improve the efficiency of solar distillation in Sri Lanka. All the methods tested significantly increased the system's capacity to produce distilled water compared to the conventional type. The flat-plate solar collector is particularly effective in raising the temperature of the basin water and air, resulting in a 73% improvement. Incorporating sponge cubes improves the efficiency of distilled output by 48.2%. The addition of a 2 cm deep river sand layer contributed to improving the productivity by 20.5%. The newly designed solar water distillation system, by combining all the methods together with a surface area of 0.48 $m^2$ was able to increase distilled production by 138%.

The distilled water output from this system has a safe pH level, electrical conductivity (EC), and total dissolved solids (TDS), and it contains very low levels of heavy metals, making it suitable for drinking purposes. However, the low concentration of minerals such as sodium, calcium, potassium, and magnesium may result in a less distinct taste of water. This deficiency can be remedied by adding minerals as necessary.

## Declaration of Conflict of Interest

Authors have no conflict of interest to declare.

## References

Abdullah, A. S. (2013). Improving the performance of stepped solar still. *Desalination*, *319*, 60-65.

Mousa, H. A. (1997). Water film cooling over the glass cover of a solar still including evaporation effects. *Energy*, *22*(1), 43-48.

Bassarn, A., & Hijleh andH, K. A. (2003). M. Rababa'h, Experimental study of a solar still with sponge cubes in basin. *Energy Cony. Management*, *44*(9).

Akash, B. A., Mohsen, M. S., & Nayfeh, W. (2000). Experimental study of the basin type solar still under local climate conditions. *Energy conversion and management*, *41*(9), 883-890.

Arunkumar, T., Raj, K., Rufuss, D. D. W., Denkenberger, D., Tingting, G., Xuan, L., & Velraj, R. (2019). A review of efficient high productivity solar stills. *Renewable and Sustainable Energy Reviews*, *101*, 197-220.

Badran, O. O., & Al-Tahaineh, H. A. (2005). The effect of coupling a flat-plate collector on the solar still productivity. *Desalination*, *183*(1-3), 137-142.

Dev, R., Abdul-Wahab, S. A., & Tiwari, G. N. (2011). Performance study of the inverted absorber solar still with water depth and total dissolved solid. *Applied energy*, *88*(1), 252-264.

Dharma-Wardana, M. C., Amarasiri, S. L., Dharmawardene, N., & Panabokke, C. R. (2015). Chronic kidney disease of unknown aetiology and ground-water ionicity: study based on Sri Lanka. *Environmental geochemistry and health*, *37*, 221-231.

Diabil, H. A. N. (2022). Experimental study to enhance the productivity of single-slope single-basin solar still. *Open Engineering*, *12*(1), 157-168.

Graham, N. (1999). Guidelines for drinking-water quality, Addendum to volume 1–recommendations, World Health Organisation, Geneva, 1998, 36 pages.

Jayalal, T. A. (2015). Chronic kidney disease of uncertain aetiology: adding vital piece of information to the national project team report of Sri Lanka. *BMC* *nephrology*, *16*, 1-3.

Jayasumana, C., Fonseka, S., Fernando, A., Jayalath, K., Amarasinghe, M., Siribaddana, S., ... & Paranagama, P. (2015). Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. *SpringerPlus*, *4*, 1-8.

Jayasumana, C., Fonseka, S., Fernando, A., Jayalath, K., Amarasinghe, M., Siribaddana, S., ... & Paranagama, P. (2015). Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. *SpringerPlus*, *4*, 1-8.

Joy, N., Antony, A., & Anderson, A. (2018). Experimental study on improving the performance of solar still using air blower. *International Journal of Ambient Energy*, *39*(6), 613-616.

Kabeel, A. E., & Abdelgaied, M. (2016). Improving the performance of solar still by using PCM as a thermal storage medium under Egyptian conditions. *Desalination*, *383*, 22-28.

Kahandage, P. D., Piyathissa, S. D. S., Ariesca, R., Namgay, Ishizaki, R., Kosgollegedara, E. J., ... & Noguchi, R. (2023). Comparative Analysis of Paddy Harvesting Systems Toward Low-carbon Mechanization in the Future: A Case Study in Sri Lanka. *Processes*, *11*(6), 1851.

Kahandage, P. D., Seyar, M. H., Noguchi, R., & Ahamed, T. (2023). Purification of Agricultural Polluted Water Using Solar Distillation and Hot Water Producing with Continuous Monitoring Based on IoT. In *IoT and AI in Agriculture: Self-sufficiency in Food Production to Achieve Society 5.0 and SDG's Globally* (pp. 75-96). Singapore: Springer Nature Singapore.

Martinez-Ferrer, A., Peris, P., Reyes, R., & Guanabens, N. (2008). Intake of calcium, magnesium and sodium through water: health implications. *Medicina Clinica*, *131*(17), 641-646.

Modi, K. V., & Modi, J. G. (2019). Performance of single-slope double-basin solar stills with small pile of wick materials. *Applied Thermal Engineering*, *149*, 723-730.

Omara, Z. M., Kabeel, A. E., & Essa, F. A. (2015). Effect of using nanofluids and providing vacuum on the yield of corrugated wick solar still. *Energy conversion and management*, *103*, 965-972.

Perveen, S. (2023). Drinking water quality monitoring, assessment and management in Pakistan: A review. *Heliyon*.

Rahman, M. M., Haque, T., Mahmud, A., Al Amin, M., Hossain, M. S., Hasan, M. Y., ... & Bai, L. (2023). Drinking water quality assessment based on index values incorporating WHO guidelines and Bangladesh standards. *Physics and Chemistry of the Earth, Parts A/B/C*, *129*, 103353.

Rajaseenivasan, T., Raja, P. N., & Srithar, K. (2014). An experimental investigation on a solar still with an integrated flat plate collector. *Desalination*, *347*, 131-137.

El-Agouz, S. A. (2014). Experimental investigation of stepped solar still with continuous water circulation. *Energy Conversion and Management*, *86*, 186-193.

Renné, D., George, R., Marion, B., Heimiller, D., & Gueymard, C. (2003). *Solar resource assessment for Sri Lanka and Maldives* (No. NREL/TP-710-34645). National Renewable Energy Lab.(NREL), Golden, CO (United States).

El-Sebaey, M. S., Shams El-Din, S., Habib, M., & El-Hanafy, A. (2013). 'An Experimental study on a new design of double slope solar still with external flatted and internal parabolic reflectors. *Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, *9*(6), 40-54.

Senavirathna, M. D. H. J., Weerasinghe, K. D. N., Maier, M., & Rosemann, H. (2011). Modification of solar distillation unit to increase efficiency in drinking water production from saline water. *Tropical Agricultural Research and Extension*, *12*(2).

Sengupta, P. (2013). Potential health impacts of hard water. *International journal of preventive medicine*, *4*(8), 866.

Tabwere, R. (2019). Investigating productivity of double slope solar still with sponge cubes.

Al-Salim, W., Darwish, A. S. K., & Farrell, P. (2022). Analysing data quality frameworks and evaluating the statistical output of United Nations Sustainable Development Goals' reports. *Renewable Energy and Environmental Sustainability*, *7*, 17