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Innovative continuous heating-enhance solar still farm- A case study for irrigation in a pistachio orchard

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ABSTRACT

Water scarcity is a global concern that has become one of the main problems for agricultural activities, especially in countries with arid and semi-arid climates like Iran. Sirjan city, a sweltering and arid city in Iran, is one of the locations where its economy mainly relies on pistachio orchards and other agricultural activities, which are highly affected by poor water quality and high TDS of wells. This city's climate, high solar irradiation, sunny sky, and the high requirement for distilled water for irrigation make utilizing solar power and solar-still desalination systems a reasonable choice. However, the low water production rate of conventional solar still systems prevents the use of this technology in field-scale projects and real agricultural activities. Therefore, we mixed solar still and solar power, to enhance the water production rate and provide water with proper TDS for a pistachio orchard in Sirjan City. In comparison to conventional solar still, the proposed continuous heating-enhanced solar still benefits from several improvements, including passing water through the grooved glass that leads to lowering the glass temperature, increasing water basing temperature by a heating element, polyurethane isolation of basin and capability of working during day and night. The mentioned improvements will lead to an increase in daily water production by 21% from 5.5 to 6.6, 24% from 5.5 to 6.8, 31% from 5.5 to 7.2, and 44% from 5.5 to 7.92 respectively. Therefore, utilizing all the mentioned approaches leads to a 120% increase in daily water production from 5.5 to 12.17 L and in comparison, to the conventional mechanisms, significantly reduces the required area for the system. The results showed that the proposed method is highly effective and could be used in real agricultural activities in arid and semi-arid climates.

Introduction

Water scarcity which defined as the point where the supply or quality of water cannot meet all consumption sectors including ecology and environment [1], is a widespread problems that cause competition for water and currently at least 4 billion people around world experiencing it consequences [2]. Considering the 72 % proportion of agricultural activity of total water usage [3], it is predictable that people living in agricultural areas are one of the most affected sector by water scarcity and research also shows almost 3.2 billion people in these areas face high water shortage [4]. It seems, in addition to the demand for agricultural products which has risen in recent years and is projected to grow by 70 % by 2050 [5], failure in securing farmers training, new irrigation methods, proper management of digging licenses [6], and cheap tariffs for irrigation water usage are the main factors that aggravate severe conditions, especially in third generation countries [5]. As a consequence, in many arid and semi-arid climates, like Kerman province in Iran, which the economy of local society highly relied in agricultural activities, farmers have been facing great concern about water shortage and in some cases its high salinity, which even harden water stress situation [7,8]. To address this issue, and align with SDGs, developing more sustainable desalination approaches using renewable energy and passive solutions which required low maintenance and material usage, not only could provide proper water for irrigation with low environmental impacts [9–11], also it can improve the quality of agricultural

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Nomenclature

Term	Description
A	Surface area, m^2
c_p	Specific heat, J/kg ^oC
h^{conv}_{sw-g}	Convective HTC from seawater to glass, W/K m^2
h^{rad}_{sw-g}	Radiative HTC from seawater to glass, W/K m^2
h^{evap}_{sw-g}	Evaporative HTC from seawater to glass, W/ K m^2
h^{tot}_{b-amb}	Overall HTC between ambient and basin
k_b	Basin thermal conductivity, W/ m ^oC
k_{ins}	Insulation thermal conductivity, W/ m per ^oC
q^{tot}_{b-amb}	Rate of total heat transfer within basin and ambient, W/m^2
q^{conv}_{sw-g}	Rate of convective heat transfer within seawater and glass, W/m^2
q^{rad}_{sw-g}	Rate of radiative heat transfer within seawater and glass, W/m^2
q^{evap}_{sw-g}	Rate of evaporative heat transfer within seawater and glass, W/m^2
l_{air}	Thickness of air, m
HTC	Heat transfer coefficient
Term	**Description**
I_{sun}	Intensity of solar radiation, W/m^2
l_{ins}	Insulation thickness, m
l_b	Basin thickness, m
P_{sw}	Partial saturated vapor pressure in seawater temperature, Pa
P_g	Partial saturated vapor pressure in glass temperature, Pa
T_{sw}	Seawater temperature, ^oC
T_g	Glass temperature, ^oC
T_b	Basin temperature, ^oC
ρ	Density, kg/m^3
t	Time, s
σ	Stephan Boltzman, W/m^2 $^oK^4$
ε_{eff}	Emissivity
l_{ins}	Thickness of Insulation, m

products and consequently enhance the economy of local community.

Although industrial desalination methods are common solutions, especially in Middle East (ME) [12], these projects mostly utilized approaches such as reverse osmosis [13], multi-effect desalination [14], multi-stage flash [15], ion exchange [16], phase change and electrodialysis [17], which some main parameters such as setup cost, operational cost, operating temperature, required maintenance, electrical energy consumption, thermal energy consumption, and waste production could be the drawbacks of these systems [18,19]. Therefore, easy to use and environmental-friendly methods like solar still are of great interest for irrigation water desalination. The popularity of this method is so high that researchers have been trying to provide a more optimal system with the same fundamental mechanism and small changes. As a result, different enhancement of solar stills including single-slope solar stills [20,21], that are conventional configuration, double-slope solar stills [22], which are designed in order to used more solar irradiation and a wider basin, pyramid solar stills [23], single basin solar stills [24], multiple basin solar stills [25], inclined solar stills [26], stepped solar stills [27], that are designed to increase the thermal conductivity between water and basin with a constant basin area and spherical solar stills [28], evacuated solar collector [29], heat pipe solar collector [30], that are trying to increase water temperature before entering to the basin, flat plate solar collector [31], that utilized to increase the solar irradiation entering to the solar still, photovoltaic modules that trying to increase the water temperature in the basin, tubular solar still [32,33], humidification-de-humidification solar desalination [34] and utilization of graphite and nanoparticles in solar still have been developed [35,36]. In addition, [37] show that, solar power systems are more efficient than using diesel generators in desalination systems and, which directed our mine into using solar power system for providing required electricity. These finding are alight with results published by Niajaili et al. [37] which they reported that though the initial outlay of the PV system is about 9 times of the conventional systems the total lifecycle costs of the PV pumping system is just 65.6 % costs of the conventional pumping system. Especially that in comprising to other renewable energies sources, like wind, it can be run with no need to huge construction.

However, in most of the researches, 4 issues have not been investigated. First, almost all of the research, and technologies just focused on desalination efficiency and water production rate during day, which limits the water production to 10 to 12 h a day and turning this system to an improper system for using in farmland, especially in arid and warm area that need to distilled water is significant. Secondly, the setup and maintenance of high-technological materials and systems like the use of nanomaterials did not consider the limitations of the farmers' technical, scientific abilities and economics in third-generation countries. Thirdly, high solar irradiation and sunny days increase the need for distilled water, especially in areas that economic condition relies on proper water for irrigation, why we don't use of solar energy for heating the water in the solar still system and enhancing the water production rate? still systems are based on the temperature difference and reducing the temperature of the glass in solar still systems can increase water production rate. How, we can reduce the glass temperature without using any power?

The authors believe that the enhancement of solar-still using conventional materials, that its maintenance does not require expert staffs is of great importance. In this regard, we proposed a solar power enhancement for solar still desalination systems. Proposed continuous heating-enhanced solar still (CHeSS) not only uses solar renewable energy to run heating elements placed in basin of solar still systems, but also uses grooves on glass to reduce the glass temperature and increase water temperature before feeding into basin of solar still. This method can enhance the efficiency of system using heating element during day and night, increase the temperature of the water in the system and improve the evaporation rate. Because of higher different temperature of water in basin and ambient temperature, desalination rate will highly be improved, which help to securing proper water in less area and using less CHeSS panels. In addition, lowering the temperature of glass and increasing the temperature of water before entering the basing significantly enhance the water production rate. In this research, the design and evaluation of water production capacity of proposed CHeSS has been conducted for a real pistachio farm in Sirjan, Iran, which highly suffered from water shortage and high TDS.

Material and methods

In this research we aim to design and evaluate a CHeSS farm to supply proper irrigation water for a pistachio orchard in Sirjan. The specifications of the land, the required water and the calculation equations are described below.

Study area

As shown in Fig. 1, Sirjan city (28° 30′- to 30° 0′ N, 55° 0′- 56° 30′ E) is located at the south of Iran with an average height of 1170 m. Required meteorological information including daily graph of wind speed, solar radiation, and ambient temperature for this city was extracted based on

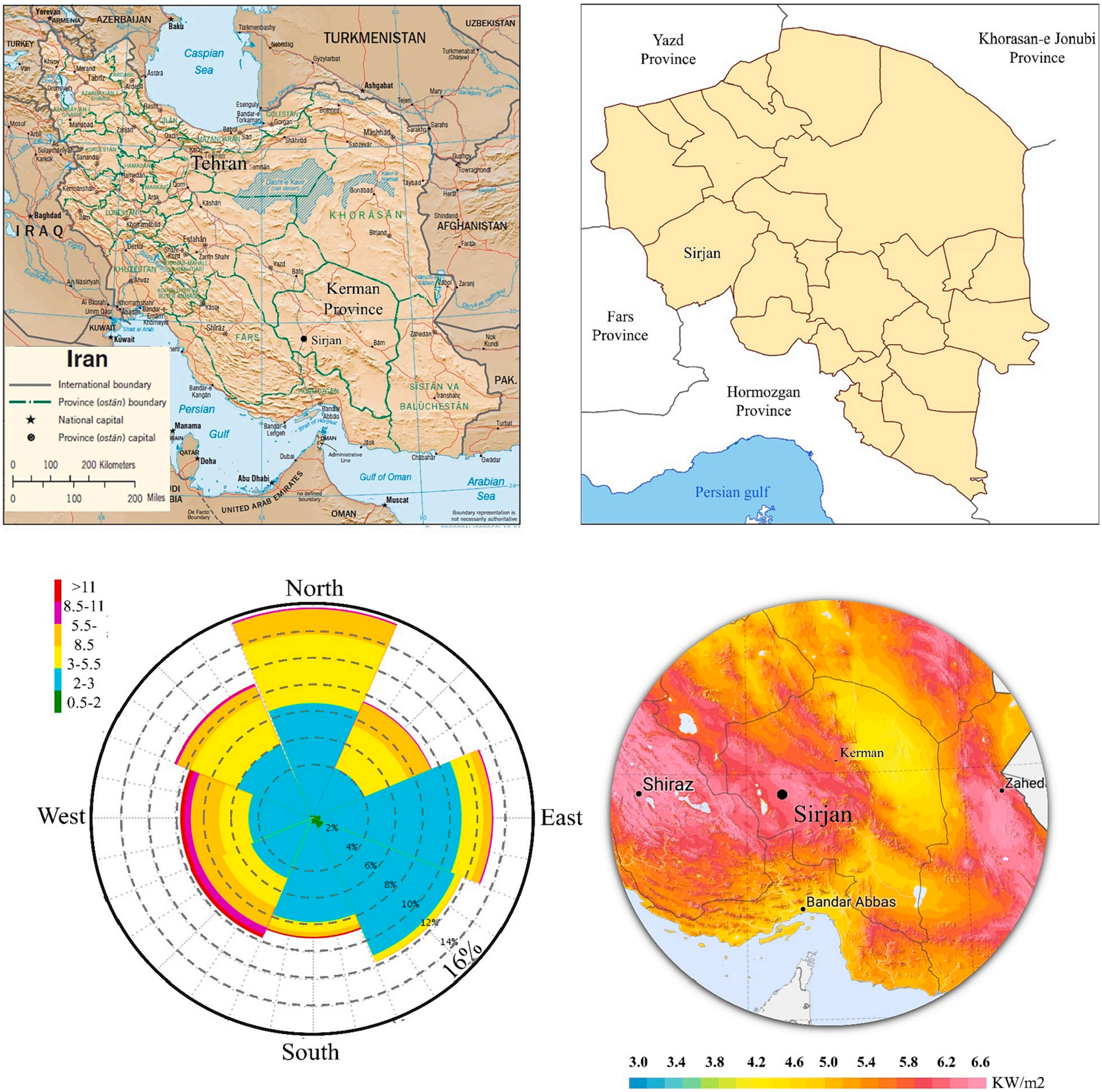

Fig. 1. Geographical location, wind rose and solar irradiation counter of Sirjan city [38,39].

provided information at national meteorological organization website [38]. The average wind speed, average ambient temperature and total day radiation is equal to 2.7 m/s, 16 C° and 6.6 Kw/m^2 respectively. In spite of the challenging arid climate that characterizes Sirjan, this region has earned a distinguished reputation as one of the foremost global hubs for pistachio production.

As shown in Table 1, TDS of current irrigation water in this area is 10000 ppm which is categorized as unsatisfactory for irrigation [40] and much higher than proper irrigation water. High salinity of water, relying the economy of local community on pistachio production and presence of Sirjan city in the list of deprived places of Iran, makes this city a remarkable candidate for this research. As the considered pistachio farm already have one URD152 water pump produced by Pump Iran co. (5 Kw and 6 m^3/hr) that uses 2-inch pipe water pump which extract groundwater from 200 m depth and a 100 m^3 capacity storage tank, we continued our calculations based on the as-built situation and trying to efficiently improve and complete the current irrigation system.

Energy analysis

An approach to assess the energy efficiency of a solar still system involves computing the ratio of system's productivity to the total solar energy absorbance. The equation presented below is a highly effective method for quantifying energy efficiency [41].

$$\eta_{daily} = \frac{m_{ev} \times h_{fg}}{I_t \times A_b} \tag{1}$$

The variables I_t (W/m^2), m_{ev} (L/h), and h_{fg} indicate the entire solar energy in a day, water production in a day, and the latent heat, respectively.

Table 1
Information for irrigation and chemical properties of untreated water.

Data	Amount	Unit	Data	amount	Unit
Orchard Area	10,000	m^2	Total required water in a year	5,000	m^3
Required irrigations per S2, S3	9	–	Adequate TDS for irrigation of farm	5,000	ppm
Required irrigations per S1, S4	5	–	Untreated water TDS	10,000	ppm
Required water in each irrigation for S3 and S4	400	m^3	Total required water in a year	5,000	m^3
Required water in each irrigation for S1 and S2	280	m^3	Total required distilled water	2,500	m^3

* Data is provided based on conducted analysis by the certified Gehrzamin laboratory in Sirjan City.
** S1, S2, S3 and S4 are represent the season 1, season 2, season 3 and season 4.

Thermal calculations

The design carried out in this research as in Fig. 2 includes, the calculation of the volume of desalination water production, the calculation of the desalinated water capacity at the presence of the heating element required working time of well pump, the electricity required to run the pumps, calculating the electricity required by the heating elements, calculating the solar panels needed to supply electricity and determining the number of desalination panels required. All the calculation conducted using Microsoft Excel 2020 and considering energy balance equations for glass, water, and basin and parameter mentioned in Table 2 [42]. For better understanding the equation and calculation steps, Fig. 3 presented below [43–45].

$$X\,volume\ of\ water_{TDS=5000} = mixing\left(\frac{x}{2}volume\ of\ water_{TDS=10000} + \frac{x}{2}volume\ of\ water_{TDS=0}\right) \quad (2)$$

$$\text{Required well pump working time per day}_{s1\ and\ s2} = 1400m^3 \text{Ã}\cdot 180 \text{Ã}\cdot 4\frac{m^3}{hr} \quad (3)$$

$$\text{Required well pump working time per day}_{s3\ and\ s4} = 3600m^3 \text{Ã}\cdot 180 \text{Ã}\cdot 4\frac{m^3}{hr} \quad (4)$$

$$RequiredKwhforrunningwellpumpperday = 5Kw \times requiredtimeperday \quad (5)$$

The energy balance of the glass cover:

$$M_g Cp_g \frac{dT_g}{dt} = Q^c_{w-g} + Q^r_{w-g} + Q^e_{w-g} - Q^c_{g-a} - Q^r_{g-s} + \alpha_g A_g I(t) \quad (6)$$

The energy balance for the water:

$$M_w Cp_w \frac{dT_w}{dt} = Q^c_{b-w} - Q^c_{w-g} - Q^r_{w-g} - Q^e_{w-g} - Q_{fw} + \alpha_w \tau_g A_w I(t) \quad (7)$$

The energy balance for the basin:

$$M_b Cp_b \frac{dT_w}{dt} = -Q^c_{b-w} - Q_{loss} + \alpha_b \tau_w \tau_g A_b I(t) \quad (8)$$

The hourly water production of the solar still:

$$m_{ev} = \frac{h^e_{w-g}(T_w - T_g) \times 3600}{h_{fg}} \quad (9)$$

In the mentioned equations, h^c_{w-g}, h^r_{w-g}, h^e_{w-g}, and h^c_{b-w} are the heat transfer coefficient of convection between the water and the glass, the radiation between the water and the glass, the evaporation between the water and the glass, and the connection between the basin and the water, respectively

$$h^e_{w-g} = 0.016237 \times h^c_{w-g} \times \frac{(P_w - P_g)}{T_w - T_g} \quad (10)$$

$$h_{fg} = (2401,67 - (2,389 \times T_w)) \times 10^3 \quad (11)$$

The convection heat transfer between the water and the glass can be calculated as [46,47]

$$Q^c_{w-g} = h^c_{w-g} A_w (T_w - T_g) \quad (12)$$

$$h^c_{w-g} = 0.884 \times \left[T_w - T_g + \frac{(P_w - P_g) \times (T_w + 273.15)}{268900 - P_w}\right]^{\frac{1}{3}} \quad (13)$$

$$P_w = \exp\left[25,314 - \left(\frac{5144}{T_w + 273}\right)\right] \quad (14)$$

$$P_g = \exp\left[25,314 - \left(\frac{5144}{T_g + 273}\right)\right] \quad (15)$$

The radiation heat transfer between the water and the glass can be calculated as:

$$Q^r_{w-g} = h^r_{w-g}(T_w - T_g) \quad (16)$$

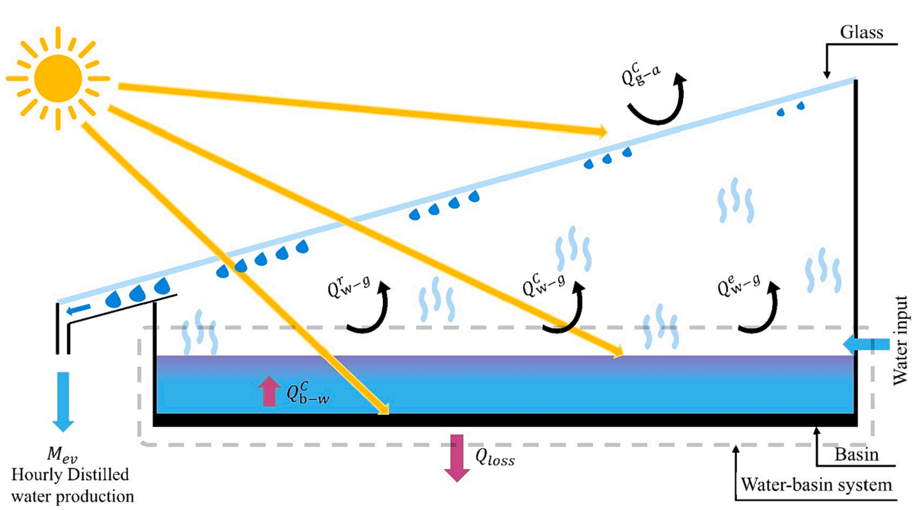

Fig. 2. Schematic diagram of the energy balance of the solar still single slope.

Table 2
Numerical parameters.

Parameter	Value	Parameter	Value	Parameter	Value
ρ_g	2500 (kgm^{-3})	ρ_b	7800 (kgm^{-3})	Water thickness	1 cm
Cp_g	840 $(Jkg^{-1}\ K^{-1})$	Cp_b	460 $(Jkg^{-1}\ K^{-1})$	Insolation thickness	5 cm
Glass thickness	4 mm	Basin thickness	2 mm	Isolation K_i	0.059 $(Wm^{-1}\ K^{-1})$
α_g(irradiation sorption)	0.05	α_w(irradiation sorption)	0.05	α_b	0.9
τ_g(irradiation passing)	0.9	τ_w(irradiation passing)	0.95	A_b(area of the basin)	1 m^2

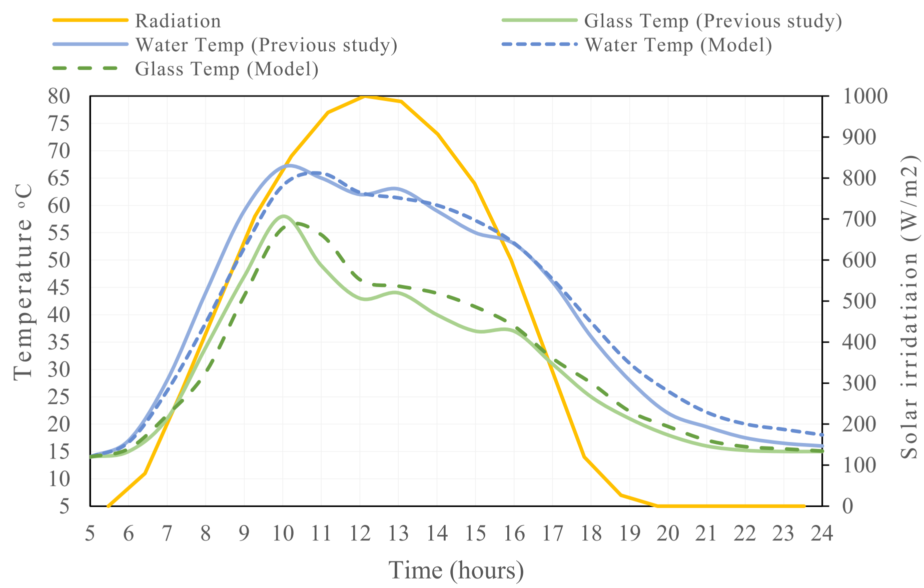

Fig. 3. Model and calculation comparison with previous published research.

$$h^r_{w-g} = \varepsilon_{eff\times}\sigma \times \frac{(T_w + 237.15)^4 - (T_w + 237.15)^4}{T_w - T_g} \tag{17}$$

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_g} - 1\right)^{-1} \tag{18}$$

The evaporation heat transfer between the water and the glass can be calculated as [45,46,48]:

$$Q^e_{w-g} = h^e_{w-g} A_w (T_w - T_g) \tag{19}$$

$$h^e_{w-g} = 16.273 \times 10^{-3} \times h^c_{w-g} \left[\frac{P_w - P_g}{T_w - T_g}\right] \tag{20}$$

The convection heat transfer between the basin and the water can be calculated as:

$$Q^c_{b-w} = h^c_{b-w} A_b (T_b - T_w) \tag{21}$$

To facilitating the calculation and by considering equal temperature of basin and water which almost is a correct assumption, Eqs. (6) and (7) can be combined and Eq. (21) will be extracted. In this research we utilized this equation. So, as it shown in Fig. 3, we consider water and basin as a system and we consider input and output energy to this system (Table 3).

$$M_w Cp_w \frac{dT_w}{dt} + M_b Cp_b \frac{dT_w}{dt} = -Q^c_{w-g} - Q^r_{w-g} - Q^e_{w-g} - Q_{fw} - Q_{loss} + \alpha_b \tau_w \tau_g A_b I(t) + \alpha_w \tau_g A_w I(t) \tag{22}$$

Table 3
Number of required solar panel.

Data	Amount	Unit	Data	amount	Unit
Q of the water pump	6	m^3/ hr	Conventional solar still water production (S3, S4)	5.5	lit/ day. m^2
Required working time of pump (S3, S4)	3.3	hr/ day	Conventional solar still water production (S1,S2)	2.35	lit \day. m^2
Required working time of pump (S1, S2)	1.3	hr/ day	Required area for solar still (S3, S4)	1819	m^2
Required KW. hr for pump (S3, S4)	15.2	Kw. hr/ day	Required area for solar still (S1, S2)	1490	m^2
Required KW. hr for pump (S1, S2)	5.2	Kw. hr/ day	Proposed solar still water production (S3, S4)	12.2	Lit/ day. m^2
Total required water in a year	5,000	m^3	Proposed solar still water production (S1, S2)	5.3	Lit/ day. m^2
Adequate TDS for irrigation of farm	5,000	ppm	Required area for new solar still (S3, S4)	820	m^2
Untreated water TDS	10,000	ppm	Required area for new solar still (S1, S2)	660	m^2

Verifying mathematical calculations

In order to ensure the applicability and reliability of the results, validation of utilized mathematical models is of great importance. In this regard, mathematical equations and input data, such as ambient temperature, radiation intensity, and area of the solar still from a previous research published by [49] have been utilized to validate the calculation process. As Fig. 3 shows, our calculations are accurate enough that the modeling, calculation, facilitating assumptions and outcome results are considered correct.

Proposed desalination system

According to the climatic conditions of the study area and previous studies in south Iran, despite of initial high cost, the use of solar energy is a good option for electricity supply in a long period of time. In addition, previous research show that the water production rate of solar desalination systems is almost 0.5 L/m^2 h, which according to this project's requirements, 2700 m^2 of solar still farm is needed. Therefore, it does not seem reasonable to use conventional solar still in this project unless utilizing a modifications approach can be greatly reduce the required area. As a result, in this project, an effort has been made to provide the required water and electricity for pistachio farm irrigation with the minimum required number of solar panels and solar still systems with no advanced system or high-tech materials. Four main drawbacks of conventional solar still systems are, high required irradiation energy for heating the water, elevated temperature of the glass during the working time, high energy loss and limited working time.

As it is shown in Fig. 4, in order to overcome to these drawbacks, a novel and innovative enhanced solar still system has been introduced in this research. In the proposed new system, the water entrance pathway changed, and after passing through the grooves of the top glass, the heated water feeds into the basin. Using grooved glass that water can move through, extremely help reducing glass temperature, increasing the water temperature before entering to the basin of the solar still and improve the water production rate. Passing water through groves has two different advantages. The thermal energy balance between feeding water and glass makes a new equal temperature balance between feeding water and glass. This condition reduces the glass temperature and increases the water temperature. As a result, more temperature differences between basin water and glass first lead to higher water production rates. secondly, the higher temperature of feeding water results in lower energy needs for the evaporation of basin water, which increases water production. Therefore, passing water through the glass could enhance the efficiency of the water production rate and the system. In addition, an 80-watt heating element, thermostat and polyurethane foam are used to monitor the temperature of the water, increasing water temperature and reducing the heat loss from basin during day and night which lead to an enhanced water production rate, even at night. Although, utilizing heating element with higher watt can highly improve the water production rate, as we consider using 400-watt solar panel for each solar still, 80-watt heating element has been chosen that solar panel can provide required energy for working of heating element. Considering 12 h sun light a day, ideally during a day solar panel can produce 2.4 kw a day which 1.92 kw is consumed by heating element, so each solar still system can provide extra 0.08 kw electricity.

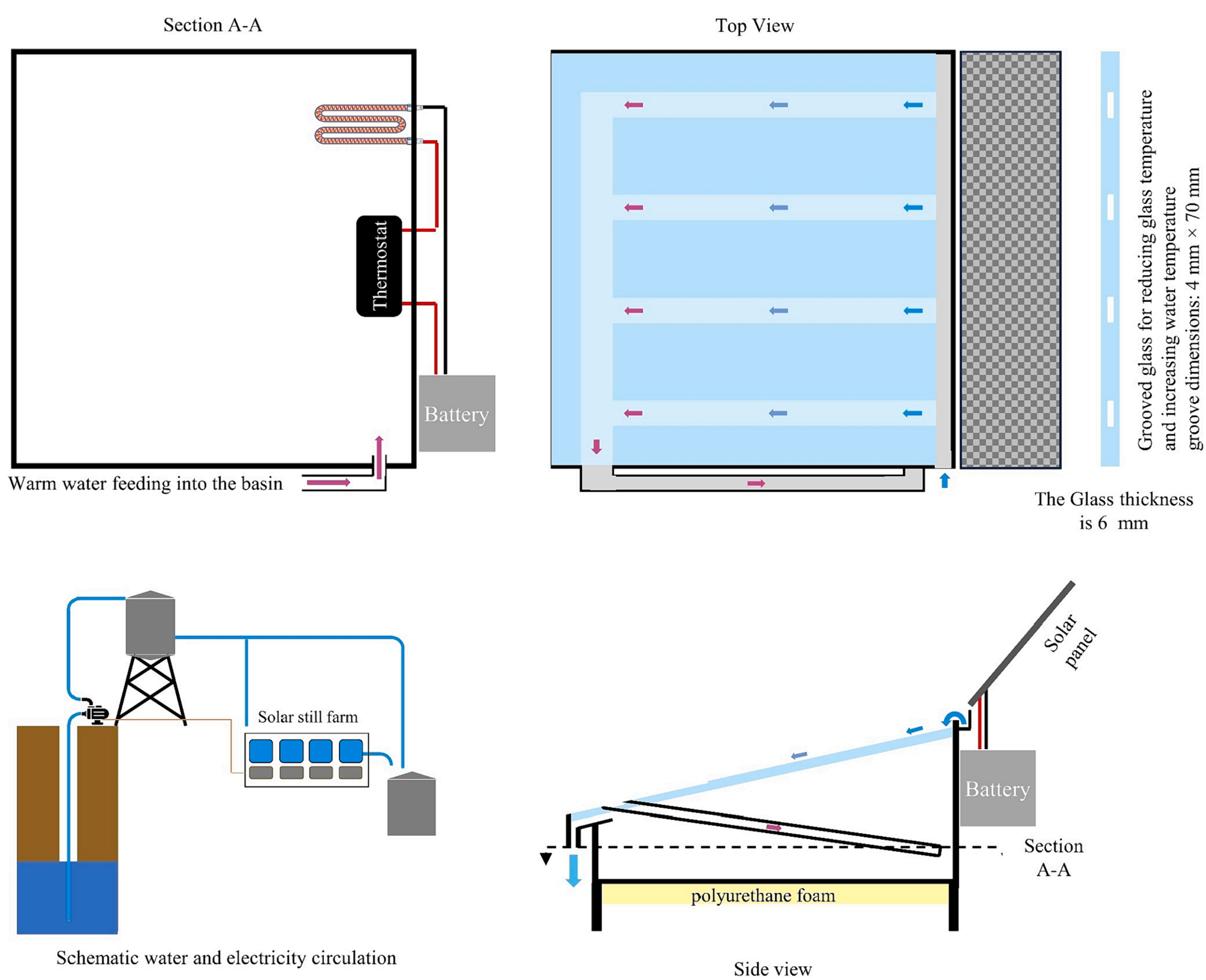

Fig. 4. Top view, side view, section and schematic water circulation of proposed solar still system.

The extra provided power can be used for running water pump.

Results and discussion

Sirjan city receives high solar irradiation and is sunny most of the year, therefore, a solar power plant is a good choice for providing required electricity for pistachio orchard and water desalination system. In this regards, proposed CHeSS system utilizes solar power as an on the mentioned enhancement mechanism. To clarifying effects of enhancement steps, water production per hour is presented in Fig. 5, and as it can be seen, these enhancements can improve the water production rate more than 120 %. Specially that Using heating element during the night, elevated the water temperature in the basin and the water can get warm under solar irradiation easier. As it is shown in Fig. 5, grooved glass method that is design in this research could improve the water production rate and the enhancement increases from early hours of day to almost 13 pm and after that, the amount of improvement is dramatically reduced. This reduction mainly is because of elevated ambient and water temperature and lowering the glass temperature due to the decreasing solar irradiation. Therefore, the effects of passing water through glass reduces.

Energy-water nexus analysis

While a few studies have attempted to improve the solar stills produce water, they have utilized advanced components such as nanomaterials or integrated the solar still system with other systems that occupy more land. However, these efforts have resulted in negligible improvements in the water-production rate. For example, in a study referenced as [50], nanomaterials and phase exchange materials were employed to increase the water production rate by 136 %. However, the complicated design of this system, which includes wicks, trays, and nanomaterials, poses challenges in terms of construction and maintenance, particularly in Less privileged areas of southern Iran. Kabeel et al. [51] enhanced the rate of heat transmission by using hollowed fins. This modification does not pose any significant challenges in terms of building or operation. Nevertheless, it just has the potential to augment water output by 1.6 L, resulting in a daily increase from 4 L to 5.6 L. Xiao et al. [52] used solar panel arrays to improve water productivity. However, the limited working hours aligned with solar irradiation hours restrict the extent of water production augmentation compared to our research design.

Fig. 5 illustrates the hourly fluctuation in freshwater production by

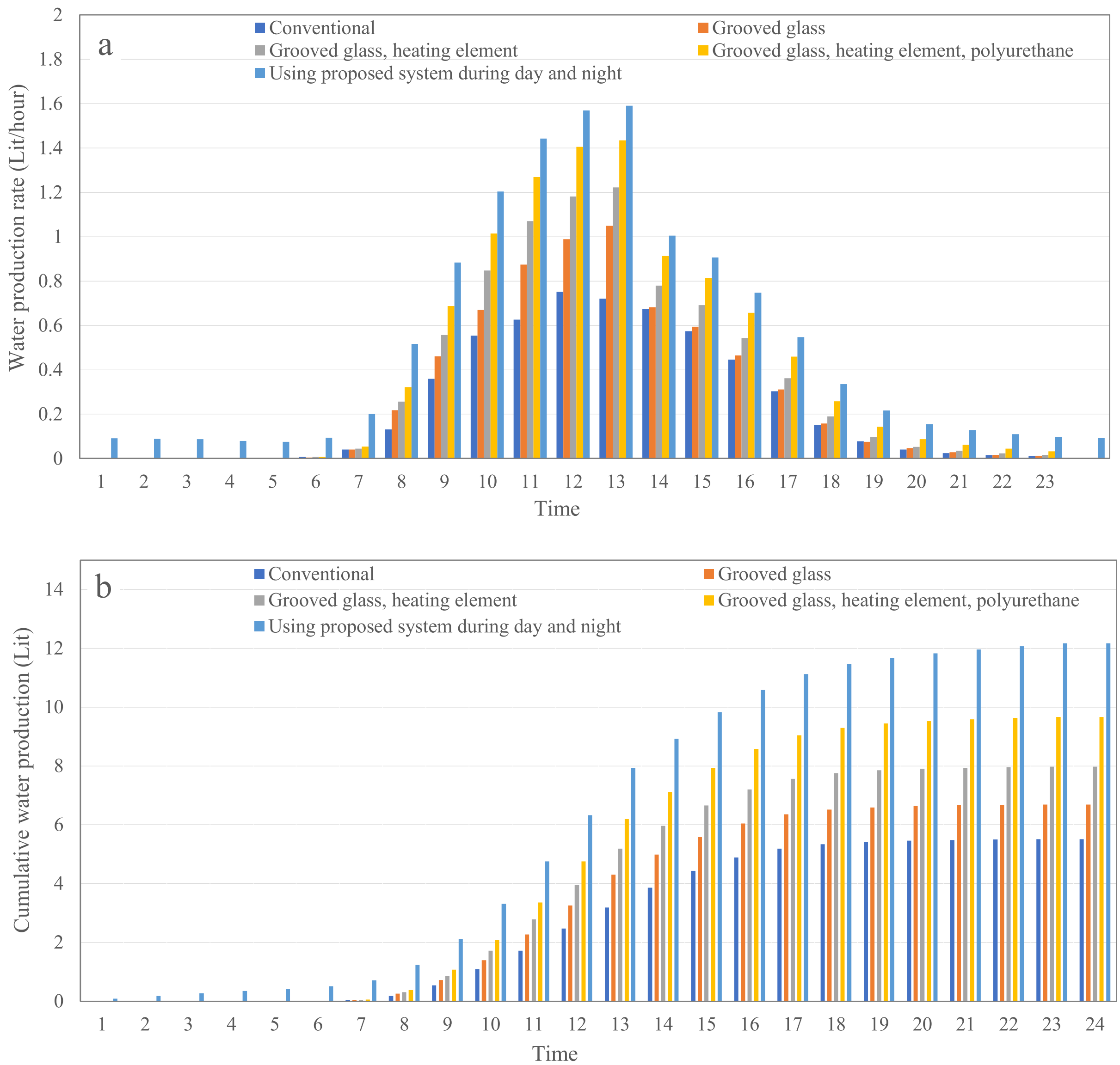

Fig. 5. Water production per hour per day (a) and cumulative water production per day (b) of proposed chess.

both the traditional and proposed systems. The water generation trend is similar at different hours in both cases. The maximum hourly production, as determined, was 0.7 L/m^2 and 1.5 L/m^2, respectively, achieved at 1p.m. The results demonstrated that the daily distillate production of the traditional and proposed methods was 12.17 L/m^2 and 5.5 L/m^2, respectively. The production increased by 121.3 % compared to that of passive ones. The creation of water persisted in the evening after 6p.m. even under low solar radiation in both. Furthermore, the amount of energy produced during the night in an active system was greater than in a passive system as a result of using storage energy in batteries for running heating element [53,54].

As mentioned, this pistachio orchard needs about 5,000 m^3 of water annually with a TDS of 5,000 ppm. Given that the TDS of produced water by solar still is zero, 1 L of saline water with a TDS of 10,000 ppm can be mixed with 1 L of fresh water with a TDS of 0 and the result of this mixture will be 2 L of suitable water with a TDS of 5000, so about 2500 m^3 distilled water is needed which dictate using 820 CHeSS solar still systems.

Economic analysis

In this section, the economic study of this project for supplying agricultural water with using 820 CheSS solar still systems have been studied. First, Capital expenditures (CAPEX) and current investment costs (operating expenses (OPEX cost)) for this project are calculated, and then the Internal rate of return (IRR) of this project is analyzed by calculating the profit from the sale of agriculture water. It is assumed that the cost of buying land and other side costs of this project will be insignificant. The construction cost for the reconstruction and construction rectangle of the land is about 5000 dollars. The cost of purchasing the device and solar panels in this project is about 143 thousand dollars. Other fixed costs such as cable, tank and pump equivalent to 16 thousand dollars are taken into consideration. The fixed investment cost (CAPEX) of this project is about 159,005 dollars. operation costs (OPEX), such as the cost of electricity supply, manpower, and maintenance, are considered to be about 5 % of the fixed cost, equivalent to $7,950 per year. Considering that in this project, 2,500 m^3 of water without salt is produced in a year, and by adding salt water, about 5,000 m^3 of water is calculated for agriculture. The cost of buying each cubic meter of water in Iran is about 5.5 dollars (Due to the lack of water in Iran, this price will increase in the coming years [55]), and the cost of selling this amount of water will be equal to 27,500 dollars. Considering the fixed and operation costs as well as the selling price of water, the Internal rate of return (IRR) of this project is equal to 13.3 %.

Conclusions

Pistachio is a main product of Kerman province in Iran and local economy is highly depended on agricultural activity which affected by high temperature, high solar irradiation, lack of proper water and lack of access to high technology. In this paper, a solar still farm is designed by mixing salt water with fresh water to prepare proper water for irrigating a pistachio orchard with an area of 10,000 m^2. The results showed that about 5,000 m^3 of suitable water with a TDS of 5,000 ppm is needed for agriculture. However, low water production rate of conventional solar still systems, dictate a very high area requirement which reduce acceptability of using this system by farmers. Using the proposed system that designed to provides total amount of required water for irrigation of the pistachio orchard, can increase the daily water production from almost 5.5 L/day to almost 12 L/day, which can be highly applicable to field-scale projects of providing water for less privileged rural areas or farmers who are faced with high-TDS water sources. In addition, although the efficiency of the proposed system is higher than that of the conventional mechanism, the decreasing rate after noon is also higher, which illustrates the significant need to use methods to lower the energy loss of the system. This research illustrates the capability of solar still systems to integrate with other systems. For future research, the following information can be provided: As a result, we proposed an enhanced solar still which increase the water production rate by 120 % and reduces the required area for solar still farm. For future investigation, the following elements could be recommended:

- Research advanced materials for construction to improve heat transfer from the storage area to the water.
- Implement solar tracking sensors to precisely monitor the path of the sun from sunrise to sunset. This ensures that the solar still maximizes its exposure to sunlight throughout the entire day.
- Analyze the environmental consequences of the solar desalination system and aim for its sustainable operation in the long run. This may involve employing environmentally friendly materials, employing recycling procedures, and minimizing any negative effects on the surrounding ecosystem.

CRediT authorship contribution statement

Siamak Hoseinzadeh: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mehdi Soltanian:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mahmud Makabadi:** Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Benedetto Nastasi:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Conceptualization. **Daniele Groppi:** Writing – review & editing, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Davide Astiaso Garcia:** Writing – review & editing, Supervision, Project administration, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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