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Experimental Investigations of a Solar Water Treatment System for Remote Desert Areas of Pakistan

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Abstract: Pakistan is among the countries that have already crossed the water scarcity line, and the situation is worsened due to the recent pandemic. This is because the major budget of the country is shifted to primary healthcare activities from other development projects that included water treatment and transportation infrastructure. Consequently, water-borne diseases have increased drastically in the past few months. Therefore, there is a dire need to address this issue on a priority basis to ameliorate the worsening situation. One possible solution is to shift the focus/load from mega-projects that require a plethora of resources, money, and time to small domestic-scale systems for water treatment. For this purpose, domestic-scale solar stills are designed, fabricated, and tested in one of the harshest climatic condition areas of Pakistan, Rahim Yar Khan. A comprehensive overview of the regional climatology, including wind speed, solar potential, and ambient temperature is presented for the whole year. The analysis shows that the proposed system can adequately resolve the drinking water problems of deprived areas of Pakistan. The average water productivity of 1.5 L/d/m^2 is achieved with a total investment of PKR 3000 (<$20). This real site testing data will serve as a guideline for similar system design in other arid areas globally.

Keywords: arid areas; Pakistan; passive desalination system; water scenario; solar still

1. Introduction

The global water demand has been continuously increasing by ~1% per year since the 1980s [1], thus stressing the existing freshwater resources [2,3]. About one-fifth of the world's population is already living in water-scarce areas, with many regions lying below the availability level of ~500 m^3 per capita per year [4,5]. Therefore, many of these regions are already using water desalination to augment their water supplies to cope with the growing demands [6,7]. Meanwhile, it is important to mention that the conventional commercial-scale desalination systems [8–10] can only reach 10–13% of their thermodynamic limits [7,11], resulting in high energy consumption. However, recently, some hybrid desalination technologies have shown improvement of the conventional processes' limitations [12–15]. The overall water cost for these systems is leveled-off at 0.9 ± 0.3 \$/m^3 [16], which is high for the low-income countries, where the average salary is close to $1–2/day [17].

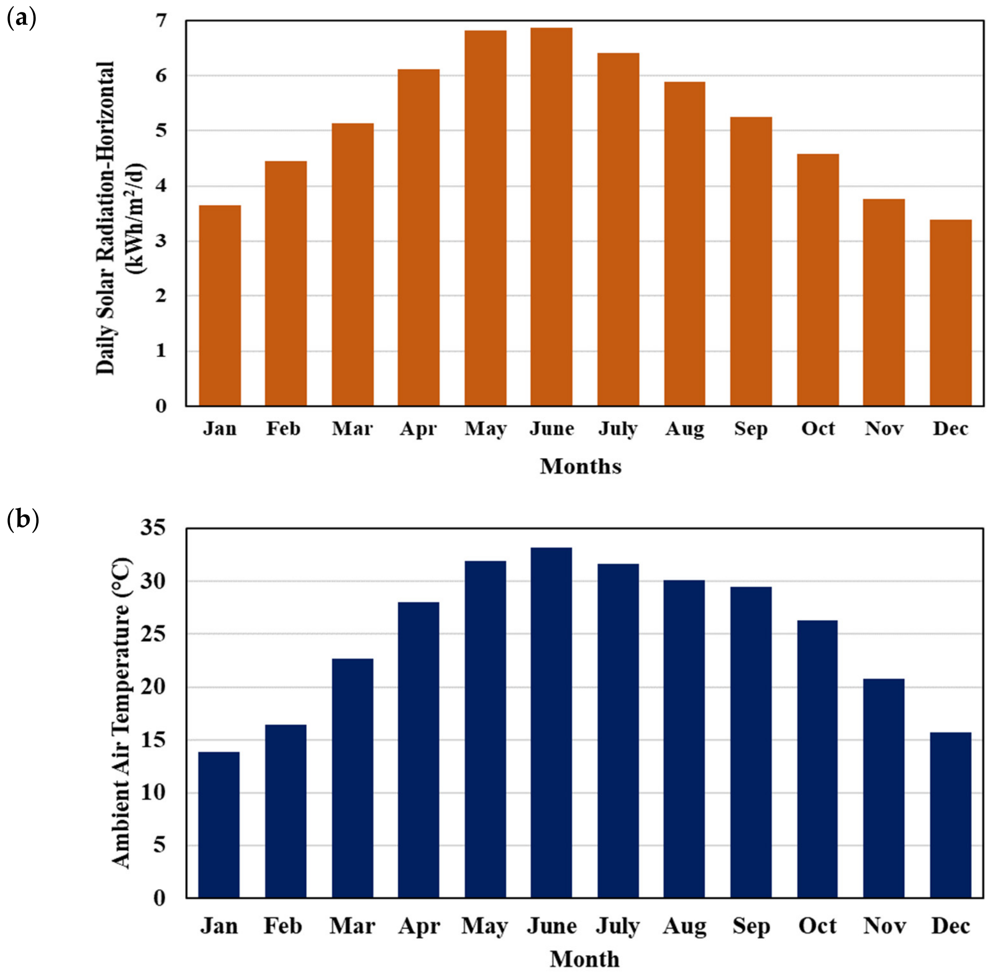
Further, the recent COVID-19 global pandemic has also unveiled many issues like food supply in remote areas, immediate budget shifts to primary healthcare, and frequent handwashing requirements [18,19]. These measures worsened the water scarcity in many countries by increasing water consumption by 20% and wastewater generation by 15–18% [20]. Therefore, the affordable freshwater supply in remote areas is a serious dilemma for both the residents and the authorities. Moreover, large-scale investments (i.e., millions of $) [21] on industrial-scale water treatment plants are not viable for technologically backward countries. Therefore, there is no time more urgent to address the world's water crisis than now when people are constantly being reminded to use water to combat the virus spread [22]. Therefore, it is the right time to focus on the implementation of small-scale water treatment systems operating on alternative energy sources [23], especially for remote areas in water-stressed countries like Pakistan where most of the population is residing in less developed regions. In this regard, first, the country's water situation is assessed comprehensively to summarize the water availability, consumption, quality, issues, and management plans as presented in the following sections.

Pakistan's Water Situation

Pakistan is the 5th most populated country worldwide, and its population is expected to increase from 207 million in 2017 to 333 million by 2050 [24,25]. According to the United Nations Development Program (UNDP-2012) report, Pakistan is likely to face a 14% increase in water demand by 2025, which could be even higher, depending upon the industrial and economic growth rate [26]. On the other hand, it is ranked 19th on the list of water-stressed countries by the World Resources Institute [27], and the freshwater supply is highlighted as a formidable challenge by the Pakistan Council of Research in Water Resources (PCRWR) [28]. Moreover, around 19% of Pakistan's GDP is associated with the agriculture sector [29], which shares about 91.6% of the total water consumption in the country [30,31]. Therefore, water shortage directly damages economic growth. Meanwhile, the quality of groundwater is another issue, and the country is ranked 80th in terms of drinking water quality [32]. From 16.71 million hectares (mha) of groundwater (especially from the Indus basin), only 5.75 mha is available for drinking and agricultural activities due to low salt concentration <1000 ppm. The remaining ~1.84 mha is slightly more concentrated at 1000–3000 ppm, and ~4.28 mha is highly concentrated at >3000 ppm, which cannot be used without treatment [33–35].

Furthermore, almost 80% of the country's water is contaminated with bacteria and other organic/inorganic pollutants causing waterborne diseases, which constitute about 80% of all diseases and are responsible for 33% of deaths [36]. Moreover, arsenic contamination is another major issue in almost all parts of the country, and ~47.5 million people are residing in regions with arsenic levels well above the WHO's permissible limits [37,38]. Therefore, overall, around 62% of the urban and 84% of the rural population in Pakistan do not have access to fresh water, resulting in high water-related health issues [39,40]. The issue is particularly severe among infants, as the country is facing around 0.06 million children deaths annually because of water-borne diseases, which cost around $1.3 billion/y [41–43]. Keeping in view the current and forthcoming water crises, Pakistan is looking forward to creating a solid platform to enhance cooperation and partnerships globally [44]. It will help to adopt the United Nations' Decade of Action (2018-2028) "Water for Sustainable Development" [45]. In line with this action plan, Pakistan's first-ever National Water Policy was approved in April 2018 [46]. A comprehensive summary of all water-related activities in the country is presented in Tables A1–A4 in Appendix A.

Furthermore, the government and NGOs are collaboratively working on establishing a small water treatment filtration system in rural areas to provide clean water at the town level [47]. However, these projects are facing halts in terms of electricity supply in the remote areas because around 40% of the rural and 7% of the urban population do not have electricity facilities [48,49]. The expansion of solar photovoltaic PV systems around the country can help to address the power requirement issues for water treatment systems, but it is time-consuming and requires large investments. Secondly, the diverse groundwater composition is an even bigger challenge (i.e., turbidity, total dissolved solids (TDS), pH, microbiology, etc.), which makes membrane selection, maintenance, and replacement complicated and expensive [50]. A current market survey [51] suggests that a domestic-scale photovoltaic reverse osmosis PV-RO unit with a capacity of 100 gallons/day needs a capital investment of PKR 21,000. Additional PKR 12,000/year are also required for operation and maintenance of the overall system for smooth operation (chemical dosing, filters, and membrane replacement, etc.). Meanwhile, the evaporation-based water treatment systems can remove the impurities more effectively and can handle a variety of feed water without affecting the operation and produced water quality. The simplest evaporation-based water treatment system is the solar still, which works on the natural evaporation-condensation cycle [52]. Many recent studies have shown the scope of this system for remote areas with different modifications such as the use of phase change materials, nanoparticles, integration of active equipment, and augmenting the productivity through parallel systems [53,54].



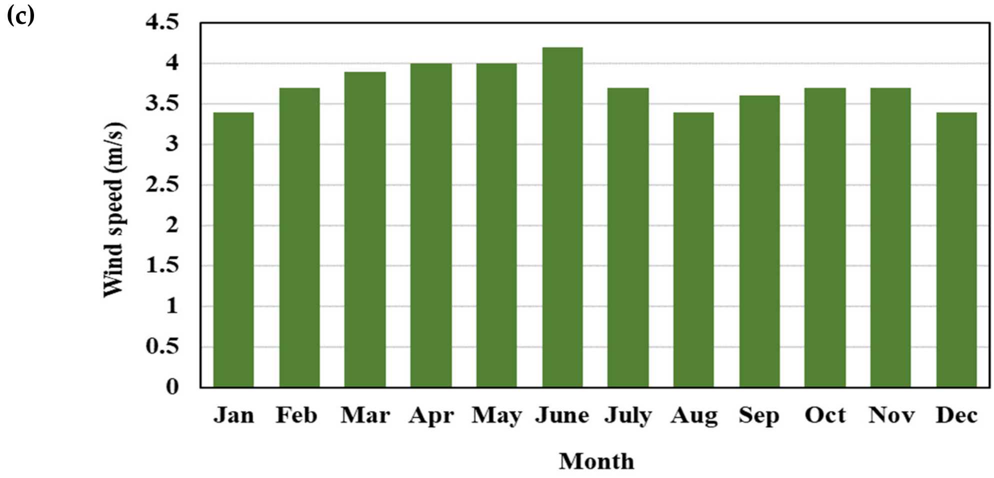


Figure 1. Monthly data for (**a**) daily solar radiation—horizontal, (**b**) ambient air temperature, and (**c**) wind speed [55].

It is important to emphasize that, despite technical suitability, severe feed water quality handling capability, fewer maintenance requirements, and economic affordability, the solar still system has not yet been developed and tested for the climatic conditions in Pakistan due to lack of design data. Therefore, the current study is focused on the fabrication and experimental investigation of two different passive solar stills (single-slope and pyramid shape) to provide detailed design specifications for future applications. In the first step, a single-slope solar still is fabricated and tested to investigate the effect of solar irradiance, wind velocity, and 24 h operation. Then, a pyramid shape system is developed for higher productivity that can be stacked in parallel to increase the capacity to support different family sizes. The proposed solar still will provide clean water at low maintenance and affordable investment requirements to the targeted community in remote hot and dry areas in Pakistan such as South Punjab and Interior Sindh.

2. Climatology and Solar Potential

The analysis was done in Rahim Yar Khan, situated in the South Punjab of Pakistan, i.e., an arid area with a relatively warm climate. It is located at 28.4° N latitude and 70.3° E longitude, at an elevation of 84 m. The highest average daily solar radiation (Global Horizontal Irradiance, GHI) ambient air temperature, and wind speed in June are 6.86 kWh/m^2/d, 33.2 °C, and 4.2 m/s respectively [55]. The daily solar GHI from March to September is recorded as >5 kWh/m^2/d [55]. The solar GHI, temperature, and wind speed for the whole year are presented in Figure 1. The proposed site not only has good GHI, but is also suitable due to the poor groundwater quality in the area, low precipitation rate, high ambient air temperature, and high solar intensity, with ~10 h long sunshine duration in summer.

The productivity of the solar still system strongly depends upon the solar radiation, ambient air temperature, wind speed, dust, and cloud cover [56,57]. Aburideh et al. [58] examined the effect of climatic conditions on double-slope plane solar still, and they concluded that an increase in productivity strongly depends on solar radiation. Hinai et al.'s [59] investigation showed that a 10 °C increase in the ambient air temperature improves production by 8.2%. El-Sebaii [60] analyzed the effect of wind speed on the outputs of solar stills and found that the output was boosted with increasing wind speed. The rate of evaporation rises with increasing wind speed. As reported in many studies, the performance of the solar still system increases with the increase in solar radiation, ambient air temperature, and wind speed [57]. Thus, the Rahim Yar Khan region has the rich potential of the solar effective operation of solar stills.

3. Proposed System and Methodology

The proposed system consists of a solar still that was fabricated and tested in two different configurations. In the first step, a single slope solar still (a simple standard configuration as shown in Figures 2 and 3) was developed and tested to investigate the performance under local operating conditions. This was followed by the development of a high-productivity advanced pyramid shape passive solar still as shown in Figures 4 and 5. A square-shaped basin of 1 m^2 area and 0.06 m height at the bottom was used to store the feed water. The feed water evaporates by absorbing solar thermal energy. The vapors rise and condense after striking the glass cover, and due to the adhesion effect, the condensate is collected in a rectangular channel (2 inch wide food grade plastic sheet) attached at the end of the glass cover. The freshwater is collected in a container attached to the channel. The product water sample collected was tested for important water quality parameters, and the results are presented in the subsequent sections in the subsequent sections. The system works in a batch process, and the brine is collected at the end of each cycle (24 h). The water basin has two apertures for feed and brine. Due to high productivity, the results are discussed in detail for pyramid shape configuration only, as the single slope system may be considered a special case as a single side of the pyramid system with lower productivity.

Meanwhile, it is important to mention that the system is sealed externally using silicon to avoid penetration of dust or water from fog or rain. However, it is also worth mentioning that the system gives productivity during sunshine because the system is designed for hot and humid areas with very rare rain seasons, since, in the other case, rainwater can be collected and used for drinking purposes. Moreover, the maintenance of the system only involves the removal of suspended particles from the basin, which can be done by removing the glass cover for which the glass lifting supports are installed as shown in Figures 3 and 5. After that, the sample collected is tested using water testing kit (TDS meter) as depicted in Figure 6.

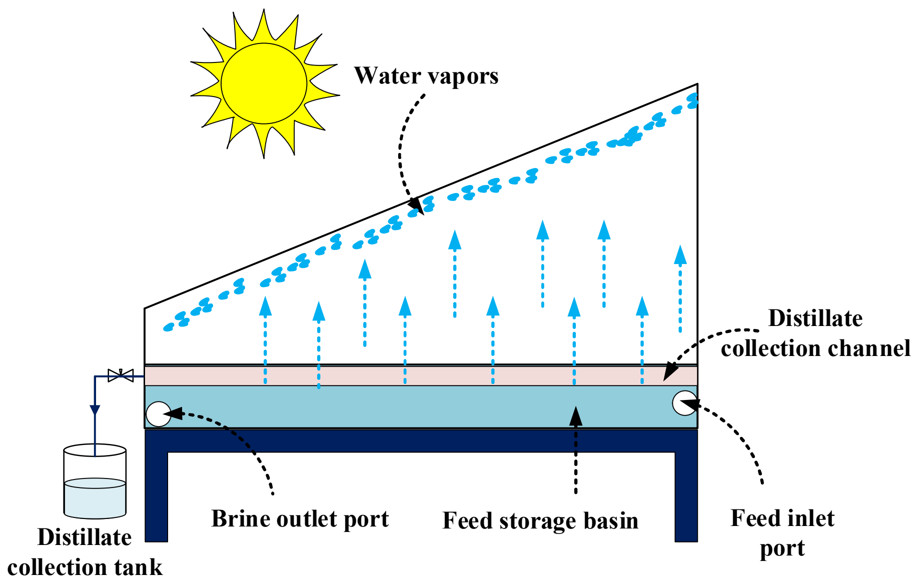


Figure 2. Schematic diagram of the single-slope solar still.

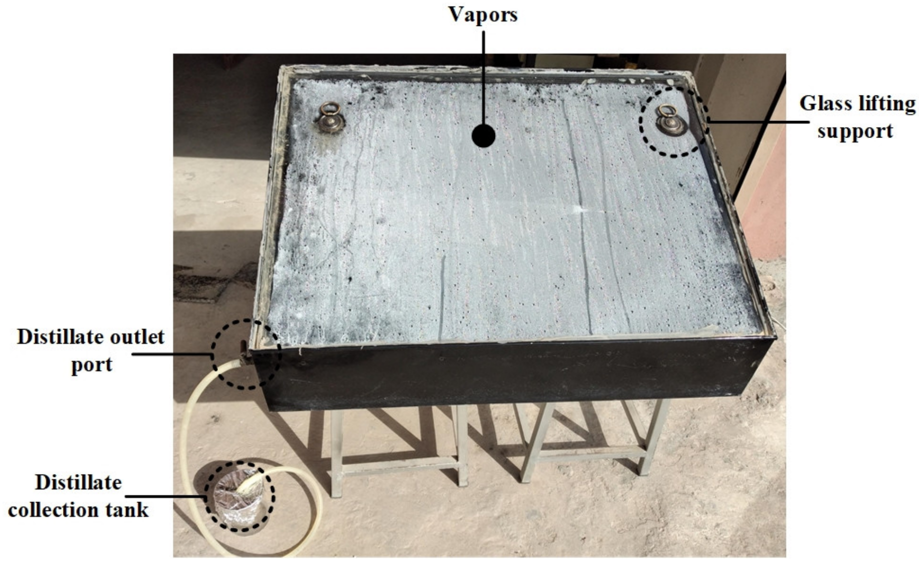


Figure 3. Single slope solar still experimental setup.

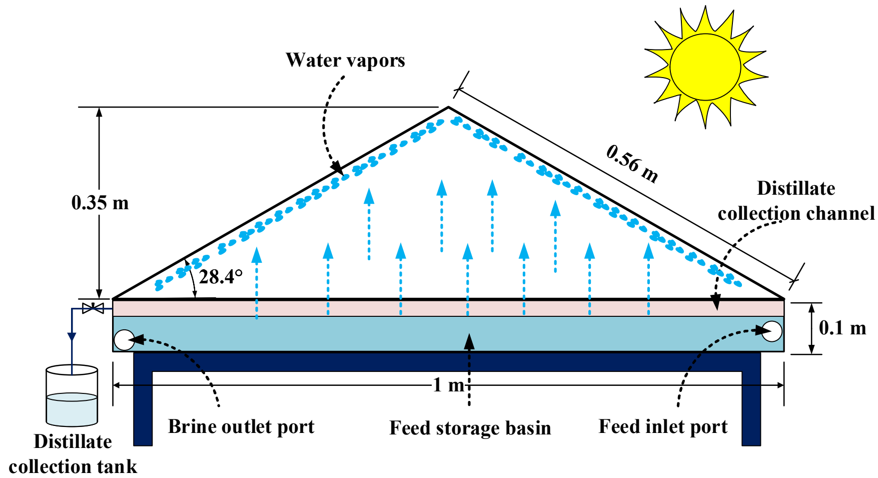


Figure 4. Schematic diagram of the pyramid solar still.

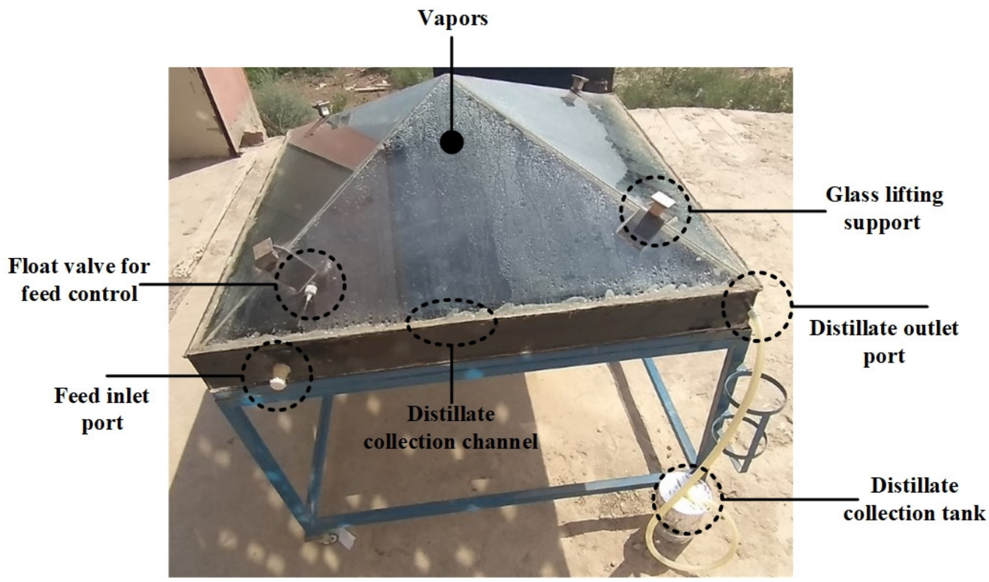


Figure 5. Pyramid shape solar still experimental setup.

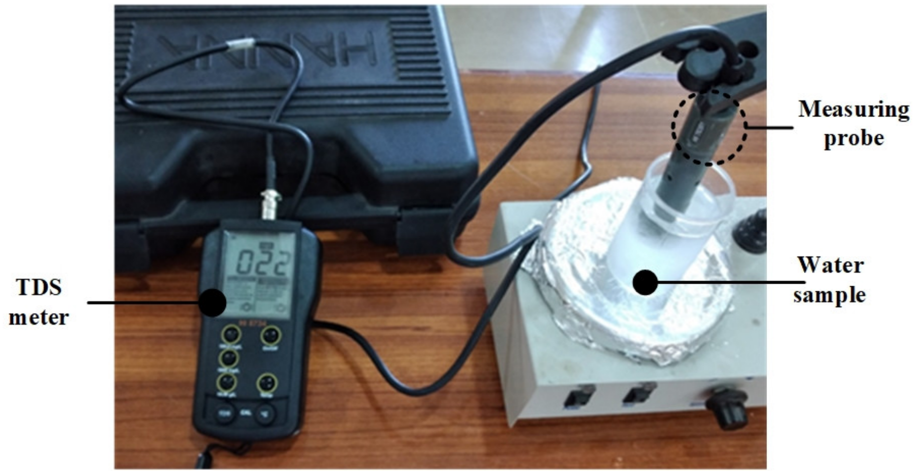


Figure 6. Total dissolved solids (TDS) measuring kit.

4. Governing Equations

The above-proposed system is also analyzed theoretically to calculate productivity. The governing equations used for this purpose include mass, material, and energy balances as given below.

$$\sum_{in} \dot{m} = \sum_{out} \dot{m} \quad (1)$$

$$\sum_{in} \dot{m}S = \sum_{out} \dot{m}S \quad (2)$$

The energy balance within the solar is still based on the thermal radiation incident, transmitted through the glass cover to the water surface, the heat losses by convection, evaporation, and radiation back to the glass cover from the water surface to cover [52]. By considering the thermal capacitance of seawater, the energy balance is given as

$$\alpha_w \tau G = q_{ga} + q_{ba} + mC_p \frac{dT_w}{dt}, \quad (3)$$

where α_w is absorptivity of water, τ is the transmissivity of glass, global irradiance, q_{ga} is heat loss from glass to air, q_{ba} is heat loss from the basin, m is the mass of water, and T_w is the temperature of feed water.

The energy losses from the body to ambient due to convection, radiation, and conduction is given as [61]

$$q_{ga} = q_r + q_c + q_e \quad (4)$$

The heat flux from the water surface to glass cover by radiation is given as [52]

$$q_r = F_s \sigma \left(T_w^{\ 4} - T_g^{\ 4} \right) \quad (5)$$

where F_s is the radiation shape factor and depends upon the geometry and solar radiations. For the case of a pyramid-shaped solar still, the shape factor is taken as 0.9 [62]:

$$q_r = 0.9 \sigma \left(T_w^{\ 4} - T_g^{\ 4} \right) \quad (6)$$

Energy loss from water body to base of the solar still is given as

$$q_b = U_b\,(T_w - T_b) \tag{7}$$

The heat flux from the water to glass cover by natural convection and evaporation is calculated as

$$q_c = h_c\left(T_w - T_g\right) = h_c \Delta T \tag{8}$$

The heat flux from water to the cover by natural convection and evaporation is given as

$$q_e = m_d\, h_{fg} \tag{9}$$

The heat loss from solar still to the outside environment depends upon the convection and radiation heat transfer coefficients, while, the radiation to the sky depends upon the effective sky temperature, which is generally taken as 11 °C less than the ambient temperature [52]. The equation for combined radiation and convection heat transfer coefficient is given as [52].

$$q_{ga} = \varepsilon_g \sigma\left[T_g^4 - \left(T_a - 11\right)^4\right] + h_{ga}\left(T_g - T_a\right) \tag{10}$$

The above equation is not valid for all types of plate types, so the modified form of the formula is given by Sparrow et al. [63], which is more reliable to determine the heat loss from glass to air. It is given by Equation (15).

$$Nu = \frac{h_{ga}\, L}{k_{air}} = 0.86\,\mathrm{Re}^{\frac{1}{2}}\,\mathrm{Pr}^{\frac{1}{3}} \tag{11}$$

The heat transfer coefficient inside the solar still due to natural convection is calculated using the correlation modified by Antar and Zubair [52] as follows.

$$Nu = \frac{h_c L}{k_{fluid}} 1 + 1.44\left[1 - \frac{1708 \sin 1.8\beta^{1.6}}{Ra\cos\beta}\right] \times \left[1 - \frac{1708}{Ra\cos\beta}\right]^{+} + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{1/3} - 1\right]^{+} \tag{12}$$

where + sign in exponent shows that the term will only be considered if it is calculated >0. Ra is Raleigh number, which is calculated as

$$Ra = \frac{g\beta\Delta T^{'}}{\nu\alpha} \tag{13}$$

where $\Delta T^{'}$ is the modified temperature difference, calculated as [52]

$$\Delta T' = (T_w - T_g) \times \left[\left(\frac{P_w - P_{wg}}{P_{ambient}\left(\dfrac{m_{dryair}}{m_{dryair} - m_{wvapour}}\right) - P_w} \right) \left(T_w + 273 \right) \right] \tag{14}$$

Finally, the mass of distillate (freshwater) is estimated based on the above-calculated heat transfer coefficient (h_c) and partial pressure of water at T_w and T_g.

$$m_d = 9.15 \times 10^{-7} h_c (\mathrm{P}_w - P_{wg}) \tag{15}$$

5. Results and Discussion

The proposed system was analyzed experimentally as well as theoretically considering the freshwater productivity as an output parameter. Table 1 summarizes the operational data and shows that the proposed system satisfactorily removed the dissolved solids from the brackish feed. Moreover, it is also observed that the system can concentrate brine to achieve a TDS of ~35,000 ppm, thus approaching zero liquid discharge. However, in the current case, the system is operated to fulfill the drinking water needs, which requires a continuous washing of brine for higher productivity.

Table 1. Operational data.

Parameter	Value
Feedwater volume, liters	17
Total freshwater collected (after 6 days), liters	15
Rejected brine volume, liters	1.5
Water lost in handling, liters	0.5
Feedwater salinity, ppm	3000
Freshwater salinity, ppm	22
Brine water salinity, ppm	33,000
Average potable water, liter/day	2.5

The developed system was operated continuously for a week to investigate the variations in productivity against temperatures, wind velocity, and solar irradiations. The data for a complete day (productive hours) are presented in Table 2. It is observed that the noticeable productivity starts between 7:00 and 8:00 a.m., when evaporation occurs. Before that, a small amount of condensate is observed because of condensation during the night due to temperature drop. The peak hourly productivity is observed between 12:00 to 16:00 due to maximum evaporation at solar noon. After that, the evaporation rate declines; however, the condensation occurs at a rather higher rate due to temperature drop. The overall per day productivity is estimated as an arithmetic means of weekly productivity as 2.5 L/day.

Table 2. Hourly data of variation in temperatures, wind speed, and productivity.

Time (h)	T_{amb} (°C)	T_g (°C	T_w (°C)	V_{Wind} (km/h)	$m_{d,ac}$ (mL/h)
7:00–8:00	32	34	38	8	20
8:00–9:00	34	36	42	9	25
9:00–10:00	36	38	45	9	50

10:00–11:00	39	43	63	10	130
11:00–12:00	40	46	68	10	175
12:00–13:00	41	48	70	13	250
13:00–14:00	42	50	73	11	275
14:00–15:00	41	52	72	11	250
15:00–16:00	41	50	70	10	200
16:00–17:00	39	48	64	10	170
17:00–18:00	36	40	56	9	100
18:00–19:00	34	38	50	9	75

The variations in ambient, glass, and feed temperatures during the day are presented in Figure 7. It is observed that these temperatures (particularly T_F) show a significant rise between 11:00 to 16:00 because of peak solar irradiance. In the meantime, the maximum productivity is observed as shown in Figure 8. A close agreement between theoretical and experimental productivity is also observed in Figure 9, which confirms the model validity as well. Moreover, it is also noticed that the wind velocity varies randomly over the day; however, the productivity is observed to be more sensitive to the temperature variations than V_{wind}. The hourly water production for three consecutive days is presented in Figure 9. This shows that productivity is almost the same for all days, with some sunshine and temperature. Therefore, it is expected to reasonably have the same productivity for the months with the same climatic conditions (i.e., February to November).

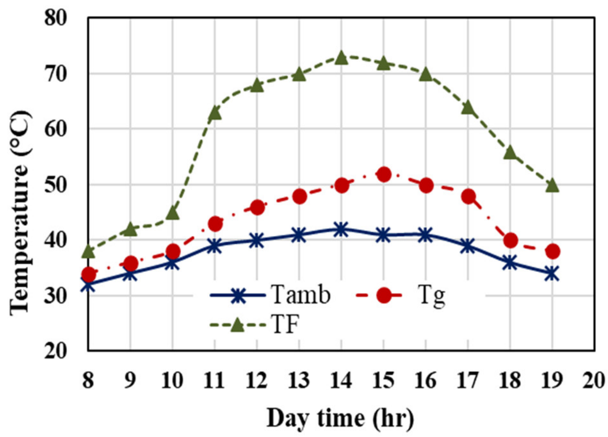


Figure 7. Temperature variation during the day (23 June 2020) and the abbreviations in the figure are as follows: T_{amb} = ambient temperature, T_g = glass temperature, and T_F = feed temperature.

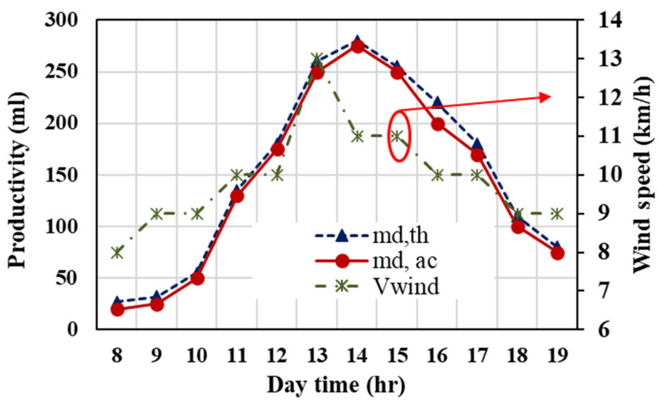


Figure 8. Productivity variation during the day (reading taken 23 June 2020) and the circle and arrow in the figure refers to the secondary axis for wind speed also the abbreviations in the figure are as follows: m_d = theoretical productivity, m_{ac} = actual productivity, and V_{wind} = Wind velocity.

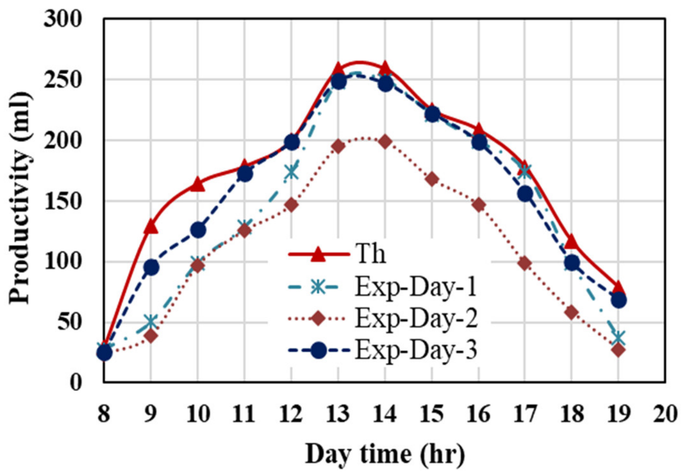


Figure 9. Productivity variations in three typical days and the abbreviations in the figure are as follows: T_h = theoretical and Exp = experimental.

The proposed solar still showed excellent potential to produce freshwater for a single household in remote areas of Pakistan. The chemical composition testing of the sample presented in Table 3 shows the suitability of distillate water for drinking purposes. Most importantly, it decoupled the water production from the grid connection using solar energy, so it can be applied in remote areas where there is either no power supply or high load shedding due to limited electricity generation. The overall cost of the system is estimated as PKR 3000 (<$20) with minimal maintenance. The proposed solar still can be designed per family member with a small increase in cost. In addition, due to simple operations, local illiterate people can easily operate without any training.

Table 3. Chemical composition test for water samples (The AQUA Solutions, RYK).

Water Quality Parameter	Feed Sample	Distillate Sample	Range
Arsenic (μg/L)	NIL	NIL	10 (WHO)
Conductivity (μS/cm)	2230	55	2000 (CPCB)
TDS (ppm)	1450	22	1000 (WHO)
pH	7.3	6.5	6.5–8.5
Carbonates (mg/L)	NIL	NIL	NGVS
Carbonates (mg/L)	500	12	300(mg/L)
Chlorides (mg/L)	344	07	250 (WHO)
Sulphate (mg/L)	211	07	250 (WHO)
Hardness (mg/L)	630	20	500 (WHO)
Calcium (mg/L)	96	04	100 (KSA)
Magnesim (mg/L)	94	02	150 (WHO)
Sodium (mg/L)	219	03	200 (WHO)

μS/cm: micro-Simens per centimeter, KSA: Kingdom of Saudi Arabian Standard, NGVS: no guidance value set, CPCB: Central pollution control board.

6. Conclusions

The solar-based passive pyramid solar still with a basin area of $1 m^2$ has been designed, fabricated, and tested in Rahim Yar Khan city of Pakistan. The effect of feed water temperature, wind speed, and ambient temperature on the experiment productivity of the solar still has been analyzed with the following findings.

The yearly average value of daily solar radiation-horizontal is >5.2 kWh/m^2/d, which is suitable for the solar desalination system. The feedwater temperature increases to a maximum of 72 °C due to the highest ambient air temperature and solar radiation in the summer season; therefore, the water productivity rises to the maximum value. The wind speed increases the external heat transfer coefficient, which is also increased due to the increase in the temperature difference between glass and feed water. The peak ambient temperature is recorded at 42 °C at noontime, and it is the maximum-productivity time. The different days of the experiment have shown different productivity, which is close to the theoretical productivity. The average daily productivity obtained was 2.5 L/m^2/day with 20 TDS and up to 7.5 pH and no arsenic content.

This project will help to increase the use of renewable energy resources to overcome water scarcity in remote and off-grid areas. It is a sustainable alternative to conventional energy-based systems and can help the implementation of National Water Policy in true spirit. It can also boost up the research in the water sector and complete the projects related to water treatment plants. It will also encourage the adoption of environmentally friendly water desalination methods for arid areas of Pakistan as well as other countries facing the same situations.

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Conflicts of 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.

Nomenclature

c_p	specific heat, kJ/kg·K
F_s	shape factor
G	solar irradiations, W/m^2
h_c	heat transfer coefficient convection, W/m^2·K
h_{fg}	enthalpy of evaporation, J/kg
h_{ga}	heat transfer coefficient convection from glass to air, W/m^2·K
h_w	heat transfer coefficient for water, W/m^2·K
L	length of basin, m
k	thermal conductivity, W/m·K
m_d	mass of distillate, kg
M_{dryair}	molar mass of dry air
$M_{w,vapour}$	molar mass of water vapors
Nu	Nusselt number
$P_{ambient}$	the partial pressure at ambient temperature, mm Hg
Pr	Prandtl number
P_w	the partial pressure at basin water temperature, mm Hg
P_{wg}	the partial pressure at a glass temperature, mm Hg
q_{ba}	heat loss from basin to air, W/m^2
q_{ga}	heat loss from glass to air, W/m^2
q_r	heat loss through radiations, W/m^2

q_c	heat loss through convection, W/m^2
q_e	heat loss through evaporation, W/m^2
Ra	Raleigh number
Re	Reynold number
T_a	temperature of air, °C
T_b	temperature of basin, °C
T_g	temperature of glass, °C
T_w	temperature of feed water, °C
U_b	overall heat transfer through a basin, W/m^2·K
V_{wind}	wind velocity, km/h
Greek letter	
α	absorptivity
α_w	absorptivity of water
β	inclination angle
ε_g	emissivity of glass
σ	Stiffen–Boltzmann constant
τ	transmittivity of glass
ν	kinematic viscosity
Subscripts	
b	basin
g	glass
w	water
Abbreviations	
AD	Adsorption
AEDB	Alternative energy development board
GDP	Gross domestic product
GHI	Global horizontal irradiance, kWh/m^2/d
IWRM	Integrated water resource management
MED	Multi effect desalination
mha	Million hectares
MSF	Multistage flash
NCBI	National Capacity Building Institute
PCRWR	Pakistan council of research in water resources
ppm	Parts per million
SWRO	Seawater reverse osmosis
TDS	Total dissolved solids
UNDP	United nations development program
UNICEF	United nations international children's emergency fund
WHO	World health organization

Appendix A

A comprehensive summary of water-related activities (policies, plans, research, and development).

Table A1. National water policy of Pakistan, agenda items and suggested actions [64,65].

Agenda Items	Suggested Action
Conservation and efficiency	Water wastage should be reduced, and water conservation and supply efficiency must be emphasized.
Storage capacity	The building of medium and small capacity dams, enhancing the life of existing storage mediums and construction of Reni Canal and Kachi Canal
Leveraging technologies	Seawater utilization, water recycling, preparation of an inventory of water resources through remote sensing and precise monitoring of irrigation water distribution.
Renewable energy	Small, medium, and large-scale hydropower projects and solar-based seawater desalination systems.
Integrated water resource management (IWRM)	IWRM should be adopted on all up-and-down streams to minimize water mining and contamination.
Comprehensive regulatory management	Food, water, and energy safety, effective and sustainable water usage, and proper wastewater management.
Planning principles	Access to safe drinking water, environmental sustainability, innovation, and feasibility of new projects.

Table A2. Government plans related to water issues [66–68].

Department	Main Points
Ministry of Planning and Development (2018)	• Adoption of "Water for Sustainable Development" and IWRM model, firm implementation of National Standards for Drinking Water Quality (2008), Canal and Drainage Act of 1873, and use of media for awareness of water-related challenges • Purification of saline water, recycling of sewerage and industrial water using local technologies, solar-based water desalination for remote areas, and low cost • Incorporation of proper pretreatment systems for better plant performance, use of nonchemical water softening techniques (magnetic treatment), improvements in the investments by central and provincial departments for sewerage water recycling and freshwater safety, suitable treatment of private housing schemes' wastewater before disposal, excavation of water wells where subsurface hydrogeology permits (seaside)
Ministry of Environment (2005)	• Improve water treatment facilities, water quality monitoring, facilitate municipal authorities for pure water supply, suitable measures for rainwater collection, artificial recharge of groundwater in arid areas, metering of water consumption to discourage unnecessary water usage, implementation of Water Conservation Act • Integrated watershed management, continued freshwater flows in the marine ecosystems, programs for clean-up and up-gradation of water bodies, and standards for the classification of surface and groundwater
Supreme Court of Pakistan (2018) [68]	• Initiation of Dam Fund by Chief Justice (CJ) and Prime Minister of Pakistan for the construction of two new dams Diamer Bhasha and Mohmand Dam

Table A3. Water research centers in Pakistan [43,69–76].

Organization	Sector Type	Focused Areas
UNICEF Pakistan (1948)	NGO	Clean water, sanitation, health and nutrition
WHO-Pakistan (1948)	NGO	Water, sanitation, and world health
Pakistan Council of Research in Water Resources (PCRWR) (1964)	Government	Water quality, water management, rainwater harvesting, and desertification control
Centre of Excellence in Water Resources Engineering, UET Lahore, (1976)	Government	Water resource management and hydropower
Pakistan Desalination Association (1994)	NGO	Desalination
U.S-Pakistan Centers for Advanced Studies in Water, Mehran University Jamshoro (2014)	USAID	Water scarcity, water quality, ecosystem and performance of water utilities
Punjab Saaf Pani Company (2014)	Government	Safe drinking water

Center for Water informatics and Technology (WIT), LUMS, Lahore (2016)	Private	Hydro-informatics and systems analysis
National Capacity Building Institute (NCBI), Collaborated with PCRWR (2017)	Government	Climate extremes, water quality, and water management

Table A4. Current status of desalination plants in Pakistan [77–80].

Plant Type	**Location and Design Capacity**	**Inauguration Date and Status**	**Sponsors**
Thermal-based system (Multi-Effect Desalination system (MED)	Defense Housing Authority (DHA), Phase-8, Karachi, (11,355 m^3/day)	Inaugurated in April 2008, Not operational	DHA Cogen Limited
Thermal-based systems (Rs 200 Million for each)	Pasni, Jewani, and Singhar (Baluchistan) (757 m^3/day)	Approved in 2008 Installed but not operational	Baluchistan Development Authority
Thermal-based (Rs. 01 Billion)	Gwadar City (7570 m^3/day)	Approved in 2008, Partially started in 2014 (with 1135 m^3/day) Partially operational	Baluchistan Development Authority
Thermal-based system	Gwadar Port (960 m^3/day)	Inaugurated Jan 2018 Operational	China Overseas Port Holding Company
Thermal-based	Gwadar City 16,600 m^3/day	Construction started in March 2018 Under construction	UAE/ Switzerland
Thermal-Nuclear based cogeneration plant (MED)	KENUPP 4800 m^3/day	Commissioned in 2012, Partially started in 2014 (with 1600 m^3/day) Partially operational	Government of Pakistan

References

1. UNESCO, United Nations World Water Development Report, 2019: Leaving No One Behind, UNESCO Publishing, 2019. Available online: https://en.unesco.org/themes/water-security/wwap/wwdr/2019 (accessed on 4 Octobber 2020).
2. Ghofrani, I.; Moosavi, A. Energy, exergy, exergoeconomics, and exergoenvironmental assessment of three brine recycle humidification-dehumidification desalination systems applicable for industrial wastewater treatment. *Energy Convers. Manag.* **2020**, *205*, 112349, doi:10.1016/j.enconman.2019.112349.
3. Shahzad, M.W.; Burhan, M.; Ghaffour, N.; Ng, K.C. A multi evaporator desalination system operated with thermocline energy for future sustainability. *Desalination* **2018**, *435*, 268–277, doi:10.1016/j.desal.2017.04.013.
4. Immerzeel, W.; Droogers, P.; Terink, W.; Hoogeveen, J. Middle-East and Northern Africa Water Outlook. *Rep. FutureWater* **2011**, *31*, 1–135.
5. Parris, A.; Bromirski, P.; Burkett, V.; Cayan, D.; Culver, M.; Hall, J.; Horton, R.; Knuuti, K.; Moss, R.; Obeysekera, J.; et al. Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA TR OAR CPO 2016. 1–33. Available online: https://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf (accessed on 4 Octobber 2020).
6. Ghaffour, N. The challenge of capacity-building strategies and perspectives for desalination for sustainable water use in MENA. *Desalination Water Treat.* **2009**, *5*, 48–53, doi:10.5004/dwt.2009.564.
7. Shahzad, M.W.; Burhan, M.; Ybyraiymkul, D.; Ng, K.C. Desalination Processes' Efficiency and Future Roadmap. *Entropy* **2019**, *21*, 84, doi:10.3390/e21010084.
8. Jamil, M.A.; Zubair, S.M. Design and analysis of a forward feed multi-effect mechanical vapor compression desalination system: An exergo-economic approach. *Energy* **2017**, *140*, 1107–1120, doi:10.1016/j.energy.2017.08.053.
9. Jamil, M.A.; Zubair, S.M. On thermoeconomic analysis of a single-effect mechanical vapor compression desalination system. *Desalination* **2017**, *420*, 292–307, doi:10.1016/j.desal.2017.07.024.
10. Jamil, M.A.; Qureshi, B.A.; Zubair, S.M. Exergo-economic analysis of a seawater reverse osmosis desalination plant with various retrofit options. *Desalination* **2017**, *401*, 88–98, doi:10.1016/j.desal.2016.09.032.
11. 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* **2020**, *477*, 114266, doi:10.1016/j.desal.2019.114266.
12. Ng, K.C.; Thu, K.; Oh, S.J.; Ang, L.; Shahzad, M.W.; Bin Ismail, A. Recent developments in thermally-driven seawater desalination: Energy efficiency improvement by hybridization of the MED and AD cycles. *Desalination* **2015**, *356*, 255–270, doi:10.1016/j.desal.2014.10.025.

13. Abid, A.; Jamil, M.A.; Sabah, N.U.; Farooq, M.U.; Yaqoob, H.; Khan, L.A.; Shahzad, M.W. Exergoeconomic optimization of a forward feed multi-effect desalination system with and without energy recovery. *Desalination* **2021**, *499*, 114808, doi:10.1016/j.desal.2020.114808.
14. Chen, Q.; Alrowais, R.; Burhan, M.; Ybyraiymkul, D.; Shahzad, M.W.; Li, Y.; Ng, K.C. A self-sustainable solar desalination system using direct spray technology. *Energy* **2020**, *205*, 118037, doi:10.1016/j.energy.2020.118037.
15. Alrowais, R.; Qian, C.; Burhan, M.; Ybyraiymkul, D.; Shahzad, M.W.; Ng, K.C. A greener seawater desalination method by direct-contact spray evaporation and condensation (DCSEC): Experiments. *Appl. Therm. Eng.* **2020**, *179*, 115629, doi:10.1016/j.applthermaleng.2020.115629.
16. Jamil, M.A.; Shahzad, M.W.; Zubair, S.M. A comprehensive framework for thermoeconomic analysis of desalination systems. *Energy Convers. Manag.* **2020**, *222*, 113188, doi:10.1016/j.enconman.2020.113188.
17. The Worl Bank, Nearly Half the World Lives on Less Than $ 5.50 a Day, 2018. Available online: https://www.worldbank.org/en/news/press-release/2018/10/17/nearly-half-the-world-lives-on-less-than-550-a-day (accessed on 13 June 2020).
18. AL-Jazeera, Pakistan Daily Wagers Struggle to Survive in Coronavirus Lockdown, 2020. Available online: https://www.aljazeera.com/news/2020/03/pakistan-daily-wagers-struggle-survive-coronavirus-lockdown-200325115143152.html (accessed on 13 August 2020).
19. WHO, Coronavirus Disease (COVID-19) Advice for the Public, 2020. Available online: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public (accessed on 9 January 2021).
20. Juela Quintuña, D.M. Estimated Impact of COVID-19 on Water Needs and Volume and Quality of Wastewater. *SSRN Electron. J.* **2020**, 3, 1-18, doi:10.2139/ssrn.3651551.
21. Ghaffour, N.; Missimer, T.M.; Amy, G.L. Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. *Desalination* **2013**, *309*, 197–207, doi:10.1016/j.desal.2012.10.015.
22. Kalbusch, A.; Henning, E.; Brikalski, M.P.; de Luca, F.V.; Konrath, A.C. Impact of coronavirus (COVID-19) spread-prevention actions on urban water consumption. *Resour. Conserv. Recycl.* **2020**, *163*, 105098, doi:10.1016/j.resconrec.2020.105098.
23. Li, C.; Goswami, Y.; Stefanakos, E. Solar assisted sea water desalination: A review. *Renew. Sustain. Energy Rev.* **2013**, *19*, 136–163, doi:10.1016/j.rser.2012.04.059.
24. PBS, Pakistan Bureau of Statistics, Census 2017, 2017. Available online: http://www.pbs.gov.pk/content/population-census (accessed on 18 February 2019).
25. n-Calculators, Geometric Population Growth Calculator, Exponential Popul. Proj. Formula Calc. 2018. Available online: https://ncalculators.com/environmental/exponential-population-projection-calculator.htm (accessed on 8 November 2020).
26. UN Water. *The United Nations World Water Development Report 4*; France, 2012; Volume 2. Available online: https://www.unwater.org/publications/managing-water-uncertainty-risk/ (accessed on 8 November 2020).
27. Luo, T.; Young, R.; Reig, P. Aqueduct Projected Water Stress Country Rankings. *World Resour. Inst.* **2015**, 1–16. Available online: https://www.wri.org/resources/data-sets/aqueduct-projected-water-stress-country-rankings (accessed on 14 August 2020).
28. PCRWR. Pakistan Council of Research in Waster Resources, 2018. Available online: http://pcrwr.gov.pk/water-quality/ (accessed on 8 November 2020).
29. Finance Division. Governmen of Pakistan, Pakistan Economic Survey, Pakistan 2019–20; 2020. Available online: http://www.finance.gov.pk/survey_1920.html (accessed on 8 November 2020).
30. PDA. Pakistan Development Advocate. Water Security in Pakistan: Issues and Challenges; Pakistan, 2016. Available online: https://www.pk.undp.org/content/pakistan/en/home/library/development_policy/development-advocate-pakistan--volume-3--issue-4.html (accessed on 8 November 2020).
31. Rehman, A.; Jingdong, L.; Shahzad, B.; Chandio, A.A.; Hussain, I.; Nabi, G.; Iqbal, M.S. Economic perspectives of major field crops of Pakistan: An empirical study. *Pac. Sci. Rev. B Humanit. Soc. Sci.* **2015**, *1*, 145–158, doi:10.1016/j.psrb.2016.09.002.
32. Nabeela, F.; Azizullah, A.; Bibi, R.; Uzma, S.; Murad, W.; Shakir, S.K.; Ullah, W.; Qasim, M.; Häder, D.-P. Microbial contamination of drinking water in Pakistan—a review. *Environ. Sci. Pollut. Res.* **2014**, *21*, 13929–13942, doi:10.1007/s11356-014-3348-z.
33. Ahmad, S. Land and Water Resources of Pakistan—A Critical Assessment. *Pak. Dev. Rev.* **2007**, *46*, 911–937, doi:10.30541/v46i4iipp.911-937.
34. Jain, M. Status of Household Water Treatment and Safe Storage in 45 Countries and a Case Study in Northern India. PhD Thesis, Massachusetts Institute of Technology, 2010. Available online: https://dspace.mit.edu/handle/1721.1/58082 (accessed on 8 November 2020).
35. WHO. *Guidelines for Drinking Water Quality*; World Health Organization: Geneva, Switzerland, 1996; Volume 2.
36. Daud, M.K.; Nafees, M.; Ali, S.; Rizwan, M.; Bajwa, R.A.; Shakoor, M.B.; Arshad, M.U.; Chatha, S.A.S.; Deeba, F.; Murad, W.; et al. Drinking Water Quality Status and Contamination in Pakistan. *BioMed Res. Int.* **2017**, *2017*, 1–18, doi:10.1155/2017/7908183.
37. Malik, A.H.; Khan, Z.M.; Mahmood, Q.; Nasreen, S.; Bhatti, Z.A. Perspectives of low cost arsenic remediation of drinking water in Pakistan and other countries. *J. Hazard. Mater.* **2009**, *168*, 1–12, doi:10.1016/j.jhazmat.2009.02.031.
38. Shahid, M.; Niazi, N.K.; Dumat, C.; Naidu, R.; Khalid, S.; Rahman, M.M.; Bibi, I. A meta-analysis of the distribution, sources and health risks of arsenic-contaminated groundwater in Pakistan. *Environ. Pollut.* **2018**, *242*, 307–319, doi:10.1016/j.envpol.2018.06.083.

39. Luby, S.; Agboatwalla, M.; Raza, A.; Sobel, J.; Mintz, E.; Baier, K.; Rahbar, M.; Qureshi, S.; Hassan, R.; Ghouri, F.; et al. A low-cost intervention for cleaner drinking water in Karachi, Pakistan. *Int. J. Infect. Dis.* **2001**, *5*, 144–150, doi:10.1016/s1201-9712(01)90089-x.
40. Azizullah, A.; Khattak, M.N.K.; Richter, P.; Häder, D.-P. Water pollution in Pakistan and its impact on public health—A review. *Environ. Int.* **2011**, *37*, 479–497, doi:10.1016/j.envint.2010.10.007.
41. UNICEF Pakistan, Pakistan Annual Report 2016, 2016. Available online: http://www.unicef.org/pakistan/FINAL_UNICEF_Annual_Report_2013_-_Version_11.1.pdf (accessed on 10 Decemebr 2020).
42. Gulab, S.A. Waterborne diseases, Pakistan Obs. 2016. Available online: https://pakobserver.net/waterborne-diseases-2/ (accessed on 31 July 2020).
43. WHO, World Health Organization, Pakistan, WHO. 2018. Available online: http://www.who.int/countries/pak/en/ (accessed on 31 July 2020).
44. UNESCO. 2018–2028 International Decade for Action, 'Water for Sustainable Development', UNESCO. 2018. Available online: http://www.unesco.org/new/en/brasilia/about-this-office/prizes-and-celebrations/2018-2028-international-decade-for-action-water-for-sustainable-development/ (accessed on 27 August 2020).
45. Kiani, K. Pakistan to Adopt UN Decade of Action for Water Sector, DAWN. 2018. Available online: https://www.dawn.com/news/1415084/pakistan-to-adopt-un-decade-of-action-for-water-sector (accessed on 27 August 2020).
46. Ministry of Water Resouces. National Water Policy, 2018; Pakistan, 2018. Available online: https://www.thethirdpole.net/en/climate/pakistan-national-water-policy/?gclid=Cj0KCQjwmcWDBhCOARIsALgJ2QdCh7jC_wQ4A6eNb-_wb1s_KzTPi6y1q1ezmxu7QUq68hBSQj_hcy8aAuxYEALw_wcB (accessed on 27 August 2020).
47. Pakistan Council of Research in Water Resources (PCRWR). PCRWR Annual Report 2013–14; Pakistan 2015. Available online: www.pcrwr.gov.pk (accessed on 27 August 2020).
48. Pakistan Bureau of Statistics, Housing Units by Source of Drinking Water, Lightening and Cooking Fuel. *Pakistan Bur. Stat.* **2020**, *1*. Available online: http://www.pbs.gov.pk/content/housing-units-source (accessed on 4 January 2021).
49. Alternative Energy Development Board. *Current Status of Solar PV Power Projects*; Alternative Energy Development Board*:* Pakistan 2020. Available online: https://www.aedb.org/ae-technologies/solar-power/solar-current-status (accessed on 27 August 2020).
50. Jamaly, S.; Darwish, N.; Ahmed, I.; Hasan, S.W. A short review on reverse osmosis pretreatment technologies. *Desalination* **2014**, *354*, 30–38, doi:10.1016/j.desal.2014.09.017.
51. Mehmood, K. Quotation for Domestic Reverse Osmosis System, Safe Water Technology, Canal Road, Rahim Yar Khan; Pakitan, 2020.
52. Antar, M.A.; Zubair, S.M. Performance evaluation of a solar still in the Eastern Province of Saudi Arabia—An improved analysis. *Desalination Water Treat.* **2010**, *22*, 100–110, doi:10.5004/dwt.2010.1618.
53. Zhang, L.; Xu, Z.; Bhatia, B.; Li, B.; Zhao, L.; Wang, E.N. Modeling and performance analysis of high-efficiency thermally-localized multistage solar stills. *Appl. Energy* **2020**, *266*, 114864, doi:10.1016/j.apenergy.2020.114864.
54. Chamsa-Ard, W.; Fawcett, D.; Fung, C.C.; Poinern, G. Solar Thermal Energy Stills for Desalination: A Review of Designs, Operational Parameters and Material Advances. *J. Energy Power Technol.* **2020**, *2*, doi:10.21926/jept.2004018.
55. NASA, RETScreen Software, NASA Agency, 2020. Available online: https://www.nasa.gov/ (15 December 2020).
56. Boukar, M.; Harmim, A. Effect of climatic conditions on the performance of a simple basin solar still: A comparative study. *Desalination* **2001**, *137*, 15–22, doi:10.1016/s0011-9164(01)00199-0.
57. Muftah, A.F.; Alghoul, M.; Fudholi, A.; Abdul-Majeed, M.; Sopian, K. Factors affecting basin type solar still productivity: A detailed review. *Renew. Sustain. Energy Rev.* **2014**, *32*, 430–447, doi:10.1016/j.rser.2013.12.052.
58. Aburideh, H.; Deliou, A.; Abbad, B.; Alaoui, F.; Tassalit, D.; Tigrine, Z. An Experimental Study of a Solar Still: Application on the sea water desalination of Fouka. *Procedia Eng.* **2012**, *33*, 475–484, doi:10.1016/j.proeng.2012.01.1227.
59. Al-Hinai, H.; Al-Nassri, M.; Jubran, B. Effect of climatic, design and operational parameters on the yield of a simple solar still. *Energy Convers. Manag.* **2002**, *43*, 1639–1650.
60. El-Sebaii, A. Effect of wind speed on active and passive solar stills. *Energy Convers. Manag.* **2004**, *45*, 1187–1204, doi:10.1016/j.enconman.2003.09.036.
61. Lienhard, J.; Antar, M.A.; Bilton, A.; Blanco, J.; Zaragoza, G. Solar desalination. *Annu. Rev. Heat Transf.* **2012**, *15*, 277–347, doi:10.1615/annualrevheattransfer.2012004659.
62. Jamil, M. A.; Goraya, T. S.; Ng, K. C.; Zubair, S. M.; Bin, B.; Shahzad, M. W. Optimizing the Energy Recovery Section in Thermal Desalination Systems for Improved Thermodynamic, Economic, and Environmental Performance. *Int. Commun. Heat Mass Transf.* **2021**, *124*, 105244, doi:10.1016/j.icheatmasstransfer.2021.105244.
63. Sparrow, E.M.; Ramsey, J.W.; Mass, E. Effect of Finite Width on Heat Transfer and Fluid Flow about an Inclined Rectangular Plate. *J. Heat Transf.* **1979**, *101*, 199–204, doi:10.1115/1.3450946.
64. MOWRP. Ministry of Water Reources, National Water Policy, Government of Pakistan, 2018. Available online: https://mowr.gov.pk/index.php/national-water-policy-2018/ (accessed on 10 December 2020).
65. Reporter, Govt Planning to Solve Water, Energy Problem Permanently, NEWS. 2018. Available online: https://nation.com.pk/25-Aug-2018/govt-planning-to-solve-water-energy-problem-permanently-minister (accessed on 6 December 2020).

66. Desk, W. Desalination of Seawater Proposed to Tackle Pakistan's Looming Water Crisis, NEWS. 2018. Available online: https://www.thenews.com.pk/latest/331972-desalination-of-seawater-proposed-to-tackle-pakistans-looming-water-crisis (accessed on 27 October 2020).
67. Ministry ofEnergy, Government of Pakistan. National Environmental Policy 2005; Pakistan 2005. https://mowr.gov.pk/wp-content/uploads/2018/05/National-Environmental-Policy-2005.pdf (accessed on 27 October 2020).
68. Kamboyo, S.H. Water Stress Matter, Supreme Court Pakistan. 2018. Available online: http://www.supremecourt.gov.pk/web/page.asp?id=230 (accessed on 10 January 2019).
69. UNICEF. UNICEF Pakistan; Pakistan, 2018. Available online: https://www.unicef.org/pakistan/reports/unicef-pakistan-annual-report-2018 (accessed on 27 October 2020).
70. PCRWR. Pakistan Council of Research in Water Resources; Pakisan, 2017. Available online: http://pcrwr.gov.pk/water-quality/ (accessed on 27 October 2020).
71. CEWRE. *Centre of Excellence in Water Resources Engineering*; University of Technology: Lahore, Pakistan, 2012.
72. Mubeen, F.M. Pakistan Desalination Association; Pakistan, 2018. Available online: https://elementalwaterfoundation.com/fight-water-crisis-donate-now/?gclid=Cj0KCQjwmcWDBhCOARIsALgJ2Qfkt2Jeac3hhFjsKnnbkQosn8ylcNA4H0UgswQw_9K9zFMAwBhNdFYaAq51EALw_wcB (accessed on 27 October 2020).
73. USPCAS-W. *U.S-Pakistan Centers for Advanced Studies in Water*; Mehran University Technology: Jamshoro, Pakistan, 2018.
74. Muhammad, D.A. Centre for Water Informatics and Technology (WIT); D.H.A, Lahore Cantt: Lahore, Pakistan 2018. Available online: https://wit.lums.edu.pk/ (accessed on 27 October 2020).
75. NCBI. National Capacity Building Institute; Lahore Pakistan, 2018. Available online: https://www.pakistanpoint.com/en/story/204498/national-capacity-building-institute-inaugurated-at-pcr.html (accessed on 27 October 2020).
76. PCRWR, Punjab Saaf Pani Company, Government of Pakistan, 2019. Available online: https://www.saafpani.org.pk/about-saaf-pani/introduction/ (accessed on 8 June 2019).
77. International Nuclear Desalination Advisory Group, Indag Newsletter, 3; Paistan, 2004. Available online: https://www-pub.iaea.org/MTCD/Publications/PDF/Newsletters/INDAG-NL-3.pdf (accessed on 8 June 2019).
78. DHA Cogen, MED Desalination Plant, 2018. http://dhacogen.com/ (accessed on 30 April 2020).
79. Zafar, M. Desalination Plant Opens at Gwadar Port, Express Trib. 2018. Available online: https://tribune.com.pk/story/1598397/1-desalination-plant-opens-gwadar-port/ (accessed on 30 December 2020).
80. Baloch, B. Four Desalination Plants Lying Idle in Gwadar Amid Water Shortage, DAWN. 2017. Available online: https://www.dawn.com/news/1310204 (accessed on 10 December 2020).