



Understanding the role of small-scale solar desalination (solar still, humidification-dehumidification) to achieving sustainable development goals (SDGs) in developing nations: a review[☆]

Seyed Maoud Parsa^{a,*}, Fatemeh Norozpour^b, Ali Hedayatizadeh^c, Davoud Javadi^c, Shahin Shoeibi^d, Hadi Kargarsharifabad^d, Siran Feng^a, Wenshan Guo^a, Huu Hao Ngo^a, Bing-Jie Ni^e

^a Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia

^b Department of Environmental Engineering, Faculty of Marine Science and Technology, North Tehran Branch, Islamic Azad University, Tehran, Iran

^c Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran

^d Production and Recycling of Materials and Energy Research Center, Qom Branch, Islamic Azad University, Qom, Iran

^e Water Research Center, School of Civil and Environmental, The University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Keywords:

Water crisis
Renewable energy
Water sanitation and hygiene (WASH)
Water treatment
Economic and cost analysis
Developing world

ABSTRACT

In the present critical review, the complex interrelation of small-scale solar desalination systems with various configurations to provide safe drinking water, in relation to achieving the United Nations Sustainable Development Goals (SDGs) by increasing the access to drinking water in developing countries is discussed. Of great importance, this paper deals with four essential and important criteria of drinking water (and their relation for realizing SDGs) that declared in numerous international action plans and instruments of SDGs which are: Affordability, Accessibility, Quality and Quantity. Solar stills and humidification-dehumidification (HDH) were considered in this context as small-scale solar desalination systems from technical and economic point of views since both are practical and currently work in real-world application. Then, regarding to the main international law instruments, including Sustainable Development (2030 Agenda), Agenda-21, General Comment No.15 of the UN, Dublin Statement etc. (with the main focus on 2030 Agenda), it is concluded that using these systems in developing countries would be one step forward to increase access to safe drinking water “Goal 6.1 of SDG 6”. Also, it was elucidated that using small-scale desalination systems to provide drinking water regarding the above-mentioned criteria (Affordability, Accessibility, Quality and Quantity) could assist for putting steps on the realization of other SDGs including SDG 3, SDG 4 and SDG 11. Indeed, the direct and indirect interrelation between SDG6 (Clean Water) with other goals including SDG 3 (Good Health & Well-Being), SDG 4 (Quality Education), and SDG 11 (Sustainable cities and Communities) were elucidated.

Introduction

Current status of drinking water crisis

“Water is needed in all aspects of life”[1], “To judge the health of a nation, count the taps not the hospital beds”[2], “Water is a precious resource and one of the greatest global risks to economic progress, poverty eradication, peace and security, and sustainable development”[3]. These are just some of the hundreds of statements made by

international instruments on the increasing crucial importance of water. The matter that if one day was a big problem is now literally crisis. The matter of water is a vast area with various kinds of sectors to be discussed, such as: water resources, wastewater treatment, surface water, ground water, grey water, freshwater, and drinking water. A sharp population increase during recent decades, leading to a subsequent increase in wastewater generation [4]. Among them, drinking water has a prior importance, because “drinking water, as a component of the right to an adequate standard of living, is essential for the full enjoyment of

[☆] This article is part of a special issue entitled: ‘10 years of SETA’ published in Sustainable Energy Technologies and Assessments.

* Corresponding author.

E-mail address: masood.parsa1988@gmail.com (S.M. Parsa).

<https://doi.org/10.1016/j.seta.2025.104423>

Received 20 April 2024; Received in revised form 18 April 2025; Accepted 24 June 2025

Available online 3 July 2025

2213-1388/© 2025 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

the right to life and all human rights”[5].

Since “The scarcity of safe drinking water sources is expected to worsen due to urbanization, population growth, desertification, drought, other extreme weather events, and climate change”[7], supplying a safe drinking water of good quality and adequate quantity is a big challenge for countries all around the world, particularly in developing world [8]. Indeed, for developing countries, this is not just a challenge. For them, it is a real risk which puts people, especially children, to death at a rapid rate whereas still a huge part of people in poor countries and undeveloped communities use unsafe/contaminated water resources for their daily need (Fig. 1). Indeed, a majority of people in the developing countries with low/middle-income use water resources with high risk of contamination with fecal contamination (Fig. 2) at the very high risk between 30 and 50 %. Sadly, this could be attribute as one of the main reasons that every 2 min, a child under 5 is dying due to diarrhea diseases that are related to using unsafe water [9].

The United Nations (UN) from the beginning of the new century proposed several actions plan like Millennium Development Goals (MDGs, 2000–2015) and Sustainable Development Goals (SDGs, 2015–2030) that focused on various aspects of human wellness and the environment [10]. Of greatest interest, one of the main important aspects in both action plans was providing safe drinking water. Although the population raised from 6 billion to 8 between 2000–2022, almost 2.1 billion people have gained to basic services of drinking water. Indeed, from the start of MDGs till the 2022 the number of people throughout world (including rural and urban regions) who have lack of basic safe drinking water apparatus reduced by around 41.4 % from 1.2 billion to 703 million (Fig. 3), however, the sharper increase of population in urban regions results in that the number of people that lack of access to basic water services increased in these regions around 11.7 % (Fig. 3). As it can be see, the problem of drinking water still is there and implementing practical action plans to solve this problem is necessary.

It is essential to note that, regarding the lower level of families’ income in developing countries, one of the principal factors to be considered in manufacturing infrastructure for providing drinking water is the matter of cost. For this, engineering has an interesting and sustainable solution: Solar Desalination. Importantly, the matter of cost effectiveness of a water desalination system is of great importance, especially in developing countries as it has become the anxiety of the Millennium Development Goals (MDGs) which is one of the most

important instruments of sustainable development. It was stated that “We are concerned about the obstacles developing countries face in mobilizing the resources needed to finance their sustained development”[12]. Moreover, another important instrument of sustainable development, *General Comment No.15*, deals with the cost matter and states requisiteness of low cost water supplies with an imperative tone. It states that: “investments should not disproportionately favor expensive water supply services and facilities that are often accessible only to a small, privileged fraction of the population”[13]. The very importance of low cost water supply services is for the reason that one of the main goals of all sustainable development instruments is to eradicate discrimination in all of its forms especially in water which is directly related to the health and life of every human being. As mentioned in some instruments, human health is of central concern in sustainable development, because “Everyone, regardless of their level of development or socio-economic status has the right to access drinking water that meets their fundamental needs in both quantity and quality.”[14]. It means that there should not be any discrimination between high-income persons and ones who have an income of just one dollar a day. The evidence is *General Comment No.15* which states clearly that: “Under no circumstances shall an individual be deprived of the minimum essential level of water”[13]. However, more than a half of those 703 million people without access to basic drinking water services lived in sub-Saharan regions which has one of the lowest average income throughout the world with another majority located in central and southern parts of Asia (Fig. 4).

Motivation, novelty and framework of present study

Although thousands of studies during the last decades presented in small scale solar desalination systems- particularly solar still and humidification-dehumidification (HDH)- interrelation of these systems with two of the most important action plans of the UN which are millennium development goals (MDGs) and sustainable development goals (SDGs) have not been realized. However, the MDGs action plan was planned for years 2000–2015, subsequently; we only focused on the SDGs which planned for years 2015–2030. It is important to note that the UN SDGs action plan contain 17 goals with 169 targets planned for human prosperous and protecting the total environment (Fig. 5). Indeed, in the present critical review, we are about to elucidate the impact of



Fig. 1. Collecting water from different contaminated water re[. Source is common practice in many places in developing world 6

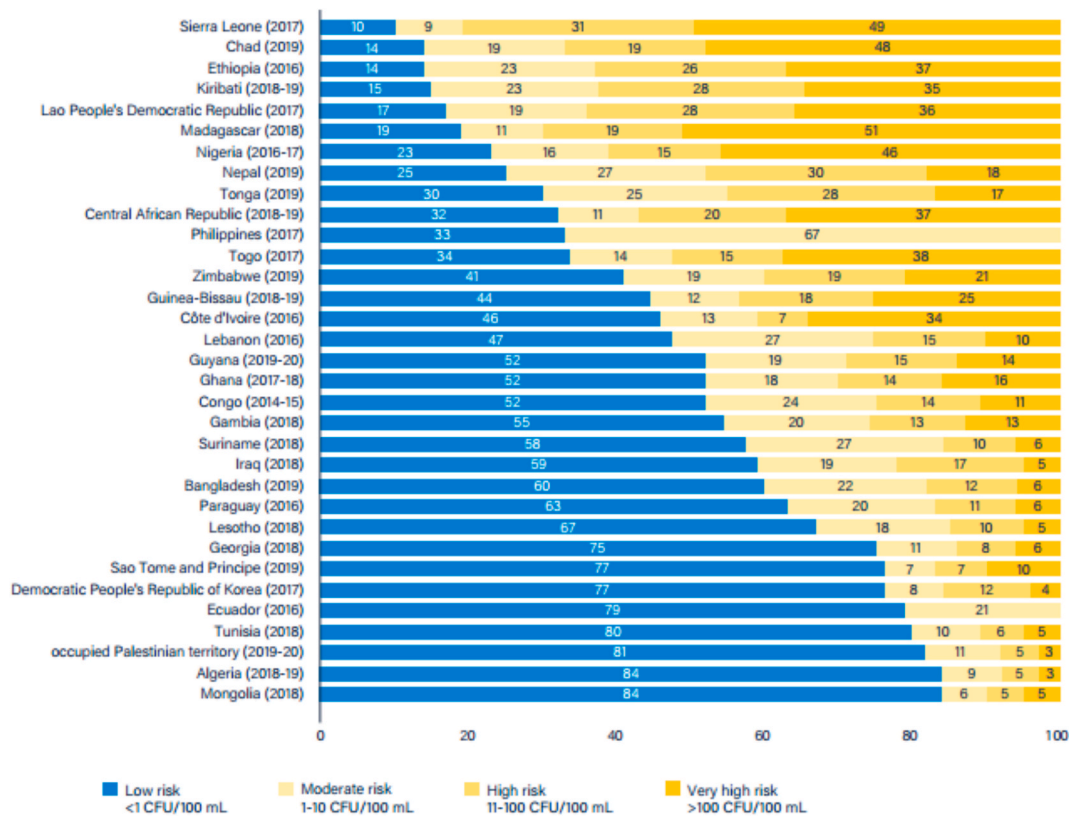


Fig. 2. Proportion of the population utilizing drinking water []. Source that categorized by the risk of fecal contamination, from selected surveys between 2014 and 2020 (Numbers are percentage “%”) 6

providing safe drinking water by solar-based small-scale desalination systems and their effect on realization of Goal 6.1 (Clean Water) of SDGs and its impact on realizing other SDGs which are Goals 3, 4, and 11. Moreover, in the present study the tight linkage between engineering (in the context of water desalination technologies) and international law instruments on sustainable development and the role engineering can play to assist sustainable development to reach its goals was discussed. Our methodology in the present study defined in several step. In the first step, two of the most abundantly and widely used solar-based desalination systems which are HDH and solar stills are briefly reviewed. In the next and most important step, we presented the Sustainable Development Goals (SDGs) instruments on water and their statements, and then investigating the conformity of small scale desalination systems with what is intended by these instruments in the context of safe drinking water that defined by four criteria which are: (i). *Affordability*, (ii). *Accessibility*, (iii). *Quality and* (iv). *Quantity*. In fact, the hidden relation between these four criteria with realization of three SDGs would be elucidated. These instruments are listed in the Sustainable Development Goals Knowledge Platform of the United Nations [15] and other instruments. In addition to these instruments, some of the Resolutions adopted by the United Nations General Assembly are used. Afterwards, the previous performed experimental studies and their appropriateness in relation to the SDGs are thoroughly discussed. To the best our knowledge, this study is one of the starting attempt to show the vital impact of the solar-driven desalination technologies in realizing Goal 6.1 of SDGs and its effect on reaching of other SDGs.

Small-scale solar desalination

In one hand, most people with lack of access to basic drinking water needs in these countries located in the remote regions, thus, employing large-scale plant is not justifiable, leading to use the small-scale systems. On the other hand, these regions usually located in off-grid areas which

making the use of alternative sources imperative rather than conventional fossil fuel sources. This make the use of renewable energy to provide safe drinking water needs as an attractive option. As mentioned above, the price of providing drinking water is crucial for regions where people have low-income while the systems also need to be practical rather than in an early stages of laboratory development. As it exhibited in Fig. 6, the two important small-scale desalination systems which have both criteria are solar stills and humidification-dehumidification (HDH) systems. It is worthy to be noted that, solar and wind considers as the main contributors in the global renewable energy market not only due to the fast-growing technological advancements, but due to the adverse fossil fuel effect on the environment [16].

Solar still

Generally speaking, the evaporation/condensation process consider as one of the simplest method to provide safe drinking water whether for large-scale plants such as MED and MSF [18,19] or small-scale such as solar stills [20,21], humidification-dehumidification [22] and recently, solar interfacial evaporation [23]. Some researchers integrated these technologies and used modified desalination configurations to boost the performance [24,25], however, such strategies may not realistic for developing world. For decades, solar stills have been considered as one of the easiest solutions to produce drinking water due to simple structure, generally in single and double slope geometries (Fig. 7). Solar stills used to separate various types of impurities from water including, pharmaceuticals, salts, biological species and chemical compounds [26]. The principle of solar still is simple. A basin or a bed filled with impure water with a specific height and the top of the floor of bed or basin (which could be in the various geometries such as concave, stepped etc. [8]) a transparent cover such as glass, plastic, plexiglass mounted. When solar radiation enters to basin, temperature of water starts to increase and water starts to evaporate. The droplets of water are forming on the

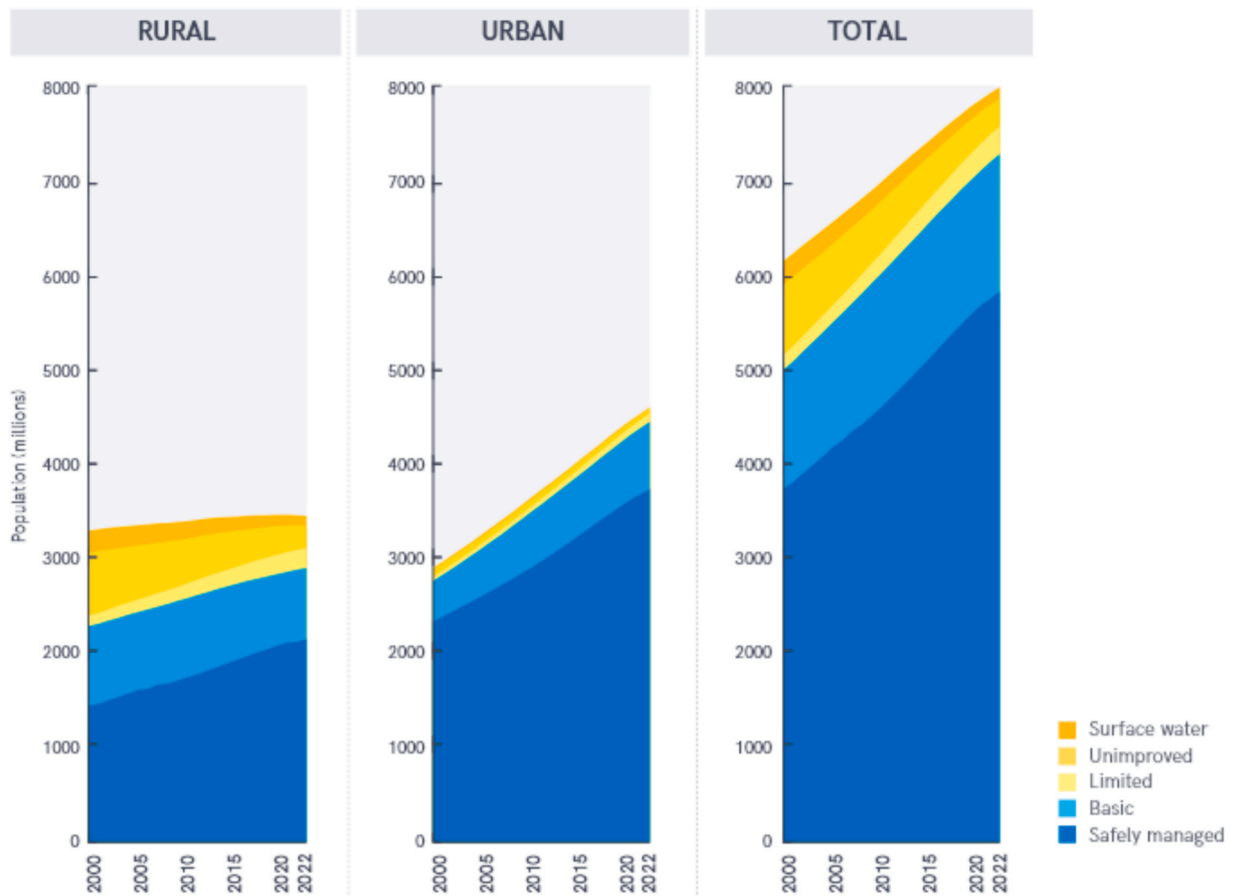


Fig. 3. Rural, urban and total populations, by drinking water service level, 2000–2022[11].

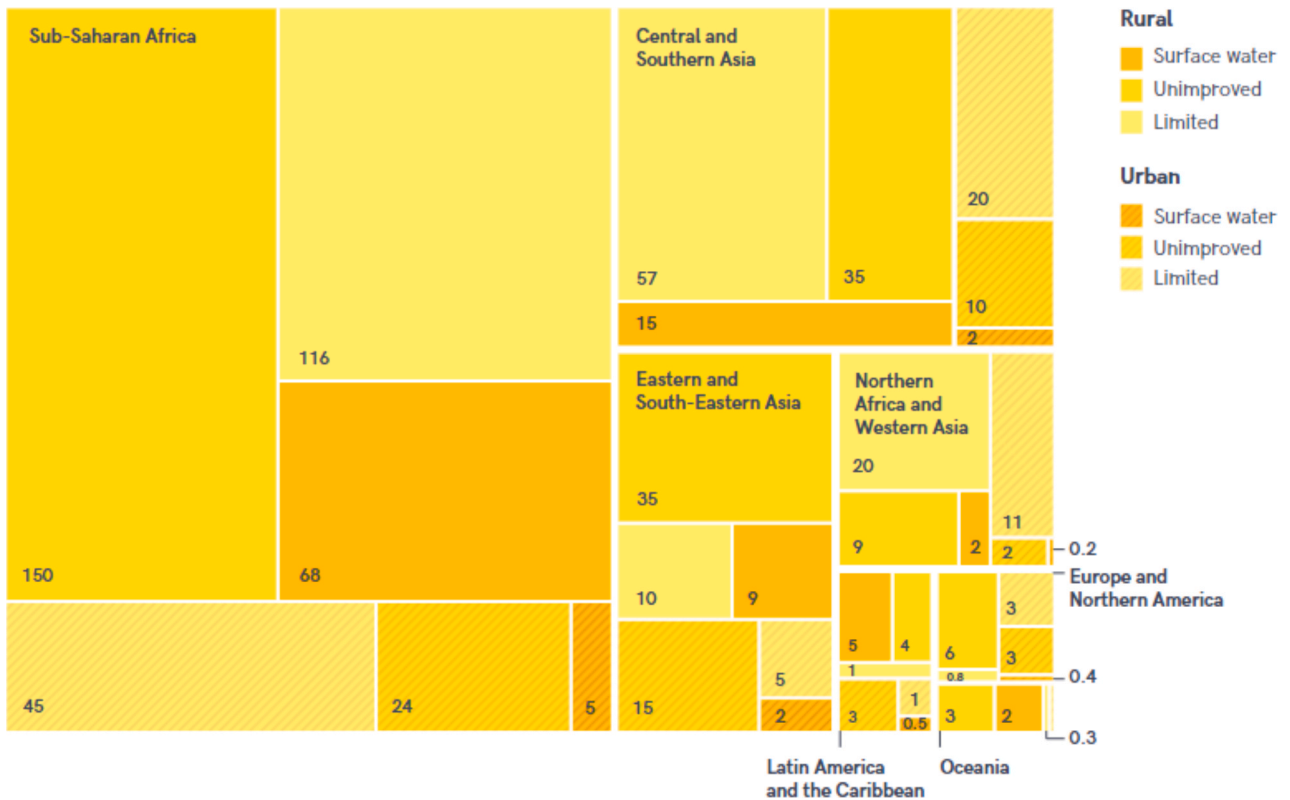


Fig. 4. Rural and urban communities without access to essential drinking water services in 2022 (Numbers are million) [11].



Fig. 5. The United Nations Sustainable Development Goals (2015–2030).

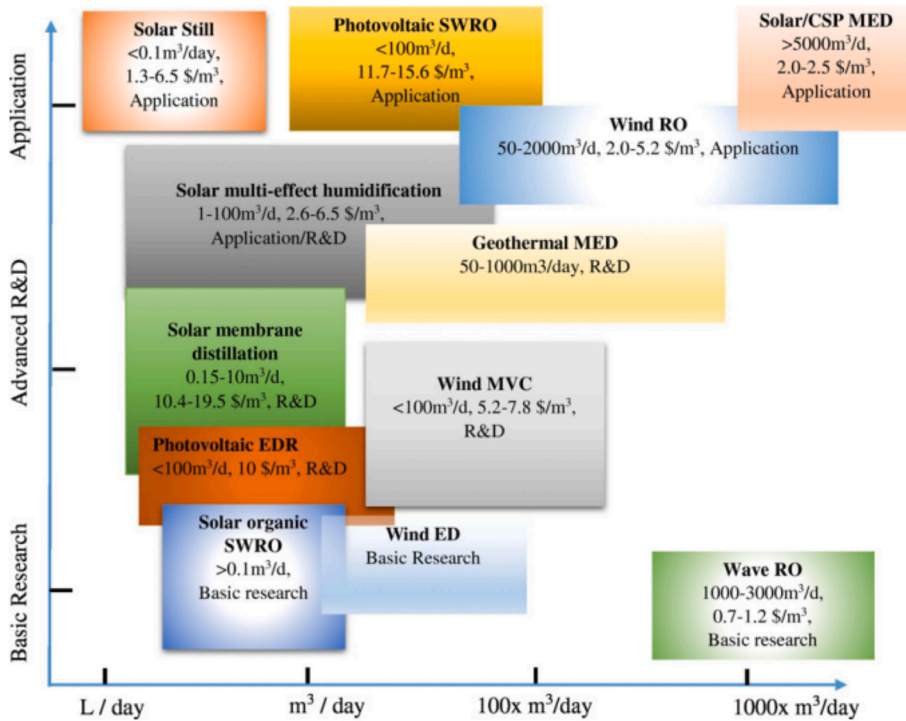


Fig. 6. Renewable-based energy desalination technologies considering the state of development and capacity [17]. Reprinted with permission from Elsevier.

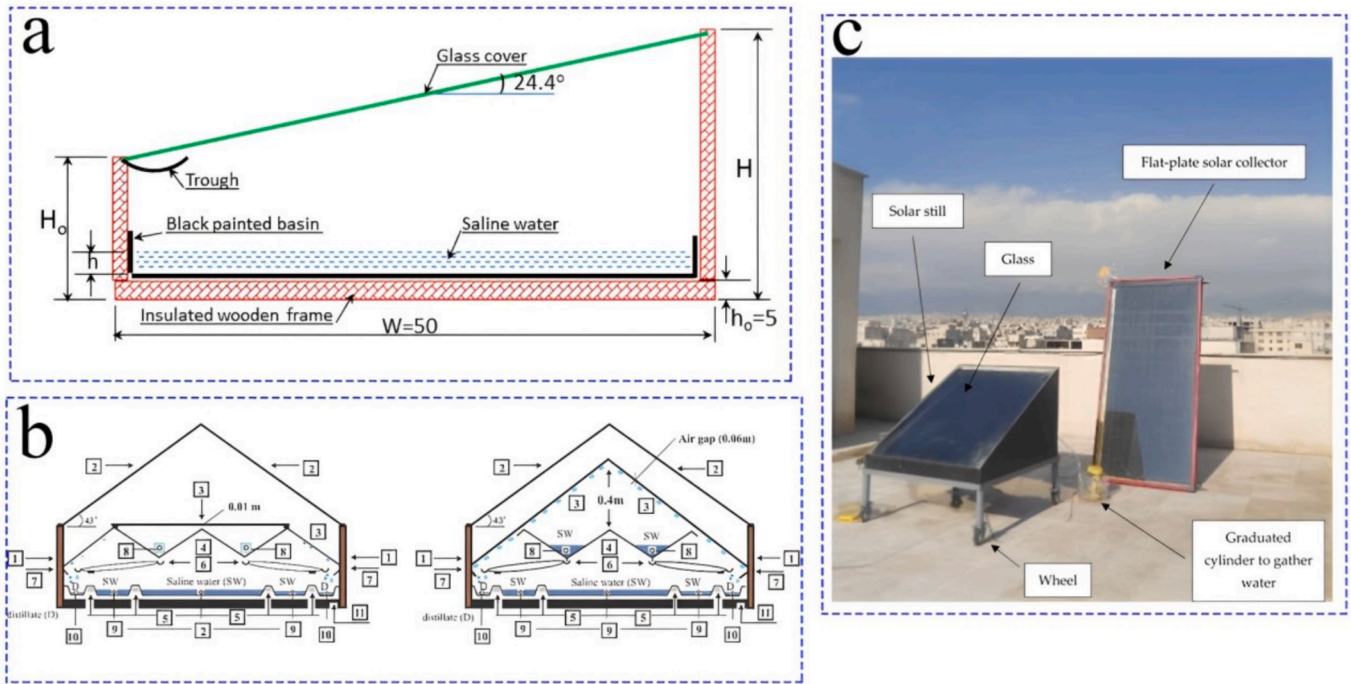


Fig. 7. Schematic of solar stills. a) single slope b) double slope c) An experimental setup [27–29].

inclined cover where the droplets slip from cover and enter into a channel or a tank which is designed to store droplets. Solar still systems are classified into two types: active and passive.

In passive solar distillation systems there is no external heat source to assist system to increase the temperature of water and only passive methods could be used to improve the performance. Some of these

Table 1
Different configuration of solar still with economic results.

Authors	Location	Type of Still	Capital Cost	Annual Cost	Annual Yield	CPL	Modification/ type of system
Attia et al. [59]	Algeria	Passive	67.6	11.97	2254.5	0.0065	Utilizing Slate Layer
Rahman et al. [60]	Bangladesh	Active	130	15.7	994.6	0.0156	external condenser + floating fins
Elamy et al. [61]	Saudi Arabia	Active	180	–	4670	0.01	Baffle + PCM + reflector + condenser
Pandy and Naresh [62]	India	Active	171	20.52	1626	0.014	Heat pipe, PCM and fins
Chang et al. [63]	China	Active	165	–	1600	0.023	Parabolic concentrator
Shoeibi et al. [64]	Iran	Active	320	14.72	1033	0.1055	Thermoelectric modules
Alshammari et al. [65]	Saudi Arabia	Active	125	–	2025–2480	0.013	ultrasonic atomizer + hygroscopic fabric
Abdallah and Badran [66]	Jordan	active	300	57.7	250	0.23	With sun tracking Device
Eesa et al. [67]	Egypt	Active	215	–	3360	0.0137	Mirror + condenser solar tracker
Kalbande et al. [68]	India	Active	503	74.96	3580	0.02213	Nano-PCM + Parabolic concentrator
Abdallah et al. [69]	Jordan	active	350	68	958	0.071	Step-wise with sun tracking
Abdel-Rehim & Lasheen [70]	Egypt	active	300	57.7	990	0.058	parabolic trough
Badran et al. [71]	Jordan	active	450	86.7	844	0.103	Flat plate collector
Badran&Al-Tahaineh [72]	Jordan	active	480	93	806	0.115	Flat plate collector
Kumar et al. [73]	India	active	250	219	1203	0.18	Flat plate collector/PV
Abad et al. [44]	Iran	active	35.3	4.48	721	0.0062	With pulsating heat pipe
Hooshmand et al. [74]	Iran	active	268	35.58	662	0.0537	Heat pipe with PV
Mamouri et al. [75]	Iran	active	160	21.34	2317	0.0092	Heat pipe with ETC
Faegh et al. [76]	Iran	active	206	27.38	1288	0.0212	Heat pipe and PCM
Shafii et al. [77]	Iran	active	235	31.219	2257	0.0138	TEG with heat pipe
Rahbar & Esfahani [78]	Iran	active	181	32.5	180	0.18	TEC with heat pipe
Esfahani et al. [79]	Iran	active	438	56.2	730	0.13	TEC
Rahbar et al. [80]	Iran	active	482.5	129.75	912	0.1422	Hot side of TEC
El-Sebai et al. [81]	Egypt	active	320	61.5	1183	0.052	Shallow solar pond (SSP)
Velmurugan & Srithar [43]	India	active	350	67.3	837	0.08	Mini Solar pond
Fath et al. [82]	Egypt	Passive	275	53	1511	0.035	Single slope
B.Jamil & N.Akhtar [83]	India	Passive	136	25	625	0.04	Single slope
Samee et al. [84]	Pakistan	Passive	190	37	585	0.063	Single slope
Kumar et al. [73]	India	Passive	250	47.8	343	0.14	Single slope
Al-Hinai et al. [85]	Oman	Passive	106	20.4	1511	0.0135	Double slope
Fath et al. [82]	Egypt	Passive	250	48	1533	0.031	Pyramidal
Wassouf et al. [86]	Australia	Passive	38	8.004	174	0.046	Pyramidal
Rahbar et al. [87]	Iran	Passive	228	39.81	584	0.0683	Tubular
Rahbar et al. [87]	Iran	Passive	171	29.86	488	0.0613	Triangular
Wassouf et al. [86]	Australia	Passive	99	21.105	335	0.063	Triangular prism
Ismail [88]	Canada	Passive	958	184.5	1026	0.18	Hemispherical

passive methods can be mentioned such as wide-range of energy storage materials[30–33], reflectors [34,35], various types of nanomaterial [36–39], and wicks [40,41]. In active solar stills, other external resources in addition to solar radiation are used to augment systems' performance. Some of these sources can mentioned such as solar pond [42,43], heat pipe[44], thermoelectric cooler (TEC) [45,46], thermo-electric heating (TEH) [47,48], electrical heater [47], external condenser [49], flat plate collector (FPC) [50,51], evacuated tube collector (ETC) [52,53], Fresnel lens [54], parabolic concentrator [55,56], and photovoltaic panel [57,58]. Since solar stills build by raw material that usually has low-cost, the price of produce water as the final product is of great importance. Thus trade-offs between the productivity and the cost of system as well as the final product should be managed. A thorough comparison on solar still in different configurations presented in Table 1 at different modifications from economic and productivity point of views.

Humidification – dehumidification (HDH)

The humidification-dehumidification (HDH) desalination system consider as a very attractive and important technology in recent years because of a low primary cost, easy to operate, easy to maintenance and its capability to coupling with low-grade energy resources. Generally, HDH fabricated as single stage or two-stage configuration (Fig. 8).

The general principle of HDH is based on the fact that air can carry a certain amount of moisture. If the temperature of air is raised, its capability to carry humidity is enhanced. Briefly, when dry air contacts

with a saline stream which is sprayed to evaporator (at humidification chamber), it absorbs the amount of steam. The humidified air by a pump moves and enters to condenser (dehumidification chamber) to distill on its surface. Generally, HDH systems are divided into four types based on its cycles which are: close air – open water, open air – open water, open air – close water, and close air – close water. Table 2 presents some of the solar-based HDH configurations with respect to their cost and daily yield.

The hidden interrelation of drinking water criteria and realizing SDGs

After a brief explanation of the proposed systems; the main discussion emerges here. How engineering in the context of water science could assist this subject matter. About many criteria of water in sustainable development instruments, there are 4 main criteria: *Affordability, Accessibility, Quality, and Quantity* [13,106]. Given that, the focus of our work is developing countries which gross national income (GNI) per capita is at a low level, the affordability of drinking water and the cost of water per liter is of greatest priority. So, by considering these criteria, the hidden connection between them and SDGs will be revealed.

Affordability

It is necessary to note that the primary cost of production and the total cost for the introduced systems are for the laboratory scale, and if these systems are manufactured in mass production, the total cost would

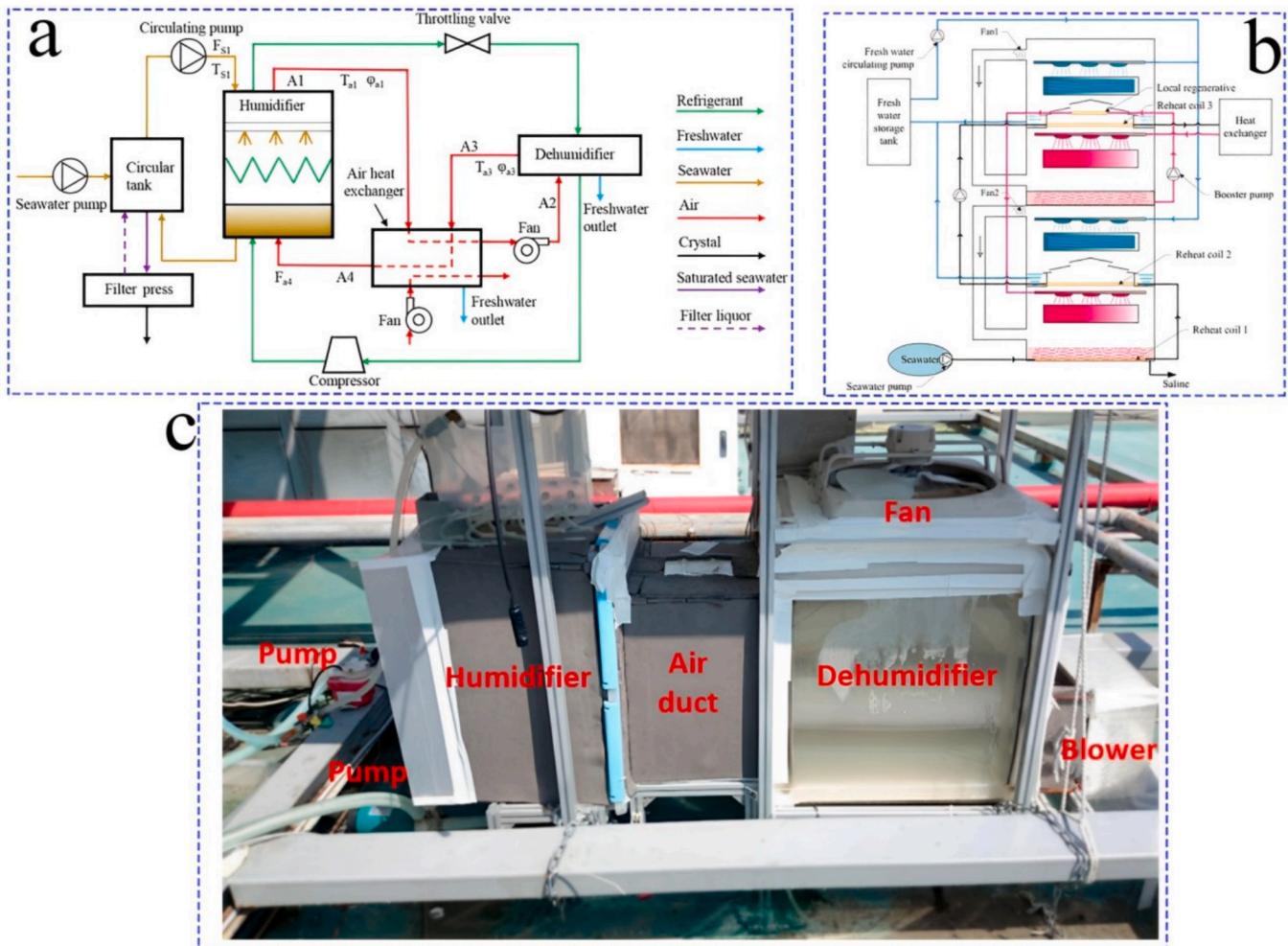


Fig. 8. Schematic of HDH configuration. a) single stage HDH b) double stage HDH c) An experimental HDH setup [89–91].

Table 2
Different configuration of HDH with economic results.

Experiment	Country	Daily product	Total cost (\$)	Cost Per Liter	Type of solar system
Tiwari and Kumar [92]	India	11.1–16.8	496.5–515	0.02–0.023	Solar air heater
Mahmoudi et al.	Iran	3.95–4.76	420	0.043	Solar parabolic dish concentrator
Abdullah et al. [93]	Saudi Arabia	7.78	210	0.0099	Solar air heater + photovoltaic thermal
Tiwari and Kumar. [94]	India	16.8	524	0.025–0.028	Solar air heater
Elminshawy et al. [95]	Saudi Arabia	30.3	783	0.035	Reflector
Zhani et al. [96]	Tunisia	20	10,775 (Euro)	0.1072	Using flat plate collector for air heating as well as water heating
Yuan et al. [97]	China	1000	32,900	0.00658	100 m ² evacuated tube collector for air heater. 12 m ² flat plate collector for water heater
Wang et al. [98]	China	47.4	206	0.0218	PV panel used to supply power for pump and heater
Alnaimat et al. [99]	USA	100	–	0.004	With flat plat solar collector
Hamed et al. [100]	Egypt	11	1442	0.057	Evacuated tube collector
Behnam & Shafii [101]	Iran	6.275	277	0.028	Evacuated tube collector with heat pipe flat plate collector used for air heater and water heater
Deniz & Çınar [102]	Turkey	10.87	732	0.0981	PV panel used to supply electrical power of HDH system
Chafik [103]	Tunisia	10,000	Varying	Varying	Flat plate collector
Houcine et al. [104]	Tunisia	355	47.972–72.092	0.03	Flat plate collector
Srithar & Rajaseenivasan [105]	India	15.23 (kg/m ²)	389	0.0257	Using dual purpose solar collector for heating air & water

be decreased substantially. The prerequisite for this matter is that United Nations (UN) and governments and international and local organizations to help this matter be realized by attributing enough financial recourse for these regions and assist to produce these systems in mass production.

According to WHO Guideline, affordability means the cost which the domestic consumers should pay for water [107]. Affordability is one of the most important criteria, which should be considered while manufacturing a water supply system, both in the price of the system itself, and the cost of produced water. The importance of an affordable drinking water and water supply systems comes from numerous sustainable development goals instruments. *Article 18.52 of Agenda 21* states that: “To ensure the feasibility, acceptability and sustainability of planned water-supply services, adopted technologies should be responsive to the needs and constraints imposed by the conditions of the community concerned. Thus, design criteria will involve cost of the planned system” [1]. Though the word “affordable” is not mentioned explicitly here, but the overall statements guide us to the fact that the cost of water should be payable even by people living in bad conditions. One of these conditions is economic which is hardest to bear compared with other conditions everyone might have. Also, paragraph 12 of *General Comment No. 3 (1990) (c) ii* states that: “Water, and water facilities and services, must be affordable for all. The direct and indirect costs and charges associated with securing water must be affordable” [13]. By this statement, all costs, related to providing drinking water, from the raw materials to manufacture a water supply system to the cost of per liter of produced water and the cost of maintenance of the systems, must be on a basis that does not make any obstacle even for poorest people to have access to a safe drinking water. The importance of affordability does not be summarized to these instruments. *Article 2 of General Comment No.15* states that: “The human right to water entitles everyone to affordable water for personal and domestic uses” [108]. The very importance of this factor is that we are talking about the developing countries who have limited financial sources themselves to provide the national needs, and people with low per Capita GNIs, and poor vulnerable people with low-income level. For example, some countries like Mali, Niger, Chad, Gambia, and Ethiopia have GNI per Capita of 1025 US dollars yearly or less [109]. Moreover, the bitter truth is that a remarkable number of the so-called “developing world” are not developing at all. That’s why the *Article 6.5 (a) iii of Agenda 21* states: “National Governments and local authorities, with the support of relevant non-governmental organizations and international organizations in the light of countries’ specific conditions and needs, should develop and implement rational and affordable approaches to the establishment and

maintenance of health facilities” [1]. If we believe that a safe drinking water is an undeniable factor of health, so this statement of Agenda 21 affirms that every system which is going to be designed and established to produce drinking water has to be affordable. Moreover, within the principle *No.4 of Dublin Statement*: “it is vital to recognize first the basic right of all human beings to have access to clean water at an affordable price” [110]. Another reason to be evaluated in relation to affordability is its remarkable impact on the use of water and selecting water sources. If the cost of water is high, the consumers would be forced to use every source of water in the vicinity which could have poor quality and contaminated and polluted which leads to some diseases that could put the consumers to death. Of course, finding a source of water, improved or unimproved, entails spending a considerable time which is a very important subject and we will discuss it in the next part. The matter of providing an affordable drinking water can be seen from another point of view. If the cost of water –direct or indirect costs – is high, there could be a risk and might makes the possibility that water turns to a leverage at the hand of abusers to enter “economic pressure” on the poor people to make a profit [12]. If we look at water as the most basic factor to the health and life of human beings, this possibility of water to be a good instrument to abuse vulnerable people is not unlikely. So, regarding the financial conditions of developing countries and their low-income, and the low direct/indirect costs of the fabricated systems, it seems that using them in these regions could be a good choice to take a step forward in order to increase access to an affordable safe drinking water. Indeed, developing an affordable system to provide drinking water directly realize the goal 6.1 of SDGs.

Besides of designing and building these systems, one of the most important duties of engineering is to bringing forward systems with a low ratio of water cost per liter. Of course, it is necessary to remind that small scale systems are more expensive than large scale systems. For example, the cost of produced water in the small scale systems is between 4 and 230 \$/m³. Accordingly, large scale systems are designed to produce water for big and highly-dense populated cities at a very low cost. On the other hand, the capital cost of constructing large-scale desalination systems is high for some of developing countries. Regarding the presented explanations, in the first step, engineering must reduce the primary cost as well as the cost-per-liter water. For example, among reviewed systems in solar stills, the proposed systems by Abad et al.[44], Mamouri et al.[75], and Attia et al. [59] is 0.0092\$/liter, 0.0062 \$/liter and 0.0065 \$/liter respectively which sounds appropriate and reasonable from the viewpoint of the cost-per-liter. Also, passive systems, due to simpler configuration and using available and cheap materials, seem more suitable options. With considering these factors,

the proposed systems by Al-hinai et al. [85], Fath et al. [82] and Wassouf et al. [86] with the cost of 0.0135, 0.35, 0.046 and 0.004 \$/liter respectively, sound more appropriate. With considering a system just by the factor of primary cost, the proposed systems by Abad et al. [44] and Wassouf et al. [86] with a cost of below 100 US dollars (35.3 and 38 US dollars), could be presented as the most affordable setups. Likewise, among introduced HDH systems, some systems are proposed by Alnaimat et al. [99] and Yuan et al. [97] have a ratio of cost of produced water per liter cheaper than other systems (0.004 and 0.00658 \$/liter respectively). However, a suitable option among them is proposed by Yuan et al. [97] regarding the total cost of produced water around 0.00658 \$/liter, which also is able to produce water by about 1000 L/day and could be considered as a good choice to be used for small communities with low population.

Accessibility

Accessibility is a crucial factor of drinking water as in many of developing countries women and children (mostly girls) had to spend hours to reach an accessible water resources (Fig. 9). According to *Mar Del Plata Action Plan* [14] “All peoples, whatever their stage of development and social and economic conditions, have the right to have access to drinking water in quantities and of a good quality equal to their basic needs”. Additionally, *18.65 of Agenda 21* states “The rural population must also have better access to a potable water-supply services” [1]. Also, *General Comment No. 15 article 12 part (C)* states: “Water and water facilities and services have to be accessible to everyone without discrimination” [13]. By the word “accessible”, it is aimed that water supply systems should be within easy reach of all persons, wherever they are- at home or at work or educational centers- and everyone must find a water supply system in a reasonable distance and at a rational time [13]. About the time and distance, there are some levels defined by WHO. In a guideline published by WHO, the minimum and maximum of various types of access to a source of drinking water is determined. At the lowest level, a distance to time ratio with more than

1 km and 30 min is defined as “no access”, and existing multiple taps within a house is defined as “optimal access” [107]. Another concept derived of accessibility, could refer to the structure of water supply systems. It means that water supply systems should have some characteristics: (i) should be made up of cheap and available materials, (ii) should be easy to operate so that even a child could use it safely, and (iii) the cost of maintenance of the system should not be high. So, regarding to above paragraph, accessibility is an important and significant criterion of drinking water. Of course, this significance comes from the impact of this factor on other goals of sustainable development, and interdependency between drinking water and other goals. In many parts of the developing countries, collecting water is a very time-consuming activity. For example, the average spent time in India to collect safe drinking water from an improved source of drinking water is 56 min. In Tanzania, school attendance for girls who live in an hour distance of a source is 12 percent less than for girls who live within 15 min [111]. Regarding the function of a desalination system which produces an acceptable drinking water from an unimproved source, the importance of the matter is demonstrated here. In much of the developing countries, a higher education level depends directly to access to safe drinking water. The reason for the matter is clear. In much of the developing countries with limited access to safe drinking water, the cultural conditions are in a way that the household occupations are entrusted to women, youth and children of the family, –one of them collecting drinking water-. Spending more times to find an improved source of drinking water means less time for education. By decreasing education times, especially for children and women who are the principal focus of SDGs, mental growth and inflorescence would be postponed. Because only through education, children are able to learn and become knowledgeable- from primary schools to universities- and turn into skillful and conversant individuals who are able to improve both their own lives and take part in making their country and society a better place to live in. Growing today children to future proficient and knowing men or women, from teachers and scientists to even political leaders or at the lowest level ones who know a way to earn income, is possible just by



Fig. 9. To access for a safe water resources children and women traversing long distances [6,116].

continuous education- from primary school to university- and every minute which is spent to find a source of drinking water is a step backward to an important SDGs (*Goal 4*) to “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” [112]. The matter of accessibility can be seen from the point of view of treatment charges. Water-related diseases are imminent consequences of lack of access to safe drinking water. In the developing world, a child could be contacted a water-related disease every four months. A family with four children is likely to have one sick child in a month. In the condition like this, even the lowest cost of providing drug is a heavy burden for parents [113]. All that is said become more important when considering the international instruments on sustainable development goals and what they said about the accessibility of drinking water. For example, the *Human Right to Water and Sanitation* “calls upon States and international organizations to scale up efforts to provide accessible drinking water” [114]. Furthermore, in the 6th session of Commission on Sustainable Development, participants noted that “water distribution and pricing systems should ensure that clean water was accessible for everyone” [115]. Gathering all together, small scale systems seems appropriate to take one step forward to making sustainable development goals realized on reducing the lack of access to safe drinking water by decreasing the time and distance needed to find an improved source of drinking water, and also, realization of another important goal of SDGs on water. It should be noted that some of these systems use solar collectors and some countries especially developing countries might not have easy access to this technology. However, we can suggest passive solar still systems that could be constructed by simple and available materials which could be found in most of the regions such as above-mentioned solar stills which made by low-cost and highly-abundant materials. Interestingly, an appropriate choice for these regions is using passive solar still systems coupled with solar ponds, due to their simplicity and unity of solar pond as an energy storage medium for continuous water production.

Quality

Another criterion for drinking water to be assessed as a safe drinking water is quality. A water supply system must be of good quality; it means that the produced water must have some characteristics. First of all, it should be free of harmful contaminants [13] and then the system itself must be safe to use. By the quality of water supply system, it is meant that the system should be made in a way and of the materials that it does not enter chemicals into the water it produces, and it must keep its quality under any climate conditions. The quality of water is considered by numerous sustainable development goals instruments. According to the *Dublin Statement*: “The rural population must also have better access to a potable water supply” [110]. Although the word “quality” is not mentioned explicitly, but it’s completely obvious that when a water is potable, it is of good quality for drinking. Also, the *General Comment No. 15* affirms on the quality of the water and being safe repeatedly. *The Article 2* states that: “The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses” [13]. Also, it states that: “The water required for each personal or domestic use must be safe, therefore free from micro-organisms, chemical substances and radiological hazards that constitute a threat to a person’s health” [13]. More clear than these instruments, *Agenda 21* states “The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet” [1]. Furthermore, water should be of an acceptable color, odor and taste for each personal or domestic use” [13]. The importance of quality of drinking water is not a unilateral importance. It could affect other goals of sustainable development and make it subject to risk. Imagine a region deprived of a safe drinking water and there are some unimproved sources of drinking water at a long distance, which however the people might spend time and take their needed water from that, it could put them to disease and death. So what could be

happened? In such a hard condition, one of the most possible solutions is migrating the settlers of these regions to a better and safer place to find a relatively good source of water to escape death. Beyond any doubt, the first choice in this condition is immigrating to cities. Consequently, and during not so much time, by this emigration and making small communities less and less populated, cities would be more populated and more population creates more pollution, and every little increase in pollution is a more serious threat to the health of human beings. If such an event happens, one of the main goals of sustainable development goals (*Goal 11*) to “Make cities and human settlements inclusive, safe, resilient and sustainable” [112] will never be realized. With all said, although the quality of the water and the ways it can be realized is more technical than legal, if a water desalination system is able to reduce the minimum level of contaminants and pollutants of the water and produce a water with an acceptable color, odor and a good taste suitable for peoples, regardless of any life conditions, based on their human rights and “human dignity” [13], it would be a success. It must be noted that States are referred to the WHO Guidelines for drinking water quality to adopt and develop national standards on the basis of that guideline. According to the WHO, allowable total dissolved solids (TDS) for water to be potable must be less than 500 while the acceptable pH for water to drinkable must be between 6.8 and 8 [83].

Table 3 shows the TDS and pH of the produced water by some solar distiller units before and after purification.

Quantity

Another important criterion of drinking water considered by SDGs instruments is quantity. According to *Mar Del Plata Action Plan* [14] “all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs”. Also, *Agenda 21* states that: “It should be ensured that rural communities of all countries will have access to safe water in sufficient quantities to meet their health needs” [1]. By *General Comment No. 15* “The human right to water entitles everyone to sufficient water for personal and domestic uses. An adequate amount of safe water is necessary to prevent death from dehydration, to reduce the risk of water-related disease and to provide for consumption, cooking, personal and domestic hygienic requirements” [13]. Also, the report from the *High Commissioner for Human Rights* states that “it is now the time to consider access to safe

Table 3
Comparison of TDS and pH of some solar stills.

Author	No Experiment	Before Desalination	After Desalination		
Rahbar et al. [80]	1	TDS(ppm) 610	pH 7.9	TDS(ppm) 95	pH 6.85
	2	500	7.8	76	6.8
	3	537	8.1	84	7.35
	4	624	8.3	108	7.6
	5	650	7.7	101	6.58
	6	570	8.2	91	7.5
	7	635	8	98	7.1
	8	568	7.8	90	7
	9	592	8.15	93	7.3
	10	581	7.6	92	6.4
Samee et al. [84]	1	370	6.72	30	6.5
	2	544	6.78	84	5.74
	3	17,663	7.58	226	6.13
Esfahani et al. [79]	1	635	8	110	7.35
	2	568	7.8	131	7.2
	3	592	8.15	128	7.25
	Day 7	565	7.9	124	6.7
	Day 11	561	8.1	108	6.9
Day 19	718	8.15	112	7.2	

drinking water as a human right, defined as the right to equal and nondiscriminatory access to a sufficient amount of safe drinking water for personal and domestic uses to sustain life and health" [117].

Although the basic amount of drinking water for a human to meet his/her daily needed water is clearer than other criteria discussed above, the way to produce enough amounts is not clear like that. The importance of quantity of drinking water comes from its impact on the health of human beings since a basic physiological requirement is needed to prevent people from dehydration, which is the most direct impact of a low amount of water. According to the WHO, the daily per capita consumption of drinking water for an adult with 60 kg of weight is about 2 L, while this amount for a 10 years child with 15 kg of weight is 1 L [107]. Of course, this amount can be varied in different regions with different weather conditions, or even by different levels of activity and in different seasons too. A brief look to Table 2 and Table 3 shows that amount of produced water are varied between 1 to 10,000 L/day for solar still and HDH systems. For example the proposed systems by [97] which is 10,000 L/day can be considered as good options for small communities or small villages. However, it could be observed that in some cases, the amount of water produced by these systems does not seem perfectly sufficient for daily uses according to WHO guidelines, but every one more drop of water more than the current amount within reach by the people of developing countries is a step forward and a remarkable victory.

In addition, the matter of quantity of drinking water could be considered as an important factor from another viewpoint and that is the impact on one of the sustainable development goals mentioned in 2030 Agenda; the Goal 3 of 2030 Agenda to "Ensure healthy lives and promote well-being for all at all ages" [112]. Although the role and importance of water is not mentioned explicitly as one of the factors of a healthy life in this instrument, by a brief looking into general factors that constitute a healthy life, the importance and necessity of an adequate amount of drinking water to have a healthy life for human beings is completely clear. The proof is not our reasoning, but it is the explicit statement of one of the sustainable development goals instruments on water mentioned in the introduction. When this instrument states "Water is needed in all aspects of life" [1], does it mean a healthy life or unhealthy? Does this instrument is codified in order to reach an unhealthy life? By this clear statement, it does not mean to say that water has a key and fundamental role in all the life of every human being, from birth to death and in all of the activities that a person has to do in his/her life? The answer is clear. No one can ignore the clear fact that from all things that the life of people depends on, water is the first and most needed element. So, sufficient (or insufficient) amount of drinking water could have a positive (or negative) impact on the realization or frustration of the Goal 3 of 2030 Agenda which is the most important instrument of Sustainable Development, and access or not access to this goal depends on the determination of all peoples who can give a help, irrespective of being trivial or of vital importance.

Discussion

In a bigger picture the impact of developing small scale solar desalination systems on realizing four of the sustainable development goals (directly and indirectly) were elucidated. However, in detail, the hidden connection of four criteria of drinking water with realization of four goals of the SDGs presented. First of all, the impact of small scale desalination systems on the realization of the goal 6.1 of 2030 Agenda-the main instrument SDGs on water- which is "By 2030, achieve universal and equitable access to safe and affordable drinking water for all" was discussed. It was revealed that a better access to safe drinking water leads to realization of the three other goals of SDGs which are goals 3, 4 and 11 mentioned in 2030 Agenda to "Ensure healthy lives and promote well-being for all at all ages", "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" and "Make cities and human settlements inclusive, safe, resilient and

sustainable" respectively.

The significance of cost

Among four criteria of drinking water the criterion "affordability" directly related to realization of Goal 6.1 as the cost of material and produced water should be low enough to be feasible to use in low-income countries. The reviews on small scale desalination systems and experimental studies from the economic standpoint, showed that such systems with the primary cost less than 100 \$, are good choices for developing countries who have limited financial recourses themselves and in some of them, GNI per capita is less than hundred dollars a month. Also, for small communities some of HDH systems (mentioned in Table 2) which produced 1000 and 10,000 L/day could be considered as a good choice for remote areas with low-dense population as well as small villages. Moreover, some solar stills with cost of produced water by 0.0138, 0.02120, 0.0092 and 0.0062, 0.0065 \$/Liter (See Table 1) could be proposed as appropriate systems for households ascribed to the least cost of produced water per liter.

The significance of accessibility and quality of water

It was demonstrated that, the criterion of "accessibility" of drinking water is related to Goal 4 which is the matter of education. Indeed, the time spent to find an improved source of drinking water could be designated to education which leads to grow people coincident with what are aimed by sustainable development goals. We brought the importance of accessibility with an example into the spotlight. If a young student had to spent 1 h every day (as some examples brought in section 4.2) to access to safe drinking water, it is not unimaginable how much progress in learning (throughout the year) would be made if she/he spend this time to education instead of bringing water from far distance places. Furthermore, the criterion "quality" related to the Goal 11 which is "Make cities and human settlements inclusive, safe, resilient and sustainable". As the term "quality" of produced water defined as final product with an acceptable color, odor and a good taste to be suitable for drinking, the lack of these criteria make it inappropriate for human consumption. Accordingly, in the case water with low-quality, one of the plausible options to access to high quality drinking water is migration of inhabitants to another place where drinking water has higher quality than their previous settlement. Again, it would not be surprising that the first choice in this condition is immigrating to cities. Consequently, during not so much time this wave of emigration makes small communities less and less populated while cities would be more populated and more population creates more pollution, without any doubt, more pollution results in more environmental risks.

The importance of quantity

Additionally, the criterion of "quantity" would be connected to two of the SDGs, the first one, obviously is the goal 6.1 that explicitly stated "equitable access to safe and affordable drinking water for all" which directly highlighted that the amount of drinking water should be enough to be consider affordable. Evidently, in situation that the amount of water is limited in a region, the price of water would be expensive. On the other hand, the criterion "quantity" has another face which is related to Goal 3, "Ensure healthy lives and promote well-being for all at all ages". Although the importance of water in realization of this goal has not explicitly mentioned, there is a hidden connection between this goal and drinking water. While the lack of drinking water would be threaten human health because of dehydration [118], mild dehydration also has direct effect on cognitive performance, mood, etc. [119,120] on different groups of people particularly on children as the most vulnerable group. This means that consuming enough amount of drinking water is critically important for human wellbeing [121]. It is important to point out that the aforementioned desalination systems are not the

only systems that can be utilized, but the recently developed system in the last decade called solar interfacial evaporation is one of the most promising high efficient methods that capable to produce drinking water in a cost-efficient, good quality and high yield with low-cost and raw materials thanks to the advancements in nanotechnology. The importance of solar interfacial evaporation is because of their exceptional performance such as high efficiency (more than 100 %) [122,123] and purifying water with any type of impurities [23], even contaminated water with radioactive elements or dangerous antimicrobial resistance pathogens like Methicillin-Resistant Staphylococcus aureus (MRSA). However, this technology is in infancy stages for practical application in the near future. By evaluating the water desalination systems made and improved by engineers, it is concluded that engineering has the capability and needed knowledge to improve and optimize small scale systems and to manufacture systems more adapted to the criteria defined by sustainable development goals instruments, such criteria as: to be affordable, to be accessible, having good quality and sufficient quantity. It is necessary to note that although engineering could make a help, and the task of providing safe drinking water is borne on governments, but if there is a desire to gain victory over the greatest challenge of the century, a strong commitment along with a revitalized global partnership and a spirit of global solidarity is needed. A tight cooperation between the UN, and the related organizations (UNICEF, UNESCO, etc.), all international and national organizations, all states, all stakeholders, private sectors, all people and every entity who believes this world has to be a better place to live is needed.

Possible Limitation and challenges of desalination technologies in developing countries

Although the advantages of solar desalination systems in realizing SDGs in developing world were highlighted, there could be some limitations and challenges for technology development. For instance, the technical expertise required for the installation, operation, and maintenance of these systems is often limited in developing countries. Moreover, the other problem is brine disposal that is less voluminous than in large-scale systems but it still requires careful management to avoid localized increases in salinity that can harm soil and small aquatic ecosystems, especially if proper disposal infrastructure is lacking in long-term. It is worthy to point out that, while small-scale units may produce less brine than large-scale plants, appropriate disposal methods and regulations are often absent or poorly managed in developing world. Technically, both solar stills and HDH systems can suffer from inconsistent performance due to fluctuating solar irradiance which could leading to unreliable water supply. Besides, scaling and fouling of the evaporative surfaces and condensers in HDH systems and the basin of solar stills can reduce efficiency over time.

Moreover, there could be potential trade-offs in utilizing solar desalination for realizing other SDGs. For example, the lack of regulations on brine disposal could have a negative effect on SDG 14 – Life Below Water – (Conserve and sustainably use the oceans, seas, and marine resources for sustainable development) and SDG 15 – Life on Land – (Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss). It should be noted that the above-mentioned trade-offs regarding solar desalination systems might not translate into the major factor preventing the other SDGs; however, it is logical to consider them that could play a minor role in the long term alongside other negative factors.

Conclusion

A significant body of research and international action plans exhibit that many efforts in the last decades have been devoted to eradicate the problem of safe drinking water in developing world. These include ratifying international instruments, action plans and practicing

engineering solutions based on the economic, climate and geographical conditions. Solar desalination as one of the most promising method in this context has been proposed as a practical solution in providing safe drinking water whereas at the same time it can put one step forward in realizing sustainable development goals particularly goal 6.1. Regarding the importance of drinking water, achieving to the goal 6.1 would be assisted in realization of the other SDGs that highlighted the crucial hidden connection between goal 6 and other SDGs including Goals 3, 4 and 11. Ascribe to tremendous advances in recent years for providing safe drinking water- particularly solar interfacial evaporation and atmospheric water generators- there is a hope to solve this crisis for a sustainable future. It is worthy to note that, although providing and increasing access to safe drinking water in the light of sustainable development goals was scrutinized in this study, it is not the only viewpoint to look at this subject. As every human being has human rights based upon his human essence, the matter of safe drinking water –which has a key role on the survival of human beings- could be observed from the human right viewpoint, since *Universal Human Right Declaration* states “Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family”.

CRedit authorship contribution statement

Seyed Maoud Parsa: Writing – original draft, Writing – review & editing, Project administration, Conceptualization, Supervision. **Fatemeh Norozpour:** Investigation, Data curation, Conceptualization, Formal analysis. **Ali Hedayatzadeh:** Writing – review & editing, Methodology, Writing – original draft, Conceptualization. **Davoud Javadi:** Validation, Investigation, Methodology. **Shahin Shoebi:** Resources, Writing – review & editing. **Hadi Kargarsharifabad:** Formal analysis, Writing – review & editing. **Siran Feng:** Writing – review & editing, Methodology. **Wenshan Guo:** Writing – review & editing. **Huu Hao Ngo:** Writing – original draft. **Bing-Jie Ni:** Writing – review & editing.

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.

References

- [1] United Nations Conference on Environment and Development, Agenda 21, Rio de Janeiro, Brazil, 3 to 14 June 1992., in: Division for Sustainable Development Goals, United Nations, 1992: p. 196. doi:10.1007/s11671-008-9208-3.
- [2] Jowitt PW. Water infrastructure, the UN MDGs and sustainable development. *Desalination* 2009;248:510–6. <https://doi.org/10.1016/j.desal.2008.05.095>.
- [3] Making every drop count. An agenda for water action, (2018) 34. doi:10.3362/0262-8104.1993.008.
- [4] Feng S, Guo W, Ding A, Parsa SM, Pan J. Enzyme sources in wastewater treatment : their influence on enzymatic bioremediation and large-scale applications. *Chem. Eng. J.* 2025;510:161891. <https://doi.org/10.1016/j.cej.2025.161891>.
- [5] UN General Assembly, The human rights to safe drinking water and sanitation: Resolution adopted by the General Assembly, 19 December 2017, A/RES/72/178, 660 (2018).
- [6] W.H.O. (WHO), State of the world’s drinking water: an urgent call to action to accelerate progress on ensuring safe drinking water for all, 2022.
- [7] UN General Assembly, International Decade for Action, “Water for Sustainable Development”, 2018-2028: Resolution adopted by the General Assembly, 21 December 2016, A/RES/71/222, 2017. doi:10.1093/oxfordhb/9780199560103.003.0005.
- [8] Shanmugan S, Djuansjah J, Ahmadein M, Alsaleh NA, Masoud S, Elsheikh AH. Chemical potential of different phases inside the pyramid stepped basin solar still through Gibbs free energy. *Case Stud. Therm. Eng.* 2023;49:103277. <https://doi.org/10.1016/j.csite.2023.103277>.

- [9] Facts and statistics | WaterAid, (n.d.). <https://www.wateraid.org/facts-and-statistics> (accessed November 26, 2018).
- [10] Parsa SM, Chen Z, Feng S, Yang Y, Luo L, Hao H. Metal-free nitrogen-doped carbon-based electrocatalysts for oxygen reduction reaction in microbial fuel cells : advances , challenges , and future directions. *Nano Energy* 2025;134. <https://doi.org/10.1016/j.nanoen.2024.110537>.
- [11] W.H.O. (WHO, PROGRESS ON HOUSEHOLD DRINKING WATER , SANITATION, 2022.
- [12] UN General Assembly, United Nations Millennium Declaration, Resolution Adopted by the General Assembly, 18 September 2000, A/RES/55/2, (2000). <http://www.un.org/millennium/declaration/ares552e.htm> (accessed November 26, 2018).
- [13] UN Committee on Economic, Social and Cultural Rights (CESCR), General Comment No. 15: The Right to Water (Arts. 11 and 12 of the Covenant), 20 January 2003, E/C.12/2002/11, 2003 (2003). doi:E/C.12/2002/11.
- [14] UN General Assembly, United Nations Water Conference, Mar Del Plata Action Plan Mar Del Plata, Argentina, 14-25 March 1977, (1977). [https://www.internationalwaterlaw.org/bibliography/UN/UN_Mar del Plata Action Plan_1977.pdf](https://www.internationalwaterlaw.org/bibliography/UN/UN_Mar_del_Plata_Action_Plan_1977.pdf).
- [15] United Nations Department of Economic and Social Affairs, Sustainable Development Knowledge Platform: Water and Sanitation, (n.d.). <https://sustainabledevelopment.un.org/topics/waterandsanitation> (accessed November 27, 2018).
- [16] Aberoumand S, Dubal D, Woodfield P, Masoud S, Mahale K, Duc H, et al. Enhancement in vanadium redox flow battery performance using reduced graphene oxide nanofluid electrolyte. *J Energy Storage* 2023;72:108343. <https://doi.org/10.1016/j.est.2023.108343>.
- [17] Wakil M, Burhan M, Ang L, Choon K. Energy-water-environment nexus underpinning future desalination sustainability. *Desalination* 2017;413:52–64. <https://doi.org/10.1016/j.desal.2017.03.009>.
- [18] Parsa SM. Mega-scale desalination efficacy (reverse Osmosis , Electrodialysis , Membrane Distillation , MED , MSF) during COVID-19 : evidence from salinity , pretreatment methods , temperature of operation. *J Hazard Mater Adv* 2023;9:100217. <https://doi.org/10.1016/j.hazadv.2022.100217>.
- [19] Hanshik C, Jeong H, Jeong KW, Choi SH. Improved productivity of the MSF (multi-stage flashing) desalination plant by increasing the TBT (top brine temperature). *Energy* 2016;107:683–92. <https://doi.org/10.1016/j.energy.2016.04.028>.
- [20] Zayed ME, Katekar VP, Kumar R, Deshmukh SS, Elsheikh AH. Predicting the yield of stepped corrugated solar distiller using kernel-based machine learning models. *Appl Therm Eng* 2022;213.
- [21] Elsheikh A, Zayed M, Abogazala A, Essa FA, Rehman S, Muskens OL, et al. Innovative solar distillation system with prismatic absorber basin : experimental analysis and LSTM machine learning modeling coupled with great wall construction algorithm. *Process Saf Environ Prot* 2024;186:1120–33.
- [22] Aboelmaaref MM, Zayed ME, Li Y, Zhao J, Rehman S, Irshad K, et al. Performance assessment of hybrid adsorption/ humidification-dehumidification desalination cycle powered by dish/stirling concentrated solar power system for sustainable freshwater production maximization. *Process Saf Environ Prot* 2025;193:1094–113. <https://doi.org/10.1016/j.psep.2024.11.109>.
- [23] Parsa SM, Norouzpour F, Momeni S, Shoebis S, Zeng X, Said Z, et al. Advanced nanostructured materials in solar interfacial steam generation and desalination against pathogens: combatting microbial-contaminants in water – a critical review. *J Mater Chem A* 2023;11:18046–80. <https://doi.org/10.1039/d3ta03343k>.
- [24] Shalaby SM, Hammad FA, Zayed ME. Current progress in integrated solar desalination systems : prospects from coupling configurations to energy conversion and desalination processes. *Process Saf Environ Prot* 2023;178:494–510.
- [25] Shalaby SM, Zayed ME, Hammad FA, Menesy AS, Refat A. Recent advances in membrane distillation hybrids for energy-efficient process configurations : Technology categorization , operational parameters identification , and energy recovery strategies. *Process Saf Environ Prot* 2024;190:817–38.
- [26] Parsa SM. Reliability of thermal desalination (solar stills) for water/ wastewater treatment in light of COVID-19 (novel coronavirus “SARS-CoV-2”) pandemic: what should consider? *Desalination* 2021;512:115106. <https://doi.org/10.1016/j.desal.2021.115106>.
- [27] Kirvel I, Zhidebayeva A, Taizhanova L, Aitimova A, Syrlybekkyzy S, Serikbayeva A, et al. Evaluation of efficiency of a finned corrugation basin in inclined basin-type solar stills in regulating the water supply of the capsciment plant. *Limnol Rev* 2024;150–63.
- [28] Technology ND, Jafari S, Hoseinzadeh S. Deep Q-value neural network (DQN) reinforcement learning for the techno-economic optimization of a solar-driven. *Water (Switzerland)* 2022.
- [29] Al-helal IM, Alsadon A, Marey S, Ibrahim A, Shady MR. Optimizing a single-slope solar still for fresh-water production in the deserts of arid regions : an experimental and numerical approach. *Sustain* 2024.
- [30] Shoebis S, Kargarsharifabad H, Mirjalilyy SAA, Muhammad T. Solar district heating with solar desalination using energy storage material for domestic hot water and drinking water – Environmental and economic analysis. *Sustain Energy Technol Assessments* 2022;49:101713. <https://doi.org/10.1016/j.seta.2021.101713>.
- [31] Vembu S, El M, Attia H, Thangamuthu M, Thangamuthu G. Energy , exergy , and economic analysis of solar still using coal cylinder fins : an experimental study. *Environ Sci Pollut Res* 2022. <https://doi.org/10.1007/s11356-022-22325-0>.
- [32] Shanmugan S, Palani S, Janarthanan B. Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials. *Desalination* 2018;433:186–98. <https://doi.org/10.1016/j.desal.2017.11.045>.
- [33] Raj G, Prabhansu D, Kumar R, Chandra P, Saurabh S. Experimental study of solar still augmented with low-cost energy absorbing and releasing materials. *Energy Sources Part A Recover Util Environ Eff* 2019;1–10. <https://doi.org/10.1080/15567036.2019.1587054>.
- [34] H. Tanaka, Y. Nakatake, Improvement of the tilted wick solar still by using a flat plate reflector, 216 (2007) 139–146. doi:10.1016/j.desal.2006.12.010.
- [35] Parsa SM, Javadi DY, Rahbar A, Majidniya M, Aberoumand S, Amidpour Y, Amidpour M. Experimental assessment on passive solar distillation system on Mount Tochal at the height of 3964 m: Study at high altitude. *Desalination* 2019;466. <https://doi.org/10.1016/j.desal.2019.05.010>.
- [36] Panchal H, Sathyamurthy R, Kabeel AE, El-Agouz SA, Ds S, Rufus T, et al. Annual performance analysis of adding different nanofluids in stepped solar still. *J Therm Anal Calorim* 2019;138:3175–82. <https://doi.org/10.1007/s10973-019-08346-x>.
- [37] Parsa SM, Rahbar A, Koleini MH, Davoud Javadi Y, Afrand M, Rostami S, et al. First approach on nanofluid-based solar still in high altitude for water desalination and solar water disinfection (SODIS). *Desalination* 2020;491:114592. <https://doi.org/10.1016/j.desal.2020.114592>.
- [38] Arani RP, Sathyamurthy R, Chamkha A, Kabeel AE, Deverajan M, Kamalakannan K, et al. Effect of fins and silicon dioxide nanoparticle black paint on the absorber plate for augmenting yield from tubular solar still. *Environ Sci Pollut Res* 2021;28:35102–12. <https://doi.org/10.1007/s11356-021-13126-y>.
- [39] Parsa SM, Norouzpour F, Shoebis S, Shahsavar A, Aberoumand S, Said Z, et al. A comprehensive study to find the optimal fraction of nanoparticle coated at the interface of solar desalination absorbers: 5E and GHGs analysis in different seasons. *Sol Energy Mater Sol Cells* 2023;256:112308. <https://doi.org/10.1016/j.solmat.2023.112308>.
- [40] Abdullah AS, Alarjani A, Abou Al-sood MM, Omara ZM, Kabeel AE, Essa FA. Rotating-wick solar still with mended evaporation technics: experimental approach. *Alexandria Eng J* 2019;58:1449–59. <https://doi.org/10.1016/j.aej.2019.11.018>.
- [41] Matrawy KK, Alosaimy AS, Mahrous AF. Modeling and experimental study of a corrugated wick type solar still: comparative study with a simple basin type. *Energy Convers Manag* 2015;105:1261–8. <https://doi.org/10.1016/j.enconman.2015.09.006>.
- [42] Dhindsa GS, Mittal MK. Experimental study of basin type vertical multiple effect diffusion solar still integrated with mini solar pond to generate nocturnal distillate. *Energy Convers Manag* 2018;165:669–80. <https://doi.org/10.1016/j.enconman.2018.03.100>.
- [43] Velmurugan V, Srithar K. Solar stills integrated with a mini solar pond — analytical simulation and experimental validation. *Desalination* 2007;216:232–41. <https://doi.org/10.1016/j.desal.2006.12.012>.
- [44] Kargar Sharif Abad H, Ghiasi M, Jahangiri Mamouri S, Shafiq MB. A novel integrated solar desalination system with a pulsating heat pipe. *Desalination* 2013;311:206–10. <https://doi.org/10.1016/j.desal.2012.10.029>.
- [45] Shoebis S, Kargarsharifabad H, Rahbar N, Ahmadi G, Safaei MR. Performance evaluation of a solar still using hybrid nanofluid glass cooling-CFD simulation and environmental analysis. *Sustain Energy Technol Assessm* 2022;49:101728. <https://doi.org/10.1016/j.seta.2021.101728>.
- [46] Parsa SM, Yazdani A, Javadi D, Afrand M, Karimi N, Muhammad H, et al. Selecting efficient side of thermoelectric in pyramid-shape solar desalination units incorporated phase change material (PCM), nanoparticle , turbulator with battery storage powered by photovoltaic. *J Energy Storage* 2022;51:104448. <https://doi.org/10.1016/j.est.2022.104448>.
- [47] Yanbolagh DJ, Mazaheri H, Saraei A, Jafari S. Experimental study on the performance of three identical solar stills with different heating methods and external condenser fully powered by photovoltaic : energy , exergy , and economic analysis, Energy sources. Part A Recover Util Environ Eff 2020;00:1–21. <https://doi.org/10.1080/15567036.2020.1817187>.
- [48] Parsa SM, Javadi DY, Rahbar A, Majidniya M, Salimi M, Amidpour Y, Amidpour M. Experimental investigation at a summit above 13,000 ft on active solar still water purification powered by photovoltaic: a comparative study. *Desalination* 2020;476:114146. <https://doi.org/10.1016/j.desal.2019.114146>.
- [49] Parsa SM, Rahbar A, Koleini MH, Aberoumand S, Afrand M, Amidpour M. A renewable energy-driven thermoelectric-utilized solar still with external condenser loaded by silver/nanofluid for simultaneously water disinfection and desalination. *Desalination* 2020:114354. <https://doi.org/10.1016/j.desal.2020.114354>.
- [50] Singh DB. Exergo-economic, enviro-economic and productivity analyses of N identical evacuated tubular collectors integrated double slope solar still. *Appl Therm Eng* 2019;148:96–104. <https://doi.org/10.1016/j.applthermaleng.2018.10.127>.
- [51] Mahian O, Kianifar A, Heris SZ, Wen D, Sahin AZ, Wongwises S. Nanofluids effects on the evaporation rate in a solar still equipped with a heat exchanger. *Nano Energy* 2017;36:134–55. <https://doi.org/10.1016/j.nanoen.2017.04.025>.
- [52] Bhargava M, Yadav A. Productivity augmentation of single-slope solar still using evacuated tubes, heat exchanger, internal reflectors and external condenser, Energy sources. Part A Recover Util Environ Eff 2019;00:1–21. <https://doi.org/10.1080/15567036.2019.1691291>.
- [53] Sadeghi G, Nazari S. Retrofitting a thermoelectric-based solar still integrated with an evacuated tube collector utilizing an antibacterial-magnetic hybrid nanofluid. *Desalination* 2021;500:114871. <https://doi.org/10.1016/j.desal.2020.114871>.

- [54] Johnson A, Mu L, Park YH, Valles DJ, Wang H, Xu P, et al. A thermal model for predicting the performance of a solar still with fresnel lens. *Water (Switzerland)* 2019;11. <https://doi.org/10.3390/w11091860>.
- [55] Elashmawy M. An experimental investigation of a parabolic concentrator solar tracking system integrated with a tubular solar still. *Desalination* 2017;411:1–8. <https://doi.org/10.1016/j.desal.2017.02.003>.
- [56] Fathy M, Hassan H, Salem Ahmed M. Experimental study on the effect of coupling parabolic trough collector with double slope solar still on its performance. *Sol Energy* 2018;163:54–61. <https://doi.org/10.1016/j.solener.2018.01.043>.
- [57] Manokar AM, Winston DP, Mondol JD, Sathyamurthy R, Kabeel AE, Panchal H. Comparative study of an inclined solar panel basin solar still in passive and active mode. *Sol Energy* 2018;169:206–16. <https://doi.org/10.1016/j.solener.2018.04.060>.
- [58] Manokar AM, Winston DP, Kabeel AE, El-agouz SA, Sathyamurthy R, Arunkumar T, et al. Integrated PV / T solar still- a mini-review. *Desalination* 2017;1. <https://doi.org/10.1016/j.desal.2017.04.022>.
- [59] El M, Attia H, Zayed ME, Kabeel AE, Abdelgaied M, Arıcı M, et al. A comparative experimental study on hemispheric distillation system integrated with metamorphic fabric materials for efficient and low-cost solar desalination. *Therm Sci Eng Prog* 2024;47:102277. <https://doi.org/10.1016/j.tsep.2023.102277>.
- [60] Rahman T, Nehar L, Prodhani Y, Shahed S, Al S, Rahman MS, et al. Enhancing solar still performance using external condensers and floating fins : a comparative study. *Clean Chem Eng* 2025;11:100167. <https://doi.org/10.1016/j.clee.2025.100167>.
- [61] Elamy MI, Essa FA, Mohammed SA, Alawee WH, Basem A, Abdullah AS, et al. Enhancing spherical solar still thermal performance with built-in baffles , reflectors , and nanoparticle phase change material. *Sol Energy* 2024;284: 113060. <https://doi.org/10.1016/j.solener.2024.113060>.
- [62] Pandey N, Naresh Y. Heat transfer , and energy , exergy , economic , exergoeconomic , exergoenvironment , enviroeconomic (6E) analysis of a modified pyramidal solar still with pulsating heat pipe. PCM and fins : an experimental investigation. *Desalination* 2025;609:118850. <https://doi.org/10.1016/j.desal.2025.118850>.
- [63] Chang Z, Yang J, Chu Y, Hou J, Su Y. Energy , exergy and economic analysis of a novel immersion tapered solar still for combination with solar concentrator. *Desalination* 2025;601:118560. <https://doi.org/10.1016/j.desal.2025.118560>.
- [64] Shoenibi S, Rahbar N, Abedini A, Kargarsharifabad H. Application of simultaneous thermoelectric cooling and heating to improve the performance of a solar still : an experimental study and exergy analysis. *Appl Energy* 2020;263:114581. <https://doi.org/10.1016/j.apenergy.2020.114581>.
- [65] Alshammari F, Alanazi N, Alshammari M, Elsheikh AH. Enhancing tubular solar still productivity : a novel rotational absorber , ultrasonic atomizer , and hygroscopic fabric integration. *Sol Energy Mater Sol Cells* 2025;287.
- [66] Abdallah S, Badran OO. Sun tracking system for productivity enhancement of solar still. *Desalination* 2008;220:669–76. <https://doi.org/10.1016/j.desal.2007.02.047>.
- [67] Essa FA, Basem A, Gadallah HY, El-sebaey MS, Alawee WH, Sh H, et al. Experimental multifaceted approach to enhance pyramidal solar still productivity : Tracking , corrugated absorber , reflectors , external condenser , and phase change material integration. *Process Saf Environ Prot* 2025;197: 107061. <https://doi.org/10.1016/j.psep.2025.107061>.
- [68] Kalbande VP, Choudhari MS, Vinchurkar S, Nakade A, Aglawe A, More K, et al. Performance evaluation of nano-enhanced phase change materials in a two-stage solar still with parabolic dish collector. *Appl Therm Eng* 2025;273:126484. <https://doi.org/10.1016/j.applthermaleng.2025.126484>.
- [69] Abdallah S, Badran O, Abu-Khader MM. Performance evaluation of a modified design of a single slope solar still. *Desalination* 2008;219:222–30. <https://doi.org/10.1016/j.desal.2007.05.015>.
- [70] Abdel-Rehim ZS, Lasheen A. Experimental and theoretical study of a solar desalination system located in Cairo, Egypt. *Desalination* 2007;217:52–64. <https://doi.org/10.1016/j.desal.2007.01.012>.
- [71] Badran AA, Al-Hallaq AA, Eyal Salman IA, Odat MZ. A solar still augmented with a flat-plate collector. *Desalination* 2005;172:227–34. <https://doi.org/10.1016/j.desal.2004.06.203>.
- [72] Badran OO, Al-Tahaine HA. The effect of coupling a flat-plate collector on the solar still productivity. *Desalination* 2005;183:137–42. <https://doi.org/10.1016/j.desal.2005.02.046>.
- [73] Kumar S, Tiwari GN. Life cycle cost analysis of single slope hybrid (PV/T) active solar still. *Appl Energy* 2009;86:1995–2004. <https://doi.org/10.1016/j.apenergy.2009.03.005>.
- [74] Hooshmand P, Shafii MB, Roshandel R. An experimental study of a solar hybrid system to produce freshwater from waste heat of photovoltaic module by using thermosyphon heat pipes. *Energy Convers Manag* 2018;158:9–22. <https://doi.org/10.1016/j.enconman.2017.12.043>.
- [75] Jahangiri Mamouri S, Gholami Derami H, Ghiasi M, Shafii MB, Shiee Z. Experimental investigation of the effect of using thermosyphon heat pipes and vacuum glass on the performance of solar still. *Energy* 2014;75:501–7. <https://doi.org/10.1016/j.energy.2014.08.005>.
- [76] Faegh M, Shafii MB. Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes. *Desalination* 2017;409:128–35. <https://doi.org/10.1016/j.desal.2017.01.023>.
- [77] Shafii MB, Shahmohamadi M, Faegh M, Sadhosseini H. Examination of a novel solar still equipped with evacuated tube collectors and thermoelectric modules. *Desalination* 2016;382:21–7. <https://doi.org/10.1016/j.desal.2015.12.019>.
- [78] Rahbar N, Esfahani JA. Experimental study of a novel portable solar still by utilizing the heatpipe and thermoelectric module. *Desalination* 2012;284:55–61. <https://doi.org/10.1016/j.desal.2011.08.036>.
- [79] Abolfazl J, Rahbar N, Lavvaf M. Utilization of thermoelectric cooling in a portable active solar still — an experimental study on winter days. *Desalination* 2011;269:198–205. <https://doi.org/10.1016/j.desal.2010.10.062>.
- [80] Rahbar N, Gharaiian A, Rashidi S. Exergy and economic analysis for a double slope solar still equipped by thermoelectric heating modules – an experimental investigation. *Desalination* 2017;420:106–13. <https://doi.org/10.1016/j.desal.2017.07.005>.
- [81] El-Sebaei AA, Ramadan MRI, Aboul-Enein S, Salem N. Thermal performance of a single-basin solar still integrated with a shallow solar pond. *Energy Convers Manag* 2008;49:2839–48. <https://doi.org/10.1016/j.enconman.2008.03.002>.
- [82] Fath HES, El-Samanouy M, Fahmy K, Hassabou A. Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations. *Desalination* 2003;159:69–79. [https://doi.org/10.1016/S0011-9164\(03\)90046-4](https://doi.org/10.1016/S0011-9164(03)90046-4).
- [83] Jamil B, Akhtar N. Effect of specific height on the performance of a single slope solar still: an experimental study. *Desalination* 2017;414:73–88. <https://doi.org/10.1016/j.desal.2017.03.036>.
- [84] Ali Samee M, Mirza UK, Majeed T, Ahmad N. Design and performance of a simple single basin solar still. *Renew Sustain Energy Rev* 2007;11:543–9. <https://doi.org/10.1016/j.rser.2005.03.003>.
- [85] Al-Hinai H, Al-Nassiri M, Jubran B. Effect of climatic, design and operational parameters on the yield of a simple solar still. *Energy Convers Manag* 2003;44:87. <https://www.sciencedirect.com/science/article/pii/S0196890401001200>.
- [86] Wousoff P, Peska T, Singh R, Akbarzadeh A. Novel and low cost designs of portable solar stills. *Desalination* 2011;276:294–302. <https://doi.org/10.1016/j.desal.2011.03.069>.
- [87] Rahbar N, Asadi A, Fotouhi-Bafghi E. Performance evaluation of two solar stills of different geometries: Tubular versus triangular: experimental study, numerical simulation, and second law analysis. *Desalination* 2018;443:44–55. <https://doi.org/10.1016/j.desal.2018.05.015>.
- [88] Ismail BI. Design and performance of a transportable hemispherical solar still. *Renew Energy* 2009;34:145–50. <https://doi.org/10.1016/j.renene.2008.03.013>.
- [89] Huang K, Qiu C, Xie W, Qu W, Zhuang Y, Chen K, et al. Design of a seawater desalination system with two-stage humidification and dehumidification desalination driven by Water (Switzerland) 2024.
- [90] Liu J, Sun Y, Zhang Y, Wang J. Theoretical study of a closed-cycle evaporation system for seawater desalination. *Separations* 2023.
- [91] Xu L, Chen Y, Wu P, Huang B. Desalination system with air-cooling condenser and cellulose evaporative pad. *Water (Switzerland)* 2020.
- [92] Tiwari A, Kumar A. Thermo-economic and sustainability analysis of solar-based humidification dehumidification seawater desalination system using different packing materials. *Sol Energy Mater Sol Cells* 2025;282:113384. <https://doi.org/10.1016/j.solmat.2024.113384>.
- [93] Abdullah AS, Elsayad MM, Almoatham S, Sharshir SW. 6E evaluation of an innovative humidification dehumidification solar distiller unit : an experimental investigation. *Therm Sci Eng Prog* 2024;56:103052. <https://doi.org/10.1016/j.tsep.2024.103052>.
- [94] Tiwari A, Kumar A. Performance evaluation of solar-assisted humidification dehumidification system for seawater desalination : an experimental approach. *Sep Purif Technol* 2025;356:129899. <https://doi.org/10.1016/j.seppur.2024.129899>.
- [95] Elminshawy NAS, Siddiqui FR, Addas MF. Experimental and analytical study on productivity augmentation of a novel solar humidification – dehumidification (HDH) system. *Desalination* 2015;365:36–45. <https://doi.org/10.1016/j.desal.2015.02.019>.
- [96] Zhani K, Ben Bacha H. Experimental investigation of a new solar desalination prototype using the humidification dehumidification principle. *Renew Energy* 2010;35:2610–7. <https://doi.org/10.1016/j.renene.2010.03.033>.
- [97] Yuan G, Wang Z, Li H, Li X. Experimental study of a solar desalination system based on humidification-dehumidification process. *Desalination* 2011;277:92–8. <https://doi.org/10.1016/j.desal.2011.04.002>.
- [98] Wang J, Gao N, Deng Y, Li Y. Solar power-driven humidification – dehumidification (HDH) process for desalination of brackish water. *Desalination* 2012;305:17–23. <https://doi.org/10.1016/j.desal.2012.08.008>.
- [99] Alnaimat F, Klausner JF. Solar diffusion driven desalination for decentralized water production. *Desalination* 2012;289:35–44. <https://doi.org/10.1016/j.desal.2011.12.028>.
- [100] Hamed MH, Kabeel AE, Omara ZM, Sharshir SW. Mathematical and experimental investigation of a solar humidification – dehumidification desalination unit. *Desalination* 2015;358:9–17. <https://doi.org/10.1016/j.desal.2014.12.005>.
- [101] Behnam P, Shafii MB. Examination of a solar desalination system equipped with an air bubble column humidifier, evacuated tube collectors and thermosyphon heat pipes. *Desalination* 2016;397:30–7. <https://doi.org/10.1016/j.desal.2016.06.016>.
- [102] Deniz E, Çınar S. Energy, exergy, economic and environmental (4E) analysis of a solar desalination system with humidification-dehumidification. *Energy Convers Manag* 2016;126:12–9. <https://doi.org/10.1016/j.enconman.2016.07.064>.
- [103] Chafik E. Design of plants for solar desalination using the multi-stage heating/ humidifying technique. *Desalination* 2004;168:55–71. <https://doi.org/10.1016/j.desal.2004.06.169>.
- [104] Houcine I, BenAmara M, Guizani A, Maâlej M. Pilot plant testing of a new solar desalination process by a multiple-effect-humidification technique. *Desalination* 2006;196:105–24. <https://doi.org/10.1016/j.desal.2005.11.022>.

- [105] Rajaseenivasan T, Srithar K. Potential of a dual purpose solar collector on humidification dehumidification desalination system. *Desalination* 2017;404: 35–40. <https://doi.org/10.1016/j.desal.2016.10.015>.
- [106] UNICEF, The Rights To Safe Water And To Sanitation, No. 3 (2014) 1. https://www.unicef.org/media/files/Current_Issues_Paper_The_Rights_to_Safe_Water_and_Sanitation.pdf.
- [107] World Health Organization, Guidelines for Drinking-water quality, (2017). <http://apps.who.int/iris/bitstream/handle/10665/254637/9789241549950>.
- [108] Li L, Li CS, Wichelns D. Assessing household willingness to pay for bottled water in rural areas of the Mekong Delta, Vietnam. *Water Resour Rural Dev* 2016;7: 36–49. <https://doi.org/10.1016/j.wrr.2016.03.001>.
- [109] Low and middle income by Countries, (n.d.). <https://data.worldbank.org/income-level/low-and-middle-income> (accessed November 26, 2018).
- [110] ICWE. The Dublin statement on water and sustainable development. *Int Conf Water Environ United Nations* 1992:1–5. <https://doi.org/10.1017/S0376892900030733>.
- [111] United Nations Development Programme, Human Development Report - Beyond scarcity: Power, poverty and the global water crisis, 2006, (2006). <http://www.undp.org/content/undp/en/home/librarypage/hdr/human-development-report-2006.html>.
- [112] UN General Assembly, Resolution adopted by the General Assembly on 25 September 2015, Transforming our world: the 2030 agenda for sustainable development, 16301 (2015) 1–35. doi:10.1007/s13398-014-0173-7.2.
- [113] O. Fontaine, P. Garner, M.K. Bhan, Oral rehydration therapy: the simple solution for saving lives., *BMJ*. 334 Suppl (2007) s14–s14. doi:10.1136/bmj.39044.725949.94.
- [114] UN General Assembly, Resolution adopted by the General Assembly, 64/292. The human right to water and sanitation, (2010) 27531. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/64/292.
- [115] United Nations Commission on Sustainable Development. Report on the Sixth Session E/CN.17/1998/20, (1998). http://www.un.org/ga/search/view_doc.asp?symbol=E/CN.17/1998/20&Lang=E.
- [116] Water, Sanitation and Hygiene (WASH) | UNICEF, (n.d.). <https://www.unicef.org/wash> (accessed March 10, 2022).
- [117] Human Rights Council, annual report of the united nations high commissioner for human rights and reports of the office of the united nations high commissioner for human rights and the secretary-general, Report of the United Nations High Commissioner for Human Rights on the Scop, GE.07-1365 (2007) 32. doi: 10.1093/oxfordhb/9780199560103.003.0005.
- [118] Chevront SN, Kenefick RW. Dehydration : physiology , assessment , and performance effects. *Compr Physiol* 2011;4:257–85. <https://doi.org/10.1002/cphy.c130017>.
- [119] Adan A. Cognitive performance and dehydration. *J Am Coll Nutr* 2012;31:71–8.
- [120] Arnaud MJ. Mild dehydration : a risk factor of constipation ? *Eur J Clin Nutr* 2003;88–95. <https://doi.org/10.1038/sj.ejcn.1601907>.
- [121] Popkin BM, Rosenberg IH. Water, hydration and health. *Nutr Rev* 2011;68: 439–58. <https://doi.org/10.1111/j.1753-4887.2010.00304.x>.Water.
- [122] Xu Z, Zhang L, Zhao L, Li B, Bhatia B, Wang C, et al. Ultrahigh-efficiency desalination via a thermally-localized multistage solar still. *Energy Environ Sci* 2020;13:830–9. <https://doi.org/10.1039/c9ee04122b>.
- [123] Zhang L, Xu Z, Bhatia B, Li B, Zhao L, Wang EN. Modeling and performance analysis of high-efficiency thermally-localized multistage solar stills. *Appl Energy* 2020;266:114864. <https://doi.org/10.1016/j.apenergy.2020.114864>.