



# A comprehensive review of the effective environmental parameters on the efficiency and suitable site selection for installing solar based water desalination systems in Iran

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## Abstract

The increase in demand for water has caused attention to non-traditional methods for water supply in many places. Solar still is a simple, economical and suitable technology for providing drinking water from salt water that can be used even in remote areas. The challenge facing these technologies is to increase their performance, which is possible through three ways: environmental, design and operational parameters. This research has investigated the potential and location of Iran for the installation of solar still using environmental parameters. The three parameters of ambient temperature, solar radiation intensity and wind velocity are the most important environmental parameters affecting the performance of solar still; hence, they were used to investigate the potential of Iran to install solar still. The long-term information of the desired environmental parameters was prepared using field and telemetry methods; then, by averaging each parameter in ArcGIS software, a map was prepared for the ease of analysis and review. The results show that Iran has a high potential for using solar still in terms of environmental conditions affecting the performance of solar still and having brackish water resources and the provinces of Sistan and Baluchistan, Hormozgan, Fars, Kerman and Bushehr are the most favorable places in the country. Iran has been investigated for the installation of solar still based on three parameters. Also, the results show that the provinces of Sistan and Baluchistan (2196 kWh/m<sup>2</sup>), Fars (2148 kWh/m<sup>2</sup>), Hormozgan (2136 kWh/m<sup>2</sup>), Kerman (2116 kWh/m<sup>2</sup>), and Kohkiluyeh and Boyer-Ahmad (2098 kWh/m<sup>2</sup>), are the regions with highest potentials for installation of solar based water desalination systems in Iran.

**Keywords** Solar still · Evaporation · ArcGIS · Desalination · Locations · Remote sensing method · Wind velocity · Solar radiation intensity

## 1 Introduction

Over two-thirds are in bergs and polar ices with difficult accessibilities. In fact, < 1% of freshwater earth resources can be accessed (El-Ghonemy, 2012; Gorjian et al., 2014; Kalogirou, 2005). Lack of freshwater resources, high rate of population growth, climatic

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changes, agriculture and industry developments, and disproportionate dispersion of water resources have increased water demand, and it is not possible to provide this amount of demand in many areas with traditional methods. The desalination method is a relatively new method to provide part of the freshwater. Using desalination method is solution to deal with water shortage that reduces dependence on rainfall, but if fossil energy is used to provide energy, it can cause an increase in cost and environmental and biological pollution (Abbasi & Choukolaei, 2023; Abbasi et al., 2022; Cai et al., 2023; Elsheikh et al., 2022; Grubert et al., 2014; Kedar, 2021; Pourkiaei, et al., 2021; Sirohi et al., 2023).

Renewable energy sources like wind energy, solar energy, geothermal energy, etc. have been mentioned in many types of research (Compain, 2012; Gorjian et al., 2011; Huang et al., 2023; Kalogirou, 1997; Koroneos et al., 2007; Lv et al., 2023; Qiblawey & Banat, 2008) and can lead to the development of this method to provide drinking water in different regions. A kind of renewable energy that is easily accessed in many parts of the world is solar energy. Although this energy has not yet been widely exploited for the supply of humans' required energy, it has been introduced as a reliable (Kabeel & Abdelgaied, 2018). Many areas receive average solar energy of 5–7 kWh/m<sup>2</sup>, which equals 1.7–2.2 MWh/m<sup>2</sup> per year (Reif & Alhalabi, 2015). This amount of solar energy equals the energy derived from 1.5 oil barrels every year (Trieb & Müller-Steinhagen, 2008). Solar stills are simple and cost-effective equipment that possess proper economic (Cao et al., 2017; Hedayatizadeh, 2020; Muthusamy & Srithar, 2017). The use of solar water desalination does not have the disadvantages of using fossil energy and can increase the quality of water in remote and poor areas (Manchanda & Kumar, 2018). Developed water vapors contact the coolant surface and give rise to condensation. Condensed water is collected inside chamber of solar stills and is steered toward the system out (Ming, et al., 2017). A sample of solar stills is shown in Fig. 1.

Contrary to the solar stills benefits, low generation rate of devices has been transformed into a challenge for researchers. Solar still management can have various consequences. In Table 1, some management implications of using solar still are presented.

Solar stills efficiency depends on environmental conditions, operational factors and design parameters (Panchal & Shah, 2014, 2015; Sharshir et al., 2016). Increasing the freshwater generation rate of solar stills that are influenced by operational, three environmental and design parameters, shown in Fig. 2. Some of these studies are presented in Table 2.

Concerning the benefits of solar stills, the exploitation of this technology is a suitable approach to using renewable energies, supplying freshwater, especially in remote areas, and coping with water scarcity (Siddique et al., 2018). Thus, this technology should be investigated meticulously so that the enhancement of the generation rate would pave the way for using this technology more than ever (He et al., 2018).

Remote sensing and geographic information system (GIS) are two powerful tools in the field of environmental studies and natural resource planning. Remote sensing uses devices such as laser scanners, radars and image processing computers to obtain information about features on the ground. This information includes height, slope, vegetation, soil type, climatic conditions, etc. Since this information is available in a detailed and large-scale form, it is used to create analytical and optimization models. Planning urban and rural development, planning forests and water resources, planning transportation routes, environmental monitoring, etc are among the vast applications of GIS. For example, in planning the installation of photovoltaic (PV) panels, telemetry is used

to determine suitable roofs according to the slope, height, orientation and amount of sunlight. Then, using GIS, this information is placed in different maps in the form of different layers such as slope, height and vegetation. These maps are used to prepare optimization models for PV installations. Therefore, remote sensing and GIS are used as effective tools in the field of planning and environmental studies, and they can also be used as effective tools in the field of PV installation. Extensive studies were done by researchers on remote sensing and GIS (Aydin et al., 2010; Kucuksari et al., 2014; Sadeghfam & Abadi, 2021; Sánchez-Lozano et al., 2013). This research has analyzed and investigated environmental parameters affecting the role and extent of influence of each factor, and the long-term average of the most important environmental parameters in Iran as a hot and dry country with salty water resources. In this regard, the parameters affecting solar stills were first identified and prioritized; then, using remote sensing methods and weather station data, the information required for the main parameters for Iran was collected, processed and analyzed to use them to achieve the following goals:

- Obtaining information on environmental parameters affecting solar stills, how they affect (positive or negative) and their amount.
- Achieving the long-term average of the main environmental parameters affecting solar stills in Iran.
- Analyzing and investigating the Iran's potential for using a solar still technology.
- Identifying suitable places for installing solar stills in Iran.

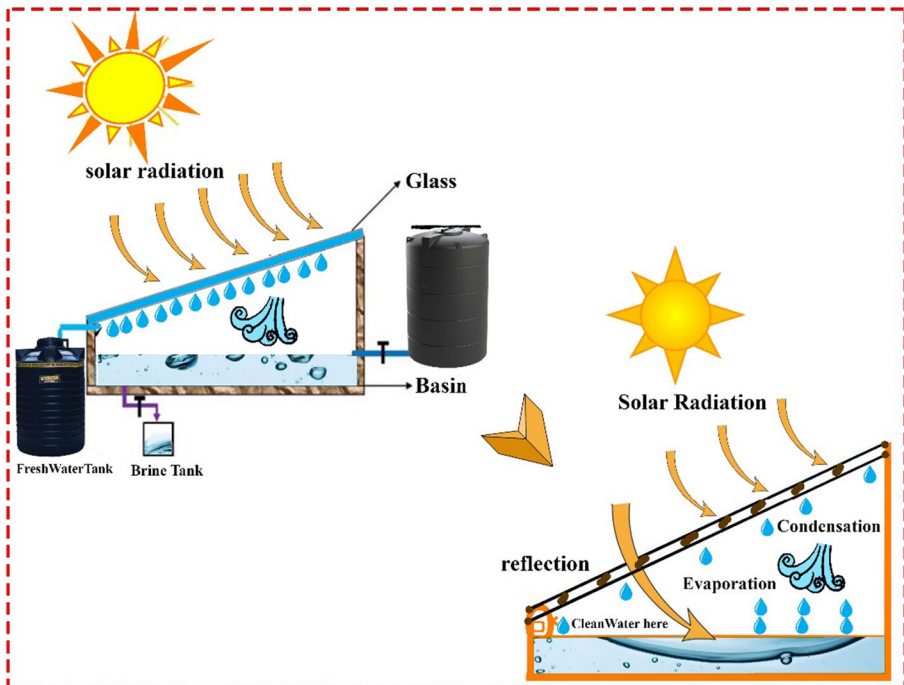
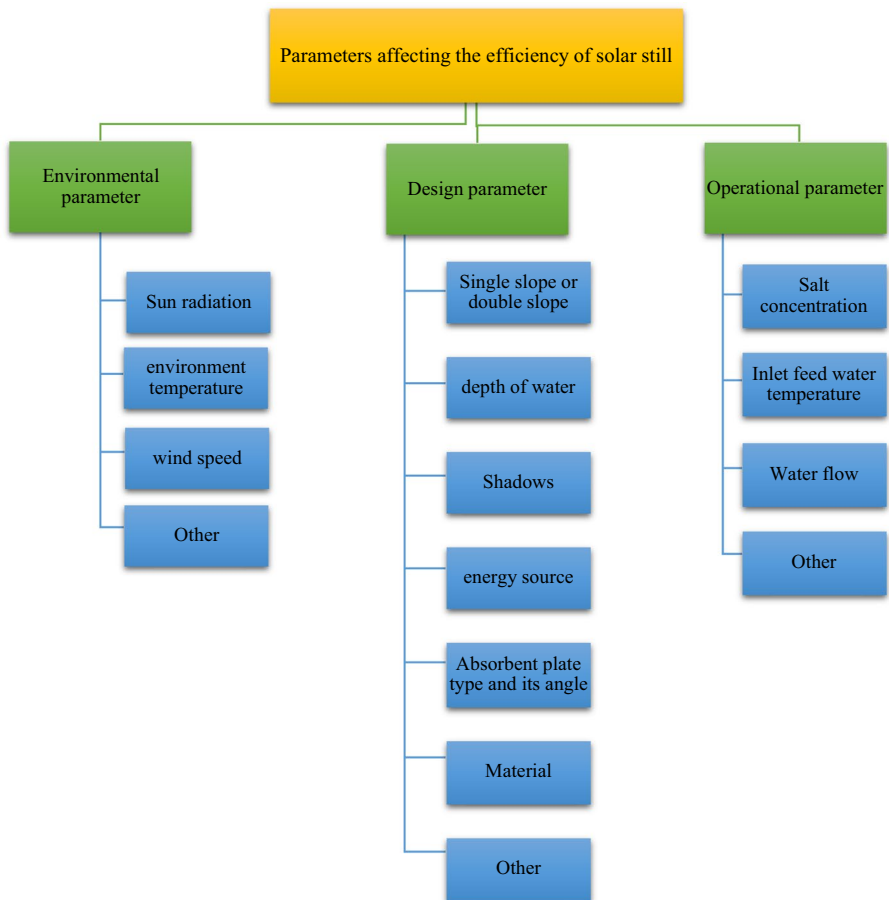


Fig. 1 General scheme of solar stills (Panchal & Patel, 2016; Sharon & Reddy, 2015)

**Table 1** Some consequences of solar still management

Reducing water costs	Using a solar still can lead to a reduction in water costs, as this device uses sunlight to purify water and does not require the use of electricity or fuel
Increase productivity	The use of solar still can improve the quality of water and increase the efficiency of devices. The water desalinated by this device has a better quality and may have a positive effect on the efficiency of the devices
Simple maintenance	Compared to other water purifiers, this device requires less maintenance and repairs. This device has simpler parts and is easily repaired
Environmental sustainability	Using a solar still can lead to a reduction in environmental pollution, because this device receives its energy from the sun and does not need to use fossil fuels. Also, this device can help reduce water consumption, which in turn can lead to saving water resources

**Fig. 2** Parameters impacting solar stills

**Table 2** Studies conducted on increasing generation rate of solar stills

Row	Parameter	References	Explanation
1	Design parameter	Bait (2019)	By creating a collecting tube in the structure of the solar desalination still, they increased the efficiency from 7 to 30% to 11 to 41%
2		Kalita et al. (2017)	By designing a new transmitter for solar desalination, they succeeded in increasing the production rate
3		Ozuomba et al. (2017)	By increasing parameters such as the surface and installation angle of glass, production rate can be increased
4		Kaviti et al. (2019)	Installation of glass cover and insulation increases production rate
5	Operational parameter	Kien et al. (2018)	Increasing water T increases productivity of device and appropriate water temperature is 55–85 °C
6		Elzahaby et al. (2016)	Operating parameters of feedwater inlet T, feedwater flow rate and salt concentration in solar desalination stills were investigated
7		Gang et al. (2016)	The efficiency of solar desalination stills at different inlet water temperatures was investigated
8		Xu and Dai (2019)	Operational parameters such as water flow rate were optimized
9	Environmental parameter	Suárez and Urtubia (2016)	Performance of solar desalination still has been studied in various places. The results show that places between 40° S and 40° N near water sources are suitable for solar desalination due to good sunlight and the presence of water sources
10		Al-Nimr and Qananba (2018)	Sunlight intensity, ambient T and wind velocity of distillation and production rate of solar desalination were studied
11		Mahmoudi et al. (2009)	By studying intensity of solar radiation, Algeria was introduced as a suitable place for installation of solar desalination stills
12		Jafari et al. (2022)	They located the country of Iran to install a solar desalination plant
13		Mahmoudi et al. (2010)	They investigated the intensity of the sun's radiation in Algeria
14		Salim (2012)	They reported the suitable places to use solar desalination stills in Egypt using the fuzzy method
15		Aldoori et al. (2020)	Using the fuzzy method, they investigated several parameters in Iraq to find suitable points
16		Aydin and Sarptas (2020)	Using the multi-criteria decision-making method and considering parameters such as ambient temperature, salt water temperature, population, radiation intensity and water price, they located potential points for establishing solar desalination stills in Turkey
17		Dweiri et al. (2018)	Using the fuzzy method and multi-criteria decision-making, they investigated suitable points for installing solar desalination stills in Iran

**Table 2** (continued)

Row	Parameter	References	Explanation
18		Pugsley et al. (2016)	They investigated the optimal locations of solar desalination stills in the world using multi-criteria decision-making
19		Colmenar-Santos et al. (2020)	To locate suitable areas for use of solar desalination stills in eastern Spain, they examined the maps of solar radiation intensity

## 2 Investigating environmental parameters impacting solar stills

Solar still is not independent of the location, and many environmental parameters like ambient temperature, intensity of solar radiation, wind velocity, evaporation, rainfall, etc. have a role in its performance (Refalo et al., 2014). Studies that address the environmental factors impacting solar stills and their locations have introduced many influential parameters, ambient temperature, including solar radiation intensity, wind velocity, cloudiness, dust, precipitation, air humidity, sunny hours, altitude, solar radiation angle, ambient pressure, vegetation and relative location of the Sun (Fath & Ghazy, 2002; Prakash & Velmurugan, 2015; Sarver et al., 2013; Sharshir et al., 2016). Figure 3 shows the kinds of environmental conditions impacting solar stills efficiency.

Many studies have examined these parameters effect on generation rate of solar stills. Some of these parameters have positive and some have negative effects on the generation rate of water. These impacting parameters outnumber, and examining them individually takes a long time. On the other hand, due to the indirect overlap of some effective environmental parameters and insignificant effects on generation rate of solar stills, some researchers have explored the most influential factors to achieve suitable establishment locations. Table 3 presents some of the studies conducted on the impacting environmental factors.

Many of these studies have prioritized the parameters of solar radiation intensity, wind velocity and ambient T (Mamlook & Badran, 2007) since mentioned parameters have the maximum effect on generation rate water in solar stills compared to other environmental factors. On the other hand, the investigation of some parameters, like radiation intensity, indirectly involves other parameters, such as cloudiness, dust, the relative location of the Sun and radiation angle. It is because radiation intensity is directly related to the relative location of the Sun and is indirectly related to cloudiness and radiation angle. As a result, a single parameter involves several other parameters effect. This study prioritized having a detailed look at radiation intensity effect ambient T and wind velocity and then examined briefly impact of other parameters.

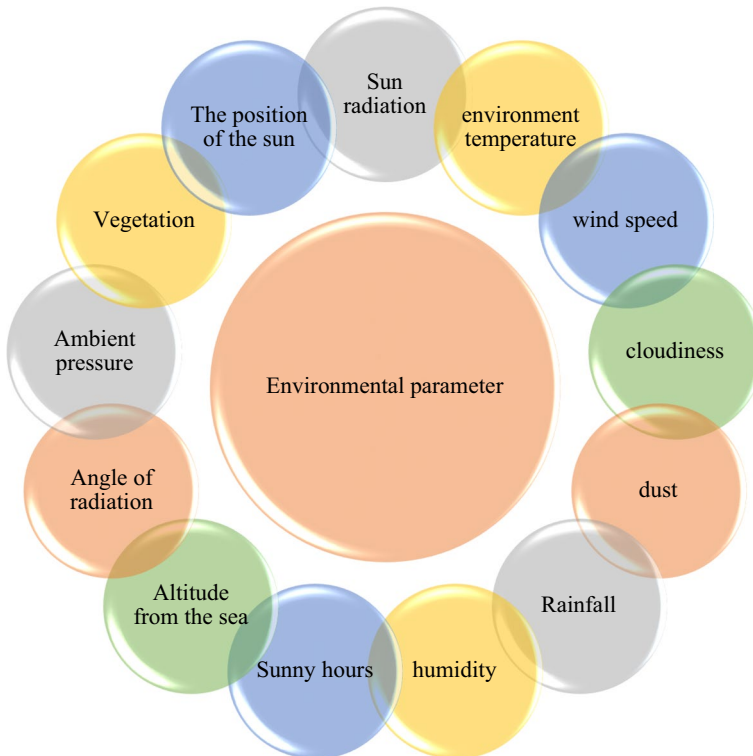
### 2.1 Solar radiation intensity

Solar radiation is paramount environmental parameter impacting the generation rate of solar stills (Muftah et al., 2014). Many researchers have studied solar radiation effect on generation rate of solar stills. Freshwater generation rate rose with the increase in the solar radiation, and generation rate and solar radiation were directly related (Nafey et al., 2001; Taamneh & Taamneh, 2012). Selvaraj and Natarajan (2018), in their study, explained that the upsurge in solar radiation intensity increased the efficiency of solar stills. Almuhanha (2014) claimed that the rise of solar radiation intensity enhanced freshwater generation. Papanicolaou et al. (2002) reported solar radiation warmed up saline water inside desalinators and catered to energy needed for its evaporation. Guogeng et al. (2011) studied solar radiation intensity effect on generation rate of solar stills. The increase in the solar radiation intensity from 400 to 550 W/m<sup>2</sup> raised generation rate from 900 to 1200 l/day. Put differently, this upsurge in radiation intensity increased the device efficiency by 33%. Some studies investigating solar radiation intensity effect on generation rate of solar stills are presented in Table 4.

Concerning the explained subjects and examining the effect of radiation intensity in previous studies, we can state that radiation intensity is the most important environmental parameter impacting the water generation rate in solar stills.

## 2.2 Ambient temperature

Ambient temperature is environmental parameter which impacts the generation rate of solar stills. Voropoulos et al. (2003) reported some environmental factors effects, like ambient T and wind velocity, differed from perspectives of different researchers. Badran (2007) and El-Sebaai (2004) explained efficiency enhancement of solar stills as possible by decreasing ambient temperature, and this factor had a reverse relationship with the efficiency of solar stills. Fath and Ghazy (2002) showed ambient temperature effect on efficiency and temperature rise was efficiency-increasing factor. The reason for these differences lies in the relationship of every environmental factor to several other parameters. In other words, the incremental or digressive effect of ambient T depends on what effect ambient T has on transmitter temperature (installed glass) since the evaporation and condensation processes take place due to T gradient between transmitter and saline water (Maoa et al., 2019). In this regard, some researchers have examined the effects of several influencing factors, like ambient T effect on T gradient, in explaining environmental factors effect. Consequently, results have not been obtained independently for the ambient temperature and reflect the



**Fig. 3** Kinds of environmental conditions impacting the efficiency of solar stills



**Table 3** Studies conducted on environmental factors impacting efficiency

Row	References	Parameters studied	Explanation
1	Feilzadeh et al. (2016)	Wind velocity, radiation intensity, ambient T, environment and so on	It has investigated radiation intensity, ambient T, wind velocity, humidity, etc. as environmental parameters
2	Al-Othman et al. (2018)	Sun radiation	The UAE was considered suitable for the use of solar desalination stills due to receiving high amounts of solar radiation in the world, and parabolic collectors (PTC) were used to increase amount of solar radiation in solar desalination stills
3	Amin et al. (2020)	Sunlight and wind velocity	Study of wind velocity and solar radiation has introduced environmental factors affecting the production rate to find a suitable location for the device
4	Zubair et al. (2017)	Seawater salinity, seawater temperature, precipitation, solar radiation, population and water prices	Suitable place for desalination using solar energy in Turkey was investigated with the considered parameters

**Table 4** Studies conducted on environmental factors effect (radiation intensity)

Row	References	Studied parameters	Explanation
1	Gorrie (2016)	Relative humidity, Solar intensity, wind velocity and ambient temperature	Studies have shown that in 30 h, water production rate in solar desalination still decreases by 44% on cloudy day compared to sunny day
2	Abujazar et al. (2017)	Sunlight intensity, wind velocity, ambient temperature relative humidity and cloud cover	Several parameters affecting water production rate were investigated and the results of the radiation intensity study show that increasing the radiation intensity from 200 to 1000 $\frac{Wh}{m^2}$ increases the freshwater production rate from 210 to 600 $\frac{mL}{m^2h}$ . In other words, a 400% increase in radiation intensity increases the production rate by about 200%
3	Parsa et al. (2020)	Solar intensity	They chose two places in Tehran with an altitude of 1171 and 3964 m above sea level. Highlands received 30% more radiation due to climatic conditions. The results show that productivity was 85% in the highlands and 44% in other places; in other words, productivity increases by more than 90% in exchange for receiving 30% more radiation
4	Ithape et al. (2017)	Wind velocity, ambient temperature, the intensity of sunlight and relative humidity	To evaluate the effect of radiation intensity, its amount was evaluated over 1 day

effect of several factors. Another factor leading to these contradictions is the difference in the design of devices. If a device is designed that saline water reservoir is positioned outside the device, the reservoir is greatly impacted by ambient T and wind velocity, and results are influenced, too. If the reservoir is positioned within the device, this effect is by far smaller. Although there is an unclear relationship between ambient temperature and distillation efficiency, several researchers used the theoretical model (Malik et al., 1982) to explain direct relationship between efficiency and ambient T (Zubair et al., 2017). This issue has been confirmed by Al-Hinai et al. (2002), whose results showed that efficiency increased 8.2% with a 10 °C increase in ambient T and constancy of other factors. Table 5 shows examples of the conducted studies.

From the conducted investigations and the viewpoints of researchers, ambient temperature is a positive environmental parameter for increasing generation rate of solar stills. A mere reason that can reverse this claim is the reduction of T gradient between transmitter (installed glass) and temperature of saline water inside solar still, a parameter that depends on ambient temperature. As a result, if an independent selection is to be made between the incremental and digressive ambient temperatures besides the selection of a location, the priority will be a location with a high temperature. It is because there are different ways to control temperature gradient; however, ambient T is uncontrollable. By using ambient T, we can import the saline water to the device at more ideal temperatures (high temperatures) and thus enhance the generation rate (Chaichan et al., 2016).

### 2.3 Wind velocity

Similar to the ambient temperature, there are contradictory results concerning effect of wind velocity on efficiency of solar stills (Gorrie, 2016). Like the ambient temperature parameter, this contradiction results from wind velocity effect on other factors, like temperature gradient of saline water and transmitter (installed glass) and whether the saline water reservoir is positioned inside or outside the device. Many studies endeavored to show wind velocity effect on desalinators. Badran (2007) and El-Sebaï (2004) argued that efficiency upsurge of solar stills was possible with rise of wind velocity and had direct relationship with solar stills efficiency. Some investigations have shown a reverse relationship between these two factors. In other words, a decline in wind velocity makes the device efficiency increase (Gorrie, 2016). By investigating wind velocity effect, ambient T and water T, Refalo et al. (2014) perceived that size effect of wind velocity depended on air temperature and water flow rate, and the generation rate decreased by 8–15% when wind velocity increased from 1 to 5 m/s. In his simulation, Barron (2006) also explained that efficiency decreased 13% by increasing of wind velocity from 1 to 9 m/s. Examples of conducted studies are presented in Table 6.

The contradictory results concerning wind velocity effect on the generation rate of solar stills made some researchers conduct more comprehensive and accurate studies to discover a thorough solution. El-Sebaï (2011), in his study, delved into wind velocity effect on daily freshwater generation in active and inactive solar stills. He showed that, depending on their design and operation against wind velocity, the generation rate of these devices increased when the wind velocity was  $V_t$ , remained constant when the wind velocity increased slightly, and then decreased. Castillo-Téllez et al. (2015), in their course of study, explored wind velocity effect on generation rate of different solar stills by considering four 2.5, 3.5, 5.5 and 6 m/s velocities. Their results disclose that the optimal generation rate emerged in

**Table 5** Studies conducted on the effect of environmental factors (ambient temperature)

Row	References	Environmental studied parameters	Explanation
1	Nafey et al. (2000)	Ambient temperature and sunlight	In the study of environmental parameters, they showed that every 5 °C increase in temperature causes a 3% increase in water production rate
2	Ahsan et al. (2014)	Solar radiation and ambient temperature	By examining ambient temperature as an environmental parameter affecting production rate of solar desalination still, they found that by increasing ambient T from 23 to 33 °C, efficiency was increased by 8%
3	Tiwari and Tiwari (2006)	Radiation intensity and ambient temperature	They showed that with a slight increase in ambient temperature during the year, productivity increases

velocity 3.5 m/s, almost remained constant up to 5.5 m/s, and declined in higher velocities. They introduced the velocity of 3.5 m/s as the optimal rate of wind velocity in many different models of solar stills. Cao et al., (2020) also investigated environmental factors effect on water generation rate. Table 7 displays results of their study and shows an optimum wind velocity existence in solar stills.

Now that wind velocity effect on generation rate of solar stills has been illuminated, it can be argued that the discovery of an optimum wind velocity in every solar still needs empirical experiments and simulations. After this optimal value is obtained, those locations that have annual velocity averages smaller than the optimal wind velocity should be selected. If a general conclusion is to be drawn about locating solar stills for the environmental factor of wind velocity, it can be claimed that since wind is an uncontrollable and fluctuating environmental factor, whose optimum magnitude is small in solar stills, the establishment of the device in low-wind regions assists with the enhancement of the generation rate when the wind velocity increases by the optimal point. On the other hand, in locations wherein the average annual wind velocities are small, a few hours experience wind velocity higher than the optimal value. Thus, the generation rate is overshadowed, a factor that helps with the efficiency of the device. Sites with slow winds are prioritized in the locating of sites with optimal wind velocity.

## 2.4 The degree of influence of environmental parameters

For the locating of environmental factors, many studies have investigated factors like ambient T, solar radiation intensity and wind velocity, since these three factors have the maximum effect on generation rate of solar stills, and other factors effect is insignificant. On the other hand, other parameters have indirect effects on generation rate of solar stills. They often impact these three main parameters and increase or decrease them. Therefore, the examination of these three main parameters encompasses many of these factors (Azooz & Younis, 2016; Gherboudj & Ghedira, 2016). In this respect, Mamlook and Badran (2007), in their study, investigated size effect of operational, different design and environmental parameters. Regarding environmental factors, they showed that solar radiation intensity effects, ambient T, wind velocity and other environmental parameters on generation rate of solar stills were 56%, 16%, 15% and 13%, respectively. In other words, 3 parameters of ambient T, radiation intensity and wind velocity include 87% of environmental factors impact, and other environmental parameters such as cloud cover, dust, rainfall, air humidity, amount of sunshine hours, altitude above sea level, degree of solar radiation, ambient pressure, vegetation and the relative position of the sun have only 13% effect, which is time-consuming to investigate, and due to the small effect of these factors, they were omitted in this research. Figure 4 shows environmental parameters effect on solar stills performance.

## 3 Area under study

With an area of 1,648,195 km<sup>2</sup>, Iran is located between 45° and 63° E and 25° and 40° N in the Middle East in semiarid and arid area of world (Castillo-Téllez et al., 2015). Water consumption in 1963 equaled 4.44 bm<sup>3</sup> in Iran. This rate increased in 1993 to 83 bm<sup>3</sup>,

**Table 6** Studies conducted on environmental factors effect (wind velocity)

Row	References	Environmental studied parameters	Explanation
1	Zurigat and Abu-Arabi (2004)	Wind velocity	They found that increasing wind velocity from 0 to 10 m/s could increase productivity by up to 50%
2	Dimri et al. (2008)	Wind velocity	They found that productivity peaked at optimum velocity and then remains constant with a slight increase in velocity
3	Garg (2000)	Wind velocity	Increasing wind velocity from 1 to 9 m/s reduces productivity by about 13%
4	Khalifa (2011)	Wind velocity and sunlight	Experimentally the rate of production rate was studied. To do this, using a fan, the wind was generated at four velocities of 1.14, 2.06, 2.92 and 4.1 m/s, and results show increasing of production rate with increasing wind velocity
5	Keshtkar et al. (2020)	Wind velocity and sunlight	Examination wind velocity effect on production rate shows that with increasing wind velocity from 1 to 6 m/s, production rate has increased by 14.4%

93.36 billion m<sup>3</sup> in 2006 and over 96 billion m<sup>3</sup> in 2019 (Zehtabian & Amiraslani, 2006). According to statistics, 59.5% of the consumed drinking water of the country is supplied by underground waters and 40.5% by surface waters. This high consumption rate of underground waters reduces the level of these resources and will intensify the water crisis in the country in the long run (Hamshahri News Agency, 2018). Figure 5 displays the map of Iran and Middle East.

Desalination of seawater and saline water resources of country is potential approach to supplying water balance and demand in Iran. It is because the country is surrounded with 3 main saline water resources, including Caspian Sea in the north and Persian Gulf and Oman Sea in southern boundaries. In this regard, 120 million m<sup>3</sup> of freshwater is supplied by traditional desalination plants in southern coastal regions of the country.

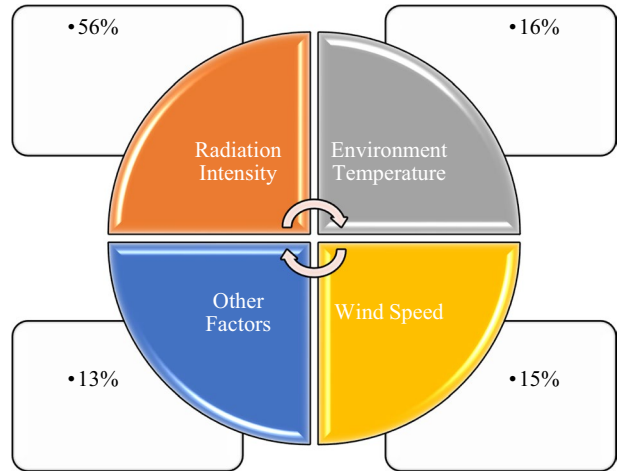
## 4 Research methods

In this section, after identifying and choosing the most important parameters affecting of solar stills performance, how to obtain information needed for the analysis and investigation of Iran was discussed. Two kinds of data have been employed in the relevant conducted studies. Some of these studies have used field data (Fath et al., 2003; Mohamed, 2020; Mwamburi, 2013) and some others the remote sensing method (Afgan & Darwish, 2011; Delgado et al., 2020). Field data are obtained by field measurement and the use of specific instruments. To this end, researchers can personally record information or employ the available information in meteorological stations (synoptic stations). Field measurements are accurate and reliable; however, high human force and equipment costs, lack of stations in all locations, unavailability of all measurement devices in some stations and inaccessibility to multi-year data in some stations are among the drawbacks of this method. Another method for measuring environmental parameters is remote sensing, which is fulfilled by satellites and UAVs. Of the merits of this sort of measurement, we can refer to its integrity, access to all regions, easy access, low cost, proper accuracy, observable scope and, above all, high-accurate zoning potential (almost 90%). The information acquired by both methods can be accessed in the form of a map or an image of the entertained location with the help of available software so that this information can be analyzed and checked easily. ArcGIS software was used for this purpose. This type of software is a type of Geographic Information System that is used to review and prepare geographic information and maps. The data required for this research were collected according to the stated contents as follows:

**Table 7** Production rate and efficiency of a solar desalination plant at different speeds (Cao et al., 2020)

Wind velocity $\left(\frac{\text{m}}{\text{s}}\right)$	Freshwater production rate $\left(\frac{\text{g}}{\text{min}}\right)$	Efficiency (%)
0.6	22	18.6
1.3	24	20.01
1.8	26	20.7
2	25	20.8
2.2	24	19.8

**Fig. 4** Effect size of environmental parameters (Mamlook & Badran, 2007)



- Radiation intensity

To analyze and check solar radiation intensity in country, a remotely sensed and processed map of solar radiation intensity in years 1999–2018, which was the last map available until this moment, was prepared through SolarGis with the unit kWh/m<sup>2</sup> (The World Bank, 2019).

- Environment temperature

To check the temperature in the country of Iran, the necessary information from the remote sensing method was obtained from SolarGis in the form of necessary data for the period of 1998–2018. The mentioned data were converted into a comprehensive map of the country with the temperature unit of °C using ArcGIS 10.7.1 software (The World Bank, 2019).

- Wind velocity

To check the wind velocity in the country, a map was prepared using the field data of 83 meteorological stations of the whole country as an average of 14 years from 2006 to 2019 and ARC GIS software with the IDW zoning method and m/s unit (Meteorological Organization of Iran, 2019).

- Prioritizing and scoring criteria

The prioritization of the criteria was determined according to the opinion of experts and professors in Iran. In this way, each of the experts prioritized the criteria based on their importance in measuring the potential of installing solar panels compared to other criteria. Then, using the AHP method, pairwise comparison of the criteria was done and weighting of the options was done and the final weight of the criteria was determined. Table 8 shows the preference scores in the pairwise comparison scale (Kurttila et al., 2000).



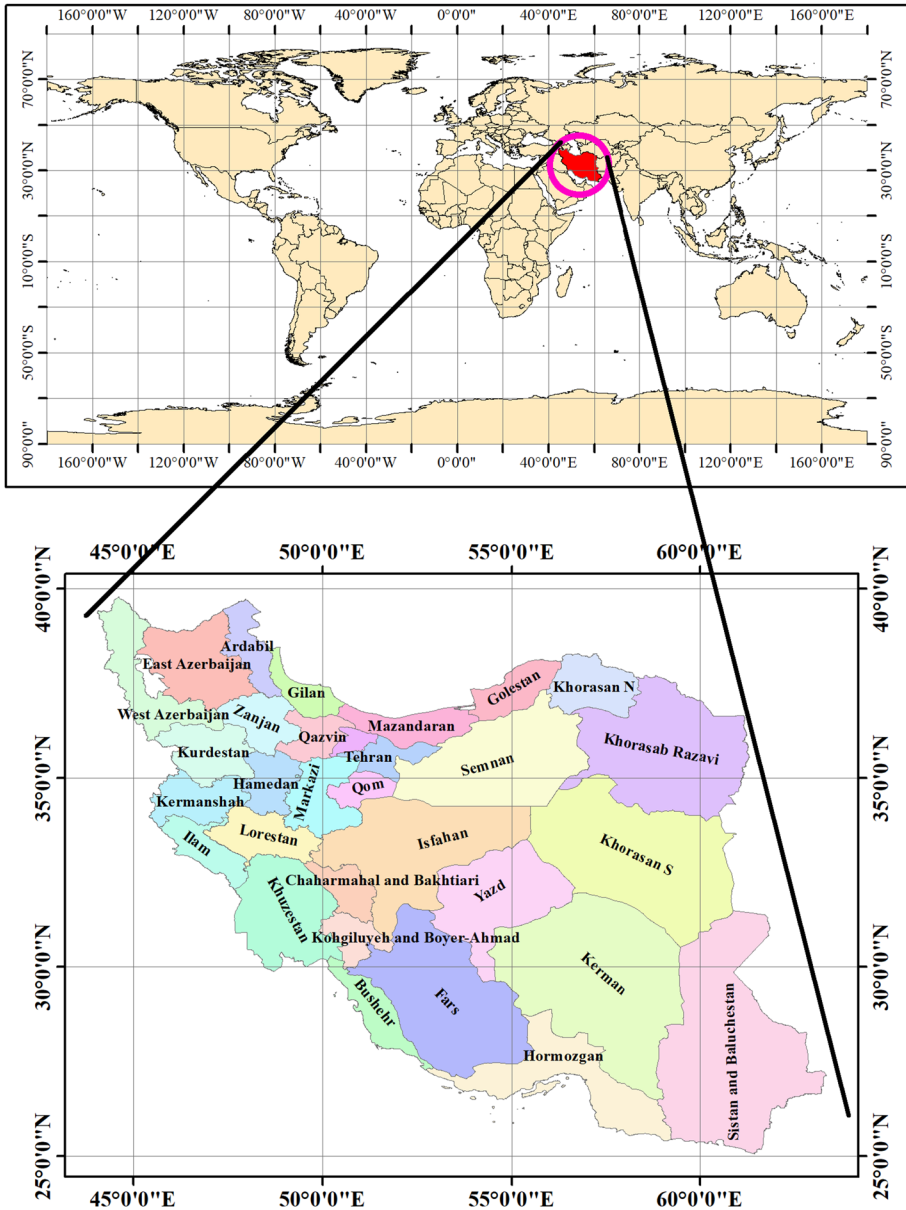


Fig. 5 Map of Iran and Middle East [Authors]

By performing pairwise comparisons by the problem analysis team in the previous step, a relative preference was obtained for each of the factors within the groups, and the relative weight of each criterion was determined as a result of the pairwise comparison in this step, which has the ability to be compared (Kurttila et al., 2000). Finally, the final weight of each factor was obtained in the AHP model. Pairwise comparison of criteria with each other and extraction of relative weight, final weight and incompatibility coefficient were done

**Table 8** Scores (scale in paired comparison)

Numerical values	Preferences (verbal judgments)
1	Same preference or desirability
3	A little preferred or a little more desirable
5	Strong preference or desirability
7	Very strong preference or desirability
9	Fully preferred or fully preferred
2–4–6–8	Intermediate preferences (when intermediate states exist)

in Expert Choice 11 software. The valuation of the considered parameters is presented in Table 9.

## 5 Results and discussion

### 5.1 Investigating solar radiation intensity in Iran

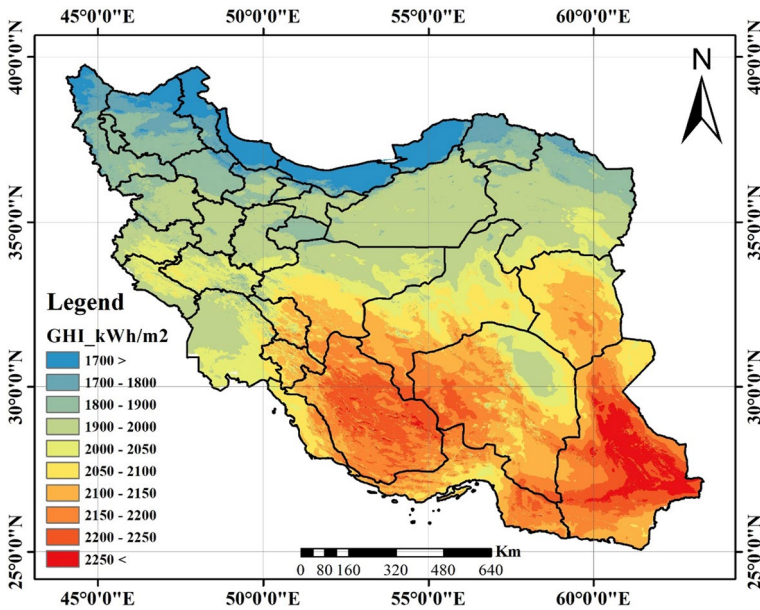
Solar radiation intensity differed in varying locations, and the monthly and yearly reception rates of solar radiation recorded in the country ranged from 3.8 to 6.2 kWh/m<sup>2</sup> and 21,387 to 2264 kWh/m<sup>2</sup>, respectively. Long-term average of solar radiation intensity in Iran is shown in Fig. 6 on an annual and daily basis. The northern areas of Iran had the least rate of solar radiation reception, which gradually increased toward the southern part of the country. Likewise, when we moved from the west to the east of the country, solar radiation incremented. Maximum energy received daily from Sun is 6.2 kWh/m<sup>2</sup>, which equals 7.4 kWh/m<sup>2</sup> in world and indicates proper potential of solar energy in country. The provinces of Gilan, Mazandaran and Golestan, respectively, have the least and Sistan and Baluchistan, Fars, Hormozgan, Kerman and Kohkiluyeh and Boyer Ahmad provinces, respectively, have the most sunlight and are more suitable for using a solar still than other provinces of the country in terms of sunlight. Table 10 shows the average long-term radiation intensity of the country's provinces.

### 5.2 Investigating temperature in Iran

Due to being an extended country, the country's temperature varied in its different points, and the average temperature ranged from -5 to 30 °C during these years. The minimum recorded temperature was related to the southern line, center and east of the country. As Fig. 7 depicts, the highest temperature in the country is related to Hormozgan, Bushehr, Khuzestan, Sistan and Baluchistan and Ilam, respectively. These regions are thermally more suitable than other areas of the country for establishing solar stills. The long-term average temperature of Iran is shown in Table 11.

**Table 9** Valuation of considered parameters

Valuation					Considered parameter	Row
[8–10]	[6–8]	[4–6]	[2–4]	[0–2]		
2200 ≥	[2100–2200)	[2000–2100)	[1800–2000)	< 1800	Radiation intensity ( $\frac{\text{kwh}}{\text{m}^2}$ )	1
25 ≥	[20–25)	[15–20)	[5–15)	< 5	Environment temperature (°C)	2
[1.5–3.5]	1.5 >	[3.5–4.5)	[4.5–5.5)	5.5 <	Wind velocity ( $\frac{\text{m}}{\text{s}}$ )	3



**Fig. 6** Long-term mean of horizontal solar radiation in Iran [Authors]

### 5.3 Investigating wind velocity in Iran

Figure 8 shows wind velocity zoning in the country in combination with the location of the meteorological stations. In many areas of the country, average wind velocity was in 2.3–5.5 m/s and 1.5–2.5 m/s ranges, and the wind velocity was only > 5.5 m/s in northern Sistan and Baluchestan. Based on the studies that investigated wind velocity effect on efficiency of solar stills, it is concluded that regions with wind velocities of < 3.5 m/s are suitable for establishing solar stills. In this regard, the regions with wind velocities of 2.3–5.5 m/s and < 2.3 m/s are prioritized, respectively. As a result, major parts of the country are suitable for establishing solar stills in terms of wind velocity, except for the eastern part of south Khorasan, central Ardebil, Hormozgan, eastern Kerman, and the north and

**Table 10** Average radiation intensity of the country's provinces from 1998 to 2018

Province	Average radiation intensity (kWh/m <sup>2</sup> )	Province	Average radiation intensity (kWh/m <sup>2</sup> )	Province	Average radiation intensity (kWh/m <sup>2</sup> )
Ardabil	1650	Ilam	2003	Razavi Khorasan	1938
Bushehr	2094	Kerman	2116	South Khorasan	2059
Charmahal and Bakhtiari	2068	Kermanshah	1973	Qazvin	1859
East Azarbaijan	1772	Khuzestan	1998	Qom	1897
West Azarbaijan	1799	Kohgiluyeh and Boyer- Ahmad	2098	Semnan	1940
Isfahan	2022	Kordestan	1912	Sistan and Baluchestan	2196
Fars	2148	Lorestan	1997	Tehran	1898
Gilan	1410	Markazi	1951	Yazd	2052
Golestan	1610	Mazandaran	1515	Zanjan	1846
Hamedan	1945	North Khorasan	1822	Alborz	-
Hormozgan	2136				

west of Sistan and Baluchestan, all enjoying the maximum wind velocity means. The long-term average wind velocity is shown in Table 12.

#### 5.4 Iran's potential for installing solar still

Examining the parameters of ambient T, radiation intensity and wind velocity as main environmental parameters affecting performance of solar still in Iran showed that this country has a suitable capacity to use this technology. The favorable environmental conditions of Iran, along with the presence of saltwater resources in the sea and underground resources, provide a good potential for this country to use a solar still technologies. Based on the investigations, influence factor of wind velocity and ambient T on performance of solar still is equal and influence intensity factor of solar radiation is three times the other two parameters. In this regard, the provinces of the country were rated from 6 to 1 according to the maximum intensity of radiation, ambient T and favorable wind velocity. Now, by scoring each province according to each parameter and the effect of the coefficient of each parameter, it is possible to identify the most suitable provinces of Iran for installing solar still, which is shown in Table 13 and Fig. 9.

The final results of the investigations show that the provinces of Sistan and Baluchistan, Hormozgan, Fars, Kerman and Bushehr, respectively, have more favorable environmental conditions for installing solar still than other provinces of Iran. It is suggested that in future research for the installation of solar still, the focus should be on these provinces and the location within each province should be considered.

### 6 Conclusion

Considering the increasing demand for water consumption, the traditional methods of water supply, especially in dry and hot regions of world, which are facing water shortages, do not meet human needs. Therefore, the supply of drinking water from alternative methods such as the use of saltwater was interest in recent years. Solar stills are simple and cost-effective equipment with good economic, environmental and social benefits that use solar energy to provide energy required for desalination. Considering availability of solar energy in many places, this technology can be used in the preparation of fresh and quality water. Weather conditions, incoming water quality and installation location are some of the limitations of solar water softeners. Solar stills require the temperature of the sun and direct sunlight. For this reason, the efficiency of these devices decreases in cloudy and rainy conditions, as well as in places where the direct contact of sunlight with desalination water is less. The management of solar still can have various consequences including reducing water costs, increasing productivity, simple maintenance and environmental sustainability. One of the obstacles to the use of these technologies is increasing their performance, which has been addressed in many studies. Increasing the performance of these technologies depends on three design factors, operating conditions and environmental conditions. In this regard, this study investigated the environmental conditions affecting solar still in Iran. The conducted studies show that the three parameters of solar radiation intensity, ambient T and wind velocity are most important environmental parameters affecting performance of solar still with 56%, 16% and 15%, respectively. The long-term information of the desired environmental parameters was prepared using field and telemetry methods; then, by averaging each

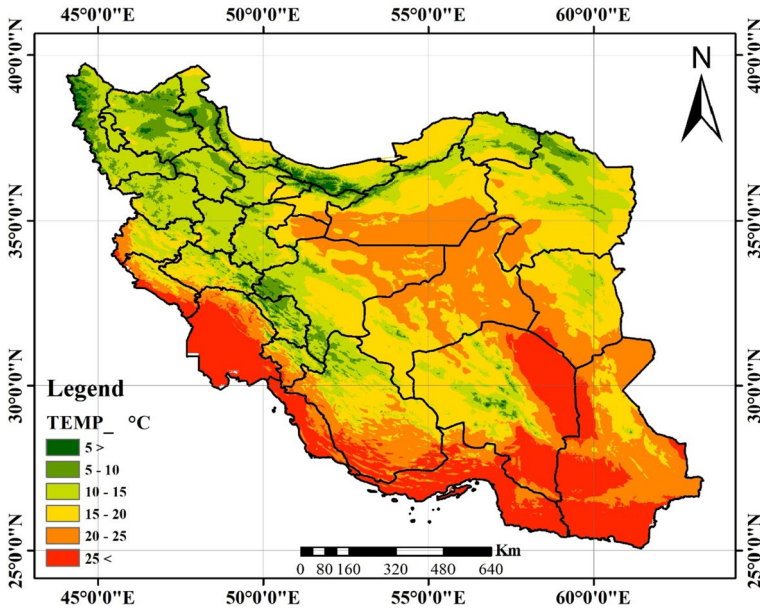


Fig. 7 Long-term mean temperature in Iran [Authors]

Table 11 Average temperature of the country’s provinces from 1998 to 2018

Average temperature (°C)	Province	Average temperature (°C)	Province	Average temperature (°C)	Province
15.9	Khorasan Razavi	21	Ilam	10.6	Ardabil
18.8	South Khorasan	20.8	Kerman	25.5	Bushehr
12.2	Qazvin	16	Kermanshah	11.1	Charmahal and Bakhtiari
18.4	Qom	24.9	Khuzestan	10.8	East Azarbaijan
18.2	Semnan	18	Kohgiluyeh and Boyer-Ahmad	10.2	West Azarbaijan
24	Sistan and Baluchestan	11.7	Kordestan	16.4	Isfahan
13.3	Tehran	14.4	Lorestan	18.9	Fars
20.3	Yazd	13.6	Markazi	12.6	Gilan
11.2	Zanjan	11.1	Mazandaran	17.2	Golestan
14.2	Alborz	13.5	North Khorasan	12.8	Hamedan
				25.7	Hormozgan

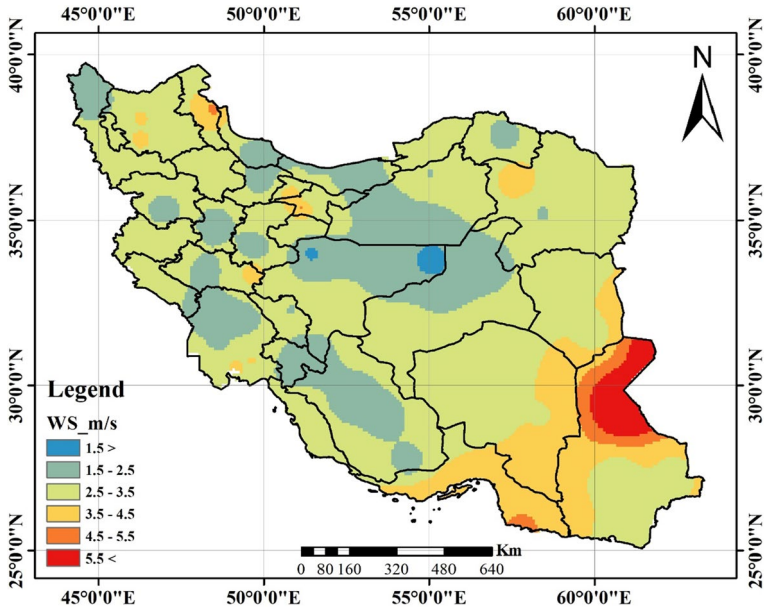


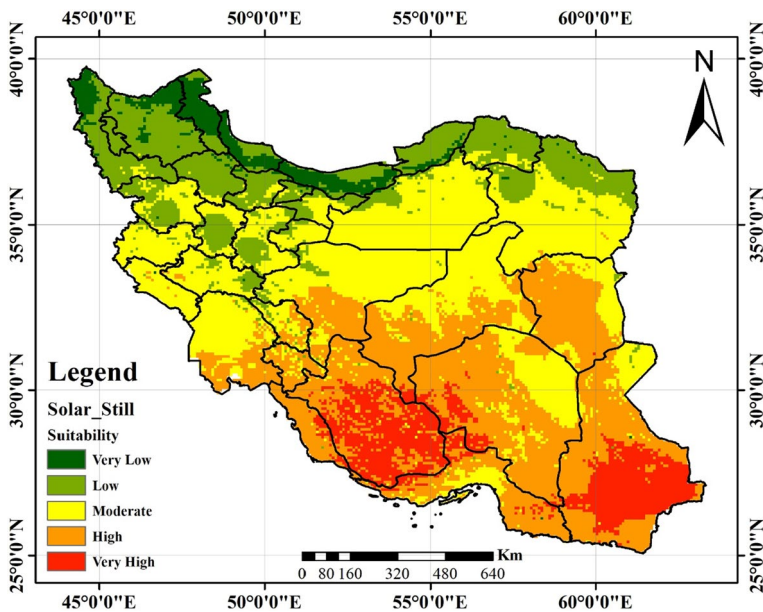
Fig. 8 Long-term mean of wind velocity in Iran [Authors]

Table 12 Average wind velocity of the country’s provinces from 2006 to 2019

Province	Average wind velocity ( $\frac{m}{s}$ )	Province	Average wind velocity ( $\frac{m}{s}$ )	Province	Average wind velocity ( $\frac{m}{s}$ )
Ardabil	3.44	Ilam	2.68	Khorasan Razavi	3.02
Bushehr	3.06	Kerman	3.36	South Khorasan	3.51
Charmahal and Bakhtiari	2.54	Kermanshah	2.7	Qazvin	2.48
East Azarbaijan	3.19	Khuzestan	2.64	Qom	2.9
West Azarbaijan	1.35	Kohgiluyeh and Boyer-Ahmad	2.24	Semnan	2.5
Isfahan	2.35	Kordestan	2.58	Sistan and Baluchestan	4.33
Fars	2.51	Lorestan	2.75	Tehran	3.11
Gilan	2.7	Markazi	2.66	Yazd	2.5
Golestan	2.8	Mazandaran	2.32	Zanjan	2.9
Hamedan	2.5	North Khorasan	2.65	Alborz	2.28
Hormozgan	3.72				

**Table 13** Score of the provinces of Iran for the installation of solar still

Row	Province	Radiation intensity (*3)	Wind velocity (*1)	Ambient temperature (*1)	Score collection
1	Sistan and Baluchestan	6	6	3	27
2	Fars	5	2	0	17
3	Bushehr	1	3	5	11
4	Hormozgan	4	5	6	23
5	Kerman	3	4	0	13
6	Kahkilouye and Boyer Ahmed	2	1	0	7

**Fig. 9** Map of provinces of Iran for the installation of solar still [Authors]

parameter in ArcGIS software, a map was prepared for ease the of analysis and review. The research results showed:

- Provinces of Sistan and Baluchistan, Fars, Hormozgan, Kerman, and Kohkiloyeh and Boyer-Ahmad have received the highest radiation energy in the long-term average in Iran by receiving 2196, 2148, 2136, 2116 and 2098 kWh/m<sup>2</sup>, respectively.
- The provinces of Hormozgan (25.7 °C), Bushehr (25.5 °C), Khuzestan (24.9 °C), Sistan and Baluchistan (24 °C) and Ilam (21 °C), respectively, had the highest long-term average temperature in Iran.
- The provinces of Sistan and Baluchistan, Hormozgan, Kerman, Bushehr and Khuzestan have more suitable wind velocities to increase solar still efficiency.



- Iran has high potential for using solar still in terms of environmental conditions affecting of solar still performance and having saline water sources.
- The provinces of Sistan and Baluchistan, Hormozgan, Fars, Kerman and Bushehr are, respectively, the most favorable places in Iran for installing solar stills.

It is suggested that in future research for the installation of solar still, the focus should be on these provinces and the location within each province should be considered.

**Data availability** The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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