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Dynamic Simulation of Solar Desalination: Investigation of Climatic Conditions and Carbon Dioxide Emissions

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Abstract

This paper examines the numerical analysis of the transient analysis of solar desalination and the effect of climatic conditions on its performance. The solar water desalination plant is intended to convert the salt water of the seas and lakes into fresh water. TRNSYS software is used for simulation. In order to study the effect of weather conditions on the efficiency of solar water desalination, the cities of Bandar Abbas, Bushehr, Isfahan, Hamedan, Kerman, Mashhad, Tabriz, Zahedan and Tehran have been considered. The effect of solar collector area and auxiliary heater power on solar water desalination efficiency has been investigated. The results show that with increasing collector area and auxiliary heater power, the outlet water temperature of the collector increases. Carbon dioxide production has decreased by about 4.5-8.6% compared to diesel desalination. Using the analytic hierarchy process decision-making algorithm, the best location for installing the desalination plant has been selected based on the two criteria of solar water desalination efficiency and distance from the sea. Bushehr city is in the first place with 75% efficiency and Tabriz city is in the second place with 61% efficiency.

Keywords: Solar water desalination, the analytic hierarchy process algorithm, weather conditions, flat plate-solar collectors

Introduction

Water plays an important role in all our daily activities, and due to the increase in human living standards, its consumption is increasing day by day. Some parts of the world are exposed to extreme stress due to lack of water and pollution. The needs of human freshwater are met only if the amount of salt water available in large quantities is converted into drinking water through a desalination plant [1].

One of several ways to sweeten water is to use solar water desalination. For years, solar energy has been used to obtain drinking water from salt water. Increasing demand for solar desalination systems by increasing the cost of fossil fuels to generate thermal and electrical energy, reducing the cost of renewable energy technologies, the need for small-scale decentralized desalination systems to work in remote areas that lack access They are electricity grids, and it is very important to worry about climate change in solar water desalination plants, especially in remote and rural areas with low infrastructure and no connection to a network. Small-scale solar desalination systems are ideal for providing a reliable source of drinking water [2].

The issue of providing the required energy has long been a human concern, and with the advancement of industry and technology, this issue has gradually become more acute. With limited current energy supplies and environmental issues, attention to other energy sources has increased over the past two decades, and the use of renewable energy to replace them with fossil fuels and reduce pollution has gradually increased. Voropoulos et al.[3] studied the behavior of a solar distillation system with a reservoir. They studied the storage of hot water and keeping the water temperature constant at different levels. In this system, the water storage tank was submerged in water and the water was heated by a heat exchanger and led to an increase in the water temperature of the tank. In fact, the hot water storage tank is considered as a heat collector and solar water desalination only acts as a distillation unit.

Velmurugan et al.[4] conducted a study in 1992 to increase the production of this type of solar water desalination plant. In this work, in order to increase the evaporation of the drain, the blades were used in desalination. So the rate of production increased and it was also used to increase the sponge further. Laboratory results were compared with the usual type of pond and pond in which the wick was used. In this study, the equilibrium energy balance equations were analyzed and compared with laboratory results. El-Sebaii et al.[5] Conducted studies to improve daily production in solar water heaters. Their study was based on the integration of a solar cascade with a sloping cover with a solar pond at relatively high temperatures. The implementation of the model was examined throughout the year with and without solar pond. Optimal values of water flow and mass flow rate for the model with solar pond were obtained as 0.03m and 0.0009 kg/s, respectively. The average annual amount of daily production and efficiency, along with the solar pond, was higher than that without the solar pond, at 8.5% and 4.5%, respectively. El-Sebaii et al. [6]used a single-tank solar distillation system with sand on the bottom of the tank as energy-absorbing material. Some of the heat absorbed by the water is transferred to the lower sand by transferring the conductive heat. A 0.7% increase in daily production compared to the absence of sand was observed as a significant heat storage material. Abdullah et al. [7] compared the discharge rate to the inactive state. The effective properties of sponges, such as their ability to absorb and penetrate, highlight their use as energy absorbers in solar distillation systems. The rate of dewatering at night increased by 5% with the use of coated metal wire sponges, by 5% in the uncovered state, and by the use of volcanic rocks by 8% [7] More information on the parameters affecting the production of solar distillation systems was presented by Velmurugan and Srithar[8]. Other research has been done on these devices, including the use of a coolant [9,10] or a reflector [11-12], adding coal or pigment to the inlet water [13-14] to reduce the pressure of the device [15] pointed to the flow of water on the surface of the liquid [16] and the flow of air inside the device [17].

Kabeel et al. [18] compared methods used to increase the efficiency of multi-storey solar distillation systems. Elango et al.[19] conducted a comprehensive review of heat modeling in various solar distillation systems that have been proposed over the years to improve the performance of these systems. They found that parameters such as economics, available materials, local climatic conditions and water quality should be considered to select a suitable configuration for this type of water desalination plant.

Since the idea of making solar desalination water in our country exists for two main reasons: one is the long hours of sunshine and intense sunlight and the second is access to the salty waters of the Caspian Sea, the Persian Gulf and the Sea of Oman. Introducing a system that can provide the required fresh water for agriculture, industry and drinking water by using these two potentials, one of the goals of this study is to help solve some of the problems of water and energy shortage in the country to some extent. Also, considering this matter and the climatic conditions of different cities of Iran, in this article, solar water desalination has been designed and the effect of climatic conditions on its performance has been investigated. TRNSYS software is used for simulation. In order to investigate the effect of weather conditions on the efficiency of solar desalination plants in Bandar Abbas, Bushehr, Isfahan, Hamedan, Kerman, Mashhad, Tabriz, Zahedan and Tehran. Depending on the performance and cost of the desalination plant, a suitable position for installing the desalination plant has been selected using the analytic hierarchy process decision-making algorithm.

Modeling solar water desalination plant

In this study, a flat panel collector was used to model the solar desalination plant. A schematic of a solar desalination plant to obtain drinking water from saline and polluted water using solar energy is shown in Figure 1.

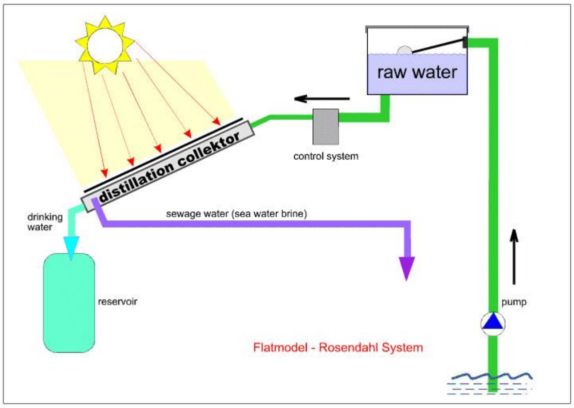

Figure 1. A schematic of a solar water desalination plant

Water enters the tank at a temperature of 22 C. From this tank, it is pumped to the collector, which is located at a height, and the water collector comes out from the other side of the collector. The distilled water is transferred to the heat exchanger, but if it has not reached the evaporation temperature, then it goes to an auxiliary heater, where this heat is given to the water, and the water reaches the evaporation temperature, and the distilled water comes out. It turns into a converter. The heat exchanger uses a heterogeneous flow type so that the cold water heats up a little before entering the collector and we have a better efficiency. In this project, a 30 watt auxiliary heater pump with a heating power of 2000 watts and a collector with an area of 2 square meters was used. In this study, Transient system simulation software (Trnsys) was used for analysis. This software is very flexible with graphic bases and the software environment is embedded for transient simulation. This software has a very extensive environment for simulating, analyzing and optimizing systems based on time. In a day when much of the simulation is focused on evaluating the performance of electrical and thermal energy systems, trnsys provides an efficient tool for dynamically simulating these systems.

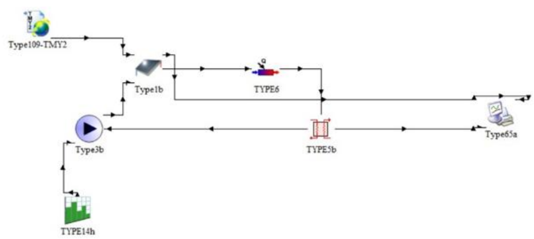

Figure 2. System designed in Trnsys software environment

Figure 2 shows a schematic of a solar water desalination flow diagram designed in trnsys software. The explanations related to the elements used in Figure 2 are summarized below:

-Type 109-TMY2: From this element, weather conditions can be determined.

-Type 14h: This element is used to program the pump.

-Type 3b: This element indicates the pump.

-Type 1b: This element indicates the solar collector that absorbs sunlight in action.

-Type 6: This element does not help the heater.

-Type 5b: This element indicates the heat exchanger used to optimize energy.

-Type 65a: This element is used to create diagrams and diagrams.

The Trnsys software uses Hottel-Whiller equation to model the thermal efficiency of a flat-panel solar collector.

The efficiency of the energy collected is estimated by applying the Hottel-Whillier equation:

$$\eta = (\tau\alpha)_e - U_L(Tp - Ta)/ Gt \quad (1)$$

The first right side term is the effective product between the transparent cover transmittance and the absorption, where U_L is the total heat loss coefficient (W/m^2 -K), Tp and Ta are the PVT rear panel temperature and the ambient temperature respectively, both in ◦C. Finally, G_t is the solar radiation in W/m^2 .

Carbon dioxide Release rate

Water distillation is the best way to convert seawater to fresh water, in which water is boiled using a distillation device, and then from the evaporation of salt water, cooling and condensing the water to pure water from where the main base This method is the use of thermal energy, so the use of this technology is cost-effective when access to thermal energy is possible, which is why the construction of thermal desalination plants along with power plants, especially in Arab countries, is common. Because this method requires a lot of energy, they use a diesel cycle to reduce energy consumption and reduce costs.

For this purpose, the diesel or Rankin cycle is implemented in a power plant. When the cycle wants to lose heat, this heat is transferred to the water by a heat exchanger, and the water evaporates to the temperature and the water vapor is evaporated. The pipes are cooled and condensed and distilled water is removed. In addition to fossil fuels and their limited resources, the diesel cycle pollutes the environment. For this purpose, we extract the amount of co_2 caused by the diesel cycle. Note the following relationship:

$$\dot{m}_{fuel} = \frac{\dot{m}}{(1-\eta)} * \frac{c_p}{LHV} * \Delta T \quad (2)$$

In this regard, $\dot{m}_{fuel}, \eta, LHV, c_p, \dot{m}$ and ΔT, respectively, fuel consumption flow, solar water desalination efficiency, fuel heat value, water heat capacity, water flow and inlet water temperature difference And output. The emission value of carbon dioxide is calculated from the following equation:

$$\dot{m}_{co2} = f_{carbon} * \dot{m}_{fuel} \quad (3)$$

In the above relation, it is f_{carbon} =0.84.

The analytic hierarchy process (AHP) algorithm

For this purpose, a The analytic hierarchy process (AHP)decision-making method [20] is used. The first part of this analysis is the selection of criteria. Then, based on the identified criteria, the grains are evaluated. The reason for reading this hierarchy is that we must first start with the goals and strategies of the organization at the top of the pyramid, and by expanding them, identify the options to get to the bottom of the pyramid. This method is one of the most widely used methods for ranking and determining the importance of factors, which is used to prioritize each of the criteria using pairwise comparisons. Hierarchical analysis is based on three relatively simple subject principles: the principle of inverse, the principle of homogeneity, the principle of sequence of levels of hierarchy. The full details of this method are in reference [20] and the following is a brief explanation of the method. Suppose n is the option and m is the criterion for evaluating them. The steps in this method are as follows:

1- Determining the criteria
2- Pair comparison of both competitors' n (n-1) / 2 for each criterion and the formation of the n × n matrix of competitors whose drives are numbers at specified distances and express the relative superiority of one over the other.
3- Obtaining the weight of each competitor for this criterion (a vector 1 × n) which is done by performing a series of linear-column operations on the previous step matrix and using the vector method in particular, and the vector is obtained whose sum of elements is one and the value of the element i[th]. That shows the weight of my competitor for this criterion.
4- Follow steps 1 to 3 of all the criteria to finally get the n vector m and form a m × n matrix by putting them together.
5- Comparison of the pair pairs of criteria and obtaining the weight of each of them from the criteria matrix that shows the superiority of the criteria over each other (a vector of 1 × m):
   1. Multiply the vector weight of the criteria in the matrix (n ×m) and finally obtain the final weight of each competitor and
   2. The compatibility test for the absence of inconsistencies in the allocation of design superiority numbers compared to the criteria.

Results

Using the modeling, the performance of the solar collector is analyzed. First, validation of PVT model with laboratory results by Sardabaradi et al. [21] which was performed in Mashhad from 9:00 AM to 15:30 PM, which is shown in Figure 3 of this comparison. The outlet fluid temperature of the solar collector in the present study was compared with by Sardabaradi et al.[21] and was less than 2.1%. In the first step, to achieve the goal (aiming to bring water to a point where it changes phase and turns from liquid to gas), we consider two methods, one is to increase the area of collectors and the other is to increase the power of the auxiliary heater.

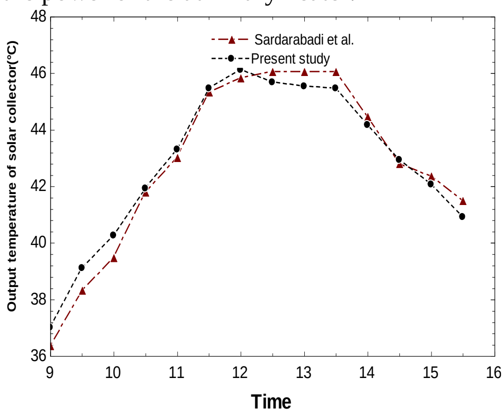

Figure 3. Validation of the present study

Changes in the outlet water temperature with time for a collector with a surface area of $2\,m^2$are shown in Figure 4.

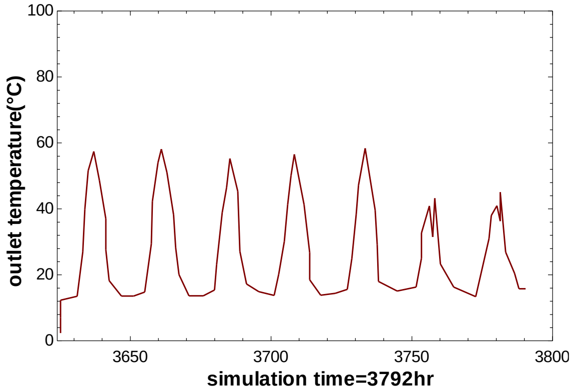

Figure4. Outlet water temperature with time

Figure 5 shows the changes in water temperature with the surface of the solar collector. It is observed that with increasing the level of the solar collector, more heat is given to the water and its temperature should be increased. In an area of 10 square meters of solar collector, the outlet temperature reaches 90 degrees. Therefore, the surface of the solar collector is considered to be 10 square meters.

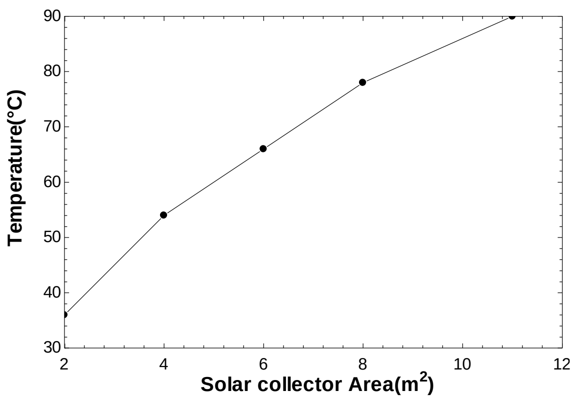

Figure 5. The effect of collector surface changes on water temperature.

The effect of auxiliary heater power

In this study, the effect of using auxiliary heater on water temperature in Figure 6 is shown. In this figure, the black line at the bottom corresponds to the output temperature of the auxiliary heater with 2000 w power, and the red line at the top corresponds to the auxiliary heater with power 4500 w.

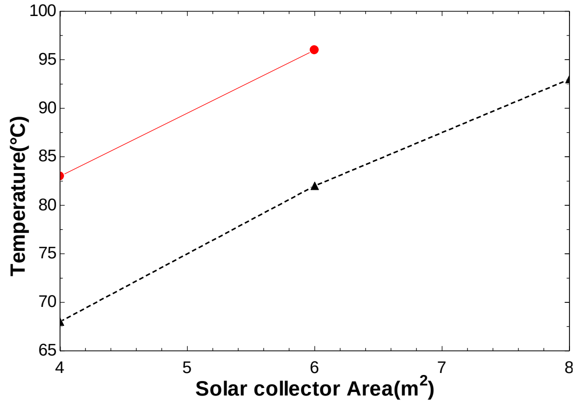

Figure 6 .Investigating the effect of auxiliary heater power

It is observed that when we put the auxiliary heater in the system with higher power, in three stages, the output temperature of the auxiliary heater cools to our desired temperature, and when we use the heater with less power, this is recorded in four steps. Considering the diagram, we can conclude that by increasing the power of the heater, we will need 6 square meters of solar panel, while if the power of the heater remains the same as 2000 watts, we will need 8 square meters of solar panel. Initially, it seemed more economical to design a desalination plant with a high-power auxiliary heater, but it should be noted that when the heater power is higher, the amount of electricity consumed for the auxiliary heater will increase, as well as the role of energy. The sun, which is renewable as energy, fades. It is also important to note that we incur more costs to install a desalination plant with more solar panels, but it is important to note that these panels are 15 to 20 years old and have a much lower maintenance cost. If we use solar energy, it will have better environmental effects, and if we consider this desalination plant in a higher comparison for a factory, this extra cost will return very soon and will become profitable.

The effect of climatic conditions on the performance of solar desalination plants

In the second step of this design, the construction site of the desalination plant has been considered, because for the construction of the desalination plant, a place must be considered that is economically justified. For this purpose, we have selected 9 provinces in Iran. Cities are such that you have a variety of indoor climates. For this purpose, we use solar panels with an area of 8 square meters and auxiliary heaters with w2000 power, so that the conditions are the same in all cities. The cities under study are: Bandar Abbas, Bushehr, Isfahan, Hamedan, Kerman, Mashhad, Tabriz, Tehran, Zahedan. The intensity of radiation in the city is shown in Figure 7. By referring to the Global Geography site, we find that the highest radiation rate is related to Bushehr and the lowest radiation rate is related to Tabriz, which confirms the above results, because the closer we get to the equator and the meridian of origin, the higher the radiation intensity.

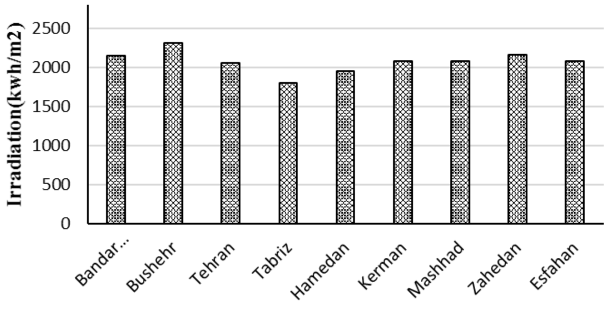

Figure 7 .The intensity of sunlight in several cities in Iran

By applying this constraint, the temperature of the water leaving the solar desalination plant is shown in Figure 8.

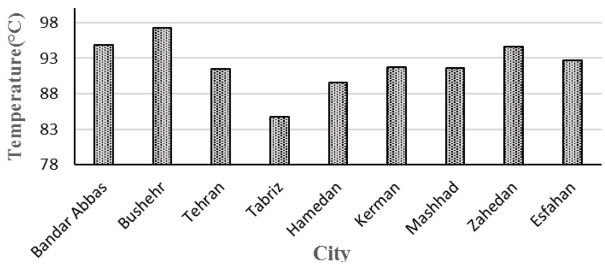

Figure 8. Outlet temperature in different cities of Iran

As can be seen from the above results, the temperature of the water leaving the system in Bushehr is at its highest temperature and in Tabriz at its lowest temperature. The reason for this behavior is that the highest radiation rate is related to Bushehr and the lowest radiation rate is related to Tabriz.

Comparison of solar water desalination with diesel type

Water distillation is the best way to convert seawater to fresh water, in which water is boiled using a distillation device, and then from pure water evaporation, cooling and condensing the water to pure water from where the main base This method is the use of thermal energy, so the use of this technology is cost-effective when access to thermal energy is possible, which is why the construction of thermal desalination plants along with power plants, especially in Arab countries, is common. . Because this method requires a lot of energy, they use a diesel cycle to reduce energy consumption and reduce costs. For this purpose, the diesel or Rankin cycle is implemented in a power plant. For this purpose, the amount of co_2produced by the diesel cycle for each of the cities we examined has been extracted, which is shown in Figure 9. As can be seen, in the city of Bushehr, which had the highest efficiency for solar water desalination, diesel desalination has the highest production ofco_2, which means more pollution in the city and damage to the environment, so from an environmental point of view, the establishment of a diesel desalination plant in Bushehr will cause damage to the environment.

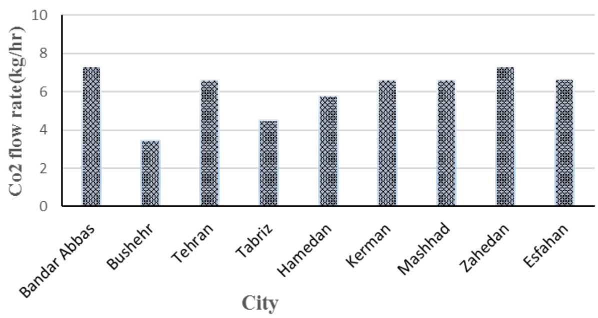

Figure 9. The amount of carbon dioxide produced for different cities

Selection of the city using a definitive hierarchical analysis algorithm

In order to make solar water desalination affordable, in addition to environmental conditions, two efficiency parameters and the distance of the city from the sea have been considered. Table 1 shows the efficiency of solar water desalination in the target cities. The highest return is related to Bushehr and the lowest return is related to Tabriz. The default desalination capacity in all cities is 8$\boldsymbol{m^3}$.

Table 1. Efficiency and test conditions for each of the cities of Iran

city	The difference between the outlet and inlet water temperatures	Efficiency
Bushehr	۷۲	%۷۵
Bandar Abbas	۷۰	%۷۲
Esfahan	٦٨	%۷۰
Hamedan	٦٥	%٦٧
Kerman	٦٧	%٦٩
Mashhad	٦٧	%٦٩
Tabriz	٦٠	%٦١
Zahedan	۷۰	%۷۲
Tehran	٦٧	%٦٩

As mentioned, one of the most important things to consider is that our chosen city should be close to a significant sea so that we do not have to pay for the transfer of brackish water to the construction site. For this purpose, the city should be a short distance from the sea. Table 2 shows the distance of these cities from the sea.

Table 2. distance from the sea of each city

city	Rank based on distance from sea (km)
Bandar Abbas	1
Bushehr	2
Tehran	3
Tabriz	4
Hamedan	5
Kerman	6
Mashhad	7
Zahedan	8
Esfahan	9

Based on the two criteria of efficiency and distance from the sea and considering the coefficients of 1 and -1, the desired location for the construction of solar desalination plant is selected for these two criteria and using AHP algorithm, respectively. The results of the ranking of cities considered using the AHP algorithm are given in Table 3. It can be seen that Bushehr is in the first place and Bandar Abbas and Tehran are in the next places.

Table 3. City statistics based on AHP method

city	Rank
Bushehr	1
Bandar Abbas	2
Tehran	3
Kerman	4
Mashhad	5
Zahedan	6
Esfahan	7
Hamedan	8
Tabriz	9

Conclusions

In this paper, the transient analysis of solar desalination (to convert the saline water of seas and lakes into fresh water) and the effect of climatic conditions on its performance are examined numerically. TRNSYS software is used for simulation. In order to investigate the effect of weather conditions on the efficiency of solar desalination plants in Bandar Abbas, Bushehr, Isfahan, Hamedan, Kerman, Mashhad, Tabriz, Zahedan and Tehran. The effect of solar collector area and auxiliary heater power on solar water desalination efficiency has been investigated. The effect of changing the collector area as well as increasing the heater power was investigated and the results show that if we increase the auxiliary heater power, we need less collector area. On the other hand, increasing the area of the collector will increase the cost of electricity equivalent to the auxiliary heater with higher power. Considering these two cases, it was decided to increase the area, because after a year, the cost of buying the collector and the maintenance of these collectors is much lower than the auxiliary heater. Carbon dioxide production has decreased by 4.5-8.6% compared to diesel desalination plants. Using decision-making algorithm, AHP algorithm, based on the two criteria of efficiency of solar desalination plant and distance from the sea (the farther the city is from the sea, the higher the cost of saltwater transportation), the best place to install a desalination plant is selected. Bushehr city is in the first place with 75% efficiency and Tabriz city is in the second place with 61% efficiency.

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