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Water quality analysis of solar still distillate produced from various water sources of El Oued region Algeria

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ABSTRACT

Arid regions of Algeria have an abundance of saline and non-potable groundwater. These regions also have huge potential for solar energy. Solar distillation is an important solution for producing drinking water in such areas. In this study, solar distillation using hemispherical solar still in the climatic conditions of the Oued region has been carried out. To compare the characteristics of the saltwater of the El Oued region and the distilled water resulting from solar distillation, seven water samples from different areas of the region of El Oued have been collected. The physical and chemical parameters of the saltwater and distilled water were tested. The experimental results showed that the daily productivity ranges between 4 to 5 kg/m^2 and the quality of the produced water is suitable for drinking according to the standards of the World Health Organization (WHO).

Keywords: Desalination; Water quality; Solar energy; Arid regions; Hemispherical solar still

1. Introduction

Drinking water scarcity is one of the major challenges of this century [1,2]. Over the past 50 y, global water consumption has tripled, while the planet's population has grown by 2.3 billion. Water scarcity already affects all continents and more than 40% of the world's population [3,4]. According to the Water Resources Institute, there are already more than 26 countries that are starting to suffer from a lack of water, and by 2032 this figure will exceed 50% of the world's population. Furthermore, the World Water Council had reported that out of a population of 6 billion inhabitants, 1.5 billion inhabitants do not have access to sufficient quality of water, and 7 million people die each year due to waterborne diseases. (WHO, 2017) [5–8]. Availability of clean water remains a basic human right and a basic criterion for the life and sustainable social and economic development of every country, according to the United Nations Assembly.

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Algeria has limited, irregular, and unevenly distributed natural resources. Natural hydraulic resources are mainly located in the Saharan region of Algeria. The overall demand for freshwater has increased considerably and rapidly. Drinking water supply has acquired priority over other uses, a priority that has been enshrined in Algerian water legislation. There is an increasing need to desalinate saltwater. In remote areas, finding new processes and resources to provide cheap drinking water through available measures and using renewable energy sources [9]. In the arid desert, rural and remote areas have much solar radiation. Therefore, there is enormous potential to use solar energy to provide freshwater [10–15].

The arid and semi-arid desert regions of Algeria, have saltwater with high concentrations of total dissolved solids (TDS), total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD). Inhabitants of Algeria have faced a severe shortage of drinking water. Besides, the available water has an undesirable taste, color, and odor [16,17]. According to the international drinking water quality standards of the WHO for drinking water [18], the quality of drinking water must satisfy the mentioned standards of the elements to protect the health of consumers. The factors affecting the quality of drinking water at high concentrations are turbidity, pH, conductivity, TSS, TDS [19]. According to Bidgoli [20], the WHO stated that drinking water should be free from microbial contamination and chemicals that have a direct impact on human health. This has led many researchers to study the quality of drinking water in all regions of the world [20,21].

Panchal et al. [22] used fins to enhance the desalination process. In this work Surjyot pond water and studied the water quality before and after desalination. Panchal et al. [23] reviewed several research papers to investigate groundwater in solar energy using thermoelectric units. Recent literature on solar still output improvement using wick [24–26], nanoparticles [27–29] was studied. Several researchers in various countries have researched water quality before and after desalination.

In India, Palpandi and Prem Raj [30] collected seawater, bore well water samples, and used it in solar still after distillate authors have tested water characteristics. In Syria, Al-Hassan and Algarni [31] tested the pH and TDS of seawater before and after distillation. In Pakistan, Raza et al. [32] used a PV tracking solar still system to enhance output and authors have studied the water quality. In Saudi Arabian conditions, Almuhanna [33] reported the effect of the evaporative cooling system in desalination and tested the water quality. In Ethiopia, Gurmu et al. [34] conducted desalination and studied input and output water characteristics. In China, Eltawil and Zhengming [35] desalinated brackish water using a solar still integrated with wind turbine and tested the water quality parameters. In Egypt, Omara et al. [36] performed desalination using a hybrid modified still and studied the presence of salts and impurities in the water. In the Netherlands, Flendrig et al. [37] researched low-cost thermoformed solar still and studied the water quality. In the UK, Shatat et al. [38] conducted desalination using a multistage modified still and studied the water characteristics before and after desalination.

From the detailed literature on water quality analysis of solar still, it was found that only a few works were reported on Algeria's climatic conditions. Hence the main objective of the present experimental study is to collect water samples at various places of Algeria and tested its water quality analysis before and after distillation. Experiments were conducted for seven different water samples taken from different areas of El Oued. Physical and chemical analyses of saline and distilled water were carried out, to estimate the quality of distilled water produced from solar still using solar energy.

2. Experimental methodology

2.1. Geographical coordinates in the region

The geographical region of southeast Algeria has located in the desert and it is known for its hot climate. In this region, water wealth is stored in between the depths of rock layers that have formed over the past ages. The southeast of Algeria contains vast amounts of saltwater. The groundwater reserve in the subterranean desert is about 50,000,000 m^2 and it is the largest water reservoir in the world. Fig. 1 shows the distribution of groundwater in the regions of southeast Algeria.

2.2. Groundwater distribution in the region of El Oued

The city of El Oued is located in the southeast of Algeria (33.3683° of latitude and 6.8674° of longitude) with an area of 54,573 km^2. This region is rich in groundwater but unfortunately, this water is not suitable for drinking, according to the analyses shown in Table 1, Fig. 2 shows the distribution of groundwater in the city of El Oued.

2.3. Characteristics of the region El Oued waters

The underground waters of the El Oued region are abundant, saline, and not suitable for drinking. Saline water contains an excess of salt, SO_4^{2-}, Cl^-, K^+, Na^+, Mg^+, Ca^{2+}. According to the WHO report, the high concentration of vital elements and mineral salts that exceed international standards causes many health problems for humans, animals, and even plants. Table 1 shows the results of the physical and chemical properties analyses of saline water samples in seven different regions of the El Oued region. From the results presented in Table 1, it can be noticed that water quality in these seven regions does not largely match the standards of the WHO, because of higher mineral salts concentrations presented in water in this region.

The results of El Oued water sample analysis showed a pH of 8.12, TDS level of 7,042 mg/L, TSS of 253 mg/L. Sodium ions were present in the highest amount (1,280 mg/L) while potassium ions were present in the least amount (23 mg/L).

When all the water samples were compared, the El Oued sample was the most basic (pH = 8.12) while the sample from Debila was nearly neutral (pH = 7.76). The electrical conductivity of the Debila sample was the highest (5,420 μS/cm) while that from Ghamra was the least (4,630 μS/cm). The water sample from Ghamra had the highest level of TDS (8,170 mg/L) and TSS (294 mg/L) while

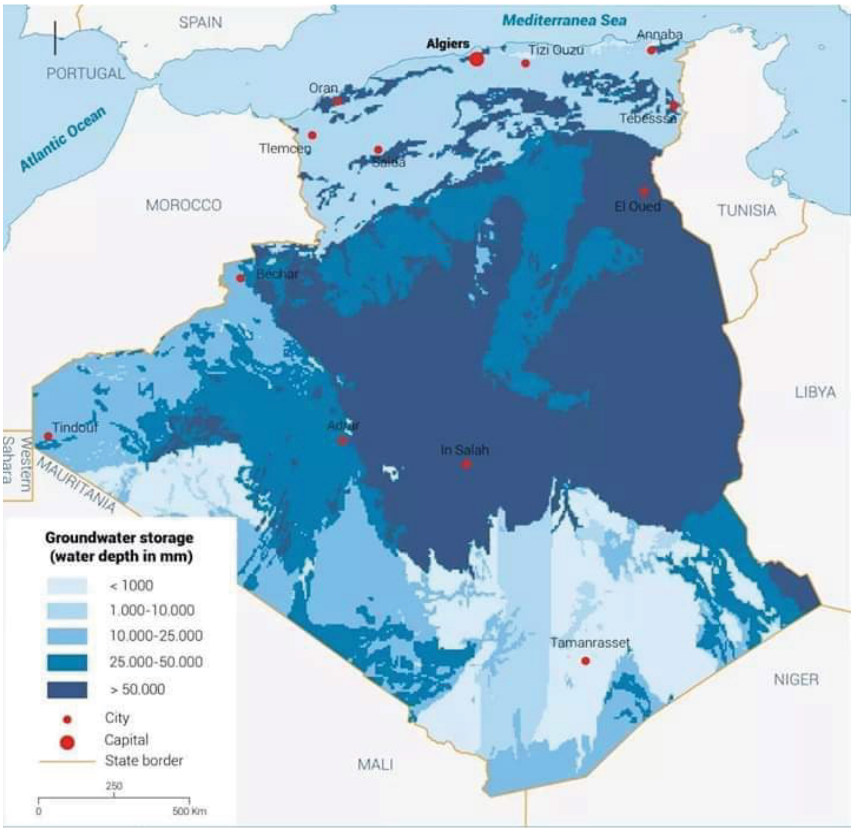

Fig. 1. A map of the groundwater distribution in southern Algeria [39].

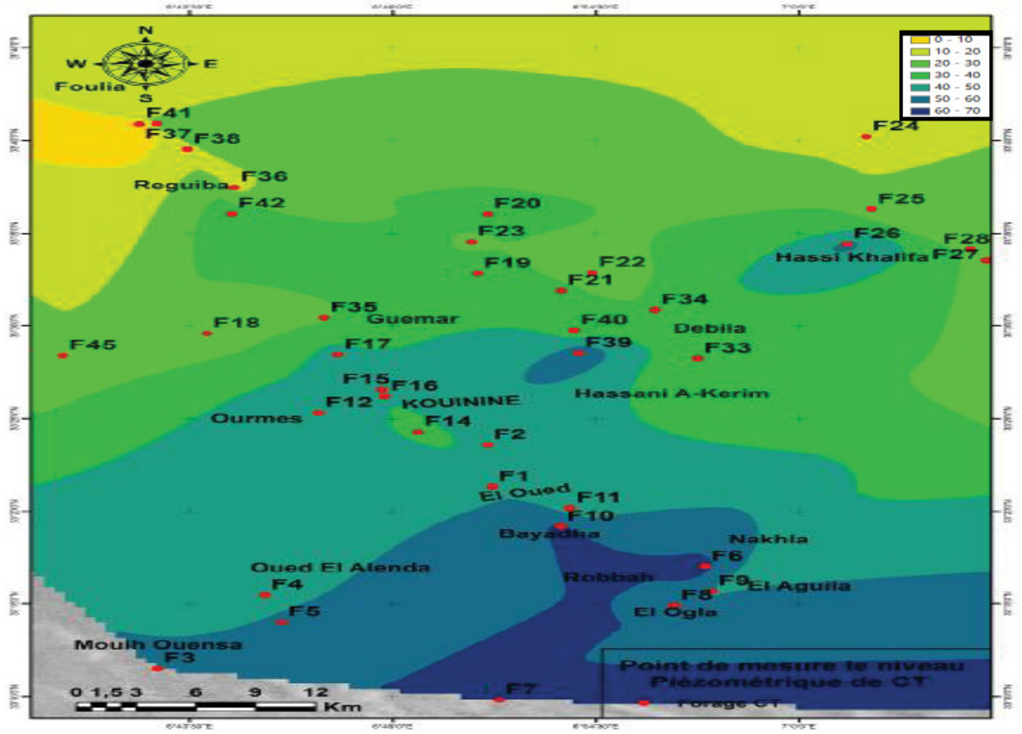

Fig. 2. A map of groundwater distribution in the region of El Oued [39].

Table 1
El Oued region water characteristics

Samples	Cites	T (°C)	pH	EC (µS/cm)	TDS (mg/L)	TSS (mg/L)	Salinity (g/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	K^+ (mg/L)	Na^+ (mg/L)	Mg^+ (mg/L)	Ca^{2+} (mg/L)
01	El Oued	29.2	8.12	5,300	7,042	253	2.86	1,033	905	23	1,280	182	180
02	Guemar	29.0	7.95	4,985	7,856	287	3.00	1,084	894	22	1,068	147	192
03	Ghamra	29.5	8.05	4,630	8,170	294	2.74	1,000	932	28	960	131	168
04	Debila	28.8	7.76	5,420	6,790	257	3.18	1,089	899	30	980	143	204
05	Hassi Khelifa	29.2	7.92	5,200	6,070	247	2.96	1,095	912	28	1,020	124	242
06	El Ogla	28.1	8.04	5,220	6,900	273	2.79	1,006	858	28	1,220	212	191
07	Nakhla	29.3	8.08	4,950	7,785	273	2.72	1,058	838	26	1,159	217	236
Average		29.01 ± 0.6	8.01 ± 0.11	5,100 ± 320	7,230 ± 940	269 ± 25	2.89 ± 0.29	1,052 ± 43	891 ± 41	26.43 ± 3.57	1,098 ± 122	165 ± 52	202 ± 40
WHO guidelines			6.5–8.5	800	500–1,000	50	0.5	250	200	20	200	50	75

T: water temperature; EC: electrical conductivity; TDS: total dissolved solids; TSS: total suspended solids.

that from Hassi Khelifa had the lowest (TDS = 6,070 mg/L, TSS = 247 mg/L). The salinity was noted to be the highest in the water samples of Debila (3.18 g/L) and lowest in the Nakhla sample (2.72 g/L). The highest sulphate concentration was observed in the Debila water sample (1,089 mg/L) when it was lowest in samples from Ghamra (1,000 mg/L). The Ghamra water sample showed the highest concentration of chloride ions (932 mg/L) while Nakhla had the lowest levels (838 mg/L). The Debila sample showed the highest levels of potassium (30 mg/L) while the water sample from Guemar had the lowest (22 mg/L). Sodium ions were present in the highest concentration in the El Oued sample (1,280 mg/L) while the Ghamra water sample had the lowest levels (960 mg/L). The water sample from Nakhla had the highest magnesium presence (217 mg/L) while the lowest concentration was observed in the Hassi Khelifa sample (124 mg/L). The presence of calcium ions was highest in the water samples from Hassi Khelifa (242 mg/L) and lowest in the Ghamra water sample (168 mg/L).

2.4. A hemispherical solar still system

Fig. 3 shows the schematic diagram of a hemispherical solar still used in this study. The hemispherical solar distiller device consists of a basin and a transparent cover. The basin is cylindrical, with a surface area of 0.1 m^2 and depth of 0.025 m, painted black from the inside, covered with a transparent plastic cover with a thickness of 3 mm. The water depth of the basin was maintained at 1 cm. The basin water evaporates and then condenses, and the condensed water droplets slide onto the clear transparent cover inner surface. Then, the amount of water was collected in a graduated cylinder. Fig. 3 shows the photograph of a hemispherical solar still device used in this study.

To measure the temperature of the system (ambient, water, basin, and transparent cover temperature) thermocouples were used. To measure the intensity of solar radiation, a solar radiation meter was used. Using a graduated flask, the amount of distilled water produced was measured. Based on data recorded for each measuring device, the accuracy of the devices, error is recorded in Table 2.

The uncertainty of instruments used in these experiments such as thermocouples and solar power meters were statistically predicted using Eqs. (1) and (2).

$$u=\left[\left(\frac{\partial S_1}{Z_1}u_1\right)^2+\left(\frac{\partial S_2}{Z_2}u_2\right)^2+\left(\frac{\partial S_3}{Z_3}u_3\right)^2+\ldots\ldots+\left(\frac{\partial S_n}{Z_n}u_n\right)^2\right]^{0.5} \quad (1)$$

The uncertainty of measuring jar is predicted by,

$$u_m=\left[\left(\frac{\partial m}{\partial h}u_h\right)^2\right]^{0.5} \quad (2)$$

where the amount of water collected in the measuring jar (mL).

3. Results and discussion

The experiments were carried out in seven days, starting from 7:00 A.M to 7:00 P.M in June 2020. Climatic

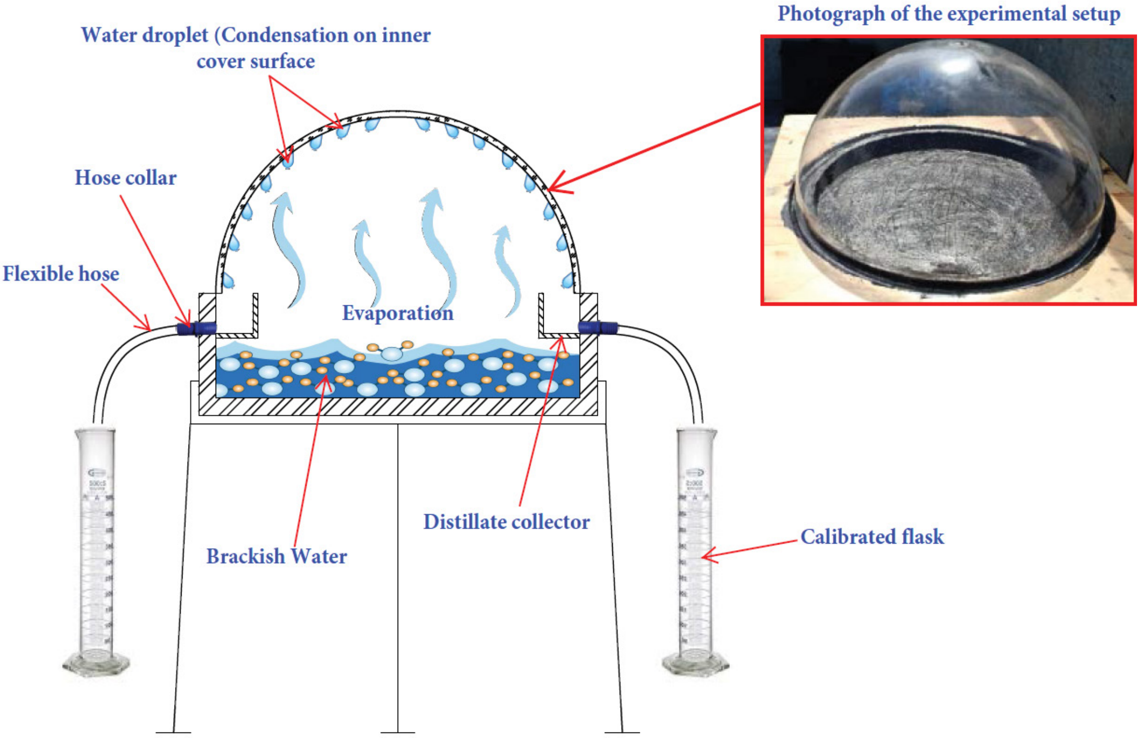

Fig. 3. Schematic representation and photographs of the hemispherical solar still.

Table 2
Errors of the measuring devices

Instrument	Accuracy	Range	Standard uncertainty
Solar power meter, W/m²	±10	0–1,999	5.77
Thermocouple, °C	±0.1	−100–500	0.06
Graduated cylinder, mL	±1	0–250	0.6

conditions and different temperatures were monitored and recorded every hour. Table 3 shows the weather data and solar still productivity during the testing days. As shown in Table 3, the minimum and maximum ambient temperatures during the experimental days were 27°C and 50°C, respectively. Furthermore, variance in solar radiation was recorded, and found the minimum and maximum solar radiations as 37 and 1008 W/m², respectively. The humidity does not exceed 24% and wind velocity was between 9 and 17 km/h. As for the productivity of the solar hemispherical distillate, it ranged between 4.6 and 4.9 kg/m²/d.

Table 4 depicts the physical and chemical properties of water obtained before and after the desalination process and its characteristics are discussed in this section. It is observed that the salinity has been completely removed using this model solar still. The distilled Debila water sample showed a neutral pH level (7.00) while the highest pH level was observed in the El Oued water sample post distillation (pH = 7.12) which was also within

Table 3
Statistical parameters of weather conditions, as well as solar still productivity during testing days

Samples	Ambient temperature (°C)		Solar radiation (W/m²)		Average wind velocity (km/h)	Average humidity (%)	Productivity (L/m²/d)
	Min	Max	Min	Max			
1	28	49	40	1,008	11	18	4.78
2	27	48	38	1,006	15	24	4.65
3	27	50	37	1,006	17	15	4.60
4	28	49	42	1,007	12	18	4.75
5	27	48	40	1,008	11	19	4.81
6	27	50	41	1,008	9	21	4.88
7	28	49	38	1,007	10	23	4.85

Table 4
Characteristics of the distilled water produced

Samples	T (°C)	pH	EC (μS/cm)	TDS (mg/L)	TSS (mg/L)	Salinity (g/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)	K^+ (mg/L)	Na^+ (mg/L)	Mg^+ (mg/L)	Ca^{2+} (mg/L)
01	31	7.12	28	22	2	00	5	9	0.25	2.2	0.82	1.83
02	32	7.05	29	24	2	00	12	12	0.169	1.98	0.95	1.95
03	30	7.05	27	18	2	00	10	10	0.21	2.0	0.79	1.68
04	32	7.00	30	25	2	00	8	11	0.158	1.95	1.03	2.04
05	31	7.11	29	20	2	00	9	12	0.205	2.05	0.82	2.13
06	33	7.08	29	17.36	2	00	10	9	0.186	2.10	1.12	1.95
07	32	7.06	28	22	2	00	12	9	0.2	2.16	0.77	2.06
Average	31.57 ± 1.5	7.06 ± 0.06	28.57 ± 1.5	21.19 ± 3.5	2 ± 00	00 ± 00	9.42 ± 2	10.28 ± 1.5	0.197 ± 0.0275	2.06 ± 0.06	0.9 ± 0.12	1.95 ± 0.06
WHO guidelines		6.5–8.5	800	500–1,000	50	0.5	250	200	20	200	50	75

T: water temperature; EC: electrical conductivity; TDS: total dissolved solids; TSS: total suspended solids.

Table 5
Comparison of distillate quality of our work with other research works

Parameters	Present work			Miloudi et al. [40]			Mohammed Shadi et al. [41]			Fahiminia et al. [17]		
	Distillation	Distillated	Removal, %	Distillation	Distillated	Removal, %	Distillation	Distillated	Removal, %	Distillation	Distillated	Removal, %
pH	8.01	7.06	NA	7.7	8.1	NA	7.82	6.42	NA	7.9	6.9	NA
EC (μS/cm)	51,00	28.57	99.43	4,771.1	9.6	99.80	4130	251	93.92	58,075	1,953	96.64
TDS (mg/L)	7,230	21.19	99.70	27,884.4	8.1	99.97	2610	159	93.91	37,749	1,233	96.73
TSS (mg/L)	269	02	99.25	671.2	0.2	99.70	NA	NA	NA	NA	NA	NA
Salinity (g/L)	2.86	00	100.00	30.7	00	100.00	NA	NA	NA	NA	NA	NA
SO_4^{2-} (mg/L)	1,052	9.42	99.10	2,394.2	0.6	99.97	790	46.4	94.13	3,067	58	98.11
Cl^- (mg/L)	891	10.28	98.85	21,499.8	3.3	99.98	800	77	90.38	22,020	710	96.78
K^+ (mg/L)	26.43	0.197	99.25	345.6	0.2	99.94	10	2.42	75.80	588	14.6	97.52
Na^+ (mg/L)	1,098	2.06	99.81	11,017.8	2.2	99.98	550	58	89.45	9,715	436	95.51
Mg^+ (mg/L)	165	0.9	99.93	1,150.4	0.7	99.94	124	9.5	92.34	1,581	31	98.04
Ca^{2+} (mg/L)	202	1.95	99.03	610.6	0.9	99.85	166	7.7	95.36	416	7.7	98.15

T: water temperature; EC: electrical conductivity; TDS: total dissolved solids; TSS: total suspended solids.

Table 6
Cost analysis (1$ = 132.78 DZD, 1€ = 156.03 DZD)

Component		Cost (DZD)	Value
Fabrication cost	(*A*)	9,000	
Maintenance	(*B*)	50	
Total cost	(*C*) = (*A*)+(*B*)	9,050	
Price for 1 L of potable water	(*D*)	60	
Productivity (L/m^2/d)	(*E*)		4.80
Water produced cost per day	(*F*) = (*D*) × (*E*)	288	
Recovery period (d)	(*G*) = (*C*)/(*F*)		31

consumable levels. Since most of the salts were removed, the electrical conductivity also decreased considerably. The highest electrical conductivity was observed in the distilled Debila water sample (30 μS/cm) while it was lowest in the water samples of Ghamra (27 μS/cm). The Debila water sample showed the highest total dissolved solids (25 mg/L) while the TDS was the least in the El Ogla water sample (17.36 mg/L). All the desalinated water samples showed 2 mg/L as the TSS value.

The Guemar sample showed the highest sulphate presence post desalination (12 mg/L) while the lowest was observed in the El Oued sample (5 mg/L). The highest chloride concentration was noted in the Guemar and Hassi Khelifa water samples (12 mg/L) while the samples of El Oued, El Ogla, and Nakhla had the lowest levels (9 mg/L). The highest potassium presence was observed in the water samples of Hassi Khelifa (0.205 mg/L) while the Debila sample showed the lowest (0.158 mg/L). Sodium ions were present in the highest concentration in the Nakhla sample (2.16 mg/L) while the Debila water sample had the lowest levels (1.95 mg/L). The water sample from El Ogla had the highest magnesium presence (1.12 mg/L) while the lowest concentration was observed in the Nakhla water sample (0.77 mg/L). The presence of calcium ions was the highest in the water samples of Hassi Khelifa (2.13 mg/L) and lowest in the Ghamra water sample (1.68 mg/L).

4. Comparison of present works with other works

Solar distillation is a technology for desalinating saltwater and providing drinking water in many semi-arid and arid regions of the world. A comparison of the characteristics of distilled water obtained from our study and other similar studies is tabulated in Table 5. In all the compared cases, the pH of the water has been successfully reduced to the drinkable limits. The electrical conductivity was also reduced by greater than 90% with the current study was increasing by 99.43%. The TDS were decreased by 99.70% in the current model while Miloudi et al. [40] could reduce it by 99.97% and the other two models could decrease it by more than 90%. This work could successfully remove 99.70% of TDS while the current model reduced it by 99.25%. The salinity was completely removed in all the cases. The present study also could remove the sulphate, chloride, potassium, sodium, magnesium, and calcium ions by more than 99% which was also achieved by the experimental models of Miloudi et al. [40] and Fahiminia et al. [42], but the work of Mohammed Shadi et al. [41] could only remove 75.80% of potassium ions and 89.45% of sodium ions from the seawater. Taking all the aspects and parameters into consideration, the current experimental model proves to provide the best quality water after effective desalination.

5. Cost analysis

To analyze the cost of our system economically profitable or not, simple payback calculations that include the invested amount and the amount of maintenance. Table 6 shows the cost analysis and it was found that the recovery period still is 31 d.

6. Conclusions

The current study was performed in the Algerian climatic conditions. A Water sample from seven different areas of the El Oued region has been collected and tested its physical and chemical properties before and after distillation. The following conclusions were obtained from this experimental work:

- The average daily yield obtained from the hemispherical solar still was recorded to be 4.80 L/m^2.
- The pH level of the impure water was reduced to drinkable levels (pH = 7.00–7.11) and salinity was completely removed (0 g/L).
- The electrical conductivity was decreased by 99.43% and total dissolved solids were decreased by 99.70%.
- The present study also could remove the sulfate, chloride, potassium, sodium, magnesium, and calcium ions by more than 99%.
- The payback period for this design was calculated to be 31 d which is profitable.
- This technology is simple, easy to use, and economic. We can obtain safe drinking water with all the impurities and salts were removed.

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