Monitoring of water quality generated by MSF and reverse osmosis at the Kahrama and Mactâa plants in West Algeria

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Abstract
Algeria has chosen and has been using seawater desalination substituting natural resources in the majority of its northern cities for nearly 20 years due to several pressing issues, including water stress relief and a lack of rain induced by global warming's adverse impacts. Indeed, Algeria currently possesses 21 desalination plants, six more under development, and 81 dams. All of these desalination plants employ reverse osmosis membrane technology, except the Kahrama plant in Arzew, Oran, which utilizes a Multi-Flash (MSF) distillation process or staged expansion. The current study assessed the quality control of desalinated water at the Kahrama and Mactâa plants. This was accomplished by comparing the physico-chemical and bacteriological characteristics of distilled water, osmosis water, and drinking water. The T-test was applied when comparing seawater, distilled water, and reverse osmosis water, as well as drinking water, with international norms. Except for iron and copper, most of the physical parameters have a p-value < 0.001. The average temperature of distilled water is 32 degrees Celsius, whereas reverse osmosis water is 20 degrees Celsius. However, reverse osmosis produces greater amounts of alkalinity, total hardness, chlorides, calcium, and magnesium than MSF does. When drinking water is compared to international standards, both findings show nearly identical pH levels but at different temperatures. Bacterial analysis indicates that drinking water is free of total coliforms, E. coli, Enterococci, and sulfite-reducing Clostridia. However, because of the brines generated during desalination, this seemingly infinite water resource harms the ecosystem.

Keywords: desalination stations in Algeria, Kahrama, Mactâa, MSF, Reverse Osmosis, seawater desalination.

Introduction

Over 80% of desalination operations in the Mediterranean region and about 60% of desalination operations worldwide are related to seawater desalination (Khordagui, 2013; UNEP/MED program, 2017; Elsaid *et al.*, 2020). Additionally, we are seeing a sharp rise in the amount of water generated via desalination, which reached 95 million m^3/day globally in 2018 after reaching 45 million m^3/day in 2017 (Abdellah and Khaldi, 2017). Many nations worldwide, particularly those in the Middle East and emerging nations, have limited supplies of freshwater (Aljohani *et al.*, 2023). According to Clayton (2011), the Gulf area is home to the majority of the nations that rely on desalination. More specifically, according to Energy (2012), 70% are effective in the Kingdom of Saudi Arabia, the United Arab Emirates, Kuwait, and even in Algeria, and Libya.

Algeria was plagued by drought for over ten years, and traditional water supplies were insufficient to sustain the country's population demands (Benssenasse and Belkacem Filali, 2014). Furthermore, managing water resources sustainably is becoming more challenging due to hydrological changes brought on by or induced by climate change. These resources are already severely strained in many parts of the world (Papa *et al.*, 2023). As a result, the Algerian government has taken substantial measures to address the nation's water scarcity issue. Considerable efforts have been made to mobilize freshwater resources, including the construction of hydraulic infrastructure, which includes wastewater treatment facilities, saltwater desalination stations, dams, and other structures (Drouiche *et al.*, 2012; Elsaid *et al.*, 2020).

Water resources are concentrated mainly in the northern regions of the country, where around 80% of the population lives (Piedra *et al.*, 2019). Algeria, which has 1600 km of coastline, currently has 21 desalination stations spread across 14 coastal wilayas (cities), six others under construction, and 81 dams (MWR, 2024) (Table 1).

Table 1. List of desalination plants in Algeria (MWR, 2024)

City	Plant	Capacity m^3 Day^{-1}	Process used	Start of plant operation
Chlef	Ténès	200.000	R.O	2015
	Béni Haoua (in construction)	5000 (planned)	R.O	Planned
Béjaia	Tighremt (in construction)	300.000 (planned)	R.O	
Tlemcen	Souk Thléta	200.000	R.O	2011
	Honaine	200.000	R.O	2011
Alger	Hamma	200.000	R.O	2008
	Staoueli (Palm beach)	7500	R.O	2021
	Ain Benian	10.000	R.O	2021
	Zeralda	10.000	R.O	2021
	Bordj El Kiffan	10.150	R.O	2022
	El-Marsa	60.000	R.O	2022
Skikda	Skikda	200.000	R.O	2009
Mostaganem	Mostaganem	200.000	R.O	2011
Oran	Kahrama Arzew	90.000	MSF	2005
	Bousfer	5500	R.O	2005
	Mactaa	500.000	R.O	2016
	Cap Blanc (in construction)	300.000 (planned)	R.O	
Boumerdès	Djinet	100.000	MSF	2012
	Corso	80.000	R.O	2023
	Cap Djinet (in construction)	300.000 (planned)	R.O	In construction
El Tarf	Koudiet Eddraouche (in construction)	300.000 (planned)	R.O	
Tipaza	Fouka 1	120.000	R.O	2008
	Fouka 2 (in construction)	300.000 (planned)	R.O	In construction
Ain Témouchent	Béni Saf	200.000	R.O	2010
	Chatt El Hillal	200.000	R.O	2009

MSF: Multi-Stage Flash, MWR: Ministry of Water Resources, R.O: Reverse Osmosis

Thermal technologies dominated Algeria's desalination business until 2003–2005, when membrane technology specifically, Reverse Osmosis surpassed them. The first seawater desalination plant in Algeria was opened in August 2005 at the Kahrama station, which is situated 40 kilometers from the city of Oran in the industrial zone of Bethioua in Arzew. It generates 90.000 m^3/day of drinking water through the Multi-Flash distillation (MSF) process, which uses energy from the production of electricity (Gacem *et al*., 2012; Drif and Moudjari, 2022). Algeria has developed and enhanced several membrane technologies, such as reverse osmosis and nanofiltration (NF), which have resulted in comparatively lower desalination prices (Tigrine *et al*., 2023). The Mactâa plant, which is situated in the western wilaya of Oran, has the largest seawater desalination capacity in Africa as of right now. It can generate 500.000 m^3/day to eventually produce more than 2 million m^3/day. It is one of the biggest reverse osmosis systems in the world, according to Dunglas (2014) and Abdellah and Khaldi (2017).

In the present investigation, the drinkable water quality produced after seawater desalination was controlled at both the Kahrama and Mactâa plants. Several physicochemical and bacteriological characteristics were assessed and compared with standard requirements.

Materials and Methods

The Study Area Mactâa plant:

The Mactâa desalination plant (35°47’6.9” North and 0°8’59.244” West) is located in the commune of Mers El Hadjadj (the Daira of Béthioua) 48 km east of the wilaya of Oran (West Algeria) and about 30 km west of the wilaya of Mostaganem. The site is crisscrossed by the national road RN°11 linking Mostaganem to Oran and is located 10 km from the Arzew industrial zone. This station produces a capacity of 500.000 m^3/day of drinking water. It is one of the largest reverse osmosis installations in the world.

Kahrama plant:

Kahrama is a joint stock company 100% owned by the company Sonatrach (Oil and Gas Company) created in 2002 by Algerian Energy Company (AEC) and put into action in September 2005. It is ISO certified (9001, 14001, and 18001 defining a system of integrated quality, safety, hygiene, and environment management) whose objective is the production of electricity (2.7 million MWh) and distilled water from seawater. The complex is located in the industrial complex area of Arzew near the port of Bethioua, 40 km from the city of Oran (West Algeria) at coordinates 35°48’26.208” North and 0°14’48.911” West. This station aims to produce water intended for human consumption, using the staged flash distillation technique or MSF (Multi Stage Flash) with a capacity of 90.000 m^3/day.

Workings of desalination plants

The operation of the Mactâa desalination plant by Reverse Osmosis:

The Mactâa station is subdivided into five sections: a seawater intake section, a pre-treatment section, a treatment facility called Reverse Osmosis, a post-treatment section, and a discharge tank. The reverse osmosis technique is summarized by bringing together two solutions of different concentrations, separated by a membrane, a movement of species is then observed from the less concentrated solution to the more concentrated solution (Himri *et al*., 2022; Kherbache and Molle, 2023). If pressure is applied to the most concentrated solution, this transfer decreases and even stops once a threshold pressure called osmotic pressure is reached. If the applied pressure exceeds this threshold pressure, the phenomenon is reversed and the species then move from the most concentrated environment to the least concentrated environment. Once desalinated, the water is disinfected and then remineralized with a solution of carbon dioxide and lime to form calcium bicarbonate. This results in an increase in pH and the formation of stable, drinkable water for distribution and human consumption. In practice, carbon dioxide is injected at a predetermined fixed dose rate of 50 mg/l and the lime dosage is controlled by pH at a set point fixed at approximately 7.8 ~ 8.2. The water is finally stored in the treated water tank.

Operation of the Kahrama desalination plant by MSF:

The desalination of seawater process using the Multi Stage Flash or MSF technique, used by Kahrama station, consists of four stages: seawater intake with filtration and pumps, pre-treatment by the addition of biocidal compounds, the desalination process itself and post-treatment (Gacem *et al*., 2012). In the MSF desalination process, seawater feed is pressurized, heated, and discharged to a chamber maintained slightly below the saturation vapor pressure of the water. Then a fraction of this water flashes into steam and condenses on the exterior surface of heat-transfer tubing. This complex also has a steam system made up of three heat recovery boilers connecting the power plant and the desalination plant.

Sample collection

To study the physicochemical parameters, seven separate water samples were taken at different time intervals, during the month of April 2022, separately at the Kahrama and Mactâa desalination plants, for each type of water: seawater (taken from the seawater receiving tank), osmosis water (water desalinated by the reverse osmosis membranes) or MSF distillation water, treated water (drinking water) and wastewater (water taken from the discharge tank) by averaging the values obtained for each case. This average is compared to the standards required by the Algerian law relating to water potability for human consumption.

Sample analysis

All samples were analyzed at the control laboratories of the Mactaa and Kahrama desalination plants and the laboratory of the SEOR Company (The Oran Water and Sanitation Company) as follows:

Organoleptic Analysis:

The organoleptic parameters are based on an assessment of the taste, color, odor, and transparency of the water (Rodier *et al*., 2016). These have no health significance, but their deterioration may indicate pollution or a malfunction in the distribution facilities. They allow consumers to make a brief judgment about the quality of the water.

- **Color measurement:**

The color of the water is expressed using the platinum/cobalt color scale (Pt/Co scale). Each unit is equivalent to the color produced by 1 mg/l of platinum in the form of chloroplatinic acid, in the presence of 2 mg/l of cobalt chloride hexahydrate. The analysis was performed by spectrophotometry at 380 nm wavelength.

- **Odor assessment:**

The odor is assessed on freshly collected water in glass containers.

- **Taste assessment:**

The flavor is assessed by tasting at the sampling point.

Physico-chemical parameters:

The pH, the temperature, and the conductivity, which are linked to the concentration and nature of the dissolved substances are measured by a conductivity meter (WTW conductivity meter InoLab Cond 7110) and are expressed in micro Siemens per centimeter µS/cm. The total hardness (TH), measured using the Metrohm 848 Titrino plus and corresponding to the overall quantity of calcium and magnesium salts, was calculated as follows:

$$TH = 2.497 \times Ca^{2+} \text{ concentration (mg L}^{-1}\text{)} + 4.116 \times Mg^{2+} \text{ concentration (mg L}^{-1}\text{)}$$

The total dissolved solid matter (TDS), representing the total concentration of substances dissolved in water, composed of mineral salts such as cations and anions as well as some organic matter, was determined by the gravimetric method according to this formula:

$$\text{Total dissolved solid matter (mg L}^{-1}\text{)} = [(P2-P1)/V] \times 10^6$$

Where P2 is the weight of the dry residue and the evaporation capsule in mg, P1 is the weight of the evaporation capsule in mg, V represents the volume of the sample (100 ml) and 10^6 is the reaction factor.

The alkalinity (unlike acidity) of water corresponds to the presence of bases and salts of weak acids. Its dosage was carried out by the titration method with the strong acid, hydrogen chloride, at the endpoint at pH = 4.23 using a "METROHM" device and according to this formula:

$$\text{Alkalinity (mg L}^{-1}\text{) = VHCL (ml) x 10}$$

Where 10 is the reaction factor.
Chlorides (Cl^-) are salts, but in very variable proportions can be present in large quantities in seawater following industrial pollution. The concentration was calculated following this formula:

$$Cl^- \text{ (mg L}^{-1}\text{) = V (ml) x 35.5}$$

Where V is the Volume of silver nitrate necessary for titration of the solution and 35.5 is the reaction factor.
Calcium (Ca^{2+}) is present in particular in limestone rocks in the form of carbonate. Its salts are present in almost all-natural waters. The concentration was calculated following this formula:

$$Ca^{2+} \text{ (mg L}^{-1} \text{ in } CaCO_3\text{) = V (ml) x 50}$$

Where V is the volume of EDTA and 50 is the reaction factor.
Magnesium (Mg^{2+}) is present in the form of carbonates or bicarbonates in seawater. The magnesium concentration is calculated by a formula making the connection with calcium.
The iron (Fe^{3+}) is generally found in ferric and precipitated form, often associated with suspended matter. Its dosage was carried out using a mini-1240 UV-type spectrophotometer and is expressed in mg L^{-1}.
The copper ($Cu2^+$), its presence follows the erosion of soil or rocks or even the activities of processing plants. Its dosage was made by spectrophotometry at 560 nm and is expressed in mg L^{-1}.
Dissolved oxygen is related to the quantity of oxygen which is in solution in water and which is available for plant and animal respiration. Its measurement was carried out using an oximeter and is expressed in mg L^{-1} (Rodier *et al.*, 2016; Bessenasse and Belkacem Filali, 2014; Mehtougui *et al*., 2018).

Microbiological study
The analysis was based on the search and enumeration of germs such as total coliforms, *Escherichia coli*, Enterococci, and sulfite-reducing Clostridia (JORADP, 2011). To carry out a reproducible and comparative study, a series of 4 samples were taken at 3-day intervals, during the month of April 2022, separately at the 2 Kahrama and Mactâa desalination plants, for each type of water: seawater, distilled or osmosis water, and drinking water. The search for *total coliforms* was carried out on a petri dish containing TTC Chapman medium and then incubated at 36 °C for 24 hours. The appearance of yellow or orange-yellow colonies implies the presence of *total coliforms*. The search for *Escherichia coli* was carried out in test tubes containing 3 ml of tryptophan medium and then incubated for 24 hours at 44 °C. The detection is done using the Kovaks reagent and the appearance of a red ring confirms the presence of *Escherichia coli*. The search for Enterococci is carried out on Petri dishes containing the Slanetz and Bartle culture medium in an oven at 36 °C for 24 hours. The appearance of red, pink, or dark brown color indicates the presence of Enterococci. The presence of Clostridia was investigated in a petri dish containing the TSC culture medium at 37 °C for 48 hours. The appearance of black colonies explains the presence of Clostridium.

Statistical analysis
Data were analyzed with SPSS 26.0 software. For the comparison of the physicochemical parameters of the seawater (before desalination) and the distilled water or reverse osmosis water (after desalination), the T-test for paired samples was used. The T-test for one sample was used to compare the parameters of the treated water (drinking water) with the international standards. Statistical significance was assumed for p-values less than 0.05 ($p \leq 0.05$).

Results
The physicochemical parameters evaluation
This study was devoted to assessing the quality of water obtained after seawater desalination using the Multi-Flash Distillation (MSF) process used by the Kahrama plant and the reverse osmosis technique utilized by the Mactâa plant.
In terms of organoleptic criteria, MSF-produced desalinated water is of higher quality and tastes better than reverse osmosis-produced water.
The results of the physical and chemical properties of the seawater compared to those of the distilled water in the Kahrama unit reveal in most cases a value of $p < 0.001$, except for iron and copper (Table 2). The pH of the distilled water was an average of 6.65 ± 0.11. The conductivity decreased significantly to an average value of 3.36 ± 0.35 µS cm^{-1}. The temperature of the distilled water was higher than that of seawater, with an average of 32.21 ± 0.85 °C.
TDS concentrations range from 39140.14 ± 111.33 mg L^{-1} in seawater to an average of 1.50 ± 0.33 mg L^{-1} in distilled water. However, distilled water had zero values for alkalinity, total hardness, chlorides, calcium, and magnesium when compared to seawater (Table 2). Concerning the dosage of iron and copper, these metals display an average value for iron at 0.02 ± 0.04 mg L^{-1} in seawater and zero in distilled water with a value of $p = 0.239$. For copper, the values are zero before and after desalination of seawater, with $p = 0.356$. Finally, dissolved oxygen shows an average value of 8.46 ± 0.04 mg L^{-1} in seawater and is zero in distilled water (Table 2).

Table 2. Physicochemical parameter comparison between seawater and distilled water from the Kahrama plant

Parameters	Seawater								MSF distilled water								P-Value
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Mean ± SD**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Mean ± SD**	
pH	8.20	8.07	7.99	8	8	8.10	8	8.02 ± 0.08	60.65	60.89	60.61	60.55	60.60	6.68	6.58	6.65 ± 0.11	p<0.001
Conductivity ($\mu S\ cm^{-1}$)	54210	54500	54134	54540	54300	54400	54500	54369.14 ± 158.00	30.20	40.10	30.10	30.30	30.10	3.30	3.40	3.36 ± 0.35	p<0.001
Temperature (°C)	21.50	21.60	20	20.10	20.10	21	21.2	20.79 ± 0.70	32.60	31.20	31.90	32.50	31.10	32.80	33.40	32.21 ± 0.85	p<0.001
Total Dissolved Salts ($mg\ L^{-1}$)	39030	39240	39245	39096	39160	38970	39240	39140.14 ± 111.33	10.60	20.05	10.59	10.65	10.05	1.29	1.25	1.50 ± 0.33	p<0.001
Alkalinity ($mg\ L^{-1}$)	120	122	120	124	122	120	121	121.29 ± 1.50	0	0	0	0	0	0	0	0	p<0.001
Total Hardness ($mg\ L^{-1}$)	5010	5050	6150	6000	6100	6000	6500	5830 ± 571.96	0	0	0	0	0	0	0	0	p<0.001
Chlorides ($mg\ L^{-1}$)	9500	9575	9585	9230	9585	9600	9570	9520.71 ± 132.21	0	0	0	0	0	0	0	0	p<0.001
Calcium ($mg\ L^{-1}$)	1000	1475	1000	1400	1450	1000	1250	1225 ± 222.20	0	0	0	0	0	0	0	0	p<0.001
Magnesium ($mg\ L^{-1}$)	867.92	868.72	886.95	886.9	868.72	850.5	820.12	864.26 ± 23.16	0	0	0	0	0	0	0	0	p<0.001
Iron ($mg\ L^{-1}$)	0	0	0	0	0	0.10	0.03	0.02 ± 0.04	0	0	0	0	0	0	0	0	p=0.239
Copper ($mg\ L^{-1}$)	0	0	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0	p=0.356
Dissolved oxygen ($mg\ L^{-1}$)	8.46	8.50	8.40	8.40	8.50	8.50	8.47	8.46 ± 0.04	0	0	0	0	0	0	0	0	p<0.001

Mean ± SD (n=7), MSF: Multi-Stage Flash, S: sample (1-7)

Furthermore, the analysis of the physicochemical parameters by reverse osmosis at the Mactâa plant shows an average pH value of 8.19 ± 0.04 in seawater (Table 3). The pH of the osmosis water decreases slightly towards an average value of 7.89 ± 0.51. The conductivity displays an average value of 55200 ± 331.66 $\mu S\ cm^{-1}$ in seawater and drops considerably in reverse osmosis water to reach an average value of 822.14 ± 136.10 $\mu S\ cm^{-1}$. The temperature remains almost identical before and after desalination and displays an approximate average value of 20 °C in the osmosis water (Table 3). Concerning TDS, alkalinity, total hardness, and chlorides, they display an average value of 38088 ± 228.85 $mg\ L^{-1}$, 118.63 ± 2.80 $mg\ L^{-1}$, 7251.71 ± 144.57 $mg\ L^{-1}$, and 19830.86 ± 1316.01 $mg\ L^{-1}$, respectively, in seawater. These concentrations drop considerably in reverse osmosis water and have an average value of 398.7 398.66 ± 60.79 $mg\ L^{-1}$ for TDS, 41.08 ± 1.32 $mg\ L^{-1}$ for alkalinity, 25.87 ± 2.96 $mg\ L^{-1}$ for total hardness, and 238.93 ± 3.99 $mg\ L^{-1}$ for chlorides (Table 3). Regarding calcium and magnesium, they display an average value of 472.69 ± 11.16 $mg\ L^{-1}$ and 1474 ± 33.53 $mg\ L^{-1}$, respectively, in seawater. These values were reduced to 5.41 ± 1.20 $mg\ L^{-1}$ for calcium and 3.27 ± 0.68 $mg\ L^{-1}$ for magnesium. On the other hand, the dosage of iron and copper in seawater shows fairly low average values equal to 0.12 ± 0.12 $mg\ L^{-1}$ for iron and 0.03 ± 0.02 $mg\ L^{-1}$ for copper, and a decrease in osmosis water with $p = 0.049$ for iron and $p = 0.004$ for copper. Dissolved oxygen displays an average value of 2.18 ± 0.37 $mg\ L^{-1}$ in seawater and an almost identical value in reverse osmosis water with $p = 0.335$ (Table 3).

Table 3. Physicochemical parameter comparison between seawater and reverse osmosis water from the Mactâa plant

Parameters	Seawater								Reverse Osmosis Water								P-Value
	S1	S2	S3	S4	S5	S6	S7	Mean ± SD	S1	S2	S3	S4	S5	S6	S7	Mean ± SD	
pH	8.2	8.1	8.2	8.2	8.2	8.1	8.2	8.2 ± 0.1	8.1	8.2	8.5	8.2	7.2	7.8	7.2	7.9 ± 0.5	p= 0.179
Conductivity (µS cm^{-1})	55200	55200	55200	55000	55000	55900	54900	55200 ± 331.7	820	697	705	815	729	1077	912	822.1 ± 136.1	p< 0.001
Temperature (°C)	21	18.5	18.9	18.4	19.2	19.5	19.8	19.3 ± 0.9	20.1	19	19.7	19.8	20.1	20.2	20.8	20.0 ± 0.5	p=0.063
Total Dissolved Salts (mg L^{-1})	38088	38088	38088	3795	37950	38571	37881	38088 ± 228.8	393.6	348	356	391	349	516	437	398.7 ± 60.8	p<0.001
Alkalinity (mg L^{-1})	117.8	116.9	118.6	119.3	111.7	120.4	117.7	118.6 ± 2.8	41.3	40.6	40.4	43.9	41.0	39.8	40.6	41.1 ± 1.3	p<0.001
Total Hardness (mg L^{-1})	7005.2	7362.8	7201.5	7133.9	7396.5	7296.8	7365.1	7251.7 ± 144.6	21.9	28.4	28.4	22.1	25.4	25.9	28.9	25.9 ± 3.0	p<0.001
Chlorides (mg L^{-1})	20436.5	20919.7	20922.7	20914.7	19533.6	18040.3	18048.3	19830.9 ± 1316.0	241.7	240.7	240.7	239.6	230.1	240.6	239.0	238.9 ± 4.0	p<0.001
Calcium (mg L^{-1})	452.6	463.7	478.3	484.2	476.1	482.2	471.6	472.7 ± 11.2	4.9	4.9	5.1	4.8	5.0	5.0	8.1	5.4 ± 1.2	p<0.001
Magnesium (mg L^{-1})	1426.3	1506.4	1458.4	1438.4	1507.1	1479.2	1502.2	1474 ± 33.5	2.3	3.9	3.8	2.5	3.1	3.3	3.9	3.3 ± 0.7	p<0.001
Iron (mg L^{-1})	0.1	0.1	0.3	0.1	0	0.3	0.1	0.12 ± 0.10	0	0.1	0.04	0	0	0.02	0.01	0.02 ± 0.02	p=0.049
Copper (mg L^{-1})	0.01	0.01	0.1	0.01	0.01	0.0	0.1	0.03 ± 0.02	0.01	0.01	0	0.01	0.01	0	0.01	0.01	p=0.004
Dissolved oxygen (mg L^{-1})	2.0	2.0	2.0	2	2.1	3.0	2.0	2.18 ± 0.4	2.1	2.0	2.1	2.0	1.9	2.3	2.1	2.07 ± 0.12	p=0.335

Mean ± SD (n=7), S: sample (1-7)

The physical and chemical parameters were investigated as well in drinking water (remineralized treated water) from the Kahrama and Mactâa plants, and the average value for each parameter was compared to the international drinking water norms (WHO, 2004) (Tables 4 and 5). The Kahrama plant's drinking water has an average pH of 7.65 ± 0.20, which meets international requirements that limit the pH to 9 (p-value =0.003) (Table 4). The average conductivity is 114.73 ± 1.32 µS cm^{-1}, thus falling within the standard limit of 2800 µS cm^{-1} (p-value < 0.001).
The average temperature of its component is 24.44 °C, which is consistent with the norm of 25 °C and a p-value of 0.600. Drinking water meets current standards, with an average concentration of 62.53 ± 2.17 mg L^{-1} for TDS, 59.79 ± 4.08 mg L^{-1} for alkalinity, 59.93 ± 2.73 mg L^{-1} for total hardness, and 41.77 ± 1.39 mg L^{-1} for chlorides. Calcium levels in drinking water were 54.93 ± 3.96 mg L^{-1}, meeting international guidelines of not greater than 200 mg L^{-1}. The total amount of magnesium, iron, and copper in drinking water is zero. The Kahma plant's drinking water possesses an average dissolved oxygen value of 6.09 ± 0.93 mg L^{-1}, that meets the required standard of 7 (Table 4).

Table 4: Physicochemical parameter comparison between Drinking water from the Kahrama plant and their international standard values

Parameters	Drinking water from the Kahrama plant								Dst	P-Value
	S1	S2	S3	S4	S5	S6	S7	Mean ± SD		
pH	8	7.80	7.50	7.40	7.61	7.60	7.65	7.65 ± 0.20	7.9	p=0.003
Conductivity (µS cm^{-1})	116.40	113.60	113	116.10	115	115.30	113.70	114.73 ± 1.32	2800	p<0.001
Temperature (°C)	22.20	22.90	22	22.80	25.20	27.50	28.50	24.44 ± 2.66	25	p=0.600
Total Dissolved Salts (mg L^{-1})	64.02	62.48	59.75	64.95	5956	64.41	62.53	62.53 ± 2.17	113	p<0.001
Alkalinity (mg L^{-1})	64	64	60	62	52.50	58	58	59.79 ± 4.08	500	p<0.001
Total Hardness (mg L^{-1})	56	60	65	61	58.50	59.50	59.50	59.93 ± 2.73	500	p<0.001
Chlorides (mg L^{-1})	42.60	42.15	42.70	42.80	42.60	40.05	39.50	41.77 ± 1.39	200	p<0.001
Calcium (mg L^{-1})	60	55	50	54	52	53	60.50	54.93 ± 3.96	200	p<0.001
Magnesium (mg L^{-1})	0	0	0	0	0	0	0	0	150	/
Iron (mg L^{-1})	0	0	0	0	0	0	0	0	0.3	/
Copper (mg L^{-1})	0	0	0	0	0	0	0	0	2	/
Dissolved oxygen (mg L^{-1})	6.40	6.65	6.50	6.30	4	6.34	6.45	6.09 ± 0.93	7	p<0.001

Mean ± SD (n = 7), Dst: Drinking water Standard values (WHO, 2004)

Drinking water provided by the Macâa plant offers an average pH of 7.91 ± 0.54, satisfying international requirements that limit pH to 9 (Table 5). The mean conductivity value is 1051.86 ± 28.68 µS cm^{-1}, which is below the required value of 2800 µS cm^{-1}. The average temperature in drinking water is 20.21 ± 0.58 °C. The average TDS, alkalinity, and total hardness measurements in drinking water are 504.29 ± 13.96 mg L^{-1}, 64.16 ± 3.87 mg L^{-1}, and 119.73 ± 21.50 mg L^{-1}, respectively. These values remain consistent with current international regulations (Table 5). The chloride dose averages 282.87 ± 24.32 mg L^{-1}, which is slightly more than the recommended limit of 200 mg L^{-1}. Calcium and magnesium levels in drinking water average 36.60 ± 5.36 mg $L^{-1}$and 6.71 ± 2.13 mg L^{-1}, respectively, and do not exceed current guidelines (Table 5). In terms of metal doses, such as iron and copper, drinking water has relatively low average values that are consistent with international standards. Dissolved oxygen has an average value of 2.02 ± 0.24 mg L^{-1}, meeting the requirement of 5 mg L^{-1} (Table 5).

Table 5: Physicochemical parameter comparison between Drinking water from the Mactâa plant and their international standard values

Parameters	Drinking water from the Mactaa plant								Dst	P-Value
	S1	S2	S3	S4	S5	S6	S7	Mean ± SD		
pH	8.38	8.16	8.36	7.93	8.23	7.12	7.17	7.91 ± 0.54	6.5 – 9	p=0.666
Conductivity (µS cm^{-1})	1031	1006	1077	1069	1039	1053	1088	1051.86 ± 28.68	2800	p<0.001
Temperature (°C)	19.90	19.60	19.70	20.20	20.10	20.90	21.10	20.21 ± 0.58	25	p<0.001
Total Dissolved Salts (mg L^{-1})	494	482	516	513	498	505	522	504.29 ± 13.96	1000	p<0.001
Alkalinity (mg L^{-1})	68.27	63.58	66.26	56.34	63.49	64.49	66.72	64.16 ± 3.87	500	p<0.001
Total Hardness (mg L^{-1})	108.31	166.87	120.47	112.57	115.20	111.97	102.75	119.73 ± 21.50	500	p<0.001
Chlorides (mg L^{-1})	298.68	297.46	297.46	294.35	297.46	246.35	248.32	282.87 ± 24.32	200	p<0.001
Calcium (mg L^{-1})	35.61	48.20	35.72	34.35	35.77	35.29	31.26	36.60 ± 5.36	200	p<0.001
Magnesium (mg L^{-1})	4.71	11.30	6.82	6.51	5.71	5.92	6	6.71 ± 2.13	150	p<0.001
Iron (mg L^{-1})	0	0.03	0.03	0	0	0.01	0	0.01 ± 0.01	0.3	p<0.001
Copper (mg L^{-1})	0.01	0	0	0.01	0.01	0	0.01	0.01 ± 0.01	2	p<0.001
Dissolved oxygen (mg L^{-1})	2	2.01	2	2	1.95	2.50	1.68	2.02 ± 0.24	5	p<0.001

Mean ± SD (n = 7), Dst: Drinking water Standard values (WHO, 2004)

Microbiological study

The search and counting of microorganisms, including total coliforms, *Escherichia coli*, Enterococci, and Clostridia, in seawater, distilled or osmosis water, and drinking water established serves as the basis for the analysis. The efficacy of MSF and the reverse osmosis process in retaining microorganisms was evaluated by comparing the obtained findings to the potability requirements for water mandated by Algerian regulations (JORADP, 2011). Table 6 shows that the drinking water of the Kahrama and Mactâa plants is devoid of Enterococci, *E. coli*, and sulfite-reducing clostridium.

Table 6. Bacteriological analysis of

Bacteria	Kahrama Plant				Mactaa Plant				DW's Standards	
	S1	S2	S3	S4	S1	S2	S3	S4	Units	Standard
Total Coliforms	0	0	0	0	0	0	0	0	CFU 100^{-1}	<10/100 ml
Escherichia Coli	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml
Enterococci	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml
Sulfate-reducing Clostridia	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml

Drinking Water at both the Kahrama and Mactâa plants

Bacteria	Kahrama Plant				Mactaa Plant				DW's Standards	
	S1	S2	S3	S4	S1	S2	S3	S4	Units	Standard
Total Coliforms	0	0	0	0	0	0	0	0	CFU 100^{-1}	<10/100 ml
Escherichia Coli	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml
Enterococci	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml
Sulfate-reducing Clostridia	0	0	0	0	0	0	0	0	CFU 100^{-1}	0/100 ml

DW's Standards: Algerian Standard for microbiological quality of Drinking Water (JORADP, 2011), S: sample (1-4)

Discussion

This study investigates the control of water quality obtained after seawater desalination employing the MSF technique used by the Kahrama station, Algeria's pioneer plant for seawater desalination, and the reverse osmosis process adopted by the Mactâa station, among the world's largest reverse osmosis installation. The physicochemical and bacteriological characteristics of distilled or osmosis water obtained by MSF and reverse osmosis need to be investigated to assess the quality of the water generated and its suitability for numerous purposes, particularly human consumption.

The results indicated that MSF-treated water tasted better than reverse osmosis water. These findings are consistent with those reported by Gacem *et al.* (2012) at the Kahrama plant level and Abdellah and Khaldi (2017) at the Mactâa plant.

The evaluation of the physicochemical characteristics revealed that the osmosis water had a little higher pH than the MSF-distilled water (Tables 2 and 3). On the other hand, the temperature in distilled water is higher due to the conditions of MSF operation, which heats the input water to roughly 110 °C. The findings indicated a considerable reduction in conductivity, TDS, alkalinity, total hardness, chlorides, calcium, and magnesium in both distilled and reverse osmosis water, demonstrating the efficiency of both procedures (Tables 2 and 3). These findings support those obtained by Bessenasse and Belkacem Filali (2014); Gacem *et al.* (2012), and El Moustapha *et al.* (2017).

Concerning the dosage of iron, an essential element for the growth of phytoplankton in a marine environment (Lee *et al*., 2017), and copper, the results showed a complete absence in distilled water and a trace amount in osmosis water, demonstrating the effectiveness of the two techniques (Tables 2 and 3). Furthermore, the results of the physicochemical parameters analyzed in drinking water from the Kahrama and Mactaa plants and compared to the international standards required by the World Health Organization (WHO) (2004) revealed values that were lower than the standards in force, except for a slight increase in chlorides in drinking water obtained by reverse osmosis (Tables 4 and 5). This final finding is explained by the application of a biocidal agent during seawater pretreatment before desalination (Bessenasse and Belkacem Filali, 2014).

Bacteriological analysis of the drinking water was conducted at both the Kahrama and Mactâa plants. Indeed, assessing the bacterial load in water, even if it is distilled, is critical to ensuring its safety for human use. Total coliforms and *E. coli* are markers used to determine fecal contamination in water. The presence of *E. coli* indicates fecal contamination and poses a major risk to human health. Coliforms and *E. coli* should not be present in drinking water. The results in Table 6 demonstrate a complete absence of total coliforms, *E. coli*, enterococci, and sulfite-reducing clostridium, proof of the effectiveness of both techniques (MSF and RO). These results are consistent with those of Tigrine *et al.* (2023) and Zioui *et al.* (2017).

From an ecological and environmental standpoint, the MSF technique is superior to reverse osmosis because the brines produced by seawater desalination are recycled through the brine recirculation distillation system, resulting in fewer negative impacts on marine fauna and flora. The major disadvantage of MSF technology is the high discharge temperature, however, the temperature at the discharge site is frequently lower and may not be sufficient to have a substantial impact on the macrobenthos (Aljohani *et al.*, 2023).

Additionally, the MSF technological advances consume a lot of energy and have a considerably greater investment cost than reverse osmosis, thus explaining why Algeria preferred membrane systems. Indeed, several membrane technologies have been developed and improved, most notably nanofiltration and reverse osmosis, which have significantly lowered desalination prices (Hamiche *et al*., 2018). A pilot study in Bou Ismaïl (Tipasa Province, Algeria) concluded that using reverse osmosis driven by solar panels yielded an optimal recovery rate of 32% (Tigrine *et al*., 2023).

However, the pioneering Kahrama seawater desalination plant remains functioning since it uses energy evacuated from the power plant whilst additionally supplying potable water to the community. Six membrane stations are under construction, with a drinking water capacity of 300,000 m^3 day^{-1}. These include Fouka 2 in Tipasa, Cap Blanc in Oran, Tighremt in Bejaïa, Cap Djinet in Boumerdès, and Koudiet Eddraouche in El Tarf.

The Bord El Kiffan station in Algiers' wilaya was recently installed and has a drinking water capacity of 10,150 m^3 day day^{-1}. Two further stations are planned: El Marsa in the wilaya of Algiers (60,000 m^3 day day^{-1}) and Corso in Boumerdès (80,000 m^3 day^{-1}) (MWR report, 2024). Algeria has 81 major dams, with a combined capacity of nine billion cubic meters. Among these is the Kef Eddir dam in the Tipaza area (west of Algiers), which plays a critical role by supplying drinking water to three wilayas: Tipaza, Ain Defla, and Chlef.

It is widely recognized that the physicochemical quality of water released by desalination plants, which consists mainly of brine, has a substantial detrimental influence on aquatic life unless extensive purification is performed to meet environmental requirements (Dairi *et al*., 2023; Omerspahic *et al*., 2022; Djoher *et al.*, 2020).

Furthermore, the chemical analysis of reverse osmosis seawater brine revealed that it contains a variety of elements and precious metals, including calcium (77,120 mg L^{-1}), sodium (343,500 mg L^{-1}), lithium (238,800 mg L^{-1}), barium (3.3 mg L^{-1}), cesium (3.4 mg L^{-1}), iron (30.5 mg L^{-1}), and magnesium (238,800 mg L^{-1}) (Khan *et al*., 2021). It would thus be prudent to extract this tremendous potential from the brines produced by desalination before they are discharged into seawater.

It would also be necessary to consider a brine neutralization station before discharge into nature to safeguard the sea's and Mediterranean coast's ecological health. Indeed, salts produced by desalination sectors can be reused on the production site or recovered in industries such as building and glass manufacture (Poirier *et al*., 2023).

Conclusion

Algeria must use seawater desalination as a means of meeting the country's rapidly rising water demands from the agricultural and industrial sectors as well as ensuring that residents of coastal cities have access to clean drinking water. There is now less fresh water available due to climate change, rising drought frequency, and these factors together. Major infrastructure including sewage treatment plants, dams, and seawater desalination stations have been put in place by the government to address this, however, large-scale desalination requires a lot of electric power. This is the driving force for Algeria's present interest in desalination using renewable energy sources. This practically limitless supply of water does, however, affect the ecology. The repercussions are mostly caused by the brines that are created during the desalination process, while chemical emissions from the process also play a part. To preserve the sea's and the Mediterranean coast's healthy ecological condition, consideration is needed to neutralize this brine before releasing it into the environment.

References

1. Abdellah K, KHALDI A (2017). Dessalement de l'eau de mer et impacts environnementaux : cas de la station d'El-Mactaâ. Journal of Water and Environmental Sciences 1:249-253.
2. Aljohani NS, Kavil YN, Al-Farawati RK, Aljohani NH, Orif MI, GhandourahMA, Bahshwan SM, Aloufi FA, Halawani RF, Salam MA (2023). The assessment of environmental parameters along the desalination plants in the Kingdom of Saudi Arabia. Open Chemistry 21(1): 20220274. *https://doi.org/10.1515/chem-2022-0274*
3. Bessenasse M, Belkacem Filali M. (2014). Impact du dessalement sur l'environnement en Algérie. Revue Agrobiologie 6: 75-81.
4. Clayton M. (2011). Santa Paula: a case study in energy efficiency. International Desalination and Water Reuse Quarterly. 20(4): 16.
5. Dairi, S.; Mrad, D.; Bouamrane, A.; Djebbar, Y. and Abida, H. (2023). Wastewater Reclamation and Reuse Trends in Algeria: Opportunities and Challenges. In: "Doklady Earth Sciences". Pleiades Publishing, Moscow, 511(2): pp. 753-760.
6. Djoher A (2020). Desalination Projects in Algeria: What Are the Environmental and Economic Issues of Seawater Desalination? Environment and Ecology Research 8(3): 59-69. *https://doi.org/10.13189/eer.2020.080301*
7. Drif MM, Moudjari R (2022). Energy Security in Algeria: Opportunities and Challenges. Finance and Business Economies Review 6(4): 266-277. https://doi.org/*10.58205/fber.v6i4.127*
8. Drouiche N, Ghaffour N, Naceur MW, Lounici H, Drouiche M (2012). Towards sustainable water management in Algeria. Desalination and Water Treatment 50(1-3): 272-284. https://doi.org/*10.1080/19443994.2012.719477*
9. Dunglas J (2014). Le dessalement de l'eau de mer une nouvelle méthode pour accroître la ressource en eau. Académie d'agriculture de France, pp :10.
10. El Moustapha MLOM, Ahmed SI, Lemine Fajel M (2017). The study of the physic-chemical quality of desalinated seawater by reverse osmosis (case of the Nouamghar seawater desalination unit in Mauritania). International Journal of Advanced Research 5(12): 1125-1135. *https://doi.org/10.21474/IJAR01/6066*
11. Elsaid K, Sayed ET, Abdelkareem MA, Mahmoud MS, Ramadan M, Olabi A (2020). Environmental impact of emerging desalination technologies: A preliminary evaluation. Journal of Environmental Chemical Engineering, 8(5): 104099. https://doi.org/*10.1016/j.scitotenv.2020.141528*
12. Energy UR (2012). Water desalination using renewable energy. IRENA, Abu Dhabi.
13. Gacem Y, Taleb S, Ramdani A, Senadjki S, Ghaffour N (2012). Physical and chemical assessment of MSF distillate and SWRO product for drinking purpose. Desalination 290: 107-114. https://doi.org/*10.1016/j.desal.2012.01.014*

14. Hamiche A, Stambouli AB, Flazi S, Tahri A, Koinuma H (2018). Desalination in Algeria: Current State and Recommendations for Future Projects. Thermo-Mechanics Applications and Engineering Technology 37- 58. https://doi.org/*10.1007/978-3-319-70957-4_2*
15. Himri Y, Rehman S, Mostafaeipour A, Himri S, Mellit A, Merzouk M, Merzouk NK (2022). Overview of the Role of Energy Resources in Algeria's Energy Transition. Energies, 15(13): 4731. *https://doi.org/10.3390/en15134731*
16. JORADP (2011). Décret exécutif 14-94 du 2 Joumada El Oula 1435 correspondant au 4 mars 2014 modifiant et complétant le décret exécutif n° 11-125 du 17 Rabie Ethani 1432 correspondant au 22 mars 2011 relatif à la qualité de l'eau de consommation humaine 2014-03-04. *https://www.fao.org/faolex/results/details/fr/c/LEX-FAOC133820*
17. Khan M, Al-Absi RS, Khraisheh M, Al-Ghouti MA (2021). A better understanding of seawater reverse osmosis brine: Characterizations, uses, and energy requirements. Case Studies in Chemical and Environmental Engineering 4: 100165. https://doi.org/ *10.1016/j.cscee.2021.100165*
18. Kherbache N, Molle F (2023). Causes and consequences of the Macta basin closure, Algeria. International Journal of Water Resources Development 39(3): 382-403. https://doi.org/*10.1080/07900627.2022.2089100*
19. Khordagui H (2013). Assessment of potential cumulative environmental impacts of desalination plants around the Mediterranean Sea. SWIM Final report, Activity 1.3.2.1. *https://www.swim-sm.eu/files/Environmental_Impacts_of_Desalination.pdf*
20. Lee J, Rai PK, Jeon YJ, Kim K-H, Kwon EE (2017). The role of algae and cyanobacteria in the production and release of odorants in water. Environmental Pollution 227: 252-262. https://doi.org/*10.1016/j.envpol.2017.04.058*
21. Mehtougui MS, Kerfouf A, Ardjoum S, Mehtougui F (2018). Assessment of the quality of water discharges from a desalination plant: case of Honaine station (Western Algeria). International Journal of Sciences: Basic and Applied Research 39: 89-95.
a. Algerian Ministry of Water Resources and Environment (MWE). (2024). Annual report.
22. Omerspahic M, Al-Jabri H, Siddiqui SA, Saadaoui I (2022). Characteristics of desalination brine and its impacts on marine chemistry and health, with emphasis on the Persian/Arabian gulf: a review. Frontiers in Marine Science 9: 845113. *https://doi.org/10.3389/fmars.2022.845113*
23. Papa F, Crétaux J-F, Grippa M, Robert E, Trigg M, Tshimanga RM, Kitambo B, Paris A, Carr A, Fleischmann A S (2023). Water resources in Africa under global change: monitoring surface waters from space. Surveys in Geophysics 44(1): 43-93. *https://doi.org/10.1007/s10712-022-09700-9*
24. Piedra J, Rodriguez M, Trillas F, Ricart JE (2019). CAP Djinet Seawater Desalination Plant (Algeria). Case study PPP for cities. *https://doi.org/10.15581/018.ST-523*
25. Poirier K, Lotfi M, Garg K, Patchigolla K, Anthony EJ, Faisal NH, Mulgundmath V, Sahith JK, Jadhawar P, Koh L (2023). A comprehensive review of pre-and post-treatment approaches to achieve sustainable desalination for different water streams. Desalination 116944.
26. Rodier J, Legube B, Merlet N (2016). L'analyse de l'eau, 10ème édition. DUNOD (éditeur), Paris, France. 1579p.
27. Tigrine Z, Aburideh H, Zioui D, Hout S, Sahraoui N, Benchoubane Y, Izem A, Tassalit D, Yahiaoui FZ, Khateb M (2023). Feasibility Study of a Reverse Osmosis Desalination Unit Powered by Photovoltaic Panels for a Sustainable Water Supply in Algeria. Sustainability15(19): 14189. *https://doi.org/10.3390/su151914189*
28. United Nations Environment Program (UNEP). (2017). (DEPI)/MED WG, 439/7.
29. WORLD HEALTH ORGANIZATION (WHO) (2004). Acceptability aspects, chap 10. In: "Guidelines for Drinking-water Quality", third Edition, Geneva, pp: 488–493.
30. Zioui D, Tigrine Z, Aburideh H, Hout S, Abbas M (2017). Brackish and Seawater Desalination by a Pilot-scale Reverse Osmosis. Journal of Materials and Environmental Science 55: 46-49.