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Health risks from desalinated seawater used for human consumption: The case of Honaine Plant (Northwest Algeria)

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Abstract
Background: Honaine desalination plant produces 200,000 m^3/day of drinking water, and applies a reverse osmosis process with sand/anthracite filters for pre-treatment.
Objective: This study aim to explore the quality of treated water (TW) and to address any potential health risks.
Methods: Samples of TW were collected daily, three times during the same period, for one month to investigate the physico-chemical characteristics of desalination. They were analyzed for calcium, magnesium, pH, alkalinity, TDS, free-chlorine, hardness, nitrite and sulfate.
Results: After comparing the standards set by WHO and Algeria, the results showed that the TW of Honaine plant had low-mineral content, with a noticeable deficiency of calcium (21.22 ± 0.6 mg L^{-1}) magnesium (1.74 ± 0.26 mg L^{-1}), and sulfate (0.02 ± 0.01 mg L^{-1}). The levels of chlorine (0.53 ± 0.08 mg L^{-1}) and nitrites (0.003 ± 0.00 mgL^{-1}) were lower than what the guidelines prescribe. The alkalinity and hardness of the water categorized it as being moderately hard. As for the taste, the TDS value (289.24 ± 26.86 mgL^{-1}) suggests that the TW is excellent but the presence of chlorine negatively influences its palatability. The values of alkalinity value (63.73 ± 1.05 mgL^{-1}) and pH (8.42 ± 0.021) of TW remain in line with recommendations. The hardness value (60.32 ± 0.73 mgL^{-1}) shows that TW is moderately hard and softer than standards.
Conclusion: Our findings showed that desalinated TW reflected significant low-mineral content of many healthy elements.
Keywords: Seawater Desalination - physico-chemical parameters - Quality guidelines - Health hazards risks.

1. Introduction

Minerals are food supplements that are crucial to maintain health and metabolic functions. These latter such zinc (Zn), calcium (Ca), magnesium (Mg), iodine (I), etc., are strongly appreciated in trendy healthful diets as they have specific roles in cell physiology. In this context, drinking water is an undeniable source of minerals necessary for human health. However, fresh water is becoming increasingly scarce, hence the need to desalinate sea water. Indeed, fresh-water scarcity is the primary purpose of seawater desalination to supply drinking water in the World. In Algeria, water management becomes the main challenge for a healthy living environment. To meet this challenge, the country relies, among other things (dams, etc.), on its desalination plants in the coastal Wilayas. This rapidly growing source is becoming during these last decades an important one of freshwater for human consumption

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especially in regions exposed to droughts and facing water shortages (1). It is obvious that water quality is based on various physical, chemical and microbiological parameters, and human health is endangered if values exceed or are below the admissible and eligible limits (2). Various research studies set exposure standards or safe limits of chemicals in drinking water. Among the mineral elements (around twenty) known or suspected to be essential for humans, fourteen of them are established as being essential for good health (3). For example, scientific studies showed that water, with adequate concentrations of Ca, Mg, HCO3 and SO4, is protective against cardiovascular diseases, osteoporosis, and premature birth death, reduce cognitive function in elderly people, diabetes and cancers (4, 5, 6, 7, 8). Water treatment processes including seawater desalination followed by re-mineralisation alters the mineral profile of drinking water compared to groundwater (9). Generally, it is assumed that food is the primary source of nutrients and hazardous substances exposures for human. In order to comply with usual standards of nutritional potability and quality, this treated seawater, not well mineralised needs further treatments. Many studies proven that low in mineral drinking water has a negative impact on homeostasis mechanisms, disturbing the hydro-mineral metabolism in the organism (9, 10). During consumption of distilled or de-mineralised water including desalinated seawater, sub-acute health effects appear within weeks to months. These show signs independent of nutritional profile in case of illness, of deep magnesium, calcium or sodium deficiency, of nausea, asthenia, headache, preeclampsia, metabolic acidosis, higher dieresis, leg and abdominal cramps, crumbly nails and hairs (11). Water can also be a source of beneficial food substances, as well as mineral imbalance and / or harmful chemicals (12, 3, and 13). Individuals, who profit of the greatest benefit from drinking water minerals, are those with deficient or marginal intakes from their dietary sources (8). A number of studies indicate that when calcium, magnesium and bicarbonate meet adequate homeostasis in drinking water, they provide a significant health benefit (14). Other scientific studies underlined that the deficiency of calcium and magnesium in water is associated with chronic health troubles as well as amyotrophic lateral sclerosis, preeclampsia in pregnant women, neurological disturbances, metabolic syndrome and high blood pressure (15). In the same way, many studies support that lower total dissolved solids (TDS) point out higher incidence rates of gastric and duodenal ulcers, chronic gastritis, cholecystitis, ischemic heart disease, goiter, hypertension, and nephritis, slower physical growth and more growth defects in children (16, 17). More, chronic consumption of water with low rates of calcium, magnesium, potassium and sodium can have an impact on the tonicity and osmolality of body fluids altering the effective cell volume and blood pressure, thus creating osmotic stress. Effectively, the intake of low-mineral water can trigger a washout of minerals from the body (18, 19). The latter, independently of its origin, can lead to chromosome abnormalities and genome dysfunction which is often a site of cancer development (20, 21). Though, the ingestion of water weakly mineralized can trigger disturbance of extracellular and intracellular electrolyte balances which may cause a spill of large amounts of trace minerals into the urine via the osmo-regulatory processes, feces and sweat (22, 23, and 24). Moreover, the osmolyte dilution effect in extracellular fluids would provoke hypo-tonicity which results to cell swelling as water spreads into them to sustain osmolality balance between the intracellular and extracellular liquid cell compartments (19, 24). These changes lead to an osmotic stress revealing an increase blood volume and pressure which must be promptly avoided by cells (22, 19, and 24).

Algeria, with its twenty seawater desalination plants spread over the 14 coastal wilayas (25), is the sixth country in the World in terms of productive capacity of drinking water by fifteen functional desalination sea-water plants (26). Amongst them, the Honaine seawater desalination plant (Northwest, Tlemcen, Algeria), with a production capacity of 200,000 m3/day, supplies drinking water to 555,000 inhabitants using anthracite sand and cartridge filters and reverse osmosis (RO) techniques.

The objective of this study was to examine the biological values of desalinated seawater quality for human consumption of this plant and its possible health effects. Our hypothesis is that the desalinated drinking water may induce imbalance in mineral profile leading to a susceptibility to physiological changes and/or many diseases.

2. Material and Methods

With a production of 200 000 m3/day, Honaine plant desalination of seawater apply the reverse osmosis process using sand/anthracite filters as pre-treatment. In order to assess the physical and chemical characteristics of desalinated seawater, samples were taken daily during one month and analyzed for pH, total dissolved solids, free-chlorine, total hardness, calcium, magnesium and total alkalinity at the plant laboratory. As for the other parameters such as nitrite and sulfate, analyses were conducted in the Regional Algerian Water Laboratory (ADE) of Tlemcen. The samples were taken 3 times during the same period. pH was measured using a calibrated multiparameter set (HANNA-Combo-Waterproof) and total dissolved solids by HANNA- Hi 991300 multi-parameter. Free chlorine was analyzed with DPD (Diethyl-p-Phenylenediamine) palintest. Total alkalinity measurement was done by titration with HCl and, total hardness and calcium by complexometric titration with EDTA. Magnesium was estimated by the difference between hardness and calcium content. As for nitrite and sulfate, analyses were carried out using a spectrophotometer type ODESSEY / HACH. DR 2500.

3. Results

In accordance with the Algerian and WHO guidelines, results will be focused especially on health risk elements on the basis of minimum, maximum and average values (Figure 1), and recommended concentrations of minerals in drinking water as proposed by Algerian and WHO guidelines (27, 28), (Table 1).

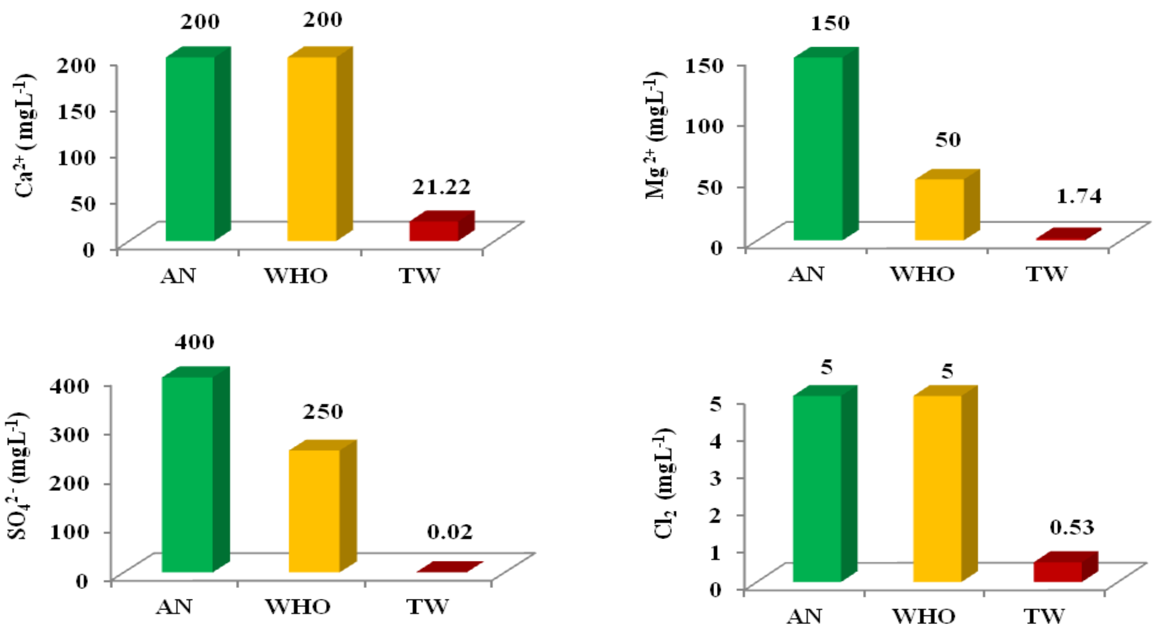
Calcium levels in desalinated treated seawater scale from 20.04 to 22.44 mg L-1 (Average: 21.22 mg L-1; SD: 0.6 mg L-1). These last are below the recommended standards of 200 mg L-1 and 100 to 300 mg L-1of the aforementioned standards. Magnesium concentrations are extremely low and vary from 1.42 to 2.37 mg L-1 (Average: 1.74 mg L-1; SD: 0.26 mg L-1). They are lower compared to the norm values recommended by the aforementioned guidelines.

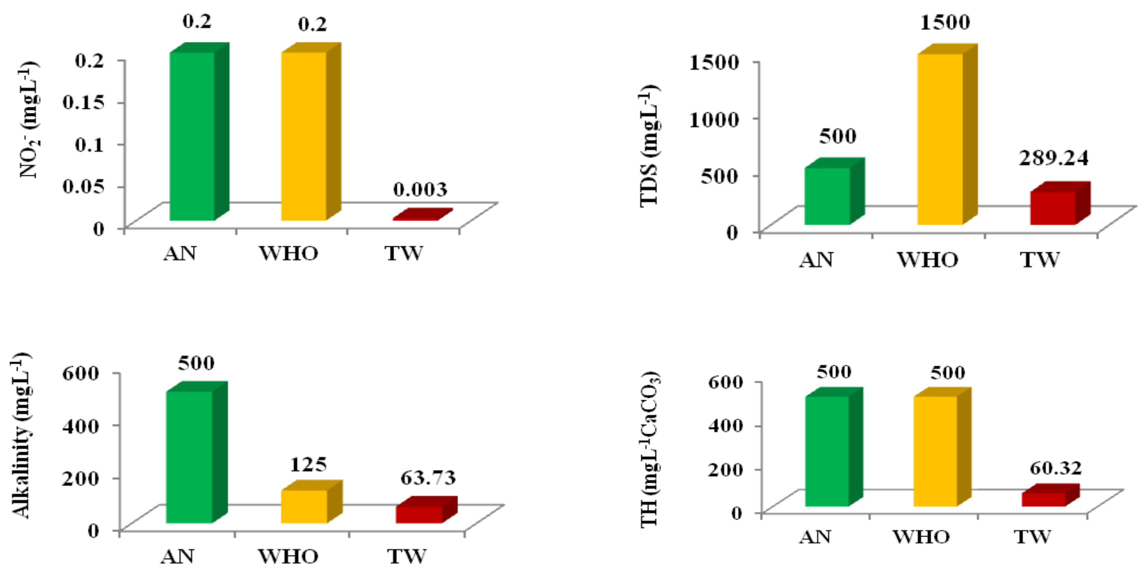
Sulfate levels of the treated seawater range from 0.01 to 0.03 mgL-1 (Average: 0.02 mgL-1; SD: 0.01 mgL-1) and are below the guideline values of 400 and 250 mgL-1 recommended by the Algerian and the WHO standards, respectively. Chlorine concentrations vary from 0.40 to 0.70 mgL-1 (Average: 0.53 mgL-1; SD: 0.08 mgL-1). Chlorine content of the treated water is slightly lower than the recommended standards. Concentrations of nitrites in the treated water scale between 0.001 and 0.01 mgL-1 (Average: 0.003 mgL-1; SD: 0.00 mgL-1). NO2- content is rather lower than the above mentioned standards (3 mgL-1), (58). The total dissolved solids (TDS) values (260-380 mgL-1; Average: 289.24 mgL-1; SD: 26.86 mgL-1) in TW of Honaine Plant is in line with Algerian and WHO standards. The total alkalinity values (61-65.88 mgL-1; average 63.73 mgL-1; SD: 1.05 mgL-1) of TW remain in line with Algerian and WHO recommended limit standards. The total hardness value ranges from 60 to 62 mgL-1 with an average of 60.32 mgL-1 and a SD of 0.73 mgL-1, (Figure 1).

4. Discussion

The reverse osmosis technique used for desalination of seawater for human consumption is a natural process involving fluid flow through a semi-permeable membrane barrier. It is selective in that the solvent passes through the membrane faster than dissolved solids. The difference in speed of passage results in solvent-solid separation. The direction of solvent flow is determined by its chemical potential which is a function of pressure, temperature and the concentration of dissolved solids. Desalination of seawater followed by remineralisation affects the mineral balance of drinking water compared with groundwater, with a negative impact on long-term health. The mineral profile of desalinated water represents a vital factor in the health of the population.

Fig. 1 Physical and chemical parameter values of TW at Honaine plant.





The obtained results showed that the profile of calcium was lower than that recommended for the hydromineral balance of health (Figure 1). Previous studies have shown that these results were similar to those found at the Souk Tleta desalination plant (Northwest, Algeria) in 2017 (29).

Table 1 Minimum and maximum values of TW at Honaine plant

Parameters	**Units**	**Minimum**	**Maximum**	**Standards**	**NA / WHO**
Calcium (Ca)	mgL^{-1}	52.1	56.1	200 100-300	NA (2011) WHO (2011b)
Magnesium (Mg)	mgL^{-1}	1.42	2.37	150 50	NA (2011) WHO (2006)
Sulfate (SO_4^{2-})	mgL^{-1}	0.01	0.03	400 500	NA (2011) WHO (2006)
Total Dissolved Solids (TDS)	mgL^{-1}	260	380	<1000	WHO (2006)
Hardness (TH)	mgL^{-1} $CaCO_3$	60	62	200ppm	NA (2011)
Alkalinity	mgL^{-1} HCO_3^-	61	65.88	500	NA (2011)
Free chlorine (Cl_2)	mgL^{-1}	0.40	0.70	5	NA (2011)
pH	-	8.35	8.45	≥ 6.5 and ≤ 9 6.5 -9.5	NA (2011) WHO (2006)
Nitrites (NO_2)	mgL^{-1}	0.001	0.1	0.2 3 (short term exposure)	NA (2011) WHO (2006)

Its potential benefits have recently been revealed in squamous cell cancer of the esophagus (30), cardiovascular diseases (31, 32), colon carcinoma (33) and hypertension (34). The protective effects against osteoporosis (35, 36) and bone fractures (37) have been strongly emphasized. Current recommendations call for strengthening food intake before the use of dietary supplements. The calcium-rich water can then balance the calcium intakes and compensate the individual impairments.

In the same context, the results showed that the magnesium level was lower than that advisable for the mineral and water balance of the human body (Figure 1). Comparable studies have highlighted that magnesium levels were similar to those recorded at the Souk Tleta desalination plant (Northwest, Algeria) in 2017 (29). In drinking water, magnesium comes out as hydrated ions which are readily taken in than magnesium food (38). Low Mg content in drinking water can exacerbate pre-existing dietary imbalances. This mineral is embroiled in the activation of over three hundred (300) enzyme systems (39, 40). It is considered as an enzyme; Na+/K+ ATPase activator and modulates cell energy metabolism, cell membrane ion transport and vascular tone. Deficiency of this mineral provokes a falloff in the levels of intracellular potassium and a raise in calcium concentration (38). The deficiency of magnesium can induce the neuromuscular hyper-excitability which is reflected in the signs of latent tetany (39, 40). Other studies suggested its involvement in many diseases ranging from simple faintness such as weariness to sickness such as diabetes type 2 (41), coronary insufficiency that can lead to myocardial infarction (42), various cardiovascular events (43), metabolic syndrome (34) and osteoporosis (44). For around 50 years, epidemiological studies in numerous countries have pointed out that water weak in calcium and magnesium, i-e soft water and water low in Mg are associated with the rate increase of morbidity and mortality from cardiovascular disease when compared to hard water and water high in Mg (45). It is admitted that calcium and to a lesser extent, magnesium in water and food are known for their anti-toxic functions. They are involved in the prevention of the absorption of various toxic elements such as cadmium and lead via small intestine into the blood, or throughout the competition for binding sites or across direct reaction leading to formation of a non-absorbable compound (46, 47). Though this beneficial effect is restricted, it should be not disregarded. Populations served with weakly mineralized water are confronted to substantial risk in terms of the harmful impacts linked to the exposure to toxic substrates vis-à-vis to those supplied with a water of average mineralization and hardness. A deficiency of calcium or magnesium in drinking water may set off lower bone mass density, high frequency of fracture and disrupted bone development in children (48-50).

Regarding sulfate levels, the results revealed lower concentrations compared with the aforementioned standards (Figure 1). Earlier studies carried out at other desalination plants showed that sulfate profile was comparable to those revealed at the Souk Tleta desalination plant (Northwest, Algeria) in 2017 (29). Note that sulfate is the major source of sulfur which is crucial for a number of proteins. Its insufficiency in drinking water could cause slowing of hair and nail growth for consumers. Ions forms (SO42-) are implied in conjugation reactions resulting into the production of 3-phospho adenosine 5'-phospho-sulfate. The latter is transferred to specific acceptors such steroid, bile acids, catecholamine, xenobiotics, etc., and then transported out via sulfotransferases enzymes. Such reactions are typically involved in the composition of the cartilage (51). It is crucial to underline the mechanisms of the detoxification of sulfur-containing amino-acids via conjugated reduced glutathione leading to the draining of electrophilic species implying glutathione-S-transferases enzymes (52).

As for chlorine, which was in slight decline than the recommended standards (Figure 1), it is well known that it represents a powerful oxidant or free radical which can affect the liver and kidney, respiratory and cutaneous systems. Besides its role of disinfectant of drinking water, it is blamed for being the source of spontaneous abortions, congenital malformations or insufficiency of birth weight (53). More, several studies showed a positive correlation between chlorinated drinking water, trihalomethane (THM) exposure and bladder cancer cases (54, 55). According to the Environment Protection Agency (EPA), 2 to 17 % of bladder cancers could be assigned to chlorination (56). Note that these studies are the subject of numerous controversies and had to be deepened to conclude on these impacts. It is important to emphasize that, the effect of drinking desalinated water is not restricted to single component; it could be an overall impact for long term period. In this context, Allam (57) has reported that drinking desalinated sea water for a long time generates abnormalities recorded in the brain, kidney and liver tissues and behaviours after drinking desalinated sea water prenatally of rats. These changes could be due to oxidative stress such as reduced glutathione, lipid peroxidation, peroxidise and superoxide dismutase.

The concentrations of nitrites prove to be lower than the standards mentioned above (Figure 1). Nitrites or nitrous nitrogen (NO2-) represents a less oxygenated and less stable form, reflecting a toxic form of the passage between nitrates and ammonium. It is known that nitrate are secreted by the salivary glands and converted to nitrite in the oral cavity and absorbed in the small intestines. In the stomach, nitrite can interact with secondary amines and amides to form N-nitrosoamines and N-nitrosoamides. These latter are among the strongest carcinogen factors (59-63).

The total dissolved solids (TDS) characterize the association of small amounts of organic matter and inorganic salts present in treated water. The main components are calcium (Ca), magnesium (Mg), sodium (Na), and potassium cations (K+) and carbonate (CO32-), bicarbonate (HCO3-), chlorine (Cl), sulphate (SO42-), and nitrate anions (NO3-), resulting from the natural contact from rocks and soil (58). The TDS values in desalinated water of Honaine Plant were in line with the recommended standards (Figure 1). According to many studies, high value of TDS is inversely linked to increased morbidity and mortality rates, i-e potential danger of soft treated water largerly reported to cardiovascular diseases (64). The total dissolved solids concentration with some essential elements are

required to insure an acceptable taste and prevent pipe corrosion and, preclude the chronic harmful effects on health coming from the long term consumption of treated seawater (15). According to the TDS value, drinking water palatability is categorised as unacceptable (≥1200 mgL-1), poor (900 - 1200 mgL-1), fair (600 - 900 mgL-1), good (300 - 600 mgL-1) and excellent (<300 mgL-1). Insipid taste of water due to hugely feeble concentration of TDS is also unacceptable (58). Depending on these TDS levels, TW of Honaine Plant has excellent palatability compared to Algerian and WHO Standards. In public health, the effect of TDS components is in general reported under hardness.
The total alkalinity results of TW showed equivalent values with recommended limit standards (Figure 1). Its value gives an estimate of nonacid constituents of water. When the staple constituents in TW are restricted to salts of calcium and magnesium, alkalinity values are equal to those of hardness. Alkalinity in TW is linked to pH, total solids, calcium, magnesium, hardness, sulfates and potassium ions (64). Effectively, alkalinity value in TW is close to that of hardness. The latter reflects the total calcium and magnesium concentration presented as calcium carbonates ($CaCO_3$). It is considered as an indicator in water quality in terms of precipitating soap. It is related to corrosivity and taste. Note that, corrosivity is primarily associated to alkalinity, pH, total dissolved solids, dissolved oxygen and hardness. Corrosive water alter flavor, color, turbidity, and metal content when metal pipes are corroded (64, 65). The total hardness include both temporary and permanent hardness determined by calcium and magnesium concentrations, according to which water is classified as soft or hard and very hard (66). Note that, these elements are the principal precipitating and significant ions in hardness value (64). Referring to hardness, drinking water with calcium carbonate is ranked as very hard (>180 mgL-1), hard (120-180 mgL-1), moderately hard (60-120 mgL-1) and soft (<60 mgL-1) (67).
According to the total hardness level (Figure 1), TW from Honaine plant desalination is moderately hard and softer than Algerian and WHO recommendations. Significant findings indicated an inverse relation between the total hardness of drinking water and the incidence of cardiovascular diseases (66, 38, and 64). Likewise, more scientific investigations in Taiwan underlined a negative significant association between morbidity/mortality of various types of cancer, hardness and calcium (38). In the same way, other studies, revealed that total hardness and magnesium were closely linked to lower cancer risks namely breast, colorectal, esophageal and prostate in Taiwan and malignant neoplasms in Slovakia (24, 15). The interpretation and enlightenment of the cancer development mechanisms via low mineral water, was adduced by Nriagu et al., (24). More, it has been factually admitted that the cause of corrosion, scaling or taste of water were practically caused by high levels of calcium and magnesium or total hardness in treated water (15).The pH value (8.37-8.45; average: 8.42; SD: 0.021) of Honaine plant desalination TW is in line with Algerian guidelines and WHO Standards. The interactions of hard water with alkalinity and pH can generate increase soap consumption and tartar deposit in the water supply system, covering metal surfaces and reducing the efficiency of heat exchangers. Fresh water, which is unstable, has the ability to cause corrosion of metal surfaces and pipes, which can lead to the production of heavy metals, such as cadmium, copper, lead and zinc in drinking water (68).

5. Conclusions

Treated seawater from desalination is an alternative source to provide drinking water for human consumption. In the organoleptic aspect, palatability of TW revealed as excellent according to TDS value, in contrary, it is negatively influenced by chlorination. Our findings showed that desalinated TW reflected low-mineral content (eg. calcium, magnesium and sulfate). The consumption of such water can alter the osmotic pressure and the hydromineral balance in the intracellular and extracellular compartments, favoring a predisposition to cellular abnormalities. More, sulfate, this important element, takes part in the detoxification mechanisms via liver enzymes of the body. Concerning nutritional status, the most credible significant contributors to dietary intake are magnesium and calcium. Note that well-regulated TW could in some circumstances contribute to nutritional balance, reducing some metabolic diseases. The practice that limestone and dolomite are usually added to introduce calcium and magnesium into desalinated water may be profitable to improve mineral profile and then safety nutrient intake and, their use had to be optimized in further investigations. Finally, the growing consensus among epidemiological findings alongside clinical nutrition evidence is sufficiently substantiated to evoke a new focus against exposure standards or safe limits concerning physical and chemical parameters for treated desalinated seawater intended for human consumption.

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Conflict of Interest

There is no conflict of interest to be declared.

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