Examining the Influence of Desalinated Water on Iodine Concentration in Tap Water in Israel

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Abstract

Introduction: In Israel, desalinated water is a major source of drinking water. Previous studies have suggested that the levels of iodine in water provided by authorities may not accurately reflect the levels reaching end-users.

Materials and Methods. We analyzed 21 tap water samples collected from different localities across Israel, 13 post-treated desalinated water samples from three of the largest Israeli desalination plants, and several natural water samples. An improved method of ICP-MS developed in our laboratory was used to analyze the content of iodine and other macro-elements, and determination of iodine was performed in alkaline media.

Results: Our results showed that it is possible to distinguish between sample groups based on iodine concentration, water hardness, and Ca/Mg ratio. The median iodine concentrations for four groups of tap water samples ranged from 0.3 to 12.3 µg/L, which is lower than the concentrations previously reported by other researchers in Israel. Based on typical consumption, the water samples can provide no more than 3.39% of the recommended dietary allowance level for iodine. The analysis of post-treated desalinated water samples indicated that these waters comply with industrial specifications but contain only trace concentrations of iodine and much less magnesium than recommended by different public health authorities for public consumption of drinking water.

Conclusion: The total iodine concentrations found were lower than several observations reported in previous years in the literature. There are currently no strict

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regulations regarding iodine and magnesium levels in drinking and/or softened (desalinated) water, but the intensive desalination plant application is already exhibiting a negative impact on public health. Further investigations are needed, but the present study provides useful insights for developing an effective policy to ensure adequate iodine supply for the population of Israel through drinking water.

Keywords: sea water desalination, total iodine, tap water, drinking water quality, ICP-MS[1]

1 Introduction

Seawater desalination is a highly reliable method for augmenting local water supplies, as seawater is abundantly available and not subject to climate or political dependencies [1].

Desalination of seawater is developing worldwide, especially in the Middle East which is the most water-scarce region in the world.

The Kingdom of Saudi Arabia produces approximately one-tenth of the world's daily desalinated water output. The United Arab Emirates has become the second-highest seawater desalination country, with a capacity of 8.4x10^{-6} m^3 per day [2].

According to Al-Khatib et al. (2009), in the Gaza Strip (Palestinian Authority), several governmental desalination plants (DSPs) are in operation, with productivity ranging from 50 to 2000 m^3 h^{-1}. Additionally, 17% of Gaza Strip residents use small Reverse Osmosis (RO) units in their homes, producing about 20 L per day. Unfortunately, a significant percentage of this desalinated water does not meet standard limits for chemical and microbiological quality [8].

In Egypt, as of 2020, 76 plants have been completed and are fully operational, with a daily capacity 850x10^3 m^3 per day [2].

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[1] **Abbreviations:** RO - Reverse Osmosis; DSW - desalinated water; DSP - desalination plant; NWC - National Water Carrier; RDA - recommended dietary allowance; EAR - estimated average requirement; TW – tap water; SWRO - sea water reverse osmosis technology; CV – coefficient of variation; CI95% - confidence interval 95%;

Desalination plants in Cyprus produced 68.7 million m^3 of water in 2017, resulting in 160 ktons of CO_2 equivalent emissions, which is about 2% of the total national emissions. Using data from governmental and corporate sources, as well as field surveys, Xevgenosa et al. (2021) assessed the environmental impacts of seawater desalination in Cyprus, which relies on reverse osmosis technology, and revealed its negative effects on carbon emissions and seagrass health [3].

Jordan and Syria, neighboring countries close to Israel, both face significant water challenges. Jordan struggles with limited water resources worsened by climate change, refugee influx, and poor planning. Two-thirds of its water comes from aquifers, but this source is unsustainable, with groundwater extraction exceeding replenishment. Jordan is considering the Red Sea-Dead Sea Water Conveyance Project, a joint effort with Israel to desalinate seawater from the Red Sea for Amman and stabilize the shrinking Dead Sea. Environmental impact and feasibility concerns surround this project [4].

Syria is also facing a severe water crisis, exacerbated by ongoing conflict. The war damaged water infrastructure, reduced access to safe drinking water, and increased waterborne disease risks. Syria heavily relies on groundwater and shared rivers, impacted by climate change, pollution, and transboundary disputes. The country’s capacity to address water challenges is limited and relies on humanitarian aid and cooperation with neighbors. As a potential solution, Syria is exploring a pipeline project with Turkey to desalinate Mediterranean seawater for irrigation and domestic use in the northern region. However, this project demands careful consideration due to its political, economic, and environmental implications [5].

It may be concluded that along with the advantages of the intensive use of desalinated water, both environmental and public health problems are common to Israel and its neighbors.

In 2020, approximately 585 million m^3 of water were desalinated in the State of Israel. The "Soreq A" plant provided 150x10^6 m^3 per year, the Hadera plant 127x10^6 m^3, the Ashkelon plant 118x10^6 m^3, the Palmachim plant 90x10^6 m^3, and the Ashdod plant 100x10^6 m^3. Additionally, several smaller DSPs have been operating in recent years. [1]. In Israel, desalinated water is not the sole source of potable water, but it plays a crucial role as an essential water source. The government-owned water supply and distribution company, "Mekorot," operates the National Water Carrier (NWC) responsible for pumping water from

Lake Kinneret, filtering it, and delivering it downstream to the south. Throughout its course, the water is blended with groundwater from over 1,000 wells across the country, and this blend is supplied to various consumers statewide. [6]. Starting from the year 2000, when the country's desalination plan began [1], the proportion of desalinated water added to the supplied blend has been increasing each year. The current output of the five largest desalination facilities in Israel stands at 585 million m^3 per year. In 2019 and 2020, concession agreements were signed for two additional plants [1]. After the completion of these plants, the overall production capacity is expected to increase to 885 million m^3 per year, accounting for approximately 85-90% of the annual municipal and industrial water consumption [7]. According to Bera et al. (2022), desalinated water currently constitutes 75% of the water used for domestic purposes in Israel, with the ultimate goal being to achieve a 100% water supply for domestic use through desalination [8]. This fact poses a public health risk. The risk of consuming desalinated water lies in its reduced levels of vital minerals like magnesium, calcium, and sulfate, which are essential for human health. For example, magnesium deficiency can cause cardiovascular problems, hypertension, and even sudden cardiac death in humans [9].

Communities supplied with tap water from NWC are considered to be almost entirely reliant on desalinated water (e.g., Rehovot). At the same time, there are still several large cities (e.g., Kfar-Saba) and a number of small settlements that are primarily supplied by local well water. [10].

Desalinated water is not suitable for direct use as it is prone to corrosion and has adverse effects on human health and the environment. Re-mineralizing desalinated water to control its pH, alkalinity, and hardness is considered an important step in post-treatment [11].

Minerals in drinking water tend to be present as free ions, making them more readily absorbed than when present in food [9]. One of the most important micro-elements in the human diet is iodine (I). Iodine is needed for thyroid hormones, which regulate carbohydrate and fat metabolism, reproductive function, growth, and development. Iodine deficiency causes goiter and mental retardation. [12].

The iodine content of most food sources is low and can be affected by soil iodine concentrations, irrigation water concentration, and that of fertilizers. Most foods provide 3–75 µg iodine per serving. Seafood has higher concentrations of iodine since marine animals can concentrate iodine from seawater [13]. Seaweed contains 16–2984 µg per serving. The other iodine-rich foodstuffs are cod (99 µg per serving), dairy products (56 µg), grain products (45 µg), and eggs (24 µg) [14].

The RDA (recommended dietary allowance) and EAR (estimated average requirement) for iodine are 150 and 95 µg per day (for female and male humans aging 14-50 years) [13].

Unfortunately, the state of Israel does not employ iodine prophylaxis (e.g., universal salt iodization), and until recently, the prevailing view was that the country was iodine-sufficient due to the proximity of its population to the Mediterranean Sea [15]. However, several national surveys conducted in Israel have led to the conclusion that most Israelis, adults and children alike, do not consume sufficient iodine [16].

Desalination typically removes almost all of the water's iodine and could increase the risk of iodine deficiency disorders [17]. The iodine content in drinking water influences human consumption directly and also via the food chain (affecting iodine concentration in dairy products and meat) [18]. Tap water is an important source of drinking water in the diet, and it is preferable for resource efficiency, whereas bottled water manufacturers have a particularly high environmental impact [19].

The mean concentration of total iodine in drinking water in the USA is 4 µg I L^{-1}, with a maximal reported value of 18 µg I L^{-1} [12]. According to a survey conducted in 2005-2006 among 2362 U.S. residents, the median iodine level in tap water they consume was found to be about 4.55 µg I L^{-1} [20]. Rasmussen et al. (2000) found the following range of iodine concentration in tap water in 41 localities in Denmark: 1 – 30.2 µg I L^{-1} [21].

There is a lack of data regarding the iodine concentration in Israeli tap water [22]. According to the Israel Ministry of Health (2017), drinking water from different non-desalinated sources contains varying concentrations of iodine (2-150 µg I L^{-1}), but these results do not reflect the actual situation with the concentration of iodine in end-user taps [23]. Barnett-Izhaki et al. (2022) have noted that non-desalinated water in Israel has relatively low iodine levels (4-20 µg I L^{-1}) [24].

Ovadia et al. (2013) demonstrated a possible iodine deficiency among 76% of the participants examined in the Ashkelon District in Israel. This percentage was higher than that reported a decade ago [17].

In a study conducted by Barnett-Izhaki et al. (2022), the urinary iodine concentration (UIC) of 166 healthy children aged 4–12 years was measured in 2020–2021. It was found that the population's iodine status has not improved in the five years that have passed since inadequacy was first identified. The median UIC found (80.1 μg L^{-1}) is below the WHO adequacy range [24].

Investigating data gathered by Israel's national health security program, Simantov (2020) found that DSW adoption results in a significant negative impact on serum blood magnesium levels, thyroid function hormones, and an increase in the use of drugs related to cardiac disease [10].

In 2016, we conducted a study on drinking water quality in Israel, measuring various minerals in 26 locations, and compared the data to a 2008 campaign before the introduction of desalinated water in the network. About half of the 2016 locations presented magnesium deficiencies, whereas none were found in 2008 [25]. We reasonably supposed that there is a similar situation with the iodine status of Israeli tap waters.

When the DSP is the sole or primary water source in the district, adjacent water consumers will receive low-mineral content water continuously. However, when different sources of water are used by the local supplier, water quality for the end users will probably be irregular [9]. It should be noted that desalination is cost-effective only when operated continuously; hence, desalinated water is planned to be the base water resource for supply, while other resources (ground and surface waters) are added only at peak demand [26].

In our previous study mentioned above [25] we found that the daily dynamics of magnesium were high in Rehovot and Ashkelon (big cities of the Central and South Districts) and were low in Kibbutz Ha-Goshrim (a small settlement in the North District). The stable mineral composition of the tap water points to constant natural water sources, whereas significant daily changes point to mixing water of different quality from several sources.

The decrease in tap water hardness is one of the consequences of the intensive use of DSW. According to Dreizin et al. (2008), after the operation of the Ashkelon plant, the water hardness was measured in the following cities: Beer Sheeba, Kiryat Gat, Ofakim, Sderot, and Netivot, which are downstream of the Ashkelon DSP. It was found that as a result of blending between DSW and water from NWC and local wells, the hardness decreased from 19 to 50% depending on the city and season [27]. Tap water softening has numerous economic benefits, such as extending the lifetime of solar panels, which may save around 60 million USD annually for all of Israel [6]. On the other hand, the lack of important minerals in tap water softened by DSW addition is a public health concern.

The objective of the current survey was to quantify the iodine status of tap water in different districts of the State of Israel and compare it with the post-treated DSW composition supplied to the national network by DSPs.

2 Materials and methods

During the period of May-June 2021, 21 tap water (TW) samples were collected from different Israeli cities or villages by volunteers (Table A1, Supplementary material, Appendix A). The samples were collected from households and non-residential premises (scientific laboratories, offices, etc.).

Thirteen samples of post-treated DSW were obtained from 3 large DSPs in Israel: Ashkelon, Hadera, and Palmachim plants. These plants process water using seawater reverse osmosis technology (SWRO) [28].

Several miscellaneous samples were taken from the natural water sources: the Mediterranean Sea, Lake Kinneret, the rivers Koren and Ha-Kibbutzim.

About 50 mL of the tap water was placed into a polypropylene flask and delivered to the laboratory on the same day. For iodine analysis, the samples were stored "as is" at 4 ºC for less than 2 weeks (the stability of iodine under these conditions was previously investigated by Rosen et al., 2022 [16]). For macro-element analysis, sample aliquots were acidified with 65% HNO_3 (to 1% HNO_3 in each sample) and then stored at room temperature.

The method for determining iodine in drinking water using ICP-MS was developed, validated, and tested in our laboratory, and the results were previously published [16]. In summary, the samples were diluted twice with an alkali matrix (2% NH_4OH+0.1% EDTA). It should be noted that the method's limit of quantification (LOQ) <0.1 µg I L^{-1}, as reported by us previously, takes into account the sample dilution (at least twice) and possible memory effect that may occur when measuring relatively high-concentration samples (more than 1 µg I L^{-1}). However, if the sample introduction system is clean and free of iodine residues, the instrument LOQ derived from calibration (0.1-5 µg I L^{-1}) is 0.009 µg I L^{-1}, and the recoveries of control standards at 0.025 and 0.05 µg I L^{-1} are 85.6% and 97.2%, respectively. Thus, it is possible to measure concentrations of about 0.02 µg I L^{-1} with higher reliability in the lowconcentrated samples diluted by a factor of 2 and achieve an actual method LOQ of 0.04 µg I L^{-1}, which is even slightly better.

The measurement details of the macro-elements (Ca, Na, Mg, K, and S) using the ICP-OES instrument are described in the same reference [16].

The pH of the water samples was determined using a 905 Titrando instrument (Metrohm), equipped with a combined pH electrode (Unitrode, Metrohm Company).

Statistical calculations were performed using JMP 16.1.0 (SAS Institute, USA).

3 Results

3.1 Tap water

All results of the iodine concentrations measured in TW samples were ranked from low to high values and were separated accordingly into 4 groups that differed significantly (Fig. 1). The median values for all 4 groups ranged from 0.3 to 12.3 µg I L^{-1} (Table 1). Distinctively, group C demonstrated higher concentrations of Mg and Ca than the other groups (Fig. B1, Supplementary material, Appendix B), and as a result, this group exhibited the highest water hardness (Table 2). Therefore, group C was treated separately in further correlation analysis.

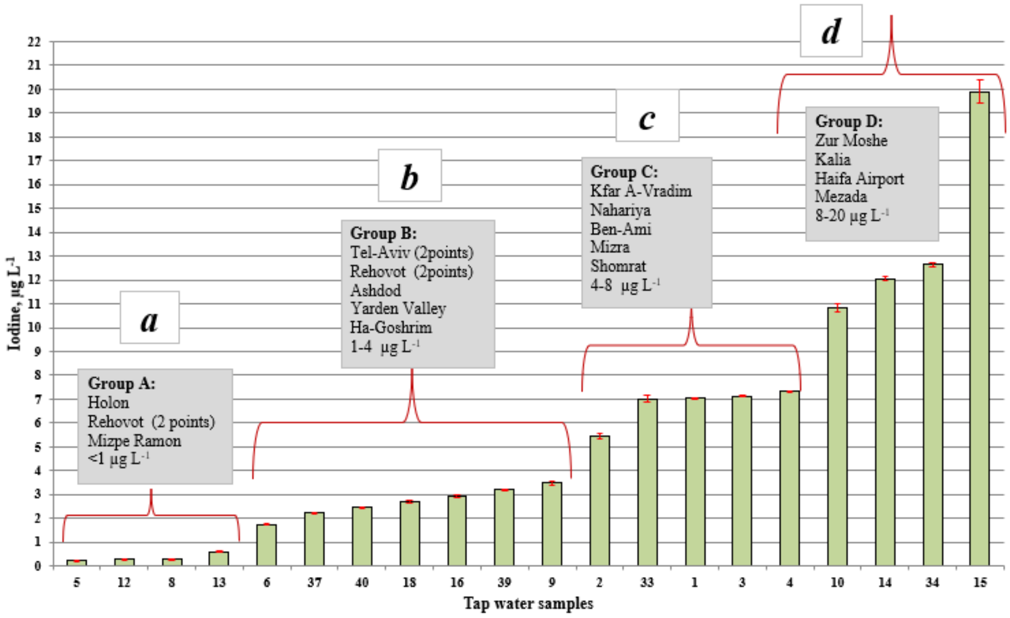

Fig. 1 Iodine concentrations in tap water samples observed across Israel (groups with different lower-case letters are significantly different at $p<0.05$ according to post-hoc Tukey-Kramer test).

In their study on developing models for blending water from different sources in the city network, Avni et al. (2013) used Mg concentration as a measure of water quality and identified the range of 10-24 mg L^{-1} as optimal for domestic and agricultural consumption [2]. Among our grouped samples, only groups C and D fall within this range of Mg concentrations. (Fig. B1).

The EU Drinking Water Directive recommends an optimum concentration range for Ca and Mg in desalinated water from a health perspective, which is 40-80 mg L^{-1} for Ca and 20-40 mg L^{-1} for Mg [11]. Our observations for tap waters in groups A and B fall below these thresholds (Fig B1).

Koren et al. (2018) found that the mean Mg level in the tap water of Israeli communities supplied with DSW was 5.4 mg L^{-1} (similar to our results for groups A and B), compared to 25.1 mg L^{-1} in tap water from naturally occurring sources (similar to our results for groups C and D) [14]. In our previously published results from the survey conducted in 2016, nearly half of the analyzed samples of Israeli tap water (13 out of 28) exhibited Mg levels lower than the minimal content recommended by the World Health Organization (WHO) (10 mg L^{-1}). However, an observation made in 2008 revealed that in seven of the locations tested, the tap water had a magnesium level higher than 10 mg L^{-1} [25].

The samples of group C are mostly from villages in the north region of Israel, where water is supplied from local wells and/or from Lake Kinneret without DSW addition. The samples from groups A and B mostly originated from the central and south regions of Israel (Fig. B2).

The samples of group D are also from the north district, excluding "sample 15" which is from the south. Groups C and D were ranked according to their hardness as "very hard", whereas groups A and B were "moderately hard". The hardness of TWs in groups C and D is significantly ($p<0.05$) higher than in A and B (Table 2).

Using a multiple regression model, we explored possible correlations between iodine concentration in tap water and other measured parameters (hardness, pH, and macro-element concentrations). In the pooled data of groups A, B, and D, iodine concentration correlated positively and significantly with all parameters except pH and Ca concentration (Table B1). In group C, iodine correlated only with Na and S concentrations.

Groups C and D demonstrated the following median values of Ca/Mg ratio: 2.56 and 2.44, respectively (Table 4), which fall within the recommended range of 2-3 [11]. For groups A and B, this ratio is much higher (36.2 and 14.6, respectively), indicating the intensive addition of DSW with low Mg concentrations in the central zones of Israel.

The difference in water chemical composition determined the variation in pH levels among the sample groups. The waters from group C are significantly more alkaline than other tap water samples. Additionally, waters from group C are significantly more alkaline than the desalinated seawater from all three plants (Table B2). This also indicates a lower percentage of more acidic desalinated seawater in the networks of C and D districts.

Comparing the total iodine concentration in tap water samples with Lake Kinneret water, we may conclude that groups C and D probably contain a higher percentage of water from this source than from others (Table B3). The hardness of C group waters is much higher than that of Lake Kinneret water, which suggests the use of local well water. Our data presented in Table B3 are in agreement with the values published by Dreizin et al. (2006) [29] which approximately estimated the hardness of natural waters in Israel as 250-350 mg L^{-1} (our range is 190 - 632 mg L^{-1}), and Lake Kinneret water (the main source of NWC) as 200-245 mg L^{-1} (our result is 245 mg L^{-1}).

Because the quantitative ratios among water inputs from different sources in the network vary with time [9], we evaluated the hourly and annually dynamics of iodine concentration in tap water. The hourly dynamics were measured in 2 Israeli cities: Holon (the central district) and Rehovot (the central-south district). The tap water samples were collected from the very same faucet in June 2021 during 24 hours with a 4-hour interval (Fig. B3). The CI95% range was 0.22-0.70 and 5.95-7.42 µg I L^{-1} with median values of 0.39 and 6.48 µg I L^{-1} in Holon and Rehovot, respectively. The mean values between the two cities were found to be significantly different ($p<0.0001$). The concentration dynamics may be characterized by CV values that were 12% and 56% for Holon and Rehovot, respectively, which were close to the same parameter measured for Mg [25]. Rehovot is known as a city supplied almost entirely by DSW (more than 80%) [10] which explains a low iodine content in the tap water.

Iodine concentration was measured for 3 years (several times per year) at the very same tap in Rehovot city (located at the campus of the Faculty of Agriculture, Food, and

Environment). The tap was connected to the main city network. The CI95% of the observed values was 2.18 - 5.68 µg I L^{-1}, with a median value of 2.9 µg I L^{-1}. No significant difference was found among the years, likely due to the high variability within the data of each year (Fig. B4). The coefficient of variation (CV) for this period was 151%.

The hourly and annually median values for TW iodine concentration in the same city (Rehovot) are quite different (0.39 and 2.9 µg I L^{-1}, respectively) and much lower than the minimal value (5-50 µg I L^{-1}) proposed by Rosborg et al. as a risk-reducing iodine content for drinking water [12].

3.2 Post-treated desalinated water

The samples of post-treated desalinated seawater were obtained from 3 Israeli DSPs: Ashkelon, Hadera, and Palmachim. The iodine concentration differs significantly among the three DSPs (Fig. 2). The median values of the total iodine content are 0.776, 0.053, and 0.166 µg I L^{-1} for Ashkelon, Hadera, and Palmachim DSPs, respectively (Table 1).

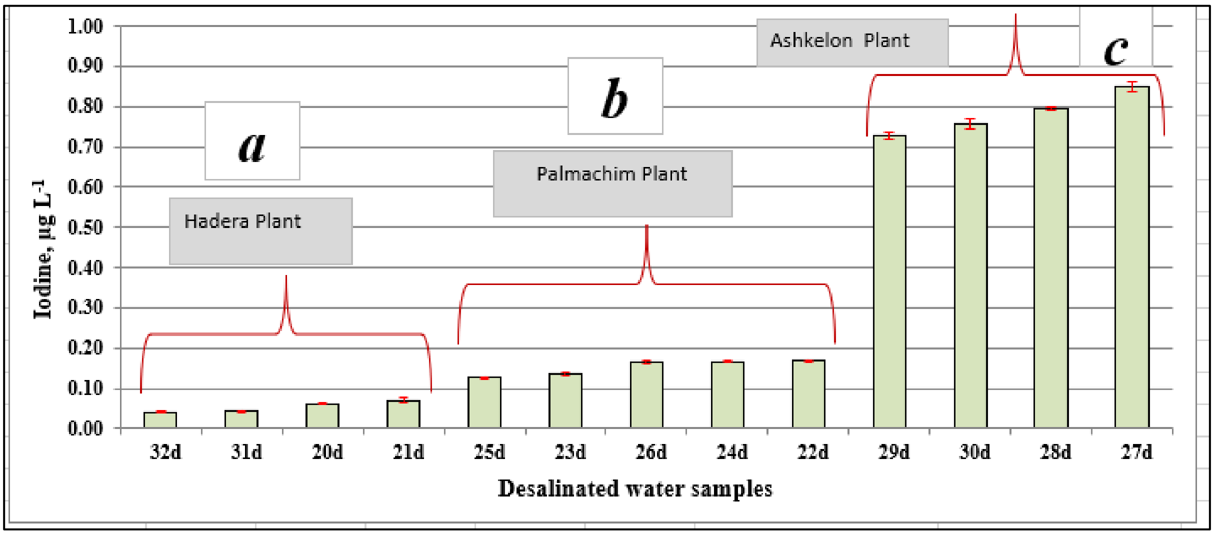

Fig. 2. Total iodine concentration in desalinated water samples.

Natural seawater is rich in iodine, which is almost completely removed during desalination [11]. We found 60 µg I L^{-1} in seawater sample collected near the Rishon Le-Tsion city coast [16] and 66 µg I L^{-1} in the sample collected approximately 16 km west of the

Haifa city coast (Table B3). It is seen that the desalination process kept less than 1 µg I L^{-1} in the water supplied then to the consumers.

When iodine content in waters from all groups of tap water (TW) and all three DSPs were compared by post-hoc Tukey-Kramer test, only TW from groups C and D were significantly higher than all other samples (Table 1). This also proves that tap waters from A, B, and D groups are likely to contain a high percentage of DSW.

The water from the Palmachim DSP demonstrated a higher Mg concentration than other DSPs (Fig. B5) but still less than 1 mg L^{-1}, which is much lower than the minimal Mg level recommended by Israeli and European authorities [11, 25]. As a result, the Ca/Mg ratio in DSW was extremely high (Table 3).

The hardness of DSW did not differ significantly from groups A and B of tap water (TW) samples (Table 2). Post-treated waters from all three DSPs were ranked as "moderately hard", similar to TW from the A and B groups.

The concentration of total iodine in waters from DSPs was positively and significantly correlated only with total S content (Table B1). The waters from Ashkelon and Palmachim plants were significantly more acidic than all TW samples (Table B2).

According to Dreizin et al. (2006), contractual requirements for the hardness of post-treated DSWs for Ashkelon, Palmachim, and Hadera plants were the following: >60, 75-100, and 80-120 mg L^{-1} (as $CaCO_3$), respectively [29]. In 2008, the Ashkelon water's actual hardness was determined to range from 90 to 110 mg L^{-1} [27]. Our median values of water hardness for the samples from Ashkelon, Palmachim, and Hadera plants were 72.9, 72.3, and 84.2 mg L^{-1}, respectively, which agree with the specifications.

According to the recommendations of the Israeli Authority for desalinated water, published by Lesimple et al. (2020), the Ca and Mg concentration (as Ca^{2+} and Mg^{2+}) in post-treated DSW should be 32-48 mg L^{-1} and 12-18 mg L^{-1}, respectively, and pH <8.5 [11]. The median values for these two essential macro-elements' concentration in DSW from Ashkelon, Hadera, and Palmachim plants, found in 2021, were: Ca - 28.5, 33.3, and 27.4 mg L^{-1}; and Mg - 0.43, 0.21, and 0.88 mg L^{-1}, respectively (Fig. B5).

The Israeli Ministry of Health recommends that the concentration of Ca in DSW should fall within the range of 32 – 48 mg L^{-1} (as Ca^{2+}), while in water desalinated from brackish water wells, the dissolved calcium concentration should not be less than 20 mg L^{-1}

(as Ca^{2+}). However, this document does not establish the minimal concentration values for Mg and iodine [30, 31]. It may be concluded that DSW produced in Israel by SWRO technology complies with the main chemical parameters specified (Ca concentration, hardness, pH), but still contains a very low concentration of Mg and a trace concentration of iodine, which should raise public health concerns.

3.3 Iodine intake from drinking water

To assess the possible influence of DSW usage on public health, we calculated the approximate iodine intake by Israeli citizens using tap water with different total iodine concentrations. The assumptions were as follows: *(i)* all daily drinking water is unfiltered tap water; *(ii)* water daily consumption is 2 L per capita per day; and *(iii)* iodine bioavailability is 90%.

The first assumption did not consider bottled water consumption. Investigating the iodine deficiency among Israeli children, Barnett-Izhaki et al. (2022) did not find statistically significant differences in median UIC in children consuming non-filtered tap, filtered, or bottled drinking water [24]. In our previous study, we demonstrated that the iodine content in bottled waters available in Israel was 7.68±2.41 (average ± standard error) with a median value of 6.89 µg I L-1 (calculated from the data published in [16]). We may, therefore, assume that bottled water is equivalent to the tap water from groups C and D in terms of its iodine concentration and, when consumed together or even instead of tap water as drinking water, cannot significantly change the overall personal iodine intake.

The second assumption was based on different literature sources that evaluate daily water consumption in Israel to be widely different, ranging from 0.7 to 5 L per day [9, 18, 25, 32]. In our study dedicated to the Mg status of Israeli tap water [25], we assumed this value to be 2 L per day per capita. To support this assumption we used the data of Spungen et al., 2013 [33] who interviewed 789 Israeli citizens from four different cities and revealed that their daily water consumption was 1943±168 mL per day per capita (average ± standard error, converted by us from U.S. cups to mL). This data shows that our assumed water intake of 2 L per day per capita is reasonable.

The third assumption is based on the statement of the USA Institute of Medicine, which states that under normal conditions, the human body absorbs more than 90 percent of dietary iodine [13]. Therefore, we assumed a 90% bioavailability of iodine from tap water and corrected all measured iodine concentrations accordingly.

Our calculated results are presented in Table 4. t is evident that in groups C and D, consumers may obtain from unfiltered tap water about 8.46% to 14.81% of the recommended dietary allowance (RDA) for iodine, whereas other groups, especially post-treated desalinated waters, may only provide less than 3.39% or even less than 1% of RDA. According to Gefel et al. (2016), unfiltered tap water was estimated to provide 16% of the mean daily iodine intake, which was assessed by a questionnaire to be 112±58 µg I per day [32]. Expressed as iodine concentration, the daily intake of this element from tap water is 17.9 µg I per day. The calculations by Gefel et al. were based on the last reported iodine concentration in the tap water of the city of Ashkelon and its nearby areas, which was 27 µg I per liter in 2008 (the research was conducted in 2012-2013). Now, during the period of our investigation in 2021, we found only one sample from group D that almost approached this value (sample N 15 from Masada - 19.9 µg I per liter), whereas other samples were much lower (Fig. 1). It is reasonable to assume that today the iodine intake from tap water is much lower than the 16% determined in 2013 by Gefel et al. [32].

4 Conclusion

The measurement of total iodine concentration in tap water samples across Israel revealed a decrease in the present-day iodine status compared with the data from literature sources [23, 32]. In sample groups with lower iodine concentration, we also observed lower Mg concentration, higher Ca/Mg ratio, and lower water hardness, which indicates a higher percentage of DSW in the final water blend supplied to consumers. The hourly and annually dynamics of iodine concentration in the tap water of big cities were found to be relatively high, pointing to constant mixing of water supplied to the final consumer. According to our calculations, tap water used as drinking water in communities supplied with a high percentage of DSW can provide only a few percent of the iodine recommended daily allowance (RDA) for adults. The post-treated DSWs produced by the 3 largest DSPs in Israel agree with the specifications and contain less than 1 µg I per liter total iodine and also a much lower Mg concentration than recommended by different authorities. Currently, there are no strict regulations regarding iodine and magnesium levels in drinking and/or softened (desalinated) water. However, the widespread application of DSW is already showing a negative impact on public health, as demonstrated by several studies conducted in Israel [10, 17, 24].

Although further investigations are needed, the present study is beneficial to developing an effective policy of providing the population of Israel with adequate iodine supply from drinking waters. Employment of means of mandatory fortification of some foodstuffs (table salt, bread) with iodine compounds are essential and therefore – highly recommended. Promising results have been obtained from the application of these measures, for example, in Europe and New Zealand [34, 35] .

Table 1. Iodine in tap and desalinated waters (summary statistics).

Water	Tap water				Desalinated water		
Group/DSP	A	B	C	D	Ashkelon	Hadera	Palmachim
N samples	5	6	5	4	4	4	5
Mean	0.627	2.837	6.795	13.853	0.782	0.054	0.153
CI 95%	0.795	0.494	0.939	6.534	0.085	0.024	0.025
Standard Error	0.286	0.192	0.338	2.053	0.027	0.007	0.009
Min. value	0.227	2.215	5.459	10.82	0.727	0.039	0.126
Max. value	1.744	3.477	7.325	19.906	0.850	0.070	0.170
Median	0.304	2.821	7.049	12.342	0.776	0.053	0.166
Tukey-Kramer test† for TW and DSW	c	c	b	a	a	b	c
Tukey-Kramer test for TW+DSW	c	c	a	b	c	c	c

† The groups do not share the same lower-case letter are significantly different at $p<0.05$

Table 2. Hardness of tap and desalinated waters

Water	Tap water				Desalinated water		
Group/DSP	A	B	C	D	Ashkelon	Hadera	Palmachim
N samples	5	6	5	4	4	4	5
Mean	89.3	114.0	406.5	220.7	72.80	83.90	72.17
CI 95%	17.0	41.6	46.6	27.4	1.99	9.82	2.86
Standard Error	6.1	16.2	16.8	8.6	0.63	3.08	1.03
Min. value	80.5	86.5	362.1	199.7	71.28	76.45	68.63
Max. value	113.1	189.2	444.5	238.7	74.16	90.77	75.03
Median	82.8	96.1	416.4	222.2	72.9	84.2	72.3
Tukey-Kramer test† for TW and DSW separately	c	c	a	b	b	a	b
Tukey-Kramer test for TW+DSW	c	c	a	b	c	c	c
Rank††	moderately hard	moderately hard	very hard	very hard	moderately hard	moderately hard	moderately hard

† The groups do not share the same lower-case letter are significantly different at $p<0.05$

††according to Tenne et al. (2011) [6]

Table 3. Ca/Mg ratio in tap and desalinated water

	Tap water				Desalinated water		
Group/DSP	A	B	C	D	Ashkelon	Hadera	Palmachim
N samples	5	6	5	4	4	4	5
Mean	40.3	14.0	2.54	3.29	66.9	171	36.4
CI 95%	25.5	3.07	0.16	3.22	8.27	89.5	12.1
Standard Error	9.19	1.19	0.06	1.01	2.60	28.1	4.34
Min. value	10.3	8.96	2.33	1.96	62.3	120	27.3
Max. value	61.3	17.4	2.68	6.30	73.2	227	49.4
Median	36.2	14.6	2.56	2.44	66.1	169	31.3

† The groups do not share the same lower-case letter are significantly different at $p<0.05$

Table 4 Iodine intake calculated for consumers of tap water from different districts and for desalinated water only.

Group	Median	Available 90%	Consumption	RDA	EAR	Iodine Intake (calculated)	% of RDA	% of EAR
	μg I L^{-1}		L day^{-1} capita^{-1}		μg day^{-1}		%	%
A	0.30	0.27	2	150	95	0.55	0.36	0.58
B	2.82	2.54	2	150	95	5.08	3.39	5.35
C	7.05	6.34	2	150	95	12.69	8.46	13.36
D	12.34	11.11	2	150	95	22.22	14.81	23.38
DSP Ashkelon	0.78	0.70	2	150	95	1.40	0.93	1.47
DSP Hadera	0.05	0.05	2	150	95	0.09	0.06	0.10
DSP Palmachim	0.17	0.15	2	150	95	0.30	0.20	0.32

Competing financial interests

The authors declare no competing financial interests.

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