

Article

Desalination and Calcium, Fluoride, and Magnesium Composition: Assessing Water Quality Variations Across Water Sources in Israel

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Abstract

Objective: Due to limited freshwater supplies, Israel increasingly depends on desalination to fulfill its drinking water requirements. However, this process reduces mineral levels such as magnesium (Mg^{2+}), calcium (Ca^{2+}), and fluoride (F^-), which could pose health concerns. In this study, we analyze the mineral concentrations across various water sources nationwide. **Materials and Methods:** We analyzed a national database on drinking water quality for levels of Ca^{2+} , Mg^{2+} , and F^- from 2014 to 2024. District-level concentrations were calculated and compared with national means and across primary water sources. Water sources were classified as primarily DSW (DSW) or primarily groundwater-based according to their dominant composition. **Results:** Nationwide median concentrations were 52 mg/L for Ca^{2+} , 12 mg/L for Mg^{2+} , and 0.15 mg/L for F^- . Ca^{2+} and Mg^{2+} showed marked regional variation, with significantly higher mean levels in the Northern District (Ca^{2+} : 72 mg/L, $p < 0.006$; Mg^{2+} : 34 mg/L, $p < 0.001$) and lowest levels in southern regions, particularly the Southern District (Ca^{2+} : 39 mg/L, $p < 0.001$; Mg^{2+} : 7 mg/L, $p < 0.001$) compared to the national average. Fluoride concentrations were generally low, with higher levels in northern regions (0.23 mg/L, $p < 0.001$) and lower levels in Tel Aviv (0.07 mg/L, $p < 0.001$) and Jerusalem (0.11 mg/L, $p < 0.001$). By predominant water source, Ca^{2+} and Mg^{2+} concentrations were lowest in DSW (Ca^{2+} : 42 mg/L; Mg^{2+} : 9 mg/L) and highest in groundwater supplies (Ca^{2+} : 83 mg/L; Mg^{2+} : 34 mg/L). Concentrations of F^- ranged from 0.12 mg/L in predominantly DSW to 0.23 mg/L in areas supplied primarily by groundwater. **Conclusions:** Ca^{2+} levels aligned with international reports, while Mg^{2+} levels, especially in desalination-reliant areas, remained consistently low. F^- concentrations stayed below both the recommended maximums and the optimal levels advised by the U.S. Public Health Service. As desalination efforts grow, concerns have been raised about the potential public health risks associated with low-mineral drinking water, particularly cardiovascular disease and bone disorders.



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1. Introduction

Water scarcity is a growing global challenge, as demand for freshwater outpaces available natural resources [1,2]. Desalination emerged in recent decades as a potential strategy to mitigate global water demand, particularly in arid countries or those with high population density [3–5]. The most widely used technique is reverse osmosis (RO), known for its energy efficiency compared to other purification methods. It employs a semi-permeable membrane and pressure to purify water [6–8].

Desalination has become a crucial component of the water supply in many countries, such as Saudi Arabia, the United Arab Emirates, Kuwait, Qatar, Bahrain, Oman, and Israel. Israel currently has five desalination plants in operation, with two more under construction. Together, they supply more than half of the country's drinking water, positioning Israel as a global leader in large-scale desalination [9,10].

Desalination technology provides a reliable water source for countries in arid regions, but it also raises concerns about the mineral composition of drinking water and its potential health implications. During the desalination process, dissolved minerals, including essential nutrients such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), as well as beneficial minerals like fluoride (F^-), are predominantly eliminated from seawater, resulting in water with a low mineral content [9,11–14].

Decreased levels of these minerals may be associated with adverse health outcomes, including cardiovascular diseases (CVD), emphasizing the importance of evaluating the long-term health effects associated with the consumption of desalinated seawater (DSW). Currently, the evidence available is limited and inconclusive.

Calcium in drinking water affects cardiovascular risk in a U-shaped pattern, with moderate levels being optimal [15–18]. A nationwide Dutch cohort of nearly 7 million people found that high calcium concentrations in drinking water were associated with increased cardiovascular mortality. Each 100 mg/L increase in calcium was associated with an 8% increase in the risk of cardiovascular disease mortality (HR 1.08, 95% CI: 1.03, 1.13). In addition, elevated risk of coronary heart disease mortality was observed at calcium concentrations below 30 mg/L, though no clear exposure-response relationship was observed across the entire exposure range [17].

Mg^{2+} has received particular attention due to its relatively well-established cardiovascular benefits. Unlike Ca^{2+} , elevated Mg^{2+} levels in drinking water have been consistently associated with a reduced risk of cardiovascular mortality, including coronary heart disease and cerebrovascular events [18–20]. One study suggested a possible U-shaped effect with a protective effect between 4 and 11 mg/L among older people [20].

Multiple studies have demonstrated that transitioning to DSW is associated with a notable reduction in serum Mg^{2+} concentrations within the population [9,13,14,21]. This is consistent with the approximately 50% bioavailability of Mg^{2+} from water, highlighting its potential contribution to overall intake [22]. While lower Mg^{2+} status is biologically linked to cardiovascular, metabolic, and cognitive risks, the population-based studies to date have reported mixed or limited evidence for direct health effects, with some suggesting associations with ischemic heart disease [23], but no clear links to diabetes, cancer, or dementia [9,13,14,21].

The influence of Ca^{2+} and Mg^{2+} ions may be at least partly attributable to their role in contributing to water hardness. This characteristic is defined by elevated concentrations of

dissolved minerals, notably calcium and magnesium, which can form deposits, including insoluble salts. The World Health Organization (WHO) currently refrains from establishing a definitive threshold for drinking water hardness. However, it acknowledges that concentrations below 100 mg/L could enhance the corrosivity of water towards plumbing materials, whereas levels exceeding 200 mg/L are correlated with scale formation [24]. Higher water hardness may influence CVD prevention and mortality rates [25,26]. Additionally, one study reported that lower water hardness was associated with an increased risk of neurological disorders such as Alzheimer's disease and vascular dementia [27]. Some evidence suggests an association between water hardness and cancer risk. A large cohort study found a U-shaped relationship between water hardness and cancer risk, with both low and high levels associated with increased incidence [28].

The current literature suggests a few possible effects of F^- levels on public health [29]. Fluoride protects dental health primarily through topical mechanisms, including enamel remineralization, inhibition of demineralization processes, and suppression of cariogenic bacterial metabolism within dental plaque [30]. Systemic fluoride exposure, particularly during tooth development, may also contribute to long-term caries prevention [31].

Despite the dental health benefits claimed by many studies, fluoride exposure has also been associated with potential adverse systemic effects. F^- levels are related to skeletal fluorosis, particularly in fluoride-endemic areas [32,33]. Several molecular pathways have been proposed through which excess fluoride can impair thyroid function, especially in pregnant women [34–36]. Neurodevelopmental effects were also suggested, with prenatal exposure playing a significant role, although available evidence is still under scientific discussion [37–39].

In Israel, only calcium is added to about 30 mg/L in RO water to prevent pipe corrosion. Mg^{2+} improves corrosion control and mineral balance; nevertheless, many desalination-reliant countries avoid adding Mg^{2+} due to high costs [40]. In Saudi Arabia, DSW is conventionally remineralized via limestone contactors with carbon dioxide addition, with emerging strategies incorporating dolomite to increase magnesium concentrations in treated water [41]. Fluoride supplementation is widely practiced worldwide, with target concentration ranges established in several countries [42]. In Israel, water fluoridation was implemented in the past but was suspended in 2014. To date, Israeli regulations do not require mineral supplementation for health reasons.

Mineral supplementation is costly. To address this issue, mixing DSW with other sources, such as groundwater and surface water, has been suggested as a cost-reducing solution, depending on their availability [43].

This approach aligns with water management strategies that balance equity, demand, efficiency, and sustainability, leading to variable water quality over time and space. Such patterns are common in desalination-dependent, arid, and semi-arid regions with multiple water sources exhibiting distinct chemical signatures [44–47]. As a case study, Israel has the capacity to alter water-source distribution to accommodate climatic and other conditions [48,49]. Water availability and distribution in Israel vary across geographic regions (Figure 1). Arid areas, primarily in the south, rely almost exclusively on DSW due to the scarcity of natural freshwater sources. Northern regions, including the Northern and Haifa districts, rely predominantly on natural sources. The Lake of Kinneret (Sea of Galilee), the largest surface water reservoir, supplies some areas, while others, such as the Golan Heights and the Upper Galilee, are primarily supplied by groundwater [21]. These regional differences are expected to influence the mineral composition of drinking water nationwide.



Figure 1. Map of the seven districts in Israel.

Although DSW has grown in Israel, its effect on mineral content has not been assessed, and no studies have examined the spatial distribution of Mg^{2+} , Ca^{2+} , and F^- in Israel. Therefore, this study investigates the mineral content of drinking water from various sources and regions in Israel, specifically analyzing the concentrations of Mg^{2+} , Ca^{2+} , and F^- in desalinated, groundwater, and mixed water sources. As drinking-water monitoring is conducted routinely and the database is publicly available, the dataset provides a robust basis for spatial and temporal analysis. Therefore, Israel provides a relevant case study for regions balancing increasing desalination use with the management of a mix of other water sources. The findings may provide insights into water quality management and inform international discussions on remineralization strategies needed to meet nutritional requirements and support population health.

2. Methods

We used available information on Mg^{2+} , Ca^{2+} , and F^- in drinking water publicly published by the Ministry of Health (MOH), which required no human approval. Sampling strategies differed by element due to regulatory requirements. Mg^{2+} and Ca^{2+} are monitored only at production facilities, and no routine monitoring is conducted within the distribution system. Therefore, we relied on a 2023 nationwide survey for consumer-level concentrations of these elements conducted by the MOH. The survey sampled 113 sites representing drinking water at central points in the distribution system, which supplies close

to 80% of the country's population. All cities with more than 70,000 residents were sampled at least once (30 cities), and another 56 settlements were also sampled to improve the survey's spatial distribution. Roughly half of the sites were sampled more than once across different seasons to account for differences in water-source allocation and their effects on mineral content. Unlike Mg^{2+} and Ca^{2+} , F^- is routinely monitored at the consumer level, and we included all available data from earlier reports from August 2014 to December 2024. Fluoride sampling frequency varied from once every 3 months in settlements supplied by a single water source to 7 times per month in settlements with multiple sources and populations exceeding 300,000 residents. Sample analysis was conducted by local water suppliers, and the results were reported to the MOH.

Means, standard deviations, medians, interquartile ranges (IQRs), and ranges of Mg^{2+} , Ca^{2+} , and F^- concentrations from both survey and routinely collected samples were calculated for the seven districts of Israel, from north to south: the Northern district, Haifa district, Central district, Tel-Aviv district, Jerusalem district, Ashkelon district, and Southern district (Figure 1).

In addition, we compared the levels of those minerals between areas supplied by different primary water sources. The MOH's 2023 survey presents a map of the country divided into three polygons, each characterized by a distinct predominant water source. These polygons are utilized in the present analysis.

Mineral concentrations were compared utilizing a ratio *t*-test with 95% confidence intervals to assess statistically significant differences between groups. Prior to analysis, assumptions of normality and homogeneity of variance were verified. In cases where these assumptions were violated, a Mann–Whitney U test or Welch's *t*-test was employed. Outliers were defined as observations 1.5 times the interquartile range below the first or beyond the third quartile. Values below the quantitation reporting limit (QRL) were imputed by QRL divided by the square root of two. Box plots were used in the present study to illustrate the distribution of mineral concentrations across districts. All data analysis was conducted using R software version 4.3.2.

3. Results

During the 2023 survey, a total of 350 and 286 samples were analyzed for Ca^{2+} and Mg^{2+} , respectively. A total of 9253 samples were analyzed for F^- as part of routine testing from August 2014–December 2024. For Ca^{2+} and Mg^{2+} , the Center District contributed the largest number of observations, reflecting its larger population. Nationwide median concentrations were 52 mg/L for Ca^{2+} (IQR: 34–72 mg/L), 12 mg/L for Mg^{2+} (IQR: 4–23 mg/L), and 0.15 mg/L for F^- (IQR: 0.07–0.25 mg/L) (Table 1).

3.1. Regional Variation

The geographical distribution of samples and the allocation of water sources are shown in Figure 2. Substantial regional variation was observed in Ca^{2+} and Mg^{2+} concentrations. The highest median Ca^{2+} concentrations were observed in the northern and central parts of Israel, most proximal to the Kinneret Lake, i.e., the Northern District (72 mg/L; IQR: 54–85 mg/L) and the Center District (71 mg/L; IQR: 54–83 mg/L). In contrast, regions distant from the lake had the lowest median concentrations of Ca^{2+} , i.e., Ashkelon (31 mg/L; IQR: 28–38 mg/L) and the Southern District (34 mg/L; IQR: 29–46 mg/L).

Mg^{2+} concentrations followed a similar spatial pattern, with a dose–response gradient corresponding to the increasing distance from the lake. The highest median Mg^{2+} concentration was recorded in the Northern District (34 mg/L; IQR: 32–37 mg/L), followed by the Center District (17 mg/L; IQR: 10–25 mg/L). The lowest Mg^{2+} concentrations were observed in Ashkelon (median: 2 mg/L; IQR: 1–9 mg/L) and the Southern District (median:

4 mg/L; IQR: 2–9 mg/L). Variability in the southern districts was relatively low, with most values below the national median (Figure 3).

Table 1. Average levels of Mg^{2+} (2023), Ca^{2+} (2023), and F^- (2014–2024) by district in Israel.

District	Overall	North	Haifa	Center	Jerusalem	TA	Ashkelon	South	<i>p</i> -Value
Ca^{2+}, mg/L									
N. obs	350	16	24	136	10	61	23	80	<0.001
Mean (SD)	55 (23)	72 (22)	52 (22)	69 (22)	41 (7)	53 (23)	33 (7)	39 (12)	
Median	52	72	46	71	42	52	31	34	
(25–75%)	(34–72)	(54–85)	(35–62)	(54–83)	(37–43)	(34–64)	(28–38)	(29–46)	
Range	18, 121	42, 121	29, 93	26, 114	30, 54	18, 116	26, 52	24, 67	
Mg^{2+}, mg/L									
N. obs	286	14	24	113	10	52	24	49	<0.001
Mean (SD)	14 (11)	34 (3)	15 (13)	19 (10)	9 (5)	11 (10)	5 (6)	7 (6)	
Median	12 (4–23)	34 (32–37)	12 (3–28)	17 (10–25)	11 (5–13)	10 (2–18)	2 (1–9)	4 (2–9)	
(25–75%)									
Range	1, 43	28, 39	1, 37	1, 43	1, 17	1, 37	1, 21	1, 22	
F^-, mg/L									
N. obs	9253	3319	857	2386	247	700	569	1175	<0.001
Mean (SD)	0.18 (0.11)	0.23 (0.11)	0.19 (0.10)	0.15 (0.09)	0.11 (0.05)	0.08 (0.03)	0.15 (0.11)	0.16 (0.11)	
Median	0.15	0.23	0.18	0.11	0.07	0.07	0.07	0.12	
(25–75%)	(0.07–0.25)	(0.15–0.30)	(0.10–0.26)	(0.07–0.21)	(0.07–0.12)	(0.07–0.07)	(0.07–0.20)	(0.07–0.20)	
Range	0.07, 0.53	0.07, 0.53	0.07, 0.50	0.07, 0.46	0.07, 0.26	0.07, 0.18	0.07, 0.51	0.07, 0.52	

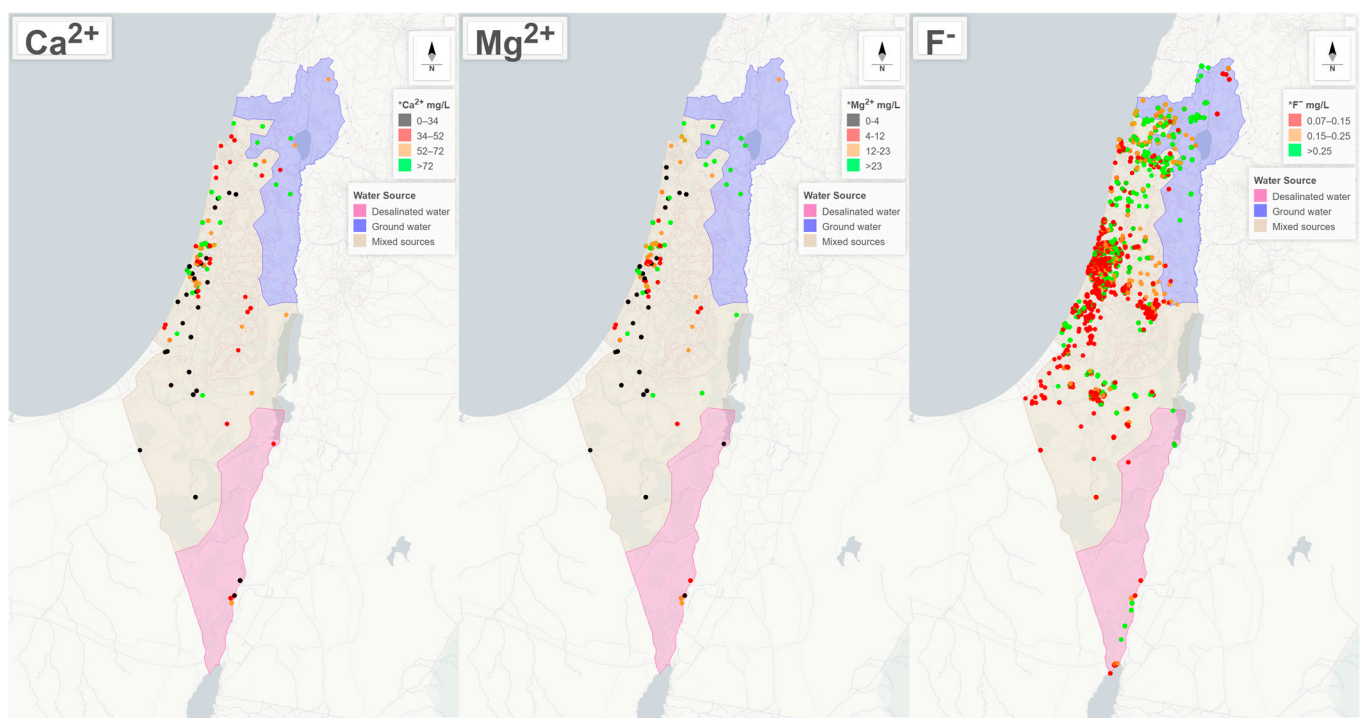


Figure 2. Geographical distribution of Ca^{2+} , Mg^{2+} , and F^- samples included in the study. * Sample Colors Represent quartiles within the study distribution.

Nationwide F^- concentrations were low, with a median of 0.15 mg/L (IQR: 0.07–0.25 mg/L). Nonetheless, clear regional differences were evident. Higher median F^- concentrations were observed in the Northern District (0.23 mg/L; IQR: 0.15–0.30 mg/L) and Haifa (0.18 mg/L; IQR: 0.10–0.26 mg/L). Lower F^- concentrations were observed in Tel Aviv (0.07 mg/L; IQR: 0.07–0.07 mg/L) and Jerusalem (0.07 mg/L; IQR: 0.07–0.12 mg/L). Intermediate F^- concentrations were observed in the Center District (median: 0.11 mg/L; IQR: 0.07–0.21 mg/L), Ashkelon (median: 0.07 mg/L; IQR: 0.07–0.20 mg/L), and the Southern District (median: 0.12 mg/L; IQR: 0.07–0.20 mg/L).

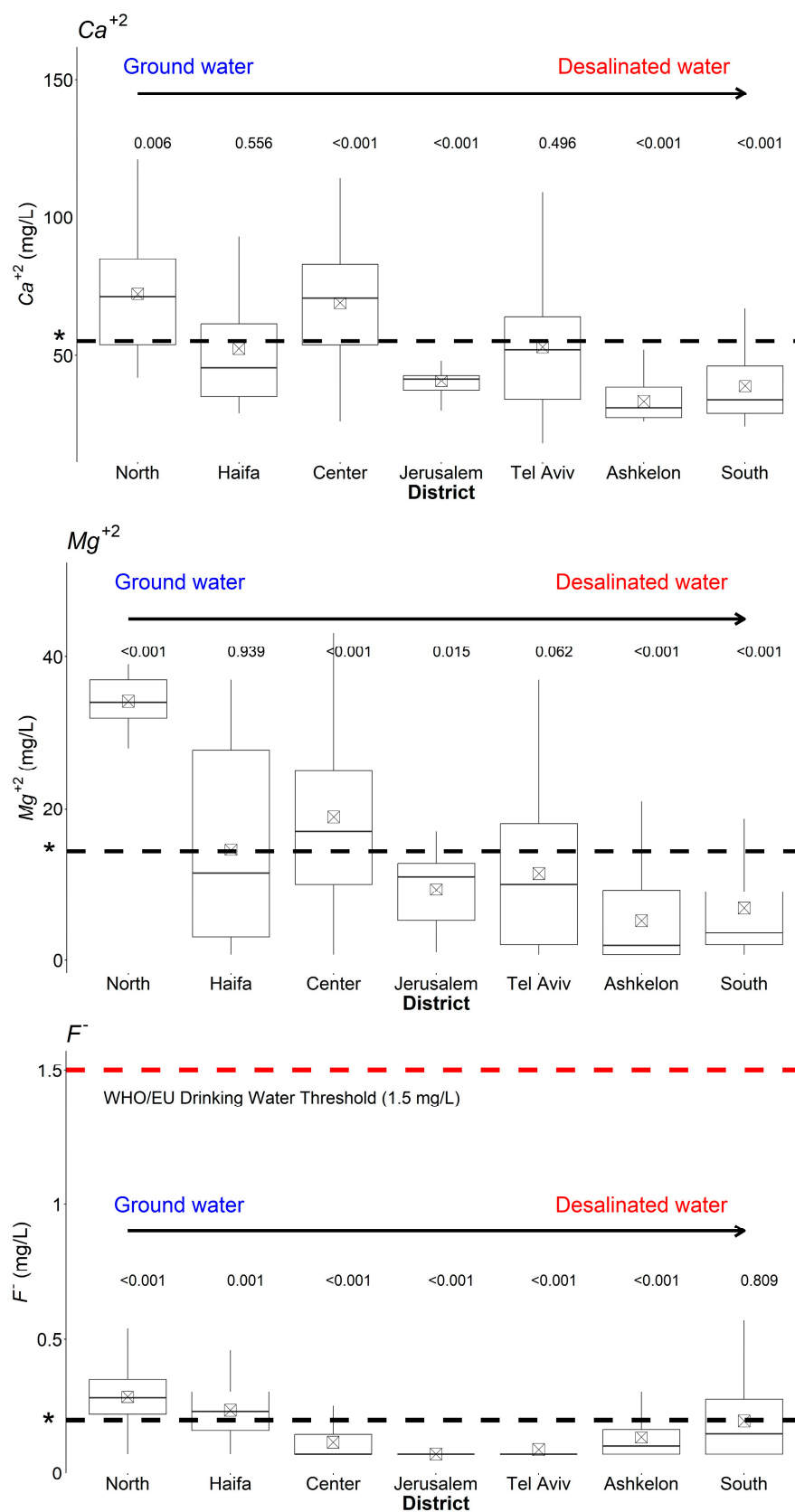


Figure 3. Graphical presentation of Ca²⁺, Mg²⁺, and F⁻ levels by districts. * The dashed line represents the nationwide average. *p*-values were calculated comparing each district to all others.

3.2. Variation by Water Source

Mineral concentrations varied by water source (Table 2). Ca^{2+} concentrations were lowest in areas predominantly supplied with DSW (median: 42 mg/L; IQR: 29–54 mg/L). Mixed-source-supplied areas showed intermediate Ca^{2+} concentrations (median: 55 mg/L; IQR: 35–75 mg/L). Areas supplied mostly by groundwater showed the highest Ca^{2+} levels (median: 83 mg/L; IQR: 54–88 mg/L).

Table 2. Levels of essential minerals, by primary water source.

Water Source	Overall	DSW	Ground Water	Mixed Sources	<i>p</i> -Value
Ca ²⁺ , mg/L					
N. obs	341	49	284	8	<0.001
Mean (SD)	56 (23)	42 (12)	77 (25)	58 (24)	
Median (25–75%)	53 (35–72)	42 (29–54)	83 (54–88)	55 (35–75)	
Range	18, 121	24, 67	46, 121	18, 116	
Mg ²⁺ , mg/L					
N. obs	277	20	250	7	0.038
Mean (SD)	15 (11)	11 (6)	32 (7)	14 (11)	
Median (25–75%)	12 (5–23)	9 (7–15)	34 (30–36)	12 (4–23)	
Range	1, 43	3, 21	18, 38	1, 43	
F [−] , mg/L					
N. obs	9216	401	7137	1678	<0.001
Mean (SD)	0.18 (0.11)	0.14 (0.07)	0.23 (0.11)	0.17 (0.11)	
Median (25–75%)	0.15 (0.07–0.25)	0.12 (0.10–0.16)	0.23 (0.15–0.30)	0.13 (0.07–0.23)	
Range	0.07, 0.53	0.07, 0.50	0.07, 0.53	0.07, 0.53	

Mg^{2+} concentrations exhibited a similar pattern. Median Mg^{2+} concentrations were lowest in areas supplied primarily supplied by DSW (9 mg/L; IQR: 7–15 mg/L). Mixed-source-supplied areas again showed intermediate Mg concentrations (median: 12 mg/L; IQR: 4–23 mg/L). Areas supplied by groundwater were the highest in Mg^{2+} (34 mg/L; IQR: 30–36 mg/L).

F^{-} concentrations also varied by water source. The lowest F^{-} concentrations were observed in areas predominantly supplied with DSW (median: 0.12 mg/L; IQR: 0.10–0.16 mg/L), followed by mixed-source-supplied areas with modestly higher F^{-} levels (0.13 mg/L; IQR: 0.07–0.23 mg/L). The highest median F^{-} concentrations were observed in areas supplied by mostly groundwater (0.23 mg/L; IQR: 0.15–0.30 mg/L).

4. Discussion

The study's results confirmed the presence of low levels of Mg^{2+} and F^{-} across the nation, with notable geographic variation seemingly linked to differences in local water sources. In contrast, Ca^{2+} levels were relatively elevated, peaking in regions where groundwater was the primary water supply. These observed patterns are not exclusive to Israel but are increasingly common in water supply systems in arid and semi-arid regions worldwide, where processes such as desalination and the blending of different water sources significantly influence the final composition of drinking water.

4.1. Water-Source Management Policies

In our study, we observed that consumers' mineral exposure is strongly influenced by water quality management policies. Israeli law designates all water resources as public property, making the state regulator responsible for both the allocation of water sources and the oversight of drinking water quality [50]. In response to increasing drought risks, the government launched a strategic plan for 2018–2030 to strengthen the water sector. The plan focuses on expanding desalination capacity, reducing water demand, integrating rural

areas into the national distribution network, and preserving natural water sources [51]. In RO desalination, water is forced at high pressure through a semi-permeable membrane that allows water molecules to pass through while blocking dissolved minerals and salts. The membrane rejects ions such as Mg^{2+} and Ca^{2+} , which are too large or electrically charged to pass through its tiny pores [12–14].

DSW also contains low levels of iodine, raising public health concerns about iodine-deficiency disorders (IDDs), particularly in populations that rely heavily on desalinated water as their primary drinking source [11]. Although drinking water is not typically a significant source of iodine, removing this source can increase the risk of deficiency in regions that already rely on low-iodine diets. Unfortunately, no monitoring data were available for our analysis on iodine levels in drinking water.

Although Ca^{2+} intake from water represents ~5–20% of the 1000–1200 mg/day RDA for adults, the bioavailability of water-derived Ca^{2+} is excellent [51]. In addition, Mg^{2+} from drinking water contributes only 10%, but Mg concentrations of 20–50+ mg/L can meaningfully increase this fraction. In the UK, real improvement in Mg nutrition is achieved only where water is genuinely hard [52]. A previous study revealed that introducing a DSW facility increased the proportion of hypomagnesemia in the population by 24% [9]. A possible strategy to address mineral deficiencies is to add minerals to drinking water, a practice that is debated in Israel due to concerns about the costs versus the health benefits. In regions supplied exclusively with low-mineral-content water, mineral supplementation can be implemented in a controlled and effective manner. For instance, even the lowest Ca^{2+} concentrations observed in the southern region of the country, which is supplied mainly by DSW, were comparable to or even higher than those reported in other countries. This is explained by deliberate enrichment of DSW with Ca^{2+} to increase hardness and mitigate corrosion. In contrast, Mg^{2+} is not supplemented in drinking water; consequently, regions relying on desalinated seawater (DSW) exhibit low magnesium concentrations (median 2–4 mg/L in some districts), below levels associated with protective cardiovascular effects (4–11 mg/L) [20], warranting further epidemiological investigation.

4.2. Thresholds for Ca^{2+} , Mg^{2+} , and F^{-} in Drinking Water

Although there are no global thresholds for Mg^{2+} and Ca^{2+} in drinking water, across the European Union (EU), a few countries recommend levels of 40–80 mg/L for Ca^{2+} , 20–40 mg/L for Mg^{2+} , and a total hardness of 200–500 mg/L [53].

With respect to F^{-} , there is greater consensus regarding threshold levels. For instance, the WHO and the EU set the upper limit in drinking water at 1.5 mg/L to prevent adverse health effects such as dental and skeletal fluorosis [54]. Australia, Canada, the European Union, and India also use 1.5 mg/L as the upper limit for F^{-} in drinking water. In the United States, the Environmental Protection Agency (EPA) sets a primary maximum contaminant level (MCL) of 4.0 mg/L for prevention of skeletal fluorosis and a secondary MCL of 2.0 mg/L for prevention of dental fluorosis and tooth discoloration. The U.S. Public Health Service recommends an optimal level of 0.7 mg/L for caries prevention in community water systems [55]. The target F^{-} levels in public drinking water in Israel prior to the discontinuation of mandatory water fluoridation in July 2014 were 0.7–1.0 mg/L. This range was considered optimal for caries prevention and was consistent with international standards for community water fluoridation, as reflected in comparative studies of optimally versus nonoptimally fluoridated municipalities in Israel [56].

4.3. International Monitoring Policies of Ca^{2+} , Mg^{2+} , and F^{-} Concentrations

In the absence of regulated threshold values, most countries do not conduct regular monitoring for Ca^{2+} and Mg^{2+} [53]. In Israel, the monitoring of Ca^{2+} and Mg^{2+} is conducted

only on the raw-water level in the product water of desalination plants or production facilities. In contrast, many countries do have established F^- drinking water regulations and therefore monitor F^- levels in drinking water, regardless of whether F^- is added or occurs naturally. This includes countries that practice community water fluoridation (e.g., the United States, Australia, and Ireland) [57–59] and those with significant geogenic F^- exposure (e.g., China, India, Pakistan, Mexico, and many African nations) [60–62]. Most European countries do not add F^- to water and rely on other sources of F^- , such as toothpaste and salt. An exception is Ireland, where approximately 71–74% of the population receives fluoridated water mandated by national legislation, and England, where about six million people (about 10% of the national population) are supplied with fluoridated water through local schemes [59,63].

4.4. International Comparison of Ca^{2+} , Mg^{2+} , and F^- Concentrations in Drinking Water

In this analysis, the nationwide average Ca^{2+} concentration in Israel (55 ± 23 mg/L) was higher than those reported in countries relying predominantly on surface water, including China (40.4 mg/L), and in countries with mixed surface water and groundwater supplies, such as Argentina (15.8 mg/L) and the United Kingdom (30.46 mg/L). In contrast, it was lower than in Denmark, where drinking water is supplied exclusively from groundwater (84.5 mg/L). Similarly, in the United States, mean Ca^{2+} concentrations were lower in surface water systems (34 mg/L) than in groundwater systems (52 mg/L) [64–69].

The average nationwide Mg^{2+} levels in our study (14 ± 11 mg/L) are similar to those reported in China (12.4 mg/L), Denmark (12.1 mg/L), and lower than those in the UK (19 mg/L) [19,65,66]. In contrast, exposure to Mg^{2+} in Swedish drinking water is lower, ranging from 5 mg/L in low-exposure areas to 10 mg/L in high-exposure areas [18]. In Serbia, Mg^{2+} levels in municipal drinking water can range from 11 to 42 mg/L [69].

Nationwide, F^- samples in our study were similar to those in analyses from European countries, which showed that more than 86% contained less than 0.3 mg/L, and more than 97% contained less than 0.7 mg/L [39,40]. In the United States, 84% of samples were between 0.6 mg/L and 2.0 mg/L [59]. In contrast, reports from countries outside Europe, such as Argentina, Pakistan, and China, showed exposure to high levels of F^- in drinking water, with 80%, 71%, and 21% of samples exceeding the 1.5 mg/L standard [70–72]. A comparison of mean levels of essential minerals across different countries is presented in Table 3.

Table 3. Comparison of mean levels of essential minerals across different countries.

Mineral	Country	Levels mg/L
Ca^{2+}	Israel	55 mg/L
	Argentina	15.8 mg/L
	United Kingdom	30.46 mg/L
	China	40.4 mg/L
	Denmark	84.5 mg/L
	United States	34 mg/L (surface water); 52 mg/L (groundwater)
Mg^{2+}	Israel	14 mg/L
	China	12.4 mg/L
	Denmark	12.1 mg/L
	United Kingdom	19 mg/L
	Sweden	5–10 mg/L
	Serbia	11–42 mg/L
F^-	Israel	0.18 mg/L
	European countries	>86% of samples < 0.3 mg/L; >97% < 0.7 mg/L
	United States	84% of samples: 0.6–2.0 mg/L
	Argentina	80% of samples > 1.5 mg/L
	Pakistan	71% of samples > 1.5 mg/L
	China	21% of samples > 1.5 mg/L

A potential solution proposed is to blend DSW with other mineral-rich sources [43]. Our findings indicate that areas where DSW was blended with other sources exhibited higher mineral concentrations than areas supplied with DSW but also greater variability, which limits the ability to reliably assess drinking-water quality at the site level. Similar patterns have been reported in highly desalination-dependent systems such as Kuwait, where post-treatment and blending processes play a key role in determining final drinking water composition [47].

4.5. Limitations

A key limitation of our study is the inability to monitor tap water mineral levels in real time, which may have led to exposure misclassification. Specifically, the samples may not accurately reflect each consumer's true exposure, especially in mixed-source areas where the supplied water source may change hourly due to the distribution pressure gradient. Furthermore, in areas where one water source predominates, some settlements may rely solely on alternative sources. That said, any such misclassification is expected to bias our estimates toward the null, thereby attenuating observed differences in mineral levels. The substantial variation observed in this study suggests that such misclassification is likely limited. Additionally, the policy of monitoring F^- is population-size dependent. Therefore, consumer exposure in rural areas may be underrepresented. Unfortunately, it was not possible to analyze the pre- and post-2014 F^- levels when fluoridation was discontinued due to the lack of data and monitoring before 2014.

In addition, this was a descriptive analysis of a national monitoring database rather than an epidemiological study. Therefore, the observed mineral concentrations should not be interpreted as evidence of health effects, and no information on individual water consumption or total dietary mineral intake was available.

4.6. Policy Implications

The study findings have important policy implications for countries that rely, or are expected to increasingly rely, on desalinated water as a primary source of drinking water. In addition to routine monitoring of conventional water quality parameters, regular surveillance of calcium, magnesium, and fluoride concentrations should be considered to ensure that mineral levels remain adequate for public health. Where appropriate, optimizing remineralization processes or blending desalinated water with alternative water sources may help restore essential minerals while maintaining water quality standards. Israel's extensive experience with large-scale desalination provides valuable insights that may inform water management strategies and public health policies in other countries facing increasing water scarcity and growing dependence on desalinated water.

4.7. Future Research

The health implications of desalinated drinking water (DSW) consumption may vary across populations according to age, socioeconomic status, dietary habits, and other factors influencing mineral intake. The findings of this study underscore the need for long-term, population-based epidemiological studies that incorporate the contribution of drinking water to total dietary mineral intake, mineral bioavailability, and the identification of potentially vulnerable population groups. Such studies would provide a more comprehensive assessment of the long-term public health implications of widespread DSW consumption.

5. Conclusions

In summary, the increasing reliance on desalination as a water source can lead to lower mineral levels in drinking water. Blending DSW with other sources or adding minerals directly can help restore mineral content. Although not explored in this study,

these findings highlight the importance of investigating potential health effects, including impacts on cardiovascular diseases, bone and kidney impairments, as well as neurological health and cancer risks. These results underscore the need for evidence-based regulations governing mineral levels in drinking water, including thresholds and monitoring strategies to ensure water quality and improve public health.

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