Potential health impacts of consuming desalinated bottled water

Candace Rowell, Nora Kuiper and Basem Shomar

ABSTRACT

This study compared physicochemical properties, anion and carbon content and major and trace elements in desalinated and non-desalinated bottled water available in Qatar, and assessed the potential health risks associated with prolonged consumption of desalinated water. Results indicate that Qatar's population is not at elevated risk of dietary exposure to As (mean = 666 ng/L), Ba (48.0 μg/L), Be (9.27 ng/L), Cd (20.1 ng/L), Cr (874 ng/L), Pb (258 ng/L), Sb (475 ng/L) and U (533 ng/L) from consumption of both desalinated and non-desalinated bottled water types available in the country. Consumers who primarily consume desalinated water brands further minimize risk of exposure to heavy metals as levels were significantly lower than in non-desalinated bottled water. Desalinated bottled water was not a significant contributor to recommended daily intakes for Ca, Mg and F^- for adults and children and may increase risk of deficiencies. Desalinated bottled water accounted for only 3% of the Institute of Medicine (IOM) adequate intake (AI) for Ca, 5–6% of the recommended daily allowance for Mg and 4% of the AI for F among adults. For children desalinated water contributed 2–3% of the IOM AI_{Ca}, 3–10% of the RDA_{Mg} and 3–9% of the AI_F.

Key words | bottled water, Ca, desalination, F, Mg, trace elements

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INTRODUCTION

As water scarcity increases globally, many countries are forced to supplement existing drinking water resources with desalinated water to meet rising demands. Approximately 75 million people worldwide rely on desalinated water with this population increasing as fresh water shortage is realized throughout the globe (Avni *et al.* 2013). Qatar, like many other arid nations, is completely dependent on seawater desalination technologies for potable drinking water, including bottled water (Darwish *et al.* 2013). This dependency creates a condition of high vulnerability to compromises in drinking water quality and quantity due in part to inadequate storage capabilities and the risk of source water contamination.

Currently, bottled water is the primary source of drinking water in Qatar and other Gulf states, due predominantly to the public perception of increased quality in comparison to municipal tap water (Wait 2008). This opinion is prevalent despite the fact that bottled water has been shown to contain higher levels of some contaminants due to inadequate regulation and monitoring, pollutant content of source water and packaging and storage conditions that give rise to trace element contamination (Shotyk & Krachler 2007a, 2007b; Westerhoff *et al.* 2008; Guler & Alpaslan 2009; Krachler & Shotyk 2009). Bottled water consumption is an important route of trace element exposure as the continued intake of heavy metals in drinking water, even at low concentrations, has been associated with various cancers, neurotoxic effects, central nervous system disorders, cardiovascular system impairments and reproductive and genetic effects (Virtanen *et al.* 2007; Mansouri & Cauli 2009; Martins *et al.* 2009; Whitfield *et al.* 2010; Olawoyin *et al.* 2012).

The trace element and micronutrient content of bottled water is highly varied, as highlighted in the meta-analysis by Cidu *et al.* (2011), resulting in unique exposure conditions for consumers. To date, studies have focused on the health impacts of bottled water derived from natural fresh water

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sources with limited to no inclusion of the chemical composition of water from seawater desalination processes and the health effects of long-term consumption of these products. Desalination technologies efficiently remove many trace elements and natural ions from product water potentially reducing the risk of exposure to trace contaminants but also reducing the intake of essential nutrients (Ludwig 2010; WHO 2011a). The inadequate intake of essential minerals from prolonged consumption of desalinated water may result in nutrient deficiencies and profound health impacts for dependent populations (Guler & Alpaslan 2009).

The aims of this multi-element study were to: (1) quantify the trace element and micronutrient content in desalinated and non-desalinated bottled water available to consumers in Qatar; (2) assess the impact of container type on trace element content; and (3) use the National Academy of Sciences Institute of Medicine (IOM) recommended daily allowance (RDA) and adequate intake (AI) values to assess the contribution of desalinated and non-desalinated bottled water consumption to Ca, Mg and F^- intakes for adults and children.

MATERIALS AND METHODS

Sample collection

Bottled water samples ($n = 56$) were obtained from eight local markets in Qatar in April 2013. The samples included both domestically produced and imported brands from 15 countries and constituted a comprehensive representation of the bottled water types available to consumers in Qatar. Desalinated water produced in Qatar, United Arab Emirates (UAE), Kuwait and Bahrain constituted 38% of all samples collected. Qatari brands represent the highest percentage (20%) of samples collected.

The majority of samples (86%) were packaged in polyethylene terephthalate (PET/PETE) containers with only eight samples bottled in glass containers.

Sample preparation and analysis

Non-acidified sample aliquots were used for all analyses excluding quantification of trace elements. Physical properties (pH, electrical conductivity and total dissolved solids (TDS)) were measured at ambient temperature using a Thermo Scientific Orion 5-Star Plus Benchtop Multiparameter Meter in Qatar Environment and Energy Research Institute (QEERI) laboratories, Doha, Qatar. Total concentrations of anions (Br^-, Cl^-, F^-, NO_3^- and SO_4^{2-}), major elements (Ca, K, Mg and Na), HCO_3^- and total organic carbon (TOC) were quantified at the Institute of Earth Sciences, Heidelberg University, Heidelberg, Germany. Anions were analyzed using an ion chromatograph (Dionex ICS-1100), major elements were analyzed using inductively coupled plasma optical emission spectrometry (Agilent 700) and HCO_3^- and TOC were analyzed with TOC-V_{CPH} Analyzer (Shimadzu).

For trace element analysis, samples were acidified with HNO_3 (Normaton for trace analysis) to pH < 2 for quantification of total As, Ag, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Th, Tl, U and Zn using inductively coupled plasma mass spectrometry (Agilent 7500ce and 7700x) at the Laboratory of Bioinorganic Analytical and Environmental Chemistry, University of Pau, France. Analysis was performed in accordance with ISO 17294. One laboratory blank was included in each analysis set of 10 samples and a certified reference material (NIST 1643e) was included in each batch to ensure optimum instrument performance. All elemental results for NIST 1643e were within 10% of the certified values indicating satisfactory method performance.

Estimates for the contribution of bottled water consumption to nutritional requirements

Contribution of bottled water to the IOM adequate intake requirements for calcium (AI_{Ca}) and fluoride (AI_F) as well as the recommended dietary allowance for magnesium (RDA_{Mg}) was estimated for adult males and females, including pregnant females, and for children aged 1–10 years. Daily intakes (DI) of micronutrients from bottled water consumption were calculated using the following equation:

$$DI\left({}^{mg}\!/_{day}\right) = C \times DC \tag{1}$$

where C refers to the concentration of the element of interest in bottled water (mg/L) and DC refers to the daily water consumption recommended by the WHO (L/day). Under average conditions, the DC for an adult female is 2.2 L/day, 2.9 L/day for an adult male and 1.0 L/day for children 18 years and younger (WHO 2005). Populations in Qatar rely on bottled water as the primary drinking water source; therefore, 100% of drinking water intake was assumed to come from bottled water sources.

RESULTS AND DISCUSSION

Trace elements and micronutrients in desalinated and non-desalinated bottled water

Trace element content and physical properties, anion and major element content are displayed in Tables 1 and 2, respectively. Concentration ranges for a given element were limited from only 10^2 (As, Ag, Ba, Be, Cd, Co, Fe, Pb, Sb, Th and Tl) to 10^5 (Cr, Cu, Mn, Mo, Ni, Se, U and Zn). Mn displayed the greatest range in concentration among all samples (approximately 10^5) whereas Cd and Be displayed the smallest (approximately 10^2). All samples were below the United States Environmental Protection Agency (USEPA), World Health Organization (WHO) and GCC Standardization Organization (GSO) guidelines for drinking water with the exception of Ni (three samples exceeded the GSO limit), Th (one sample exceeded the USEPA limit) and NO_3 (two samples exceeded the USEPA limit). Overall, the results indicate bottled water consumption is not a significant route of exposure for As, Ba, Be, Cd, Cr, Pb, Sb and U for populations in Qatar. Guideline values for Ag, Co, Fe, Tl or Zn are currently unavailable; however, concentrations ranged within expected levels for these elements.

Physical parameters and concentrations of major ions did not notably vary between the non-desalinated water brands, with the exception of select parameters. Samples from Germany contained significantly higher mean concentrations of TDS ($p = 0.001$) and Be ($p = 0.003$), while bottled water imported from France contained significantly higher mean As concentrations ($p = 0.001$). Samples from the United Kingdom contained significantly higher mean concentrations of nitrate ($p < 0.001$) and those from Scotland contained significantly lower mean pH levels ($p = 0.003$).

Variations observed between desalinated and non-desalinated bottled water samples were particularly interesting in regards to their potential impacts on consumers. Desalinated water produced in Qatar, UAE, Kuwait and Bahrain had significantly ($p < 0.05$) lower levels of the essential ions Mg and Ca and the non-essential trace elements As, Co, Ba and U when compared to the non-desalinated samples (Table 3). The mean Ca concentration for the desalinated bottled waters (11.3 mg/L) was significantly less than the WHO minimum requirement of 20 mg/L ($p < 0.001$) whereas the mean concentration from the non-desalinated waters was 57.5 mg/L, within the optimum range. The same was observed for Mg; desalinated bottled water contained an average of 10.9 mg/L while the mean concentration measured in the other bottled water samples was 18 mg/L. The low major and trace element content observed in desalinated water samples is indicative of the effective removal of dissolved inorganic constituents by the thermal desalination technologies currently used by the Gulf nations. While the removal of non-essential trace elements from drinking water is protective to consumer health, the removal of essential nutrients presents unique health risks.

Drinking water can contribute up to 20% of the daily requirements for Ca and Mg, providing an important dietary supplement, and is a significant source of F^- (WHO 2005; Galan *et al.* 2002; Avni *et al.* 2013). As Ca and Mg are present as free ions in water, they may be more readily absorbed and have increased bioavailability in drinking water over other food sources (Galan *et al.* 2002; Avni *et al.* 2013). Studies suggest Ca and Mg deficiencies are associated with an increased risk for a number of cancers including kidney, colon and lung (Yang *et al.* 1997, 1998; Chen *et al.* 2012). Ca deficiencies have also been associated with rickets in children and osteoporosis in adult women (WHO 2005). In addition, decreased heart health has been linked with dietary Mg deficiencies (Chiuve *et al.* 2013; Del *et al.* 2013). Kousa *et al.* (2006) directly linked Mg deficits in drinking water with increased risk of acute myocardial infarction showing that a 1 mg/L increase in drinking water Mg levels reduced the risk by 4.6%. Fluoride deficiencies have been associated with long-term consumption of desalinated water resulting in increased oral health risks such as dental

Table 1 | Mean and range of trace element content in bottled water samples and guideline values from USEPA, WHO and GSO

					Desalinated water				Non-desalinated water											
	USEPA[a]	WHO[b]	GSO bottled water[c]	GSO drinking water[d]	Qatar	Kuwait	Bahrain	UAE	Lebanon	Morocco	Turkey	France	Scotland	Germany	Italy	Austria	Fiji Islands	New Zealand	Switzerland	UK
N					12	3	1	7	4	1	6	9	2	4	7	1	1	1	1	1
Ag (ng/L)					30.9 (<30.0–149)[e]	496 (<30.0–1,459)[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[e]	87.9 (<30.0–255)[e]	<30.0[e]	41.7 (<30.0–95.0)[e]	19.5 (<30.0–42.0)[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[d]
As (ng/L)	10,000	10,000	10,000	10,000	78.4 (<25.0–223)[e]	314 (<25.0–917)[e]	<25.0[e]	14.8 (<25.0–26.0)[e]	261 (104–497)	<25.0[e]	221 (<25.0–532)[e]	2,831 (298–6,243)[f]	1,799 (1,645–1,953)	769 (27.0–1,290)	494 (238–1,308)	186	897	<25.0[e]	234	169
Ba (μg/L)	2,000	700	700	700	19.6 (<0.25–72.74)[e]	19.3 (<0.25–57.3)[e]	<0.25[e]	0.400 (<0.25–1.07)[e]	5.66 (4.89–6.49)	0.330	8.72 (1.75–14.1)	101 (0.490–349)	408 (407–409)[f]	53.2 (2.20–142)	35.8 (1.08–85.0)	75.3	5.65	0.560	245	15.8
Be (ng/L)	4,000				<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]	11.4 (<10.0–23.0)[e]	<10.0[e]	63.7 (<10.0[e]–130)[f]	7.00 (<10.0–17.0)[e]	<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]	<10.0[e]
Cd (ng/L)	5,000	3,000	3,000	3,000	21.1 (<20.0–56.12)[e]	<20.0[e]	<20.0[e]	<20.0[e]	<20.0[e]	<20.0[e]	9.50 (7.00–10.00)	43.1 (<20.0–137)[e]	<20.0[e]	39.4 (<20.0–98.3)[e]	25.3 (<20.0–69.1)[e]	<20.0[e]	<20.0[e]	<20.0[e]	<20.0[e]	<20.0[d]
Co (ng/L)					98.6 (<25.0–221)[e]	70.3 (25.0–97.0)	<25.0[e]	28.0 (<25.0–48.0)[e]	133 (87.0–181)	<25.0[e]	44.2 (<25.0–107)[e]	366 (<25.0–774)[e]	115 (81.0–149)	252 (100–423)	160 (<25.0–462)[e]	578	<25.0[e]	53.0	301	253
Cr (ng/L)	100,000	50,000	50,000	50,000	667 (252–1,549)	1,031 (501–1,816)	656	792 (519–1,313)	431 (266–623)	678	929 (0–3,203)[e]	1,364 (370–3,023)	1,933 (1,706–2,160)	1,271 (265–2,699)	638 (171–855)	266	679	1,323	212	208
Cu (ng/L)	1,300,000	2,000,000	1,000,000	1,000,000	3,514 (325–9,312)	749 (<650–1,598)[e]	325	606 (<650–1,229)[e]	<650[e]	<650[e]	1,012 (<650–2,685)[e]	10,727 (<650–37,600)[e]	2,844 (2,614–3,073)	11,925 (<650–22,870)[e]	1,348 (<650–3,433)[e]	4,573	878	<650[e]	<650[e]	<650[e]
Fe (μg/L)					12.2 (<3.00–77.6)[e]	2.00 (<3.00–3.00)[e]	<3.00[e]	<3.00[e]	<3.00[e]	<3.00[e]	5.18 (<3.00–10.7)[e]	55.8 (<3.00–213)[e]	6.65 (<3.00–11.8)[e]	41.6 (<3.00–122)[e]	6.77 (<3.00–33.1)[e]	<3.00[e]	<3.00[e]	<3.00[e]	38.5	<3.00[e]
Mn (ng/L)			400,000	400,000	1,801 (<200–12,980)[e]	227 (<200–480)[e]	<200[e]	190 (<200–391)[e]	470 (205–774)	233	611 (<200–2,094)[e]	7,884 (<200–30,720)[e]	637 (382–892)	36,693 (420–91,110)	1,583 (<200–7,817)[e]	567	376	287	445	<200[e]
Mo (ng/L)				70,000	884 (<200–4,414)[e]	442 (<200–928)[e]	<200[e]	226 (<200–855)[e]	2,573 (1,263–4,924)	<200[e]	951 (<200–2,529)[e]	2,044 (364–7,030)	<200[e]	2,126 (<200–3,815)[e]	7,402 (621–38,740)	3,232	1,153	<200[e]	1,224	<200[d]
Ni (ng/L)		70,000	20,000	70,000	3,637 (386–15,520)	889 (317–1,536)	291	640 (298–1,135)	2,056 (1,345–2,419)	215	1,684 (0–6,569)[e]	8,823 (338–29,660)	1,719 (1,138–2,300)	10,425 (1,470–23,640)	2,532 (257–6,231)	5,919	739	639	2,780	3,279
Pb (ng/L)	15,000	10,000	10,000	10,000	168.8 (<150–971)[e]	<150[e]	<150[e]	118 (<150–335)[e]	<150[e]	<150[e]	<150[e]	762 (<150–2,261)[e]	175 (<150–274)[e]	939 (<150–1,968)[e]	134 (<150–428)[e]	381	<150[e]	<150[e]	<150[e]	<150[d]
Sb (ng/L)	6,000	20,000	5,000	20,000	522.9 (77–941)	169 (102–268)	111	124 (70.0–193)	692 (234–1,088)	486	235 (106–409)	1,082 (294–2,112)	44.5 (37.0–52.0)	450 (97.0–853)	405 (<20.0–865)[e]	233	998	399	286	406
Se (ng/L)	50,000	40,000	10,000	10,000	180 (<40.0–1,596)[e]	<40.0[e]	<40.0[e]	<40.0[e]	282 (<40.0–1,068)[e]	<40.0[e]	49.0 (<40.0–122)[e]	853 (<40.0–3,632)[e]	<40.0[e]	98.7 (<40.0–256)[e]	122 (<40.0–363)[e]	<40.0[e]	<40.0[e]	<40.0[e]	<40.0[e]	<40.0[e]
Th (ng/L)	2,000				<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	356 (<200–2,144)[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[e]	<200[d]
Tl (ng/L)					16.5 (15–31)	<30.0[e]	<30.0[e]	<30.0[e]	24.0 (<30.0–51.0)[e]	32.0	26.0 (<30.0–81.1)[e]	<30.0[e]	<30.0[e]	304 (<30.0–682)[e]	97.3 (<30.0–509)[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[e]	<30.0[d]
U (ng/L)	30,000	30,000			212 <15.0–834)[e]	248 (<15.0–730)[e]	<15.0[e]	9.25 (<15.0–18.0)[e]	671 (460–971)	<15.0[e]	375 (<15.0–961)[e]	720 (279–2,269)	396 (387–405)	232 (<15.0–446)[e]	2,059 (54.0–7,910)	821	45.0	<15.0[e]	1,091	201
Zn (μg/L)					66.7 (0.630–281.7)	7.63 (1.40–15.3)	2.10	6.52 (0.630–18.0)	20.4 (0.630–60.5)	3.40	48.7 (0.630–125)	147 (0.630–630)	11.7 (10.7–12.6)	128 (0.630–380)	24.6 (0.630–107)	3.00	12.8	8.90	5.70	0.625

[a]USEPA (2009).
[b]WHO (2011b).
[c]GCC Standardization Organization (2012, GSO 987/2012).
[d]GCC Standardization Organization (2008, GSO 149/2008).
[e]Value is less than the instrumental detection limit.
[f]Mean value is significantly higher ($p < 0.05$) than all other countries of origin.

Table 2 | Mean and range of pH, total dissolved solids, anions and major elements in bottled water samples ($n = 56$) and guideline values from USEPA[a] and WHO[b] and GSO

				Desalinated bottled water				Non-desalinated bottled water											
	USEPA	WHO	GSO bottled water	Qatar	Kuwait	Bahrain	UAE	Lebanon	Morocco	Turkey	France	Scotland	Germany	Italy	Austria	Fiji Islands	New Zealand	Switzerland	UK
pH				7.73 (7.15–8.09)	7.32 (6.56–7.91)	7.06	7.42 (7.05–7.80)	7.95 (7.79–8.11)	7.97	7.72 (7.28–8.08)	6.77 (5.51–7.70)	5.35 (5.31–5.38)[e]	6.86 (6.21–7.65)	6.52 (4.69–8.17)	7.86	7.35	6.94	7.67	7.75
Electrical conductivity (μS/cm)				206 (90.4–403)	243 (182–323)	189	254 (224–283)	424 (346–504)	260	139 (89.0–198)	1,053 (212–2,021)	315 (306–323)	1,810 (341–3,060)	473 (43.0–1,313)	1,054	297	154	644	551
Total dissolved solids (mg/L)				101 (44.0–197)	119 (89–158)	92.0	124 (110–139)	208 (169–247)	128	68.0 (43.0–97.0)	516 (104–989)	154 (150–158)	887 (167–1,499)[f]	230 (2.00–647)	516	145	76.0	316	270
Br^- (mg/L)				0.056 (0.010–0.120)	0.040 (0.040–0.040)	n/a[d]	n/a[d]	0.0167 (0.010–0.020)	0.060	n/a[d]	0.079 (0.020–0.20)	n/a[d]	0.083 (0.010–0.160)	0.122 (0.020–0.310)	n/a[d]	0.040	n/a[d]	n/a[d]	0.040
Cl^- (mg/L)				13.9 (0.40–52.7)	24.5 (11.4–46.0)	n/a[d]	45.9 (28.8–57.3)	3.95 (1.20–6.70)	11.1	0.683 (0.300–1.50)	24.5 (3.10–50.6)	2.05 (1.90–2.20)	36.7 (7.30–74.0)	13.0 (0–44.6)[a]	1.50	9.00	35.8	4.60	12.2
F^- (mg/L)	4.0	1.5	1.5	0.070 (0.040–0.100)	0.050 (0.050–0.050)	n/a[d]	n/a[d]	0.0667 (0.050–0.100)	0.200	n/a[d]	0.554 (0.090–1.09)	n/a[d]	0.405 (0.090–0.840)	0.405 (0.370–0.440)	0.560	0.270	n/a[d]	0.060	0.060
NO_3^- (mg/L)	10	50	50	0.399 (0.01–2.33)	3.62 (0.060–10.7)	0.030	0.220 (0.060–0.570)	0.730 (0.230–1.36)	n/a[d]	1.31 (0.930–1.88)	4.06 (0.370–6.81)	1.80 (1.06–2.53)	2.49 (0.100–5.63)	3.20 (1.67–5.92)	1.59	1.22	0.060	0.610	22.5[f]
SO_4^{-2} (mg/L)				6.77 (0.100–33.1)	34.7 (0.900–55.4)	73.6	6.74 (2.50–11.4)	8.25 (2.90–14.0)	41.2	4.78 (2.00–7.00)	129 (6.50–626)	3.30 (2.40–4.20)	29.3 (11.1–51.5)	126 (1.40–438)	394	1.40	n/a[d]	n/a[d]	5.40
HCO_3^- (mg/L)				10.4 (0.790–3.36)	4.17 (0.880–8.10)	2.86	5.75 (3.43–8.46)	33.0 (20.79–44.38)	10.8	11.5 (6.54–16.6)	62.6 (12.4–171)	21.5 (17.4–25.7)	103 (29.07–203)	16.6 (0.860–43.9)	42.2	26.0	0.770	n/a[d]	21.7
Total organic carbon (mg/L)				2.28 (1.67–3.49)	2.26 (1.68–2.70)	4.72	2.74 (1.67–7.07)	4.03 (3.40–4.77)	2.33	2.26 (1.89–2.83)	15.6 (2.27–89.2)	2.25 (1.78–2.71)	8.25 (3.14–14.9)	2.65 (1.53–4.61)	3.12	3.74	1.98	n/a[d]	3.52
Ca^{+2} (mg/L)		20 (min) 50 (optimum)		18.6 (0.012–39.1)	15.7 (0.176–34.0)	0.116	10.6 (3.76–19.3)	39.2 (26.1–57.7)	14.3	16.7 (10.5–26.2)	115 (11.6–234)	31.7 (23.3–40.0)	61.9 (47.6–88.4)	56.9 (1.88–169)	171	17.7	13.5	68.1	83.4
K^+ (mg/L)				0.196 (0.018–0.850)	0.805 (0.100–1.39)	0.042	2.05 (0.060–7.00)	0.643 (0.290–0.890)	2.04	0.213 (0.088–0.306)	5.19 (0.710–9.85)	0.485 (0.380–0.590)	8.91 (1.67–17.4)	1.04 (0.260–2.28)	0.550	4.53	2.68	1.19	0.500
Mg^{+2} (mg/L)		10 (min) 20–30 (optimum)		6.24 (0.002–25.3)	8.65 (4.79–12.2)	18.7	10.1 (3.97–18.4)	17.3 (10.1–22.5)	7.79	3.36 (1.47–6.20)	36.6 (4.54–82.5)	7.64 (6.47–8.81)	45.5 (6.25–81.0)	15.0 (0.482–49.8)	41.5	14.0	2.92	23.0	1.58
Na^+ (mg/L)				3.56 (0.620–9.14)	9.20 (7.52–11.7)	2.70	12.9 (4.67–20.5)	3.06 (1.16–4.56)	23.7	2.78 (1.25–5.02)	48.6 (6.90–162)	4.96 (4.00–5.92)	138 (8.80–295)[f]	11.2 (1.85–32.2)	2.15	17.4	1.41	6.05	7.02

[a]USEPA (2009).
[b]WHO (2011b).
[c]Value is less than the instrumental detection limit.
[d]Element was not measured in this sample.
[e]Mean value is significantly lower ($p < 0.05$) than all other countries of origin.
[f]Mean value is significantly higher ($p < 0.05$) than all other countries of origin.

Table 3 | Statistically significant ($p < 0.05$) linear regression coefficients between non-desalinated and desalinated bottled water

Parameter	β-coefficient	p-value
NO_3^- (mg/L)	−2.12	0.030
Ca (mg/L)	−47.3	0.001
K (mg/L)	−1.96	0.030
Mg (mg/L)	−13.1	0.016
As (ng/L)	−921	0.008
Ba (μg/L)	−55.8	0.036
Co (ng/L)	−127	0.008
U (ng/L)	−613	0.042

caries, especially in children less than 9 years of age (WHO 2005; Pizzo *et al.* 2007).

There is evidence of dietary Ca and Mg deficiencies in many parts of the world today; these deficiencies may become increasingly exacerbated as reliance on desalinated water increases (WHO 2011a). The contribution of drinking water to Ca, Mg and F^- intake for populations dependent on desalinated water is explored in the following section.

Contribution of desalinated bottled water consumption to recommended daily intakes for Ca, Mg and F^-

Drinking water contributes between 1 and 5% of the total dietary intake of several micronutrients. The contribution is much higher for Ca and Mg, up to 20%, as well as F^-, up to 80% of the daily dietary requirement (WHO 1996, 2005). Table 4 shows the IOM AI_{Ca}, AI_F and RDA_{Mg} for adult males and adult females, including those who are pregnant, and the contribution (given as percent) of desalinated and non-desalinated bottled water consumption to the recommended intakes.

Desalinated bottled water contributed a significantly lower percentage of the AI_{Ca} ($p = 0.001$) and RDI_{Mg} ($p = 0.016$) for adults when compared to non-desalinated water sources. The contributions were not significantly different for F^- at the $\alpha = 0.05$ level, however, they were notable, with desalinated bottled water contributing approximately 5 times less than the other types. For adult males, non-desalinated bottled water contributed approximately 14% of the AI_{Ca} and 15% of the RDA_{Mg}, whereas desalinated brands only accounted for approximately 3% of AI_{Ca} and 6% of the RDA_{Mg}. The same was observed for adult females, both pregnant and non-pregnant. The deficit in Ca and Mg content in desalinated seawater increases the risk of Ca and Mg deficiencies among populations dependent on desalinated water. Beyond direct contribution to nutrient intake, cooking with water of low mineral content has been shown to decrease mineral content in cooked foods; therefore, the low Ca and Mg content in desalinated water may indirectly impact the dietary intake of these elements and further increase the risk of deficiencies (Haring & Van Delft 1981).

Children are uniquely susceptible to mineral deficiencies and are at higher risk of developmental impacts (WHO 2005). Table 5 shows the contribution of desalinated and non-desalinated bottled water to the AI_{Ca}, RDI_{Mg} and AI_F for children ages 1–10 years. Desalinated bottled water contributed between 2.7 and 3.8% of the AI_{Ca} while non-desalinated brands ranged from 11.3 to 15.3%. For the

Table 4 | AI[a] (Ca and F) and RDA[b] (Mg) values for adults and contribution of bottled water consumption to recommended daily intake

	Pregnant females			Females ≥19 years			Males ≥19 years		
Mineral	RDA/AI	%RDA/AI (desalinated)[c,d]	%RDA/AI (non-desalinated)[c,e]	RDA/AI	%RDA/AI (desalinated)[c,d]	%RDA/AI (non-desalinated)[c,e]	RDA/AI	%RDA/AI (desalinated)[c,d]	%RDA/AI (non-desalinated)[c,e]
Ca[a]	1,000	3.3	14	1,000	3.3	14	1,300	3.3	14
Mg[b]	355	5.1	13	310	5.9	15	400	6.0	16
F[a]	3	4.6	27	3	4.6	27	4	4.6	27

[a]Adequate intake (AI) value (mg/day) (IOM 1997).
[b]Recommended daily allowance (RDA) value (mg/day) (IOM 1997).
[c]Calculations based on WHO drinking water reference values for hydration (2.2 L/day for adult females and 2.9 mg/L for adult males) under average conditions (WHO 2005).
[d]Contribution estimated using mean concentration of all desalinated samples.
[e]Contribution estimated using mean concentration of all non-desalinated samples.

Table 5 | AI[a] (Ca and F) and RDA[b] (Mg) values for children and contribution of bottled water consumption to recommended daily intake

	Ca	Mg	F
1–3 years			
RDA/AI (mg/day)	400[a]	80[b]	0.70[a]
% RDA/AI (desalinated)[c,d]	3.8	10	9.1
% RDA/AI (non-desalinated)[c,e]	15	27	53
4–6 years			
RDA/AI (mg/day)	450[a]	130[b]	1[a]
% RDA/AI (desalinated)[c,d]	3.3	6.4	6.3
% RDA/AI (non-desalinated)[c,e]	14	16	37
7–8 years			
RDA/AI (mg/day)	550[a]	130[b]	1[a]
% RDA/AI (desalinated)[c,d]	2.7	6.4	6.3
% RDA/AI (non-desalinated)[c,e]	11	16	37
9–10 years			
RDA/AI (mg/day)	550[a]	240[b]	2[a]
% RDA/AI (desalinated)[c,d]	2.7	3.4	3.2
% RDA/AI(non-desalinated)[c,e]	11	8.9	19

[a]Adequate intake (AI) value (mg/day) (IOM 1997).
[b]Recommended daily allowance (RDA) value (mg/day) (IOM 1997).
[c]Calculations based on WHO drinking water reference values for hydration (1.0 L/day) for children under average conditions (WHO 2005).
[d]Contribution estimated using mean concentration of all desalinated samples.
[e]Contribution estimated using mean concentration of all non-desalinated samples.

RDA of Mg, desalinated water provided between 3.4 and 10.3% while non-desalinated types provided between 8.9 and 26.7%. This discrepancy was also present for the adequate intake of F^-; desalinated water contributed between 3.2 and 9.1% while non-desalinated bottled water contributed up to 53.3% of the AI_F.

Owing to social and cultural preferences for bottled water, children in many countries throughout the Gulf rely on bottled water as their primary drinking water source. The nutrient requirements for adolescents place them at higher risk of health complications from dietary deficiencies. Insufficient intake of Ca during puberty increases the risk of bone fracture and osteoporosis in adulthood as approximately 40% of total bone mass is accumulated during this stage (Greer & Krebs 2006). Low dietary intake of Mg has shown decreased lung function among children, particularly among those with asthma and other respiratory diseases (Gilliland et al. 2002). Given the low mineral content in desalinated drinking water, children relying on this water source may require dietary supplements to minimize health risks.

Effect of container type on elemental content

Samples were bottled in either glass ($n = 8$) or PET/PETE ($n = 48$) containers. The majority of samples were still water ($n = 47$), only nine samples were carbonated. Water stored in glass bottles contained significantly higher concentrations of select essential and non-essential parameters including Be ($p = 0.001$), Mn ($p = 0.011$), As ($p = 0.038$), Ba ($p = 0.0006$), Tl ($p = 0.025$) and Pb ($p = 0.039$) (Table 6).

Studies comparing glass and PET bottle types have varied in their observations. Cidu et al. (2011) did not observe significantly higher trace element concentrations in natural mineral waters bottled in glass containers; however, several studies have found higher levels of trace elements including K, Li, Na, Pb, U and Zr in glass bottles compared to plastic containers (Misund et al. 1999; Shotyk & Krachler 2007b). All but one glass bottled sample contained carbonated drinking water; the impact of each variable (e.g. container type or CO_2) on trace element content requires further investigation.

Table 6 | Average concentrations for parameters with significant differences ($p < 0.05$) between samples in glass containers and in PET/PETE containers

Parameter	Units	Average concentration for glass container	Average concentration for PET/PETE container	p-value
pH		6.05	7.48	<0.001
TDS	mg/L	582	186	<0.001
Br^-	mg/L	0.154	0.055	0.004
HCO_3^-	mg/L	69.7	18.4	<0.001
Ca	mg/L	82.2	37.0	0.014
K	mg/L	4.76	1.52	0.005
Mg	mg/L	33.8	13.0	0.003
Na	mg/L	75.1	11.3	<0.001
As	ng/L	1,534	521	0.038
Ba	μg/L	134	33.6	0.006
Be	ng/L	27.8	6.19	0.001
Mn	μg/L	14.5	2.02	0.011
Pb	ng/L	574	205	0.039
Tl	ng/L	124	28.1	0.025

CONCLUSIONS

Many countries in arid or semi-arid regions already rely on alternative water resources (such as treated wastewater and desalinated seawater) to meet growing water demands. The Gulf region is in a state of acute water stress and depends solely on seawater desalination for potable water. The health implications of this dependency have been poorly researched thus far. This study was prompted by Qatar's dependence on seawater desalination and preferences for bottled water by local populations.

Trace element content in bottled water samples from local markets within Qatar did not exceed drinking water guidelines of the USEPA, WHO or GSO. Results indicate that Qatar's population is not at elevated risk of dietary exposure to As, Ba, Be, Cd, Cr, Pb, Sb and U from consumption of both desalinated and non-desalinated bottled water types available in the country. Consumers who primarily consume desalinated water brands further minimize risk of exposure to As, Ba, Co and U as levels were significantly lower than in non-desalinated bottled water.

Desalinated bottled water contained significantly lower levels of Ca, Mg and F^- than other water types. This deficit may increase the likelihood of nutrient deficiencies among populations dependent on desalinated water as results indicate desalinated bottled water consumption was not a significant contributor to recommended daily intakes for Ca, Mg and F^- for adults and children.

Drinking water guidelines should reflect the low mineral quality of finished water and impose minimum nutrient requirements to minimize adverse human health impacts. A variety of cost-effective remineralization techniques are currently available to increase nutrient content of desalinated seawater.

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