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الخواص الفيزيائية والكيميائية لجودة مياة الشرب في الكويت: مياة الصنبور والمعبأة

***عبد الرحمن الصليلي، **مشاري الحربي و *خولة الطواري**
*كلية الهندسة والبترول، قسم الهندسة المدنية، جامعة الكويت، الكويت
** كلية العلوم الحياتية، ادارة التقنيات البيئية، جامعة الكويت، الكويت

الخلاصة

على الرغم من الجهود المكثفة التي تبذلها معظم الحكومات لضمان إيصال مياة الشرب عالية الجودة للمستهلكين. فهناك بعض حالات انعدام ثقة المستهلكين في مياة الصنبور بسبب التلوث الكيميائي أو التلوث الجرثومي أو غالباً ما يكون مصحوب بوجود طعم أو رائحة غير مرغوب فيها. ولذلك، فإن الاستهلاك العالمي من المياه المعبأة في زجاجات تتزايد بشكل مطرد. الأهداف الرئيسية لهذة الدراسة هي، أولاً، للتأكد من أن نوعية مياه الصنبور في دولة الكويت تلبي المعايير الدولية لمياه الشرب، وثانياً، دراسة معايير جودة المياة المعبأة التي تباع في السوق الكويتي ومقارنتها مع التراكيز المذكورة من قبل المصنعين. وقد تم تحليل ثلاثة وأربعين عينة لمياة الصنبور وواحد وعشرين عينة للمياه المعبأة (6 محلية و15 مستوردة) والتي تباع في الكويت لفحص الخواص الفيزيائية والكيميائية لها. وقد تم تحليل أثر المعادن والأيونات الرئيسية باستخدام ICP-MS(Bruker 820-MS) و ICP-OES(GBC Quantima) و IC-DIONEX (Sequential) كما تم قياس المواد الصلبة الذائبة (TDS)، ودرجة الحموض (pH) والموصلية الكهربائية باستخدام جهاز القياس المتعدد. بينت النتائج أن تركيز الأيونات الرئيسية في كل من مياه الصنبور والمياه المعبأة كانت أقل من القيم القصوى التي نصت عليها معظم الوكالات الدولية، بأستثناء الكلوريد (C1-) في ماء الصنبور، حيث أن 18.6% من العينات التحقيق تجاوزت معايير ادارة الأغذية والعقاقير(FDA) ومنظمة الصحة العالمية (WHO) 200 ملغ/ لتر. معظم محتويات أثر المعادن في معظم عينات المياه المعبأة موافقة لمواصفات مياه الشرب، بإستثناء (Se) في أثنين من العلامات التجارية المحلية (Abraaj ABC). أما عينات مياه الصنبور فإن متوسط تراكيز B, As, Zn تجاوزت بعض القيم الدولية. هذة النتيجة تنجم عن عدة أسباب مختلفة، بما في ذلك تسرب هذه المواد من التكوينات الجيولوجية خلالها تدفق المياه الجوفية أو ذوبان المواد الكيميائية من أي مصادر طبيعية أو من أنظمة السباكة المنزلية. كما تم قياس الخواص الكيميائية والفيزيائية للمياه المعباة ومقارنتها بالقيم المعلنة من قبل المصنعين وتبين وجود بعض التناقضات الواضحة في معظم العلامات التجارية للمياه المعبأة. وتخلص هذه الدراسة إلى أن الرصد المنهجي لجودة المياه من قبل السلطات المسؤولة أمر ضروري ومطلوب سواء لمياه الصنبور أو المياه المعبأة وضرورة وجود نظام موحد لمراقبة الجودة في صناعة المياه المعبأة.

Physical and chemical characteristics of drinking water quality in Kuwait: tap vs. bottled water

Abdalrahman Alsulaili*, Meshari Al-Harbi** and Khawlah Al-Tawari*

**Department of Civil Engineering, College of Engineering and Petroleum*
E-mail: a.alsulaili@ku.edu.kw
***Department of Environmental Technology Management, College of Life Sciences, Kuwait University, P.O. Box 5969 Kuwait, Safat 13060, Kuwait*

ABSTRACT

Despite the extensive efforts made by most governments to ensure the delivery of high-quality drinking water, the public lacks confidence in tap water due to pollution, bacterial contamination and its undesirable associated taste and odor. Thus, the worldwide consumption of bottled water has been steadily increasing. The main objectives of this study are, first, to determine whether that the quality of tap water in Kuwait meets international standards for drinking water, and second, to examine the drinking quality parameters of bottled water sold on the Kuwaiti market and compare them with the corresponding labeled values. Forty-three tap water samples and twenty-one bottled water brands (6 local and 15 imported) sold in Kuwait were analyzed for different chemical and physical parameters. Trace metals and major ions were analyzed using ICP-MS (Bruker 820-MS), ICP-OES (GBC Quantima Sequential) and IC-DIONEX. Total dissolved solids (TDS), pH and electrical conductivity were measured using a multi-purpose meter. The results show that the concentrations of major ions in both tap and bottled water were below the drinking water threshold values stipulated by most international agencies, with exception of the chloride (Cl^-) content in tap water, where 18.6% of the samples investigated exceeded the FDA and WHO standards of 200 mg/L. The trace metal contents in most of the bottled water samples met the drinking water standards, except for the Se content in two local brands (ABC and Abraaj). For the tap water samples, the mean concentrations of Zn, As, and B exceeded some international regulatory values. This finding may result from a number of different reasons, including the geological formations through which the ground water flows and substances dissolving from either natural sources or from household plumbing systems. Concerning bottled water, the labeled and measured physiochemical parameters of the samples were compared. Discrepancies between the labeled and measured values were clear in most of the bottled water brands. This study concludes that the systematic monitoring by drinking water authorities of water quality is essential and that a uniform system for quality control and assurance is required in the bottled water industry.

Keywords: Bottled water; Drinking water quality; Tap water.

INTRODUCTION

The evaluation of water quality has gained worldwide attention because the majority of diseases that cause morbidity and mortality are water-related (Shayo *et al.,* 2007). Over at least the past two decades, there has been increased concern regarding the quality of tap water due to pollution and its undesirable taste and odor (Saleh *et al.,* 2001; Ikem *et al.,* 2002). The pollution of tap water could originate from several sources, including contamination from water pipes and storage tanks (Parag & Roberts , 2009) and, in the absence of proper and periodic maintenance, from disinfectant by-products resulting from the treatment of water by ozonation and chlorination (Richardson 2003; Chen & Westerhoff , 2010). Thus, for the sake of safety and quality, people are switching from tap water to bottled water.

The worldwide consumption of bottled water has increased rapidly over the last two decades, as people have become more aware of the importance of water to their health and diet. It was reported that the global annual growth rate of bottled water consumption was 5.5% in the period between 2004 and 2009, which reached a consumption of 203 million metric tons of bottled water in 2009 (Rodwan, 2009). Kuwait was ranked 19th among the 76 countries with reported bottled water consumption (Gleick , 2004) with an average consumption of 20.1 gallons per capita. Comparing Kuwait's bottled water consumption value to the 23.2 gallons per capita for both Saudi Arabia and also the United States over the same time period indicates that the consumption of bottled water is large and growing quickly (Gleick, 2004). Although it is not clear that bottled water is better quality than tap water (Lalumandier & Ayers, 2000; Saleh *et al.,* 2001; Ward *et al.,* 2009) its global consumption has nevertheless increased dramatically. It has been speculated that bottled water is tap water filled into bottles with or without additional treatment. In a previous consumer survey in the United States in 2006, it was shown that 44% of all bottled water was, in fact, bottled tap water (Gleick & Cooley, 2009). The other possible sources of positive consumer perceptions of bottled water could involve the variety of the brands, sizes, sources, types, and flavor; however, there is very little scientific proof to support the belief that bottled water is better quality than tap water (Napier & Kodner, 2008). In Canada, a survey of a southwestern Ontario community revealed that 37% of the residents drink bottled water as their only drinking water source due to their discomfort with the tap water flavor (Pintar *et al.,* 2009).

Any potable water that is offered for sale in a sealed container is considered to be bottled water. Sources of bottled water may be natural mineral water from springs, wells, lakes, or glaciers, or from distilled municipal water, or any other potable water source. It may be carbonated, distilled, ozone treated or purified. Regardless of its source, potable bottled water undergoes a long production process that may include, but is not limited to, filtration, distillation, de-ionization, reversed osmosis, ozone disinfection and exposure to ultraviolet (UV) radiation (US EPA, 2009).

Worldwide, tap water is regularly controlled by certified authorities because it is used for drinking and cooking. In contrast, bottled water goes through less comprehensive testing, which also occurs less frequently. Additionally, most of the regulatory standards applied to tap water do not apply to bottled water. For this reason, the chemical composition of bottled water must be investigated so that potential risks from exposure to potentially dangerous contaminants can be minimized, which is of particular concern because of the increase in bottled water consumption. In one study (Alam & Sadiq, 1988), nine bottled water brands marketed in Saudi Arabia were assessed. The results showed that the level of calcium (Ca^{2+}) and sodium (Na^{+}) in two bottled water brands were higher than the values printed on their labels. In another study in Saudi Arabia, fourteen domestic and seven imported brands of bottled water were tested. In that study, the levels of total dissolved solids, Ca^{2+}, magnesium (Mg^{2+}), Na^{+}, potassium (K^{+}), nitrates (NO_3^{-}), chloride (Cl^{-}), and sulfate (SO_4^{2-}) were found to be within the acceptable limits of local and international standards (Alabdula'aly & Khan, 1999). Moazeni *et al.,* (2013) studied twenty one bottled water brands in Iran and found that the content of K^{+} and SO_4^{2-} in 43% and 52% of the samples, respectively, had values higher than the values reported on the product's label. Additionally, the level of Ca^{2+} and Cl^{-} ions and the pH were approximately 71%, 48%, and 67% less than the values reported on the label, respectively. Hussein *et al.,* (2014) investigated the chemical composition of 20 bottled water brands in Iraq and found that most bottled water is safe to drink, with little discrepancy between the labeled and measured values of the constituents. Aris *et al.,* (2013) tested the physiochemical parameters of 20 bottled water brands and found that all of the tested samples were in accordance with the guidelines set by the WHO and the Malaysian Ministry of Health, except for one sample, which was below the pH limit of 6.5. Ikem *et al.,* (2002) examined bottled water and found that spring bottled water contains more dissolved substances than distilled water. The study also determined that the chemical composition of water varies within each geographical area and that wide variation exists between countries. Al-Mudhaf *et al.,* (2009) surveyed the organic contaminants in 113 bottled water samples in Kuwait. The results showed that styrene, toluene, total xylenes and ethyl benzene levels increased substantially with storage time, suggesting that these volatile organic compounds (VOCs) may have been transferred from the polystyrene containers to the water. However, the VOC concentration was not affected by storage temperature. The main pollutant found in all 200 mL and 250 mL polystyrene containers was styrene, with levels higher in five imported brands than the WHO recommended value of 20 µg/L.

Due to increased public concern about the drinking quality of bottled water and tap water, this study aims to evaluate the physical and chemical water quality parameters of locally produced and imported bottled water brands sold on the Kuwaiti market.

Additionally, tap water samples from various regions across Kuwait were investigated. The measured parameters were then compared with various international and Kuwait Environment Public Authority (KUEPA) regulatory standards, as well as with the labeled values for the bottled water samples. The standards considered in this study come from the Food and Drug Administration (FDA), the World Health Organization (WHO), the United States Environmental Protection Agency (US-EPA), the GCC Standardization Organization (GSO), and the Kuwait Environment Public Authority (KUEPA) (Tables 1 and 2).

Table 1. Standards for major ions and physical parameters

Parameter	Ca mg/l	Na mg/l	K mg/l	Mg mg/l	F mg/l	Cl mg/l	NO_2 mg/l	SO_4 mg/l	NO_3 mg/l	pH pH unit	TDS ppm
FDA	-	-	-	-	-	250	1	250	10	-	500
WHO	-	50	12	50	1.5	-	3	-	50	-	-
WHO aesthetic	200	200	200	-	-	200	-	250	-	6.5-8.5	600
KUEPA	200	200	10	150	1.5	250	3	250	50	6.5-8.5	1000
GSO	-	-	-	150	-	-	-	-	-	6.5-8	600

Table 2. Standards for trace metal health guidelines

In (μg/l)	**WHO aesthetic**	**WHO health**	**FDA**	**KUEPA**	**USEPA**	**GSO**
Be	-	-	4	-	4	-
B	-	2400	-	300	-	500
Al	100	100	200	200	-	100
Cr	-	50	100	50	100	50
Mn	100	-	50	500	-	100
Fe	300	-	300	300	-	300
Ni	-	70	100	20	-	20
Cu	5000	2000	1000	2000	1300	1000
Zn	4000	50	5000	3000	-	100
As	-	10	10	10	10	10
Se	-	40	-	10	50	10
Mo	-	70	-	70	-	70
Ag	-	50	100	-	-	-
Cd	-	3	5	3	5	3
Sb	-	20	6	5	6	20
Ba	-	700	2000	700	2000	700
Hg	-	6	2	1	2	1
Pb	-	10	5	10	15	10
U	-	30	-	-	30	15

METHODOLOGY

For the bottled water analysis, six domestic and fifteen imported bottled water brands were collected from different supermarkets within the State of Kuwait. The name of each brand and its country of origin are provided in Table 3. All brands are sold in 0.33, 0.50 and 0.60 L plastic bottles with plastic screw caps, except one imported brand (Sultan), which is sold in 2 L sizes. For the tap water analysis, 43 tap water samples were collected from all six governorates in the State of Kuwait (Figure 1 and Table 4), taking into consideration random sampling to avoid self-selection bias.

Three bottles of each sample were collected and analyzed separately for different chemical and physical parameters. Trace metals (Al, As, Ag, Ba, Be, B, Ge, Hg, Hf, Sb, Ti, Th, V, Cd, Cr, Cs, Co, Ni, Zr, Nb, Mo, Fe, Cu, Mn, Pb, Sn, Se, W, U, and Zn) were analyzed using ICP-MS (Bruker 820-MS). Major cations (K, Na, Ca, Sr, and Mg) were analyzed using ICP-OES (GBC Quantima Sequential), and major anions (F, Cl, NO_3, NO_2, Br, PO4 and SO_4) were analyzed using IC-DIONEX. For all of the bottled and tap water samples, the total dissolved solids (TDS), pH and electrical conductivity (EC) were measured using a multi-purpose meter.

Three data sources were used in this study: a) the laboratory analysis reports from the purchased bottled water, b) the reported chemical composition on the labels of the samples, and c) international and regional drinking water standards (Tables 1 and 2). Pearson correlation analysis was also conducted to analyze the relationship between each parameter analyzed in the bottled water samples.

Table 3. The domestic and imported water brands investigated in this study

no	Sample	Size (ml)	Note	Production of
1	ABC	600	Sterilized by ozone	Kuwait
2	ABC Peekaboo	330	-	Kuwait
3	Abraaj	500	Sterilized by ozone and UV	Kuwait
4	Adan	330	Natural mineral water	Jordan
5	Aquafina	600	-	Kuwait
6	Arwa	330	-	Kuwait
7	Bahcepinar	500	Natural spring water	Turkey
8	Berdawni	330	Natural mineral water	Lebanon
9	Deva	330	Groundwater	Jordan
10	Emirates	500	Natural spring water	UAE
11	Evian	330	Natural mineral water	France
12	Hayat	330	Natural mineral water	Turkey
13	Highland Spring	500	Still natural mineral water	Scotland
14	Masafi	500	Natural mineral water	UAE
15	Rawdatain	330	Natural mineral water	Kuwait
16	Sultan	2000	Natural spring mineral water	Lebanon
17	Ultra	330	Fluoride and sodium free	Jordan
18	Ultra Baby	330	Fluoride and sodium free	Jordan
19	Vida	330	Natural alkaline water	Jordan
20	Vio	500	Natural still mineral water	Germany
21	Volvic	500	Natural mineral water	France

Table 4. Regions from which tap water samples were collected

Sample ID	Area name	Sample ID	Area name
A-1	Al-Munqaf	A-23	Sulaibiya
A-2	Al-Qurain	A-24	Rumaithiya
A-3	Sharq	A-25	Bayan
A-4	Hadiya	A-26	AlRawdah
A-5	Al-Khairan	A-27	Saad Alabdulla
A-6	Al-Rawda	A-28	Al-Dahar
A-7	Al-Adailiya	A-29	Mahboula
A-8	Al-Sabahiya	A-30	Kaifan
A-9	Al-Surra	A-31	Salwa
A-10	Abdulla Almubarak	A-32	Al-Qairawan
A-11	Mishref	A-33	Al-Fahaheel
A-12	Al-Ruqqa	A-34	Jaber Alali
A-13	Al-Ardiya	A-35	Al-Salam
A-14	Al-Andalus	A-36	Al-salmiya block 4
A-15	Al-Jabriya	A-37	Alshuwaikh
A-16	Al-Farwaniyah	A-38	Al-Farwaniyah
A-17	Ishbiliya	A-39	Al-Yarmuk
A-18	Sabah Alnasser	A-40	Al-Adan
A-19	Hawally	A-41	Bayan
A-20	Khaitan	A-42	Al-Waha
A-21	Al-Salmiya	A-43	Al-Khaldiya
A-22	Al-Rabia		

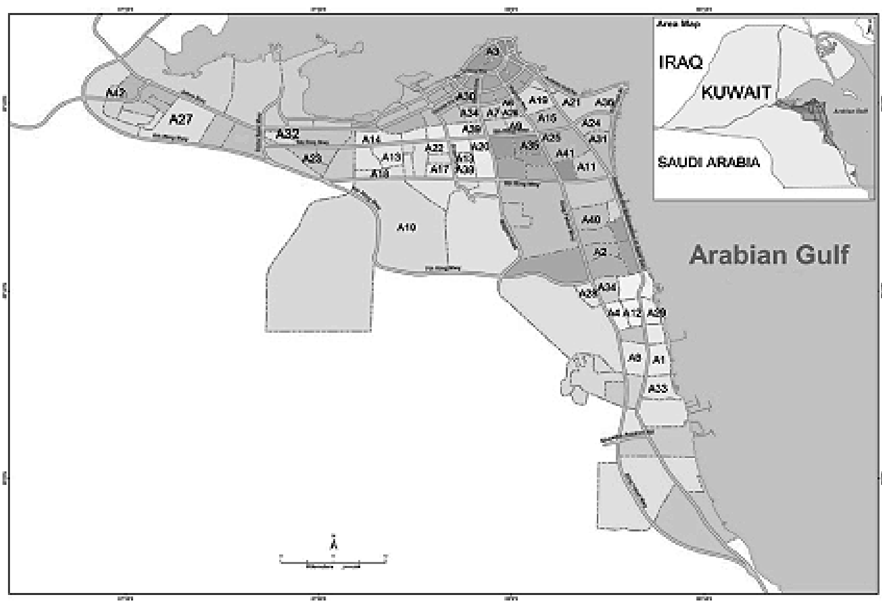

Fig. 1. Map of the regions from which tap water samples were collected

RESULTS AND DISCUSSION

The results from the physical and chemical analysis of the bottled and tap water were compared with standards recommended by the FDA, WHO, US-EPA, GSO, KUEPA, as well as the reported values listed by the manufacturers on the product label in the case of bottled water.

Bottled water analysis

Physical Parameters

Table 5 shows the individual physical and chemical analyses of six locally produced and fifteen imported bottled water samples. Table 6 presents the corresponding descriptive statistics. The pH values ranged between 6.32 and 7.67 for the domestic bottled water brands, with an average pH value of 7.1, whereas it varied between 6.9 and 8.1 for the imported bottled water brands, with an average pH value of 7.56. All of the pH values for the local brands were within the acceptable range (of 6.5–8.5) as determined by the WHO, except for Aquafina (pH = 6.3). For the imported bottled water brands, Adan (pH = 8.1) and Berdawni (pH = 8.04) do not comply with the GSO allowable pH range of 6.5–8.

The electrical conductivity (EC) varied between 94 µS/cm and 342 µS/cm in the local brands of bottled water, with an average value of 231.8 µS/cm. The EC in the imported bottled water brands ranged from 9 µS/cm to 760 µS/cm, with an average value of 333.4 µS/cm. It should be noted that there are no health guidelines for the minimum allowable electrical conductivity of water. The measured TDS in the local bottled water samples ranged between 47 mg/l and 171 mg/l, with an average value of 124.1. In the imported brands, the TDS ranged between 4 and 380 mg/l, with an average value of 166.1 mg/l. We note that the TDS of both the local and imported bottled water brands were below the FDA limit of 500 mg/l and the WHO acceptability standard of 600 mg/l. Trivedi & Goel (1984) reported that EC is indicative of TDS content in water samples. Indeed, it has been found that water samples with high EC values often contain high levels of TDS (Abdullah *et al.,* 2007). In this study, there was a strong correlation (r = 1.0) between EC and TDS, which is consistent with observations reported previously (Trivedi & Goel, 1984).

Major cations

In the local bottled water brands, the lowest concentration of calcium (Ca^{2+}) was 0.88 mg/l and highest concentration was 30.58 mg/l, with an average Ca^{2+} concentration of 10.82 mg/l. In the imported bottled water brands, the lowest concentration of Ca^{2+} was 0.76 mg/l and highest concentration was 51.71 mg/l, with an average Ca^{2+} concentration of 22.69 mg/l. All of the local and imported brands were below the WHO acceptable limit of 200 mg/l.

The mean concentration of sodium (Na^{+}) was 8.17 mg/l (range: 0.072–10.71 mg/l) in the local bottled water brands compared with 9.4 mg/l (range: <0.01–36.29 mg/l) in the imported brands. Sodium levels above 200 mg/l may affect the taste of drinking water (Saleh *et al.,* 2001); however, the Na^{+} levels in both the local and imported brands were below the WHO's health guideline of 50 mg/l and adequacy standard of 200 mg/l.

The average concentrations of potassium (K^{+}) and magnesium (Mg^{2+}) in the domestic bottled water brands were 2.5 and 7.3 mg/l compared with 1.65 and 10.2 mg/l in the imported brands, respectively. All values of K^{+} were under the WHO health guideline of 12 mg/l and the WHO acceptability standard of 200 mg/l. The magnesium levels in both the local and imported bottled water brands were also below the 50 mg/l health guideline suggested by the WHO. The mean concentrations of the major cations were as follows: 19.3 mg/l for Ca^{2+}; 9.2 mg/l for Mg^{2+}; 8.3 mg/l for Na^{+}; and 1.9 mg/l for K^{+}. Compared with measurements of 15 bottled water samples from Iraq (Ismail *et al.,* 2013), the twenty-one bottled water brands examined in this study possessed lower concentrations of Ca^{2+} (19.3 mg/l vs. 45.3 mg/l) and Mg^{2+} (9.2 mg/l versus 70.4 mg/l) but higher concentrations of Na^{+} (8.3 mg/l versus 10.04 mg/l) and K^{+} (1.9 mg/l versus 0.63 mg/l). However, the results of major cations in the present study are in agreement with those observed in Malaysia (Aris *et al.,* 2013) and Saudi Arabia (Abed & Alwakeel , 2007).

Table 5. bottled water major ions and physical properties

no	Sample	Ca	Sr	Na	K	Mg	F	Cl	SO_4	Br	PO_4	pH	TDS	Conductivity
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	pH unit	ppm	µS/cm
1	**ABC**	10.9	0.006	5.54	0.51	7.08	<0.01	16.88	<0.01	0.124	<0.01	6.89	120	241
2	**ABC Peekaboo**	2.3	0.004	0.07	7.6	1.91	0.018	3.865	<0.01	0.072	<0.01	6.99	47	94
3	**Abraaj**	19.2	0.007	3.44	1.05	4.10	0.033	14.8	<0.01	37.91	0.291	7.19	127	255
4	**Adan**	9.5	0.077	31.1	4.6	9.39	0.107	8.12	<0.01	28	0.078	8.1	175	350
5	**Aquafina**	0.88	0.004	10.7	1.38	11.26	0.024	7.29	<0.01	<0.01	<0.01	6.32	125	251
6	**Arwa**	1.11	0.012	2.88	0.56	12.85	0.028	1.242	<0.01	<0.01	0.13	6.64	104	208
7	**Bahcepinar**	12.2	0.019	2.01	0.56	5.17	0.058	1.28	<0.01	4.8	0.491	7.67	86	172
8	**Berdawni**	34.2	0.026	1.7	0.62	12.68	0.088	1.53	<0.01	12.59	0.085	8.04	173	346
9	**Deva**	42.4	1.007	36.3	5.82	25.61	1.076	21.25	<0.01	<0.01	0.068	7.81	380	760
10	**Emirates**	14.4	0.01	8.01	0.29	4.87	0.031	10.87	<0.01	49.4	0.124	7.67	123	246
11	**Evian**	51.7	0.271	4.7	1.16	19.72	0.057	2.90	<0.01	27.17	0.105	7.16	305	610
12	**Hayat**	19.4	0.041	<0.01	0.44	4.77	0.026	0.29	<0.01	7.11	0.288	7.94	94	187
13	**Highland Spring**	35.4	0.159	3.7	0.83	7.95	0.048	1.55	<0.01	9.49	0.111	7.9	168	336
14	**Masafi**	2.57	0.005	13.7	0.84	12.82	0.03	18.67	<0.01	22.78	0.175	7.56	149	299
15	**Rawdatain**	30.6	0.566	7.3	1.77	4.59	0.1	6.21	<0.01	<0.01	0.112	7.67	171	342
16	**Sultan**	32	0.048	1.47	0.59	11.2	0.089	1.45	<0.01	17.14	0.099	7.83	164	327
17	**Ultra**	1.3	0.026	0.24	0.27	0.41	0.047	0.079	<0.01	0.078	0.082	6.9	4	9
18	**Ultra Baby**	0.76	0.015	0.28	0.33	0.55	0.027	0.092	<0.01	0.068	0.1	6.9	4	9
19	**Vida**	37.5	0.972	34.8	5.53	26.01	1.062	21.24	<0.01	<0.01	0.33	7.76	380	759
20	**Vio**	38.4	0.144	6.98	1.27	4.73	0.116	4.069	<0.01	23.4	0.15	7.63	179	358
21	**Volvic**	8.85	0.034	8.34	4.51	6.31	0.221	4.99	<0.01	16.23	0.46	7.09	117	234

Table 6. statistical values of the results

		Ca	**Sr**	**Na**	**K**	**Mg**	**F**	**Cl**	**SO_4**	**Br**	**PO_4**	**pH**	**TDS**	**Conductivity**
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	pH unit	ppm	µS/cm
local	**min**	0.88	0.004	0.072	0.51	1.91	<0.01	1.24	0	<0.01	<0.01	6.32	47	94
	max	30.6	0.57	10.7	7.6	12.85	0.1	16.9	0	37.91	0.29	7.67	171	342
	average	10.6	0.097	8.72	2.5	7.31	0.052	8.34	0	16.53	0.15	7.11	124.14	248.7
imported														
	min	0.76	0.005	<0.01	0.28	0.41	0.026	0.079	0	<0.01	0.07	6.9	4	9
	max	51.7	1.01	36.3	5.82	26	1.076	21.25	0	49.4	0.49	8.1	380	760
	average	23.6	0.198	9.4	1.65	10.2	0.21	6.45	0	15.85	0.19	7.56	166.14	332.3
KUEPA standard		200	---	200	10	150	1.5	250	250	---	---	6.5-8.5	1000	---

Major anions

The results of the major anions for the local and imported bottled water samples and their descriptive statistics are shown in Tables 5 and 6, respectively. The results for fluoride (F^-) in the domestic bottled water brands showed an average concentration of 0.052 mg/l, whereas the corresponding concentration in the imported brands was 0.21 mg/l. We note that both concentrations are below the 1.5 mg/l health guideline limit of the WHO.

The average concentrations of chloride (Cl^-) and bromide (Br^-) in the local bottled water brands were 8.34 and 16.53 mg/l, compared with 6.45 and 15.85 mg/l in the imported bottled water brands, respectively. Concerning Cl^-, its concentration in all the local and imported bottled water brands were below the acceptability standard limit of 250 mg/l suggested by the FDA and WHO. There has been no health guidelines established by the WHO for Br^- because it occurs at concentrations that do not appear to pose a risk to human health.

In the 21 bottled water brands examined in this study, the major anions F^- (Ave= 0.16 mg/l), Cl^- (Ave= 7.1 mg/l), and Br^- (Ave= 12.2 mg/l) possess lower concentrations than those reported in two previous studies in Saudi Arabia (Abed & Alwakeel, 2007; Ghrefat, 2013). Additionally, it is instructive to compare our measured value for Cl- (Ave= 7.1 mg/l) with the results obtained in Pakistan (Cl^- range: 11–131 mg/l) (Yaqub & Hamid, 2014) and Iraq (Cl^- range: 5.97–28.78 mg/l) (Hussein *et al.,* 2014).

Comparison of major ions in bottled water brands

Fig. 2 shows a clear variation in the concentrations of Ca, Na, K, Mg and Cl among the locally produced and imported bottled water brands. Among the local bottled water brands, Rawdatain contains the highest concentration of Ca (30.6 mg/l). The lowest concentration of Ca was measured in Aquafina (0.88 mg/l). The high level of Ca in the Rawdatain brand could be related to its water source because it is a natural mineral water, but the other bottled water brands are produced from desalinated municipal water. Abraj and ABC are ozone-sterilized bottled water brands (Table 3) that contain 37.91 mg/l and 0.124 mg/l of Br, respectively. These concentrations may be cause for concern, because Br reacts with O_3 to produce the toxic bromate BrO_3 compound. The FDA set the BrO_3 health guideline to 10 μg/l, and it is suggested that water with Br concentrations higher than 60 μg/l should use control measures to lower bromate formation during the ozone disinfection process (Bollyky 2002). Arwa contains the lowest concentration of Cl^- (1.24 mg/l), and the highest concentration of Cl^- was found in the ABC brand (16.9 mg/l). The highest K concentration was measured in ABC Peekaboo (7.606 mg/l), whereas the lowest concentration of K (at 0.51 mg/l) was detected in the ABC bottled water brand. The concentration of F is negligible in all of the local bottled water brands (<0.033 mg/l), except for Rawdatain, which possessed a F concentration of 0.1 mg/l. However, this concentration is lower than the minimum recommended value of 0.6 mg/l. This variation may be related to the production process as all of the brands share the same source, except for Rawdatain as noted above.

Variations of major ions among the imported bottled water brands were also investigated (Figure 4). The highest Ca concentration was measured in the Evian brand (51.7 mg/l), and the lowest concentration was measured in the Ultra Baby brand (0.76 mg/l). The concentration of Mg was highest in the Deva brand (25.6 mg/l), and the lowest concentration was measured in the Ultra brand (0.41 mg/l). We note that both measured Mg concentrations are less than the permissible values set by the WHO (50 mg/l) and the KUEPA and GSO (150 mg/l). The Deva brand of bottled water contains the highest concentration of Cl^- (21.3 mg/l). The lowest concentration of Cl^- was measured in the Ultra brand (0.08 mg/l). The concentration of F ranges from 0.03 to 1.08 mg/l; however, both of these values are lower than the recommended value of 1.5 mg/l suggested by the WHO and KUEPA. Again, variations among the major ions in imported bottled water can be attributed to the different production processes and water sources (Table 3).

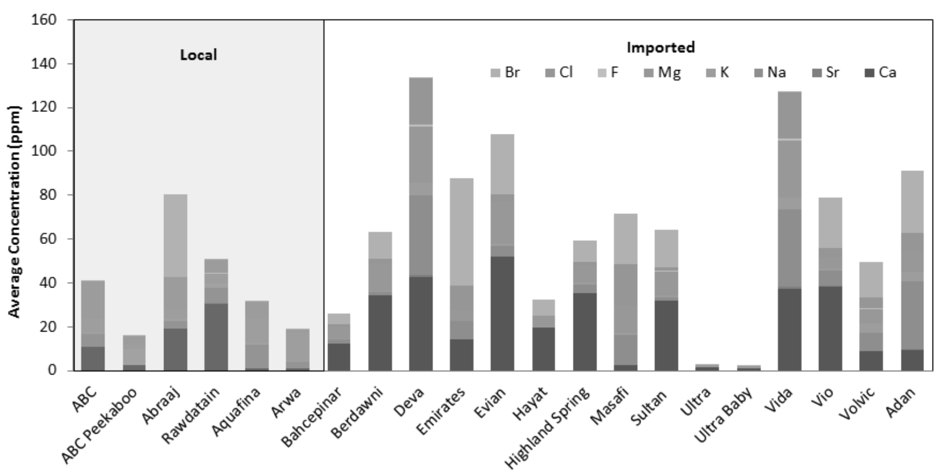

Fig. 2. Comparison of major ions measured in the bottled water brands

Labeled vs. measured values

Differences between the labeled and measured values of major ions and the physical properties of bottled water were also investigated. The percentages of variation between the labeled and measured values are listed in Table 7. A negative value indicates that the measured value is less than the labeled value, whereas a positive value indicates that the measured value is higher than the labeled value. In all of the local bottled water brands, calcium demonstrates a negative percentage of variation (between -15.1 and

-82.4), except for the Arwa brand, which exhibits a large positive variation (+456.7%). Similar observations were observed in the imported bottled water brands, except in the Hayat and Highland Spring brands, which both showed comparable values between the labeled and measured values (with percentages of variation of 0.193% and 0.996%, respectively). Like Ca, the percentage of variation of Mg and Na were negative in most of the local and imported bottled water brands, which indicated that the measured values were less than values reported on the bottled water label (Table 7). Generally, percentages of variation for K are opposite to those observed with Ca, Mg, and Na; that is, percentages of variation for K were positive values for most of the local and imported bottled water brands. The highest percentage of variation in K in locally produced bottled water brands was observed in the ABC (+408%) and Arwa (+463%) brands, whereas the highest variations in the imported bottled water brands were found in Vida (+691%) and Masafi (+320%). The percentages of variation in Cl ranged from -81.5 (Bahcepinar) to + 24.2 (Arwa). The percentages of variation of TDS and pH in locally and imported bottled water were also tested. Variations in TDS were in the range of -10 (Volvic) to +20.5 (ABC Peekaboo), while the percentage of variation in the pH varied from -7.1 (Aquafina) to +5.8 (Sultan).

No agreement between the measured values and the values reported on the product label was observed with the Ultra or Ultra Baby brands. It is reported on the labels of these brands that they are free from Ca, Mg, Na, K and F; however, our measurements revealed the presence of these ions. Although the concentrations of Ca, Mg, Na, K and F were not high (Table 5), it is nevertheless important to report these values. Adan, which is an imported bottled water, has a reported pH value of 8.4, which violates the GSO pH limit of 8. ABC Peekaboo has a reported concentration of 9.8 mg/l for potassium (K), which is very close to the 10 mg/l allowable limit suggested by KUEPA.

Table 7. Percentage of variation with respect to the values reported on the product label[a]

Brand	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	TDS ppm	pH pH unit
ABC	-27.3	-29.2	-44.6	408	-69.9	14.3	-4.31
ABC Peekaboo	-15.8	6.21	N/A	-22.4	-61.3	20.5	-0.14
Abraaj	-23.2	-18	-31.3	N/A	-73.1	N/A	-2.84
Adan	-26.9	-13.9	N/A	7.65	N/A	-5.4	-3.57
Aquafina	-82.4	-13.4	-33.1	37.76	N/A	13.6	-7.1
Arwa	456.7	-28.6	43.8	463	24.21	-10	2.154
Bahcepinar	N/A	N/A	-4.03	N/A	-81.5	N/A	-1.03
Berdawni	1.65	8.41	-7.53	24.87	-61.8	8.81	2.95
Deva	-28.1	11.3	N/A	731	N/A	20.3	-1.76
Emirates	-10	18.8	-19.9	47.18	-68.9	2.5	3.65
Evian	-35.4	-24.2	-27.8	16.14	-57.3	-1.3	-0.56
Hayat	0.193	18.7	-95.5	120.4	N/A	N/A	5.17
Highland Spring	1.0	-6.43	-37.6	-17.2	-79.3	23.5	1.28
Masafi	-24.4	-32.5	36.9	320	-60.3	N/A	-3.08
Rawdatain	-15.1	-6.33	-26.1	-11.6	-65.1	N/A	2.27
Sultan	-3.1	-30	-36.1	97.06	-79.3	9.33	5.811
Ultra	100	100	100	100	N/A	N/A	N/A
Ultra Baby	100	100	100	100	N/A	N/A	N/A
Vida	-36.5	13.1	N/A	691	N/A	19.5	-2.39
Vio	-10.8	-21.2	-36.5	N/A	-77.4	N/A	N/A
Volvic	-23.1	-21.1	-28.1	-27.3	-63	-10	1.286

[a] A negative value indicates that the measured value is less than the labeled value, whereas a positive value indicates that the measured value is higher than the labeled value.

Tap water analysis

To avoid the possibility of a self-selection bias, tap water samples were collected randomly from forty-three cities distributed in all six governorates of the State of Kuwait (Figure 1 and Table 4). The physiochemical parameters of the tap water and their descriptive statistics are shown in Tables 8 and 9, respectively.

Physical parameters

The pH values of the tap water samples ranged between 6.96 and 7.87, with an average value of 7.57. All values are within the WHO acceptable range of 6.5–8.5 and the GSO allowable range of 6.5–8. The electrical conductivity of the tap water samples varied from 28.5 to 822 µS/cm, with an average value of 224.5 µS/cm. We note that there are no known health guidelines for the minimum allowable electrical conductivity in drinking water.

Table 8. Physiochemical parameters of tap water

Area	Major cations					Major Anions					Physical	
	Na	K	Mg	Ca	Sr	F	Cl	SO_4	Br	NO_3	Cond.	pH
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µS/cm	pH unit
A-1	7.23	0.42	0.002	0.001	0.001	0.15	2.20	0.48		1.32	28.46	6.95
A-2	16.07	0.87	1.17	12.11	0.001	0.15	135.2	109.3		4.4	184.5	7.56
A-3	52.72	3.1	3.90	19.0	0.001		1232	85.2	2.64		822.0	7.87
A-4	10.16	0.80	1.14	12.2	0.001	0.15	14.74	121.5	0.15	5.2	205.4	7.54
A-5	13.25	0.89	0.71	13.14	0.001	0.31	120	108	0.18	1.8	187.8	7.71
A-6	13.97	0.77	3.33	32.65	0.030	0.34	13.7	153.7		2.4	320.3	7.78
A-7	121	7.2	16.1	211.6	0.001	0.12	109	96.3	0.36	0.06	211.9	7.80
A-8	72.5	3.23	3.27	39.91	0.001	0.15	139	122.9	0.16	4.86	191.1	7.58
A-9	35.79	1.96	3.42	23.25	0.001	0.18	386	23.5	0.88	3.75	424.0	7.68
A-10	18.13	0.85	2.35	18.63	0.015	0.34	203	110.4	0.21	9.73	341.0	7.75
A-11	16.95	0.98	2.72	22.96	0.040	0.24	250	64.8	0.30	7.78	306.7	7.76
A-12	16.93	0.92	1.58	17.52	0.001	0.13	18.36	112.1	0.25	4.66	214.7	7.1
A-13	12.37	0.71	2.12	15.44	0.001	0.27	27.3	104.6	0.35	1.43	261.9	7.47
A-14	15.69	0.63	1.48	16.41	0.001	0.21	115	33.5	0.36	0.84	234.9	7.65
A-15	19.32	0.78	2.1	16.67	0.001	0.24	258	82.5	0.22	8.31	314.3	7.22
A-16	17.82	1.03	2.68	16.96	0.001	0.25	273	99.6	0.30	4.83	234.7	7.38
A-17	14.98	2.4	5.79	39.69	0.426	0.72	21.1	585	0.32	10.7	307.3	7.60
A-18	19.37	1.04	4.14	30.19	0.058	0.43	176	259.3	0.41	3.36	219.9	7.46
A-19*	---	---	---	---	---	---	---	---	---	---	---	---
A-20	44.84	2.44	3.45	26.8	0.001	0.14	672	16.4	1.34	1.94	396.0	7.63
A-21	13.78	0.74	1.36	13.95	0.055	0.15	135	108.7	3.46	1.22	129.3	7.27
A-22	35.34	0.92	3.43	24.22	0.155	0.21	121	45.2	0.58	1.02	190.6	7.59
A-23	23.47	0.69	2.25	21.24	0.066	0.17	225	132.7	0.59	0.95	190.4	7.67
A-24	11.85	0.57	2.87	20.0	0.192	0.20	5.6	39.9	0.24	2.84	136.4	7.44
A-25	39.89	0.69	2.74	23.3	0.255	0.24	150	70.2	0.25	7.70	199.9	7.40
A-26	31.62	1.01	12.13	46.5	0.237	0.33	124	43.8	0.44	10.3	333.3	7.76
A-27	57.09	3.67	4.74	91.95	0.001	0.07	88	54.1		2.08	220.9	7.67
A-28	30.33	0.51	2.81	19.6	0.102	0.22	12.4	50.7		3.05	140.7	7.48
A-29	16.65	0.42	1.78	11.95	0.007	0.12	95	89.1	0.38	1.78	128.9	7.68
A-31	18.55	0.42	1.88	12.74	0.108	0.36	3.8	45.4	0.41	3.43	139.8	7.65

A-32	28.03	0.70	3.82	29.12	0.229	0.25	142	70.1	0.32	1.16	161	7.59
A-33	8.00	0.38	0.79	8.16	0.035	0.12	117	103.3		4.10	100.6	7.63
A-34	19.38	0.53	2.72	14.99	0.165	0.48	188	159.7	0.36	1.96	178.1	7.44
A-35	33.80	0.86	3.9	25.75	0.311	0.24	91	88.7	0.28	5.22	177.5	7.54
A-36	13.31	0.40	1.95	12.12	0.103	0.20	16.1	55.2		2.99	141.6	7.55
A-37	9.22	0.54	1.83	13.1	0.073	0.23	31.7	45.4	1.02	2.33	152.7	7.75
A-38	17.30	0.65	3.33	21.02	0.205	0.36	51.3	160.7	0.65	1.70	185.2	7.70
A-39	15.09	0.43	2.5	21.25	0.129	0.20	118.2	35.86	0.31	0.95	145.1	7.83
A-40	29.66	0.56	1.6	19.83	0.036	0.13	50.2	98.3	0.54	2.25	171.1	7.59
A-41	15.72	0.55	2.34	18.7	0.185	0.24	200	69.02	0.24	5.56	184.4	7.23
A-42	24.69	0.55	2.39	20.7	0.225	0.28	171	87.96	0.17	9.14	216.0	7.46
A-43	38.18	1.16	1.99	19.2	0.047	0.11	434	99.97	0.86	3.37	289.8	7.79

* Sample A-19 was eliminated from the analysis due to damage of the sample during transportation.

Table 9. Statistical values of tap water

	Na	**K**	**Mg**	**F**	**Cl**	**Ca**	**SO_4**	**Br**	**NO_3**	**pH**	**Conductivity**
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	pH unit	µS/cm
Max	121.04	7.18	16.13	0.72	1232	212	585	3.46	10.7	7.87	822.
Min	0.001	0.31	0.002	0.07	2.2	0.001	0.48	0.15	0.06	6.95	28.5
average	25.5	1.15	3.03	0.24	165	26.3	99	0.57	6.30	7.57	224.5
KUEPA Standard	200	10	150	1.5	250	200	250	---	50	6.5-8.5	---

Major cations

The values of the major cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} were in the range of 11.95–91.95 mg/l, 0.002–16.13 mg/l, 7.23–72.5 mg/l, and 0.42–7.2 mg/l, respectively. All Ca^{2+} values were below the 200 mg/l acceptability standard of the WHO. For Mg^{2+}, all of the measured values were below the 50 mg/l health guideline of the WHO. As for Na^{+}, all of the samples had concentrations below the health guideline of 50 mg/l and the aesthetic standard of 200 mg/l suggested by the WHO. Concerning K^{+}, all of the measured values were below the KUEPA suggested guideline of 10 mg/l, the health guideline of 12 mg/l suggested by the WHO, and its acceptability standard of 200 mg/l.

Major anions

The fluoride (F^{-}) contents of the tap water samples collected from all of the sampled cities ranged from 0.11 to 0.72 mg/l, which are below the 1.5 mg/l health guideline suggested by the WHO. Chloride (Cl^{-}) concentrations were found to vary from 2.2

mg/l to 672 mg/l. The concentration of Cl^- in a total of 8 samples in the regions A-9, 10, 11, 15, 16, 20, 23 and 43 (Table 8) were above the acceptability standard limit of 200 mg/l suggested by the FDA and the WHO. The increased concentration of Cl^- in some water tap samples could be the result of the disinfection process utilizing chlorination. Another concern associated with chlorination is the formation of disinfection byproducts (DBPs) such as trihalomethanes (THMs), which have been shown to induce human bladder and rectal cancers (Morris *et al.,* 1992; Villanueva *et al.,* 2001). The results for bromide (Br^-) show a minimum concentration of 0.15 mg/l and a maximum concentration of 3.46 mg/l, with an average concentration of 0.57 mg/l in all of the tap water samples examined. Currently, there are no health guidelines suggested by the WHO regarding Br^- in drinking water because it occurs at concentrations that do not appear to pose a risk to human health. The concentrations of sulfate (SO_4^{2-}) were between a minimum of 0.48 mg/l and a maximum of 585 mg/l, with an average concentration of 99 mg/l in all of the tap water samples examined. All of the results for sulfate were below the FDA and WHO acceptability standard of 250 mg/l, except for those from the regions A-17 (585 mg/l) and A-18 (259 mg/l). The measured concentrations of NO_3^{2-} had a minimum concentration of 0.06 mg/l and a maximum concentration of 10.7, with an average concentration of 6.3 mg/l in all of the tap water samples examined. The results for NO_3^{2-} are compatible with the allowable FDA guidelines of 10 mg/l and the WHO health guideline of 50 mg/l.

Bottled vs. tap water

Major ions

The average concentrations of major ions in both the local and imported bottled water samples and the tap water samples are shown in Figure 3. No significant differences were observed between the bottled water and tap water for Ca^{+2}, K^+, Sr^{+2} and Mg^{+2}. The sodium concentration in the tap water (25.5 mg/l) was measured to be 2.5 times higher than in the imported bottled water, and it was 6 times higher than in the local bottled water (Fig 3). The fluoride content in the local bottled water (0.04 mg/l) was measured to be five times lower than in the imported bottled water samples and six times lower than in the tap water. Significant variations were observed in the concentration of Cl^- between the bottled and tap water, the Cl^- concentration in the tap water (156.4 mg/l) was measured to be 24 times higher than in the imported bottled water and 19 times higher than in the local bottled water brands. Conversely, the Br^- concentration in the tap water (0.6 mg/l) was measured to be 28 times lower than in the imported bottled water brands and 21 times lower than in the local bottled water brands.

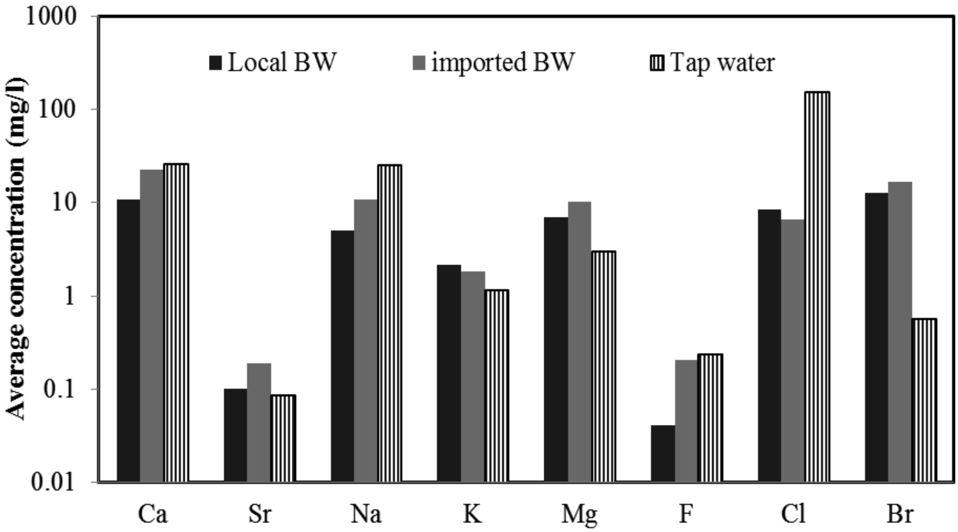

Fig. 3. Comparison of major ions

Trace elements

The mean concentrations of trace elements in the imported and local bottled water, as well as in the tap water, are shown in Figure 4. The zinc (Zn) concentration in the local bottled water brands (Range: 0.21–7.12 µg/l, Ave = 3.9 µg/l) was found to be lower than those in the imported bottled water brands (Range: 0.2–22 µg/l, Ave=3.4 µg/l) and the tap water (Range: 2.28 – 589 µg/l, Ave= 141.5 µg/l). The zinc concentrations in the bottled water were below the WHO health guideline of 50 µg/l and the GSO health guideline of 100 µg/l. However, the average Zn concentration in the tap water exceeded the regulatory values suggested by both the WHO and the GSO (Table 2). The concentrations of Zn in both the bottled and tap water samples were below the FDA value of 5000 µg/l and the WHO acceptability standard of 4000 µg/l. Although Zn is crucial for human health (Aggett 1985; Pleban *et al.,* 1985), as it functions as a catalyst for enzymatic activity, excessive concentrations of this metal can cause harmful side effects such as an acceleration of the conditions associated with anemia (Tayyeb *et al.,* 2004). The concentration of arsenic (As) was found to be higher in the tap water (14.4 µg/L) than in the bottled water (local=1.87 and imported = 2.12 µg/L). The concentration of As measured in the tap water was higher than that observed in tap water samples from the Dakhlia governorate of Egypt (0.29 µg/l) (El-Harouny *et al.,* 2009). The concentration of As in 27 out of the 43 tap water samples exceeded the allowable health guideline of 10 µg/l suggested by the GSO, EPAKW, FDA, WHO, and US-EPA. The concentration of mercury (Hg) in all of the bottled water brands was <1 µg/l, which is below the detection limits of ICP-MS, and lower than the US-EPA and FDA limit of 2 µg/l and the WHO health guideline of 6 µg/l.

However, the mercury levels in the tap water (Ave = 1.1) were close to the GSO and KUEPA guideline of 1 µg/l, which indicates that Hg levels should be carefully monitored in tap water. The concentration of boron (B) in the local bottled water brands varied between 10.11 µg/l and 276.5 µg/l, with an average concentration of 65.4 µg/l. In the imported bottled water brands, the concentration of B ranged from 0.34 µg/l to 145 µg/l, with an average concentration of 51 µg/l. The concentrations of B in both the local and imported brands were below the health guidelines from the WHO (2400 µg/l) and the GSO (500 µg/l), However, the local bottled water brand Abraj possessed a concentration of B of 276.5 µg/l, which is close to the EPAKW recommended limit of 300 µg/l. In the tap water, the concentration of B was higher than those observed in the bottled water samples, where it varied from 16.6 to 745 µg/l, with an average B concentration of 75.6 µg/l. The concentration of B in A-3 was 704.5, which is well above the GSO limit of 500 µg/l. Further, the concentrations of B in A-20 (295.4 µg/l) and A-43 (275.4 µg/l) are close to the KUEPA recommended limit of 300 µg/l. Apart from these areas, the concentrations of B in all of the tap water samples were below regulatory limits. The concentration of cadmium (Cd) was higher in the tap water (0.87µg/L) than in the local (0.57 µg/L) and imported (0.27 µg/L) bottled water samples. All of the Cd concentrations were below the GSO, EPAKW, FDA, and WHO health guidelines, as well as the values suggested by the US-EPA. The remaining trace elements investigated in the present work (Figure 4) were all found to be below regulatory limits.

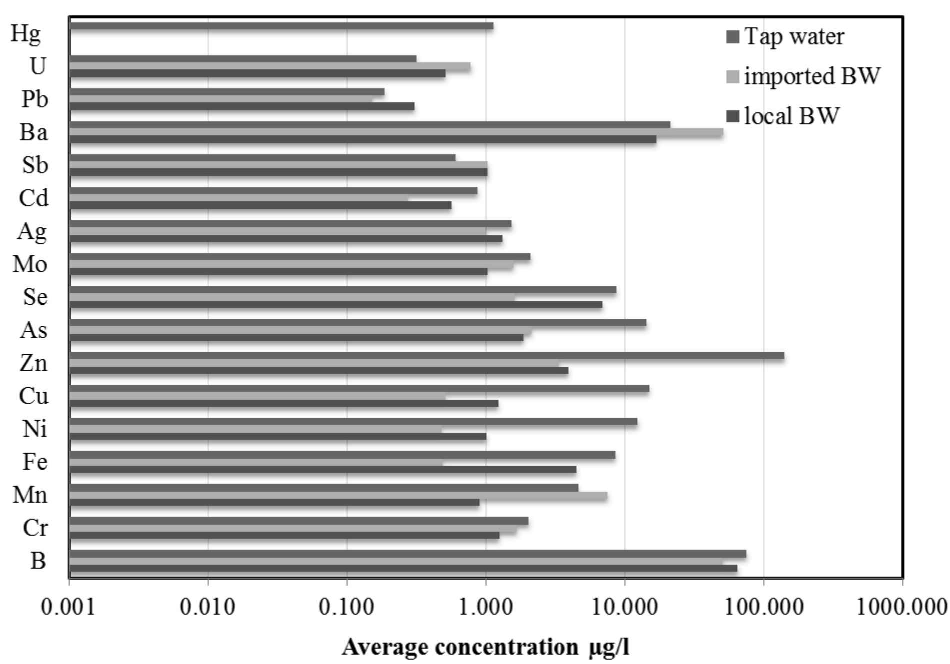

Fig. 4. Comparison of trace metals

Several studies have reported that storage bottles can contaminate the water held in the vessel (Lloyd & Heathcote, 1985; Hall, 1998; Misund *et al.,* 1999; Reimann *et al.,* 2007). Misund *et al.* (1999) examined the concentrations of 66 elements in 56 European bottled mineral water samples. The authors found clear signs of water contamination originating from the container, such as Pb and Zr from glass bottles. In another study (Al-Mudhaf *et al.,* 2009), the concentrations of styrene, toluene, total xylenes and ethyl benzene increased with storage time, which suggests that water contamination by volatile organic compounds (VOCs) is likely to be caused by a shift of these compounds from the polystyrene containers to the water samples. Another source of bottled water contamination could be attributed to the adsorption of trace elements into the walls of the bottle, which are subsequently transferred into the water samples (Feldmann, 1974; Lindquist *et al.,* 1991). It should also be noted that colloids can similarly sorb large concentrations of trace elements (Horowitz *et al.,* 1996). Colloids in a water sample can form and disappear frequently over time. In this study, however, only slightly elevated levels relative to national and international standards of trace elements were observed in some bottled water brands. The tap water in Kuwait is a blend of 93–97% distilled water and 3–7% brackish groundwater. The high concentrations of Zn, As, and B measured in this study could be attributed to several factors, including the geological formations through which the ground water flows (Fiket *et al.,* 2007) and substances dissolving from either natural sources or from household plumbing systems, such as pipes, solder, fittings, or the service connections to homes (Al-Saleh & Al-Doush, 1998; Lytle , 2007).

Numerous epidemiological studies have shown a direct association between the presence of trace metals and the incidence of various diseases in humans, mostly cardiovascular diseases, kidney-related disorders, neuro-cognitive effects and various forms of cancer (Isacson *et al.,* 1985; Ling-Wei *et al.,* 1988; Goldberg *et al.,* 1990). This study concludes that high concentrations of Zn, As, and B in tap water must be carefully monitored to avoid any possible detrimental health impacts.

CONCLUSION AND RECOMMENDATIONS

In this study, the drinking quality of tap and bottled water in Kuwait was thoroughly investigated. A total of 43 tap water samples and 21 bottled water brands (6 local and 15 imported) sold in Kuwait were analyzed for different chemical and physical parameters. The results show that the concentrations of major ions in both tap and bottled water were within or below the threshold levels in most international drinking water guidelines. The only concern was about the chloride (Cl^-) content in the tap water, as 18.6% of the samples exceeded the FDA and WHO standards of 200 mg/L. Regarding trace metal content, most of the analyzed elements in both the tap and bottled water were below regulatory drinking water standards, with some exceptions.

As for bottled water, the levels of Se in two local bottled water brands (ABC and Abraaj) were above drinking water standards, whereas the average concentrations of Zn, As, and B in tap water exceeded some international regulatory values. The high levels of Zn, As, and B in tap water are attributed to geological formations through which the ground water flows and substances dissolving from either natural sources or from household plumbing systems. The physiochemical parameters of bottled water were compared with the measured values. Inconsistencies were evident between the labeled and measured values in most of the bottled water brands investigated. In terms of the drinking quality, tap water is closely matching the bottled water. Therefore, tap water drinking quality should not pose any serious the public threat. One main recommendation of this study is that water supply and public health authorities should address the high level of chemicals present in an individual water supply that may pose a public health risk from long-term exposure. To protect human health, proper drinking water monitoring systems should be implemented to ensure that the physiochemical parameters of drinking water match acceptable national standards.

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