Journal of Food and Nutrition Research, 2014, Vol. 2, No. 1, 25-33
Available online at http://pubs.sciepub.com/jfnr/2/1/5

DOI:10.12691/jfnr-2-1-5

Quality Characteristics of Commonly Consumed Drinking Water in Riyadh and Effect of Domestic Treatments on Its Chemical Constituents

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Received October 10, 2013; Revised January 10, 2014; Accepted January 20, 2014

Abstract Quality analysis of drinking water quality provides important information about the sources of water pollution and guidelines for health protection. This study gives information of major quality constituents of twenty bottled water brands, household water from different zones in Riyadh and zamzam water commercially available in Riyadh and the effect of domestic treatments commonly used in Saudi Arabia on its chemical constituents. Samples were allowed to warm up at ambient temperature after acidifying in 0.5% nitric acid and then aspirated directly into the inductively coupled plasma spectrometry. Concentration of major cations (calcium, magnesium, potassium and sodium) and trace elements (lead, arsenic, barium, cadmium, chromium, copper, iron, manganese, molybdenum, nickel, selenium and zinc) in all samples were far below the maximum guidelines set by World Health Organization (2011) and Saudi Arabian Standards Organization (1984). This study led to the conclusion that zamzam water has a rich essential mineral profile. Except for sodium the concentration of other major cations (calcium, magnesium, and potassium) reported on the labels of most of the bottled water were higher than values observed in the laboratory. Home treatments such as rolling boiling and reverse osmosis didn't show any significant ($p \geq 0.05$) effect on the chemical constituents of water. Regular and proper monitoring programs should be established to assure that the quality of drinking water remains within acceptable national standards.

Keywords: *bottled water, Riyadh, health, zamzam, inductively coupled plasma spectrometry, trace elements*

Cite This Article: Doha Al Nouri, Badriah Al Abdulkarim, Shaista Arzoo, and Zubaida Abdel Nabi Bakeet, "Quality Characteristics of Commonly Consumed Drinking Water in Riyadh and Effect of Domestic Treatments on Its Chemical Constituents." *Journal of Food and Nutrition Research*, vol. 2, no. 1 (2014): 25-33. doi: 10.12691/jfnr-2-1-5.

1. Introduction

Water plays an essential role in digestion, absorption and waste elimination [1] and safe drinking water is an internationally accepted human right [2]. Fertilizers, pesticides, animal and human wastes, discharge of wastewater from industries [3], disposal of sludge's to the sea and spillages of oil and industrial chemicals are the various reasons for contamination of drinking water [4]. Quality (physico chemical and microbiological) analysis of drinking water quality provides important evidence about the sources of water pollution and guidelines for health protection [4]. Water contains macro elements such as sodium, calcium and magnesium which are necessary to sustain biological life and trace elements function chiefly as catalysts for enzymatic activity in human bodies. However, their accumulations cause acute or chronic poisoning and have to be removed from drinking water [5]. Elements such as cobalt, chromium, iron, manganese, molybdenum, nickel, selenium, vanadium and zinc are essential for growth. However, at high concentrations they become toxic to the human body [6].

Abundant industrial growths during the past decades have caused severe environmental pollution throughout the world. Therefore, regular monitoring of the drinking water quality is very necessary. Although the trace elements represent only a minute fraction of the total food uptake, epidemiological studies have shown a strong correlation between the occurrence of several diseases such as cardiovascular disease, cancer, kidney-related disorders, neuro-cognitive effects, rare congenital malformations in human and the presence of trace elements (e.g., copper, cadmium, mercury, arsenic, zinc) in drinking water [7]. Quality and safety of the drinking water is an important public health issue [8]. Minerals present in water are in ionic form and are easily absorbed by the gastrointestinal tract, so drinking water can be an important source of mineral intake [7].

In Saudi Arabia drinking water is mainly obtained from desalinated seawater, ground water from wells [9] and zamzam well. Zamzam well is located in the holiest mosque of Muslims in the city of Makah. The demand for bottled water has constantly augmented during the last decades [10]. Bottled water remains the highest consumable product especially for the middle and high income group in urban areas. Bottled water is not necessarily "better" or "worse" than tap water – it depends on the specificity of the particular cases. Several studies compared bottled and tap water and concluded that it is not always necessary that bottled water have better quality than tap water [11,12]. This study focus on the determination of major and trace elements in bottled, household and commercial zamzam water, comparison of lab and levelled value of bottled water and effect of domestic treatments (rolling boiling and reverse osmosis) on its chemical constituents.

2. Materials and Methods

2.1. Samples Collection and Preparations

Bottled water of different manufacturing dates and commercial zamzam water was purchased from the local markets in Riyadh, Saudi Arabia. To keep the brand name anonymous, bottled water samples were given numerical code from 1 to 20. Polyethylene bottles of 1litre capacity were used to collect the samples (household water) from different regions of Riyadh. Houses were selected randomly to collect household water and a small survey was carried out to select bottled water. Standards and samples were prepared using deionized water under clean conditions. All chemicals and reagents used were of analytical grade. All glassware and plastic wares were washed repeatedly with deionized water, and then soaked over nightly in 20% nitric acid. After soaking the glassware's were rinsed repeatedly with deionized water and dried. The bottles for collecting samples were cleaned by soaking in 0.5% nitric acid overnight followed by washing with tap water and rinsing with deionised water.

2.2. Analysis of Riyadh Household Water and Commercially Available Bottled and Zamzam Water

2.2.1. ***pH:*** Five ml of sample was used to determine the pH by pH meter (Mettler Toledo, MP 220, Switzerland). The pH was calibrated with standard buffers (7, 9) before pH was measured.

2.2.2. Determination of Major Cations and Trace Elements byInductively Coupled Plasma Spectrometry

On reaching the laboratory small portions of the samples were separated and acidified in 0.5% nitric acid for the analysis of cations and trace elements in Riyadh household water from different zones and commercially available bottled and zamzam water by inductively coupled plasma spectrometry. Prior to analysis, samples were allowed to warm up at ambient temperature and then aspirated directly into the inductively coupled plasma spectrometry.

2.3. Effect of Treatments on Chemical Constituents of Drinking Water

A sample was randomly selected and divided into three parts. First part was treated as control and the second part was kept on flame for 10 minutes for rolling boiling (CDC, 2001) [13]. The third portion was domestically treated by the process of reverse osmosis in reverse osmosis drinking water system (Aquatec, USA).

2.4. Statistical Analysis

Each data in table was presented as average of replicates ± SD. The data obtained to find the effect of treatments on chemical constituents of drinking water was subjected to statistical analysis by conducting analysis of variance (ANOVA), using SPSS software package (version 9.0). The significant differences of their means were compared using least significance difference (LSD) tests and p value was considered significant at 95%.

3. Results

This study aims to evaluate some minerals of health concern in commonly used drinking bottled water in Riyadh and its comparison with household water and commercially available zamzam water in concern of their chemical quality. Most of the analyzed elements in different brands of bottled water were found to be in concentrations far below the recommended maximum concentration limit guideline by WHO [14] and SASO [15]. Table 1 shows the concentration of major cations and trace elements in Riyadh household water and commercially available bottled and zamzam water. The numbers shown are the average measure of replicates for each sample. Major cations (calcium, magnesium, potassium and sodium) were found as ppm and reported as mg/l and trace (lead, arsenic, barium, cadmium, chromium, copper, iron, manganese, molybdenum, nickel, selenium and zinc) elements were reported as µg/l.

3.1. Analysis of pH and Major Cations in Riyadh Household Water and Commercially Available Bottled and Zamzam Water

The pH of all samples (bottled, household and zamzam) was around neutral and within the recommended maximum concentration limit guidelines by WHO. All the samples were found to be clear in visibility and acceptable in taste. A number of scientific reviews have demonstrated the increasing awareness of the fundamental role that calcium (Ca), potassium (K), magnesium (Mg), and sodium (Na) plays in health and diseases. Table 2 shows the average of pH and major cations in Riyadh household water and commercially available bottled and zamzam water.

Calcium level ranged between 0 to 34.96, 0.082 to 64.95 and 51.03 for bottled, household and commercial zamzam respectively. Potassium concentration varied between 0.051 to 1.836, 4.547 to 5.666 and 43.55 for bottled, household and commercial zamzam water respectively. Magnesium concentration varied from 0 to 12.99, 0.095 to 5.469 and 11.06 for bottled, household and commercial zamzam. Average of calcium, potassium and magnesium were found to be in the order of commercial zamzam > household > bottled. These values were much below the maximum guideline limits of SASO. Sodium concentration varied between 2.749 to 42.52, 75.15 to 436.2 and 107.5 for bottled, household and zamzam. Average of sodium was in the order of household > commercial zamzam > bottled. None of the values except household water from the northern part of Riyadh exceeded the maximum limit (100 mg/l) for aesthetic quality by SASO.

Table 1. Concentration of Major Cations and Trace Elements in Riyadh Household Water from Different Zones and Commercially Available Bottled and Zamzam Water

	Cations (mg/l) Wavelength				Trace Elements (µg/l) Wavelength											
S.No	**Ca 422.6**	**K 766.4**	**Mg 279.5**	**Na 818.3**	**Pb 216.9**	**As 193.7**	**Ba 233.5**	**Cd 214.4**	**Cr 205.5**	**Cu 324.7**	**Fe 259.9**	**Mn 257.6**	**Mo 284.8**	**Ni 314.4**	**Se 196.0**	**Zn 213.8**
Bottled Water (BW)																
1	ND	1.199±0.0125	12.99±0.0464	15.25±0.1080	2.53±0.0038	3.153±0.0013	0.434±0.0005	0.317±0.0004	0.321±0.0003	1.194±0.0006	0.274±0.0005	0.312±0.0005	2.212±0.0039	0.921±0.0021	2.175±0.0010	0.064±0.0003
2	11.00±0.0758	1.179±0.0081	3.944±0.0492	29.09±0.1768	3.24±0.0016	1.099±0.0011	1.433±0.0008	0.034±0.0000	0.021±0.0001	0.747±0.0009	0.064±0.0001	0.007±0.0002	ND	1.867±0.0014	0.887±0.0004	ND
3	9.807±0.0271	1.444±0.0024	4.545±0.0021	23.74±0.0219	0.811±0.0016	1.081±0.0013	0.276±0.0006	0.049±0.0003	1.035±0.0006	0.742±0.0002	0.046±0.0001	0.079±0.0002	0.6±0.0009	2.732±0.0012	ND	ND
4	14.92±0.0362	0.785±0.0047	2.212±0.0053	27.11±0.1561	ND	0.560±0.0002	1.759±0.0007	0.045±0.0003	0.400±0.0002	0.709±0.0010	0.072±0.0001	0.078±0.0000	ND	3.858±0.0031	0.507±0.0009	0.012±0.0003
5	13.38±0.0582	0.051±0.0013	2.312±0.0083	13.03±0.0318	3.323±0.0037	0.112±0.0013	0.014±0.0007	0.049±0.0003	0.015±0.0009	0.894±0.0007	0.074±0.0001	0.086±0.0005	ND	ND	0.147±0.0012	ND
6	9.209±0.0402	1.014±0.0025	3.961±0.0304	26.33±0.0597	0.666±0.0019	0.096±0.0010	1.511±0.0003	0.015±0.0002	0.633±0.0001	1.106±0.0008	0.074±0.0002	0.099±0.0009	ND	ND	ND	2.161±0.0002
7	34.96±0.1510	0.120±0.0019	4.745±0.0189	24.17±0.1287	1.378±0.0021	1.118±0.0002	0.554±0.0005	0.042±0.0004	0.005±0.0000	1.344±0.0001	0.044±0.0002	0.059±0.0002	ND	0.437±0.0012	0.046±0.0007	ND
8	8.275±0.0373	1.280±0.0082	3.238±0.0173	34.10±0.1614	3.382±0.0039	ND	3.179±0.0009	0.029±0.0002	0.079±0.0009	1.214±0.0006	0.059±0.0002	ND	ND	0.243±0.0017	ND	3.043±0.0005
9	ND	0.263±0.0017	ND	2.749±0.0467	2.764±0.0018	0.808±0.0005	0.027±0.0001	0.046±0.0004	ND	1.113±0.0002	0.075±0.0000	0.770±0.0006	ND	ND	0.548±0.0007	0.781±0.0006
10	13.06±0.0375	0.740±0.0021	4.591±0.0311	17.48±0.2563	2.863±0.0019	ND	2.052±0.0009	0.045±0.0004	0.236±0.0001	1.113±0.0003	0.049±0.0000	0.056±0.0002	ND	3.516±0.0027	0.195±0.0012	0.401±0.0009
11	12.52±0.1702	0.992±0.0026	3.390±0.0044	24.98±0.0531	2.230±0.0017	1.106±0.0006	1.803±0.0005	0.075±0.0007	0.189±0.0007	0.827±0.0008	0.060±0.0000	0.082±0.0002	ND	0.447±0.0012	ND	ND
12	4.717±0.0128	1.019±0.0014	1.890±0.0257	42.52±0.1602	6.187±0.0039	0.206±0.0010	1.738±0.0004	0.011±0.0001	0.053±0.0009	1.085±0.0004	0.064±0.0000	0.071±0.0000	ND	ND	2.135±0.0011	0.097±0.0009
13	11.07±0.0766	1.126±0.0061	3.927±0.0156	15.20±0.1151	0.027±0.0019	ND	1.427±0.0008	0.029±0.0001	0.584±0.0000	0.924±0.0002	0.066±0.0001	ND	ND	2.286±0.0014	0.788±0.0014	0.817±0.0007
14	17.50±0.1725	0.078±0.0014	7.905±0.0476	7.332±0.0447	1.194±0.0026	0.560±0.0007	0.824±0.0001	0.045±0.006	0.106±0.0007	1.204±0.0002	0.060±0.0002	0.095±0.0000	ND	ND	0.077±0.0008	0.021±0.0002
15	10.99±0.0103	0.812±0.0031	4.158±0.0074	19.28±0.0492	1.771±0.0003	0.737±0.0006	2.541±0.0005	0.027±0.0003	0.064±0.0001	1.177±0.0007	0.070±0.0002	0.098±0.0006	ND	2.181±0.0008	0.400±0.0016	4.824±0.0004
16	7.487±0.0207	1.071±0.0037	2.961±0.0103	35.29±0.0377	6.057±0.0011	0.120±0.0014	2.659±0.0007	0.025±0.0003	0.174±0.0001	1.041±0.0001	0.064±0.0000	ND	ND	0.433±0.0008	1.110±0.0018	1.032±0.0009
17	12.14±0.0759	0.973±0.0073	3.803±0.0335	32.85±0.248	0.941±0.0044	ND	1.470±0.0007	0.035±0.0005	2.045±0.0001	1.164±0.0001	0.082±0.0002	0.053±0.0005	ND	3.609±0.0011	1.733±0.0011	5.337±0.0004
18	21.07±0.15	1.836±0.01	3.565±0.02	12.69±0.07	2.047±0.00	0.716±0.00	2.857±0.00	0.049±0.00	0.102±0.0001	1.125±0.00	0.066±0.00	ND	ND	2.507±0.00	ND	0.979±0.00

	65	47	18	40	38	14	03	02		01	01			10		04
19	5.620±0.0163	0.399±0.0020	2.150±0.0025	18.36±0.0611	0.071±0.0019	ND	1.155±0.0005	0.031±0.0002	0.036±0.0002	1.140±0.0001	0.065±0.0002	0.077±0.0002	0.068±0.0002	0.609±0.0026	0.614±0.0008	0.307±0.0009
20	7.530±0.0637	1.143±0.0077	3.057±0.0074	33.71±0.1759	1.968±0.0023	ND	3.049±0.0001	0.031±0.0000	0.198±0.0008	1.393±0.0002	0.069±0.0000	ND	ND	0.337±0.002	0.317±0.0002	2.599±0.0005
Household water (21-East, 22-West, 23-Central, 24-North and 25-South) (HW)																
21	50.20±0.3544	4.547±0.0199	4.416±0.0249	75.15±0.1400	2.934±0.0036	ND	8.688±0.0007	0.049±0.0004	7.191±0.0008	3.511±0.0009	0.002±0.0002	0.092±0.0005	1.325±0.0006	22.78±0.0020	1.338±0.0006	15.94±0.0008
22	63.14±0.2933	5.645±0.0468	5.429±0.0359	91.20±1.320	4.350±0.0032	ND	12.27±0.0003	0.024±0.0002	3.908±0.0004	2.727±0.0002	0.045±0.0002	6.497±0.0007	0.031±0.0005	34.71±0.0009	1.590±0.0008	1195±0.0317
23	63.69±0.3343	5.666±0.0104	5.469±0.0405	91.97±0.0831	4.688±0.0024	0.482±0.0005	12.52±0.0007	0.038±0.0007	4.476±0.0001	5.557±0.0025	6.199±0.006	5.033±0.0005	1.379±0.0007	51.96±0.0025	0.961±0.0004	934.9±0.1144
24	0.082±0.0589	5.426±0.0972	0.095±0.0010	436.2±2.569	ND	0.123±0.0009	0.207±0.0002	0.057±0.0003	0.511±0.0004	1.604±0.0006	0.983±0.0006	1.942±0.0007	0.774±0.0005	ND	ND	4.118±0.0007
25	64.95±0.3365	5.572±0.0604	5.357±0.0213	91.14±0.9421	3.272±0.0004	ND	10.22±0.0005	0.064±0.0002	6.234±0.0004	4.324±0.0001	0.032±0.008	0.407±0.0003	1.438±0.0007	30.10±0.0003	1.931±0.0010	72.27±0.0295
Commercial Zamzam (CZ)																
26	51.03±0.2845	43.55±0.1543	11.06±0.0415	107.5±0.2920	ND	5.9±0.0008	28.97±0.0001	0.034±0.0002	0.126±0.0004	1.612±0.0003	0.016±0.0004	0.056±0.0003	42.24±0.0009	15.66±0.0018	2.447±0.0018	1.646±0.0009

Data are mean ± S.D of replicates

Table 2. Average of pH and Major Cations in Riyadh Household Water and Commercially Available Bottled and Zamzam Water and its Comparison with WHO and SASO Guidelines for Drinking Water

	BW	HW	CZ	WHO	SASO
pH	7.41 ± 0.18	7.76 ± 0.15	7.73 ± 0.06	6.5-8.0	-
Ca (mg/l)	11.27 ± 7.58	48.41 ± 27.67	51.03 ± 0.28	75	200
K (mg/l)	0.88 ± 0.48	5.37 ± 0.47	43.55 ± 0.15	-	-
Mg (mg/l)	3.97 ± 2.62	4.15 ± 2.07	11.06 ± 0.04	-	150
Na (mg/l)	22.76 ± 10.22	157.13 ± 156.2	107.5 ± 0.292	-	100

Data are mean ± S.D of replicates

Table 3. Average of Trace Elements in Riyadh Household Water and Commercially Available Bottled and Zamzam Water and its Comparison with WHO and SASO Guidelines for Drinking Water

Trace Elements	BW	HW	CZ	WHO	SASO
Pb (μg/l)	2.172 ± 1.736	3.049± 1.853	0 ± 0	10	50
As (μg/l)	0.574 ± 0.748	0.121 ± 0.209	5.9 ± 0.00083	10	50
Ba (μg/l)	1.538 ± 0.986	8.781 ± 5.043	28.97 ± 0.00012	700	700
Cd (μg/l)	0.046 ± 0.065	0.052 ± 0.010	0.034 ± 0.000001	3	5
Cr (μg/l)	0.351 ± 0.493	4.464 ± 2.574	0.126 ± 0.00042	50	50
Cu (μg/l)	1.063 ± 0.195	3.545 ± 1.508	1.612 ± 0.00034	2000	1000
Fe (μg/l)	0.192 ± 0.598	1.452 ± 2.68	0.016 ± 0.000042	-	300
Mn (μg/l)	0.087 ± 0.165	2.794 ± 2.848	0.056 ± 0.000031	-	100
Mo (μg/l)	0.176 ± 0.519	0.989 ± 0.598	42.24 ± 0.00089	70	-
Ni (μg/l)	1.299 ± 1.371	27.91 ± 18.939	15.66 ± 0.0018	70	-
Se (μg/l)	0.584 ± 0.702	1.164 ± 0.741	2.447 ± 0.00244	40	10
Zn (μg/l)	1.124 ± 1.634	444.44 ± 574.45	1.646 ± 0.00096	3000	5000

Data are mean ± S.D of replicate

3.2. Analysis of Trace Elements in Riyadh Household Water and Commercially Available Bottled and Zamzam Water

Table 3 depicts the average of trace elements in Riyadh household water and commercially available bottled and zamzam water. Lead (Pb) has not been detected in commercial zamzam and its concentration in bottled and household water was much lesser than the maximum limit guidelines by WHO (10 μg/l) and SASO (50 μg/l). None of the studied samples crossed the arsenic (As) maximum limit guidelines of 10 μg/l and 50 μg/l by WHO and SASO respectively. Highest concentration of arsenic was found in commercial zamzam followed by bottled and household. None of the studied samples crossed the barium (Ba) maximum limit of 0.7 mg/l (700 µg/l) by WHO and SASO.

Highest concentration of barium was found in commercial zamzam followed by household and bottled water. Cadmium (Cd) concentration was also found to be much lesser than the maximum limit guideline of WHO (3 µg/l) and SASO (5 µg/l). Highest concentration of cadmium was found in household water followed by bottled water and commercial zamzam. Household water showed the highest measured chromium (Cr) concentration followed by bottled and commercial zamzam. All samples contained less chromium, values lesser than the limit of WHO guidelines and SASO standards (50 µg/l). Household water showed the highest measured copper (Cu) concentration followed by commercial zamzam and bottled water. Highest concentration of iron (Fe) was observed in household water followed by bottled water and least in commercial zamzam. The concentrations were far below the SASO recommendation (300 µg/l). Household water showed the highest measured manganese (Mn) concentration followed by bottled and commercial zamzam. The concentrations were less than the SASO (100 µg/l) recommendation. Highest concentration of molybdenum (Mo) was observed in commercial zamzam followed by household and bottled water. The concentrations were below the WHO recommendation (70 µg/l).

Highest concentration of nickel (Ni) was observed in household followed by commercial zamzam and least was observed in bottled water. The concentrations were also below than the WHO recommendation (70 µg/l). Highest concentration of selenium (Se) was observed in commercial zamzam followed by household and bottled water. Selenium concentration was also found to be much lesser than the maximum limit guideline of WHO (40 µg/l) and SASO (10 µg/l). Maximum concentration of zinc (Zn) was observed in household followed by commercial zamzam and bottled water. None of the samples crossed the maximum permissible limit of WHO (3000 µg/l) and SASO(5000 µg/l).

3.3. Accuracy of Bottled Drinking Water Label Content

Labelled value of calcium, magnesium and potassium of most of the samples were found to be higher than the laboratory value while for sodium, labelled value of most of the samples were lesser than the laboratory value (Figure 1 (A-D)).

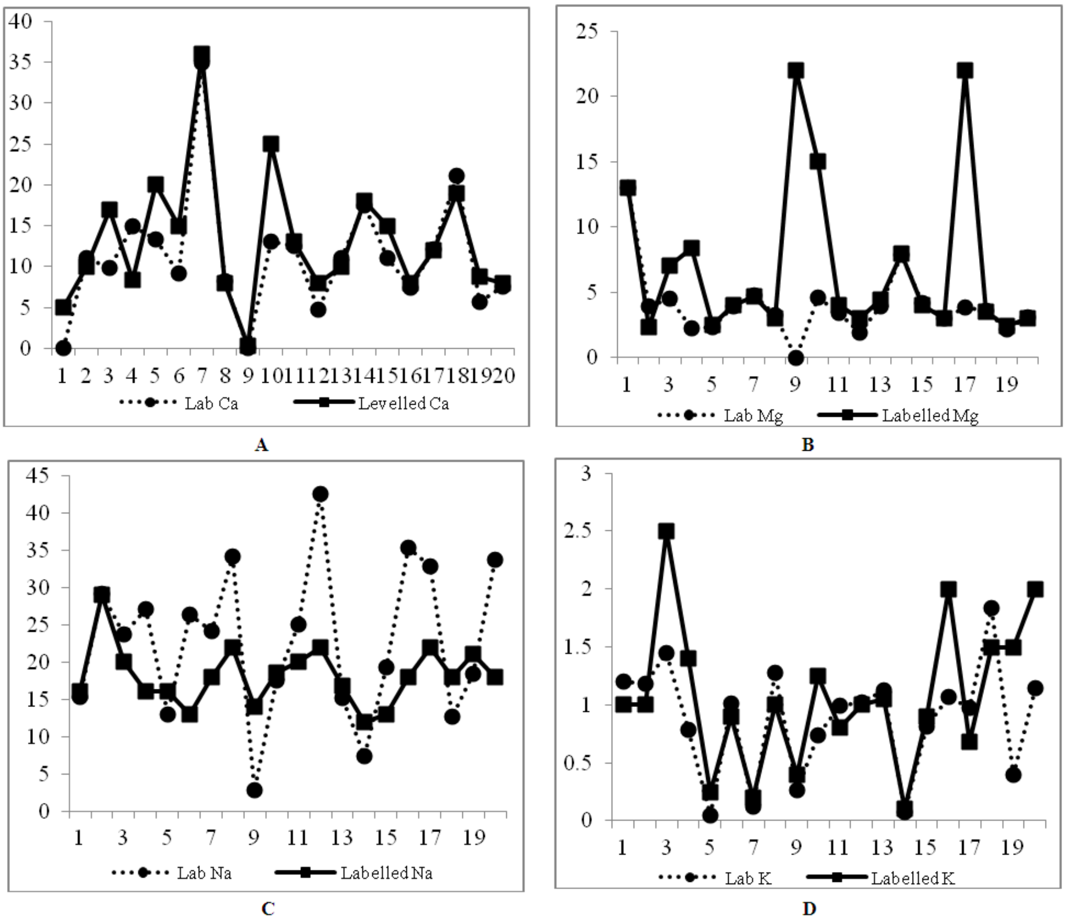

Figure 1. (A-D). Accuracy of Bottled Drinking Water Label Content Commercially Available in Riyadh

A-Lab and labelled value of calcium, B-Lab and labelled value of magnesium, C-Lab and labelled value of sodium, D-Lab and labelled value of potassium

3.4. Effect of Treatments on Chemical Constituents of Water

No significant ($p \geq 0.05$) difference between the control and treated samples (rolling boiling and reverse osmosis) were observed for the major cations in this study. Calcium, potassium and magnesium of boiled water were found to be little higher than the control, although the difference in chemical constituent between the control and treated sample was not significant (Figure 2). Similarly, no significant (p ≥ 0.05) difference between the control and treated samples was found for trace elements (Figure 3).

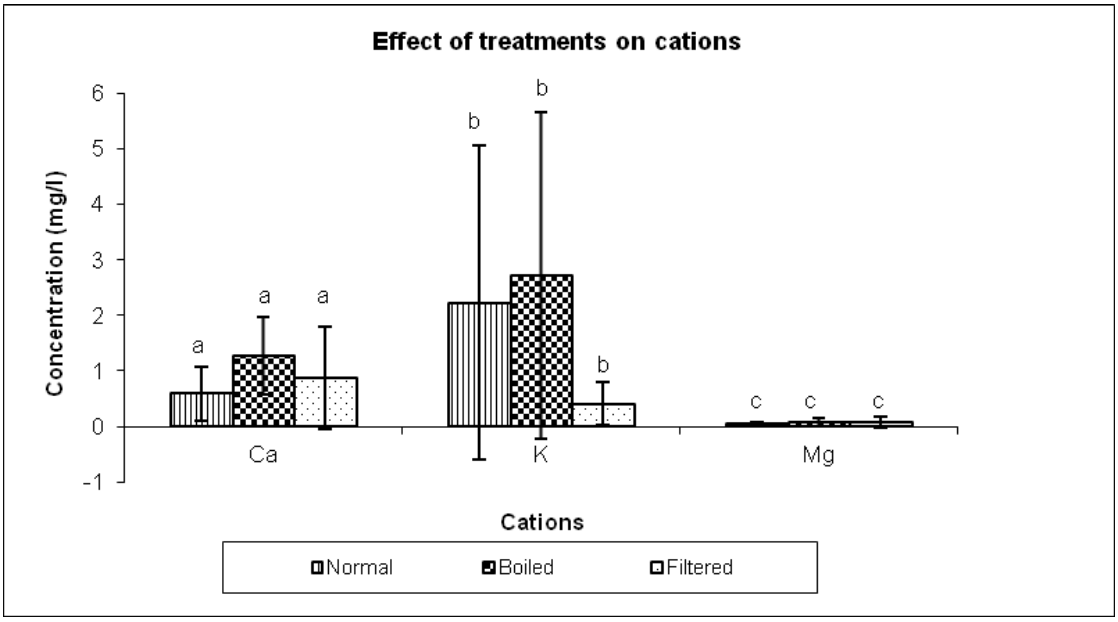

Figure 2. Effect of Rolling Boiling and Reverse Osmosis on Cations

Data are mean ± S.D of replicates; Mean values having different superscripts letters for each element are significantly different (p ≤ 0.05)

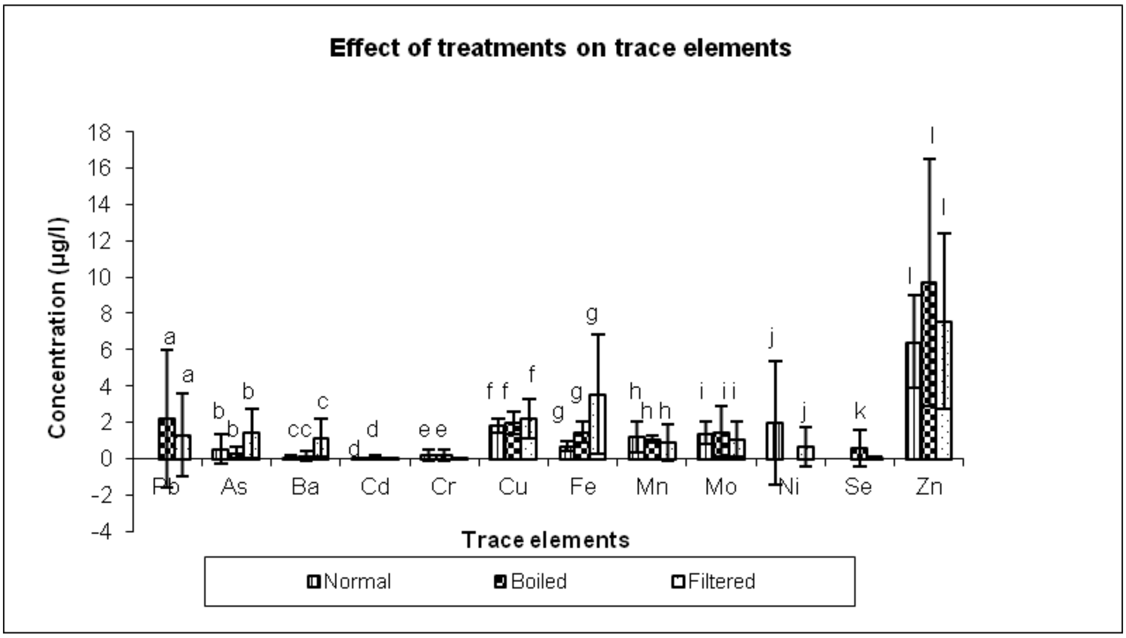

Figure 3. Effect of Rolling Boiling and Reverse Osmosis on Trace Elements

Data are mean ± S.D of replicates; Mean values having different superscripts letters for each element are significantly different (p ≤ 0.05)

4. Discussion

The pH of all samples was within the recommended maximum concentration limit guidelines by WHO (6.5-8.0). Average of pH was found to be in the order of household > commercial zamzam > bottled.

Both low and high pH is problem because water with low pH can be acidic which can damage metal pipes and water with high pH signifies high level of alkalinity [16]. Higher pH prevents the corrosion and contamination from pipes [17]. When compared to the recommended daily intake of calcium, magnesium, potassium and sodium; mineral content of bottled water was found to be very low, but was quiet comparable with household and commercial zamzam water, although lower than the recommended daily intake. None of the values crossed the recommended maximum concentration limit guidelines of WHO and SASO standards. Average of calcium was found to be in the order of commercial zamzam > household > bottled. The result of household water is in accordance with the result obtained by Abed and Alwakeel in Riyadh (43.42 mg/l) [1] but higher than the results obtained by Ahmad and Bajahlan in Yanbu (21.91 mg/l) [17]. The concentration of calcium in bottled water obtained in this study was lesser than the previous studies [1,17]. Calcium intake is important at all ages but the need for calcium is higher during childhood, fetal growth, pregnancy and lactation [18]. A diet fortified with calcium may reduce the risk of osteoporosis [19]. It decreases neuromuscular excitability, plays important role in myocardial system, heart and muscle contracting, intracellular inflammation, transmission and blood clotting [17]. In this study, potassium content in household water was found to be higher and in bottled water it was found to be lower than the previous studies [1,17]. Average of potassium was in the order of commercial zamzam > household > bottled water. Potassium does not cause intoxication because it is excreted by healthy kidney rapidly and also because large doses cause vomiting. However after acute ingestion of potassium greater than 55 g for a 70 kg adult by individual with normal kidney function overwhelm homeostatic mechanism and caused death [20]. In humans, magnesium is a cofactor in more than 300 enzymatic reactions, particularly that involving energy utilization [17]. An inverse correlation between magnesium in drinking water and mortality from ischemic heart disease has been reported previously [4]. In present study, the average of magnesium was in the order of commercial zamzam > household > bottled water. Magnesium content in household water was found to be higher and in bottled water it was found to be lower than the previous studies [1,17]. Magnesium in water is highly bio-available and the absorption of waterborne magnesium is approximately 30% faster and better than magnesium from food [21]. Sodium content in household water was found to be much higher than the previous studies [1,17]. Numerous studies have shown that Na^+ intake is associated with hypertension and dietary Na^+ restriction achieved by not adding salt and avoiding Na^+ rich food, may effectively reduce blood pressure [18]. An excess of sodium more than 200mg/l may cause a salty taste or odor as well as presents long term health effects. This is a key element in water and is essential for health. In healthy adults excess sodium is excreted but in sensitive adults high Na^+ levels may cause problems [22]. The acute effect of drinking water having high content of sodium includes nausea, vomiting, convulsions, muscular twitching and rigidity, cerebral and pulmonary oedma [23].

The average of trace elements in Riyadh household water and commercially available bottled and zamzam water is shown in Table 3. Lead is a highly toxic metal and its exposure is associated with adverse health effects including central and peripheral nervous systems, renal function, vascular system [24], impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes [25]. Children are the most susceptible to its adverse health effects [26]. In Saudi Arabia, Tayyeb *et al.* [5] analyzed lead in drinking galloned water and bottled water but it was also within the maximum permissible WHO level. Epidemiological studies show that consumption of high levels of arsenic through drinking-water leads to the development of cancer at several sites, particularly bladder, lung and skin [27]. Higher concentration of arsenic has been reported in the bottled zamzam previously, but it ranged between 9.68 – 10.75 µg/l which was within the admissible range set by different regulatory agencies and also in agreement with SASO standards for drinking water [28]. There is no evidence that barium is carcinogenic or mutagenic. Deliberate or unintentional ingestion of barium compounds causes gastroenteritis, hypopotassaemia, cardiac arrhythmias, hypertension, and skeletal muscle paralysis [29,30].The result of cadmium concentration coincides with the Saleh *et al*. [12] in Cairo and Tayeb *et al*. [6] in Saudi Arabia as they also found slightly higher cadmium in tap water than bottled water. Al Saleh and Al Doush [4] reported higher level of cadmium in both bottled (0-2.3 µg//l) and tap water (1.36 µg//l) than the values obtained in this study. Kidney appears to be the most sensitive organ with its chronic oral exposure. Kidney, especially the proximal tubular cells is primarily affected by cadmium toxicity [31]. Although cadmium and cadmium compounds are classified as carcinogenic through inhalation, but there is no clear evidence for the genotoxicity and its carcinogenicity by the oral route [25]. Al Saleh and Al Doush [4] reported higher level of chromium in bottled (0-19.4 µg//l) and low level in tap water (1.42 µg//l) than the values obtained in this study. In the study performed by Al-Otaibi *et al*. [32] 60.00% of the groundwater crossed the maximum permissible limit for copper. Al Saleh and Al Doush [4] reported higher level of copper in both bottled (0-19.6 µg//l) and tap water (15.74 µg//l) than the values obtained in this study. Copper is both an important nutrient and a drinking-water contaminant. Oxidative damage to biological systems, take place at higher concentrations of copper [33]. Highest concentration of iron was observed in household water followed by bottled water. Similar findings have been reported previously in other countries [34,35]. Al Otaibi *et al*. [32] found that 26.67% of groundwater samples exceeded the permissible limit set by Saudi standard (0.3mg/l) but none of the bottled water crossed this limit. Al Saleh and Al Doush [4] reported that 71.4% of bottled water contained iron; and in the present study iron was found in all samples but the iron content reported earlier [4] in tap water was too much higher than the values obtained in this study. Corrosion of steel and cast iron pipes during water distribution or the use of iron coagulants might be the reason for the presence of iron in drinking-water [36].

Al Otaibi *et al*. [32] found that 68.75% of bottled water and 53.33% of ground water exceeded the maximum permissible limit of manganese. Al Saleh and Al Doush [4] reported that 52.38% of bottled water contained manganese ranged from 0-2.3 µg//l and in this study 75% of bottled water contained manganese ranged from 0-0.7 µg//l. Its concentration in tap water detected by Al Saleh and Al Doush [4] was lesser than the result obtained in this study. Manganese is an essential element for humans and other animals. Adverse effects can result from both deficiency and overexposure. Manganese is known to cause neurological effects following inhalation exposure, lethargies and symptoms stimulating Parkinson's syndrome [36,37]. In previous study [4] nickel was detected in all bottled water samples but in this study, it has been detected in only 75% samples and in the earlier study its concentration in tap water was lesser than the result obtained in this study. In the general population, allergic contact dermatitis is the most common effect of nickel. Al Saleh and Al Doush [4] reported lesser level of selenium than the result obtained in this study. Selenium is an essential element for humans. Acute toxicity includes hypotension and tachycardia and chronic toxicity shows nail changes and alopecia [38]. Al Saleh and Al Doush [4] reported higher level of zinc than the result obtained in this study. Zinc is considered as an important trace element and in human bodies; it works as catalyst for enzymatic activity. However, its accumulation in the human body causes destructive effects such as speeding up of anemic conditions [6] and it is also associated with nervous system depression and tremors [39]. From the Table 2 and Table 3 it has been depicted that mineral content of the commercial zamzam water best fits within the maximum limit guidelines recommended by WHO and SASO. The results of water samples tested by European laboratories showed that zamzam water has a unique physique that makes it beneficial water, especially because of the quantity of calcium and magnesium salts, the content of these was slightly higher in zamzam water [40].

The guideline of bottled water contents is not stringent and the concentration mentioned on the labels may not be accurate [41]. Several studies were conducted to compare the actual level of different element to the concentration printed on the bottle [42,43]. None of the brands shows complete chemical parameters levels on their labels. Calcium, magnesium, sodium and potassium were the common elements mentioned on each label, so their values mentioned on the label was compared with the laboratory values. Labelled value of calcium, magnesium and potassium of most of the samples were found to be higher than the laboratory value while for sodium, labelled value of most of the samples were lesser than the laboratory value (Figure 1 (A-D)). Previous studies also indicates that in various countries the levels of essentials elements in some bottled water are either lower or higher than the recommended level of the countries standard limits [44,45].

Rolling boiling and reverse osmosis didn't show any significant effect on the chemical constituents of water. Slight but insignificant increase in most of the chemical constituent after boiling shows that when temperature increases, the minerals are released. A study on the effect of boiling time (5, 10 and 15 min) on mineral content of soft drink also showed highest level of calcium, potassium and magnesium after boiling for highest time [46]. In previous study absence of impact of treatments such as rolling boiling or filtration on chemical constituents and other components has been reported [47].

5. Conclusions

This study has provided important information regarding the analysis of the chemical composition of different types of water commonly consumed in Riyadh, Saudi Arabia. None of the results presented here can be considered typical of any specific manufacturer or product. Concentration of major cations and trace elements were below the maximum guidelines set by WHO and SASO. This study led to the conclusion that zamzam water has a rich essential mineral profile. Except for sodium the concentration of other major cations (calcium, magnesium, and potassium) reported on the labels of most of the bottled water were lower than values observed in the laboratory. Home treatments such as rolling boil and reverse osmosis doesn't show any significant effect on the chemical constituents of water. Studies are required to investigate the effect of some more techniques on the chemical constituents of water and this study will help in assisting more focused design of further research.

Acknowledgement

The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research project number NFG2-13-33.

Statement of Competing Interest

The authors have no competing interest.

List of Abbreviations

BW-Bottled water.
HW-Household water.
CZ-Commercial zamzam water.

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