Current World Environment Vol. **12**(1), 06-16 (2017)

ICP-MS Determination of Trace Metals in Drinking Water Sources in Jazan Area, Saudi Arabia

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http://dx.doi.org/10.12944/CWE.12.1.02

(Received: February 16, 2017; Accepted: March 11, 2017)

ABSTRACT

Requisite reference facts about essential elements in treated and plastic bottled drinking water is usually mentioned on the products. However, more information is sometime crucial regarding trace elements in treated, bottled and other sources of drinking water such as tap water to evaluate their quality. This study is aimed to evaluate drinking water quality in the main governorates (Jazan, Sabya and Abu Arish) of Jazan province located in the South-Western region of Kingdom of Saudi Arabia. This is the first such study carried out in Jazan city so that the research team can come out with valuable recommendations in the issue. The research team has collected a sum of 68 water samples from different sources comprising hospitals (treated tap water), stations for drinking water treatment (large blue bottles of drinking water) and bottled drinking water (purchased from local markets). Using inductively coupled plasma-mass spectrometry (ICP-MS), the concentrations of 20 elements were determined. The physiochemical parameters of water samples were measured. All parameters were within the recommended limits of the World Health Organization (WHO, 2011) and Gulf Cooperation Council Standardization Organization (GSO, 2008). Trace and major elements were found to be below the standard guideline values, except for uranium in some tap water samples. This preliminary study will significantly improve the awareness and knowledge among the society about the drinking water quality in Jazan area.

Keywords: ICP-MS; trace elements; drinking water, water quality, Jazan, Saudi Arabia

INTRODUCTION

Pure drinking water is one of the basic needs for every human being in the world. For a large portion of the African and Asian populations, safe drinking water is not effectively accessible[1]. Out of the 7 billion individuals on earth, more than one billion and half need to get pure and safe drinking water and around 2.7 billion do not have admittance to satisfactory sanitation administrations[2,3]. Not with standing these deficiencies, different sorts of waterborne illnesses execute more than 6 million kids every year i.e. around 20,000 kids a day[4,5]. Water covers 70 percent of the globe's surface, mostly saltwater. Freshwater covers only 3 percent of the world's surface and quite a bit of it falsehoods solidified in the Antarctic and Greenland polar ice[5]. New water that is accessible for human utilization

originates from waterways, lakes and subsurface aquifers. These sources represent just a single percent of total water on the earth. Six billion individuals rely on the supply water and a noteworthy segment of the total populace is confronting water deficiencies (Fig.1)[5].

Groundwater represents the main source of drinking water in Saudi Arabia[6,7]. The quality of water is of scientific as well as public concerns, till now no serious issue in drinking water quality has been reported in the country[8]. Many resources of chemical and microbial contaminations of groundwater including wastewater, pesticides, fertilizers, and industrial wastes have been reported[9,10].

In the recent years, there was a considerable increase in the consumption of bottled drinking water. This means that systematic and regular independent tests on the quality of bottled drinking water must be applied, and different organizations worldwide set standards for bottled drinking water[11,12].

Jazan is located in the South-Western part of the Saudi Arabian Peninsula [16°53'21"N 42°33'40"E], and it is considered the second smallest province which comes after Al Bahah region of the kingdom in terms of area considerations. Jazan spreads over 300 km along the southern coast of the Red Sea directly north of Yemen. A total of 11,671 km² is the representative area of Jazan province with total population of 1,365,110 according to the 2010 census. Jazan city itself is the capital of the province with its 14 governorates, table 1[13].

In this area, the drinking water is mainly provided either as bottled water of various capacities ready to use, or filled after treatment in plastic containers (20L or larger). However, the information about the concentrations of heavy metals in the drinking water supplied to Jazan area is inadequate. The aim of this study was to measure the levels of essential and toxic elements, and evaluate the physicochemical properties of drinking water from different available sources. To the best of our knowledge, this is the first scientific effort for determination of heavy metal contents in drinking water from all types of resources in Jazan area.

Table 1: The region of Jazan province is sub-divided into 14 governorates and the main four of these governorates are listed here with necessary data

S. No.	*Name*	*Census 15 September 2004*	*Census (Preliminary) 28 April 2010*
1	*Abu Arish*	*123,943*	*197,112*
2	*Jazan*	*255,340*	*157,536*
3	*Sabya*	*198,086*	*228,375*
4	*Samtah*	*128,447*	*201,656*

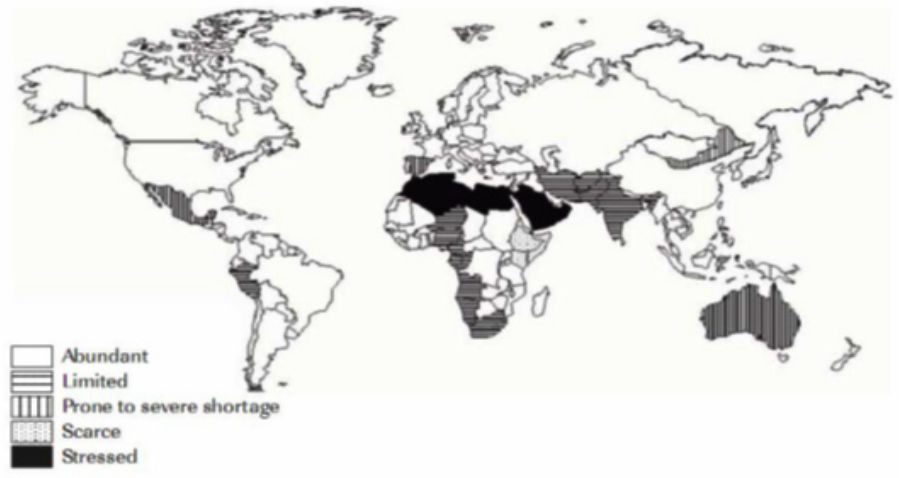

Fig. 1: Water availability in the world; Saudi Arabia is one of the threatened areas [5]

MATERIALS AND METHODS

Water Sample Collection

Three types of drinking water samples were collected: bottled, filled treated and tap water. The samples of all the three types of water sources were collected during August-September 2016. A total of 68 samples were collected including; (I) tap water samples (n = 12) from 4 different hospitals in the Jazan province, (II) treated (filtered and ozonized) drinking groundwater (n = 17), and (III) bottled drinking water (n = 39) of different brand available in the market. After collection the samples were directly transported to the laboratory and stored in their original package at 4°C till analysis.

Analytical Methods

The physiochemical parameters such as Electrical Conductivity and pH were measured using a Bluelab combo meter (Tauranga, New Zealand) in the laboratory of Pharmaceutical Analytical Chemistry, Faculty of Pharmacy, Jazan University.

Major and trace elements (beryllium Be, magnesium Mg, calcium Ca, aluminum Al, titanium Ti, chromium Cr, manganese Mn, cobalt Co, nickel Ni, copper Cu, zinc Zn, arsenic As, rubidium Rb, strontium Sr, cadmium Cd, cesium Cs, barium Ba, lead Pb, and uranium U) were measured by inductively coupled plasma-mass spectrometry ICP-MS (X-Series^{II}; Thermo-Fisher Scientific Inc., Waltham, MA, USA) equipped with an autosampler (Cetac ASX-520 with 4 × 60 place sample racks). The operation condition of ICP-MS is summarized in table 2.

Table 2: Operation conditions of ICP-MS

Parameter/unit	Setting
RF power (W)	1500
RF Matching (V)	1.7
Carrier gas (L/min)	0.9
Makeup Gas (L/min)	0.27
Sampling depth (mm)	8
S/C temp (ºC)	2
Nebulizer pump (rps)	0.1
Torch-horizontal (mm)	1.2
Torch-vertical (mm)	1.4
Extract 1 (V)	4.3
Extract 2 (V)	-99
Omega Bias-ce (V)	-16
Omega Lens-ce (V)	2.6
Cell Entrance (V)	-26
Cell Exit (V)	-20
Channel spacing	0.02
QP Focus (V)	5

RESULTS AND DISCUSSION

Table 3 summarizes the recommended values of heavy metals and physico-chemical properties of the drinking water. In the tables (4-13) the levels of all tested parameters are presented for the samples from all types of water resources.

Physico-chemical Properties

To know the different physico-chemical parameters of drinking water is very essential for the safety of human beings. The average pH values were compared for all the samples within a type of water and also for the samples of the different types. It was found that the tap water samples and collected from stations have recorded comparatively higher pH values than those of bottled drinking water samples (Tables 4, 5, and 10). Within the tap water

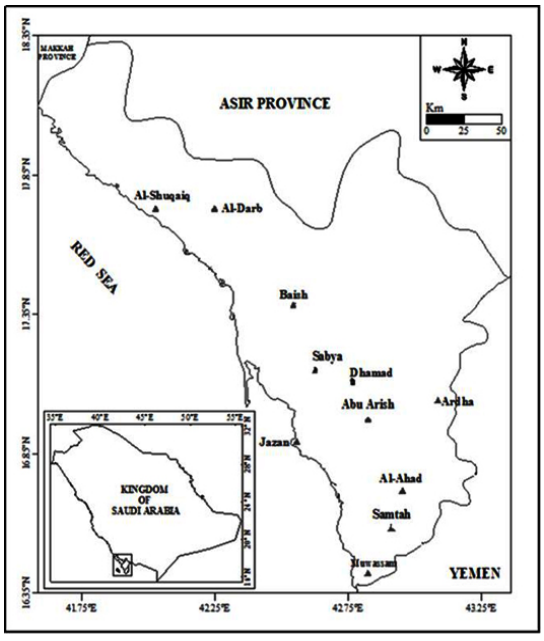

Fig. 2: Location of the sampling areas (the three governorates) in Jazan Province, South-Western region of the Saudi Arabian Peninsula

from hospitals, the sample from Abu Arish Public Hospital showed the highest pH (7.86). The overall variation may be due to the presence of the materials that coagulate and which utilized for purification of water.

Overlapping in the pH values was observed between the range of pH of treated samples from stations of drinking water and those of bottled drinking water. Still the range is within the permissible limit of WHO and other national and international organizations regulating the water quality and related health issues [14]. This permissibility is not excluding the tap water samples from hospitals. In general, the pH values of water samples in this study were found to be within the acceptable and permissible limit. Thus, it may be concluded that valuable positive outcome is indicated from water treatment processes in terms of pH, a significant physico-chemical parameter. Even though, pH values of some water samples are marginally near the highest permissible values recommended by WHO and other related organizations. A proper control and follow up is required during all the stages of water treatment and distribution to the consumer points so that to maintain the purity of drinking water and minimize the associated health risks. This will also participate in minimizing water corrosion through distribution systems[15].

Although the values of other physico-chemical parameters such as EC, TDS and TH were found to be within the acceptable range set by the national and international organizations' guidelines, a considerable variation was observed among all the water samples.

Table 3: Regulatory limits of different parameters and trace elements levels in the treated and bottled drinking water [17].

Organization		WHO [14]	USEPA [18]	GSO [19]	SASO [20]
Parameter	Unit	Guideline value	Guideline value	Guideline value	Guideline value
pH		6.5–9.5	6.5–8.5	–	6.5–8.5
EC	µS/cm	–	–	–	800–2,300
TH	mg/L	500	–	–	500
TDS	mg/L	1,000	500	–	1,500
Li	µg/L				
Be	µg/L	-	-	-	-
Mg	mg/L	–	–	–	30–150
Ca	mg/L	–	–	–	200
Al	µg/L	200	50–200	–	–
Ti	µg/L	–	–	–	–
Cr	µg/L	50	100	50	–
Mn	µg/L	400	50	400	50
Co	µg/L	–	–	–	–
Ni	µg/L	70	–	70	–
Cu	µg/L	2,000	1,300	1,000	–
Zn	µg/L	3,000	5,000	–	–
As	µg/l	10	10	10	–
Rb	µg/L	–	–	–	–
Sr	µg/L	–	4.2 mg/L	–	–
Cd	µg/L	3	5	3	–
Cs	µg/L	–	–	–	–
Ba	µg/L	700	2,000	700	–
Pb	µg/L	10	15	10	–
U	µg/L	15	30	15	–

Major Elements

Presence of sodium, calcium, magnesium and potassium in drinking water is considered to be essential to the heath of mankind is ranging between 10 mg/L to 100 mg/L for sodium and calcium respectively and between 1 mg/L to 10 mg/L for magnesium and potassium[16]. In this study, sodium is not included as one of the 20 elements under investigation. However, calcium (Ca) and magnesium (Mg) concentrations in all representative samples were measured. Treated drinking water of stations and bottled drinking water samples have scored the lower concentrations of the two major elements compared to the samples of tap water from hospitals.. (Table 4, 5 and 8). Depletion of these elements during the treatment processes may be the significant cause of their varying results. Only two samples (Alrraidah, Jazan and Aljisr-Bish) from treated drinking water samples of stations were found to contain calcium (Ca). On the other hand, calcium is not detected in bottled drinking water samples indicating the deficiency of this major element in all the brands of bottled water samples tested.

Table 4: Parameters measured in treated tap water samples from hospitals of Jazan region

Parameter	Unit	P.M.H.a n= 3	A.P.Hb n= 3	K.F.Hc n= 3	J.P.Hd n=3	Permissible limits WHO, 2011	USEPA, 2009	GSO, 2008	ASAO, 1984
pH		7.22	7.86	7.72	7.48	6.5–9.5	6.5–8.5	NM	6.5–8.5
EC	µS/cm	1222	1468	1396	NM 1272	NM	NM		800–2300
TH	mg/L	3017	6179	1059	2516	500	NM	NM	500
TDS	mg/L	686	1242	597	1124	1000	500	NM	1500
Li	µg/L	42.82	40.94	38.91	39	NM	0.005	NM	NM
Be	µg/L	62.22429	Nil	Nil	Nil	NM	NM	NM	NM
Mg	Mg/L	3017	6179	1059	2516	NM	NM	NM	30–150
Ca	Mg/L	Nil	Nil	Nil	Nil	NM	NM	NM	200
Al	µg/L	Nil	Nil	Nil	Nil	200	50–200	NM	NM
Ti	µg/L	5.217	5.188	5.183	5.183	NM	NM	NM	NM
Cr	µg/L	Nil	Nil	Nil	Nil	50	100	50	NM
Mn	µg/L	Nil	Nil	Nil	Nil	400	50	400	50
Co	µg/L	Nil	Nil	Nil	Nil	NM	NM	NM	NM
Ni	µg/L	Nil	Nil	Nil	Nil	70	NM	70	NM
Cu	µg/L	Nil	Nil	Nil	Nil	2,000	1300	1,000	NM
Zn	µg/L	311.8	215.6	59.18	88.45	3,000	5000	NM	NM
As	µg/L	94.96	27.88	Nil	Nil	10	10	10	NM
Rb	µg/l	2947	720.1	142.5	264.8	NM	NM	NM	NM
Sr	µg/L	640.7	117.2	21.31	41.59	NM	4.2 mg/L	NM	NM
Cd	µg/L	Nil	Nil	Nil	Nil	3	5	3	NM
Cs	µg/L	Nil	Nil	Nil	Nil	NM	NM	NM	NM
Ba	µg/L	Nil	Nil	Nil	Nil	700	2,000	700	NM
Pb	µg/L	5.779	8.25	4.558	5.532	10	15	10	NM
U		2.018	Nil	Nil	Nil	15	30	15	NM
Total No. of Samples						12			

Key: a = Prince Mohammed Bin Nasir Hospital (Al-shawajrah); b= Abu Arish Public Hospital (Abu Arish); c = King Fahd Hospital (Abu Arish); d = Jazan Public Hospital (Jazan); n = No. of samples from each hospital; NM = Not mentioned; Nil = Not available in the sample

Table 5. Parameters measured in treated water samples collected from different governorates of Jazan region (group I elements)

Information about samples		Concentrations (µg/L)					Physico-chemical parameters			
Code-S No.	Station Name	Li	Be	Mg	Al	Cr	pH	EC µS/cm	TH mg/L	TDS mg/L
Y-1	Alrraidah, Jazan	38.97	Nil	1544	Nil	Nil	7.21	124.5	1.6674	698.2
Y-2	Rafhaa Waters	138.99	Nil	302.7	Nil	Nil	7.34	187.3		140.2
Y-3	Alssadeem Labs-Jazan	39.06	Nil	1141	Nil	Nil	7.54	211.6	1.141	346.6
Y-4	Faris-Beesh	38.86	Nil	2662	Nil	Nil	7.56	222.4	2.662	432.4
Y-5	Aljisr-Beesh	39.10	Nil	546	384	Nil	8.14	198.1	0.594	211.6
Y-6	Alghariya Waters-Jazan	38.98	Nil	1694	124.7	Nil	7.43	344.5	1.694	789.3
Y-7	RoohAlfirdos Labs-Jazan	38.89	Nil	2213	Nil	Nil	7.22	31.6	2.213	812.4
Y-8	QatratSehab Waters-Jazan	39.19	Nil	1509	20.86	Nil	7.28	198.2	1.509	562.3
Y-9	Marwiah-WadiJazan	38.84	Nil	1490	Nil	Nil	7.55	256.8	1.490	665.4
Y-10	Alrayan-WadiJazan	38.97	Nil	1689	Nil	Nil	7.98	229.8	1.689	698.5
Y-11	Alqana'a Lab-WadiJazan	39.02	Nil	1727	Nil	Nil	8.12	276.7	1.727	885.8
Y-12	Alkauther Waters-Sabeya	39.12	Nil	2876	49.98	Nil	8.06	290.0	2.876	316.6
Y-13	Aishifa Waters-Sabeya	38.95	Nil	1551	0.3609	Nil	7.87	265.7	1.551	498.6
Y-14	Dafa Waters-Sabeya	43.52	Nil	537.6	907.2	Nil	7.76	318.4	0.5376	756.3
Y-15	Alnaqa'a-Sabeya	39.12	Nil	2389	149.8	Nil	7.30	341.6	2.389	357.9
Y-16	Tohama Lab-Sabeya	38.97	Nil	870.3	112.1	Nil	8.11	309.2	0.8703	1034.6
Y-17	Almanhal-Sabeya	39.17	Nil	3292	184.1	Nil	7.86	299.7	3.292	622.4

Key: = Not available in the sample

Trace Elements

Although, the trace elements contribute in the natural occurrence of dissolved constituents in groundwater by only 1 %, there should be a periodical follow up and measurement of trace element in bottled and treated drinking water to avoid contamination by these toxic metals from unexpected sources. Some of the trace elements are essential to human health such as vanadium, selenium, cobalt and nickel upto certain concentration range. On the other hand some of these trace elements are toxic to human beings such as cadmium, aluminum, arsenic and lead with concentrations not exceeding 1 µg/L and uranium with a concentration lower than 10 µg/L [16].

Water samples of treated tap water and from stations recorded the highest values of Rb and Sr. However, their concentrations did not exceed the recommended values of the organizations including WHO**.** The average concentrations of a total of 14 trace elements measured in all the samples were within the permissible limits except three samples from treated drinking water of stations [Alkauther

Table 6: Parameters measured in treated water samples collected from different governorates of Jazan region (group II elements)

Information about samples		Concentrations (µg/L)				
Code-Ser No.		Mn	Co	Ni	Cu	Zn
Y-1	Alrraidah, Jazan	Nil	Nil	Nil	Nil	28.34
Y-2	Rafhaa waters	Nil	Nil	Nil	Nil	21.86
Y-3	Alssadeem Labs-Jazan	Nil	Nil	Nil	Nil	27.36
Y-4	Faris-Beesh	Nil	Nil	Nil	Nil	50.93
Y-5	Aljisr-Beesh	Nil	Nil	Nil	Nil	80.59
Y-6	Alghariya Waters-Jazan	Nil	Nil	Nil	Nil	33.25
Y-7	RoohAlfirdos Labs-Jazan	Nil	Nil	Nil	Nil	28.73
Y-8	QatratSehab Waters-Jazan	Nil	Nil	Nil	Nil	34.43
Y-9	Marwiah-WadiJazan	Nil	Nil	Nil	Nil	19.5
Y-10	Alrayan-WadiJazan	Nil	Nil	Nil	Nil	19.5
Y-11	Alqana'a Lab-WadiJazan	Nil	Nil	Nil	Nil	16.16
Y-12	Alkauther Waters-Sabeya	Nil	Nil	Nil	Nil	30.11
Y-13	Aishifa Waters-Sabeya	Nil	Nil	Nil	Nil	15.38
Y-14	Dafa Waters-Sabeya	Nil	Nil	Nil	14.14	98.47
Y-15	Alnaqa'a-Sabeya	Nil	Nil	Nil	Nil	31.09
Y-16	Tohama Lab-Sabeya	Nil	Nil	Nil	Nil	33.25
Y-17	Almanhal-Sabeya	Nil	Nil	Nil	Nil	51.32
	GSO,2009					
	WHO, 2011					

Key: Nil = Not available in the sample

Table 7: Parameters measured in treated water samples collected from different governorates of Jazan region (group III elements)

Information about samples		Concentrations (µg/L)				
Code-S. No.	**Names of stations**	**Ca**	**As**	**Rb**	**Sr**	**Cd**
Y-1	Alrraidah, Jazan	123.4	Nil	89.04	11.86	Nil
Y-2	Rafhaa waters	Nil	Nil	28.09	1.470	Nil
Y-3	Alssadeem Labs-Jazan	Nil	Nil	159.7	23.32	Nil
Y-4	Faris-Bish	Nil	Nil	169.2	25.36	Nil
Y-5	Aljisr-Bish	48.08	Nil	3.114	ND	Nil
Y-6	Alghariya Waters-Jazan	Nil	Nil	149.5	22.06	Nil
Y-7	RoohAlfirdos Labs-Jazan	Nil	Nil	195.5	29.71	Nil
Y-8	QatratSehab Waters-Jazan	Nil	Nil	201.2	30.91	Nil
Y-9	Marwiah-WadiJazan	Nil	Nil	127.4	17.92	Nil
Y-10	Alrayan-WadiJazan	Nil	Nil	139.8	20.18	Nil
Y-11	Alqana'a Lab-WadiJazan	Nil	Nil	140.2	20.40	Nil
Y-12	Alkauther Waters-Sabya	Nil	Nil	249.9	38.79	Nil
Y-13	Aishifa Waters-Sabya	Nil	Nil	125.7	18.18	Nil
Y-14	Dafa Waters-Sabya	Nil	Nil	16.10	0.6073	Nil
Y-15	Alnaqa'a-Sabya	Nil	Nil	176.2	26.62	Nil
Y-16	Tohama Lab-Sabya	Nil	Nil	75.66	9.535	Nil
Y-17	AlmanhalSabya	Nil	Nil	201.2	31.04	Nil

Key: Nil = Not available in the sample

Table 8: Parameters measured in treated water samples collected from different governorates of Jazan region (group VI elements)

Information about samples		Concentrations (µg/L)				
Code-Ser. No.	Names of stations	Cs	Ba	Tl	Pb	U
Y-1	Alrraidah, Jazan	Nil	Nil	5.178	7.590	Nil
Y-2	Rafhaa waters	Nil	Nil	Nil	5.176	5.195
Y-3	Alssadeem Labs-Jazan	Nil	Nil	5.175	4.325	2.016
Y-4	Faris-Beesh	Nil	Nil	5.176	4.777	Nil
Y-5	Aljisr-Beesh	Nil	Nil	5.186	5.624	Nil
Y-6	Alghariya Waters-Jazan	Nil	Nil	5.179	5.394	22.18
Y-7	RoohAlfirdos Labs-Jazan	Nil	Nil	5.175	4.393	Nil
Y-8	QatratSehab Waters-Jazan	Nil	Nil	5.178	4.261	42.34
Y-9	Marwiah-WadiJazan	Nil	Nil	5.175	4.216	Nil
Y-10	Alrayan-WadiJazan	Nil	Nil	5.174	4.213	Nil
Y-11	Alqana'a Lab-WadiJazan	Nil	Nil	5.180	4.265	Nil
Y-12	Alkauther Waters-Sabeya	Nil	Nil	5.181	4.244	22.18
Y-13	Aishifa Waters-Sabeya	Nil	Nil	5.174	4.264	Nil
Y-14	Dafa Waters-Sabeya	Nil	Nil	14.22	15.71	Nil
Y-15	Alnaqa'a-Sabeya	Nil	Nil	5.186	5.225	Nil
Y-16	Tohama Lab-Sabeya	Nil	Nil	5.183	4.935	Nil
Y-17	Almanhal-Sabeya	Nil	Nil	5.178	5.600	Nil

Key: Nil = Not available in the sample

Table 9: List of bottled drinking water samples, brands, codes and number of samples in each brand collected from the market of Jazan city

Serial	Brand	Code	Number of Samples (n)
Z-1	QatratSahab	QS	2
Z-2	Hana	H	2
Z-3	Pure life	PL	3
Z-4	Hada	HD	1
Z-5	Aquqfina	AF	1
Z-6	Panda	P	2
Z-7	Arwa	A	2
Z-8	Fayha	F	2
Z-9	Nova	N	2
Z-10	Mozen	M	2
Z-11	Al-gassim	AQ	1
X-12	Najran	NJ	1
Z-13	Hilwa	HL	1
Z-14	Maeen	MA	2
Z-15	Haley	HA	2
Z-16	Dala	D	3
Z-17	Zamzam	Z	2
Z-18	Manhal	ZM	3
Z-19	Juman	J	2
Z-20	Safa	S	2
Z-21	One	O	1
Z-22	Al-wadi	AW	1
Total No. of Samples			39
Total No. of Brands			22

Waters-Jazan (22.18 mg/L), QatratSehab Waters-Jazan (42.34 mg/L) and Alkauther Waters-Sabeya (22.18 mg/L)] in which the uranium level exceeded the permissible limits of all national and international organizations including Who which might due to the geophysical properties of Sabeya area.

Improvement of distribution systems and application of systematic regular maintenance may be effective to avoid the existence of these toxic elements. These elements can be considered safe at the lower concentrations levels as shown in (Table 3). Cobalt concentration values were very low in all the tested samples and also remained undetected in some of the water samples. The strontium is a naturally occurring element and its permissible limit is 4200 µg/L which is very high as

Table 10: Parameters measured in bottled drinking water of samples collected from supermarkets of different governorates of Jazan city (group I of elements)

Samples	Concentrations (µg/L)					Physico-chemical parameters			
Brand name	Li	Be	Mg	Al	Cr	pH	EC µS/cm	TH mg/L	TDS mg/L
QatratSahab	38.35	Nil	804.6	Nil	Nil	6.9	98.5	0.8046	6.7
Hana	37.89	Nil	477.9	Nil	Nil	6.8	231.5	0.4779	4.2
Pure life	38.73	Nil	7602	Nil	Nil	7.2	453.5	7.602	11.26
Hada	38.22	Nil	1765	Nil	Nil	6.7	135.9	1.765	4.2
Aquqfina	4.225	Nil	118.5	Nil	Nil	7.4	211.4	1.18.5	3.5
Panda	38.49	Nil	781.1	Nil	Nil	7.3	460.2	0.7811	2.6
Arwa	37.88	Nil	927.5	Nil	Nil	6.9	104.5	0.9275	2.1
Fayha	38.13	Nil	689.1	Nil	Nil	6.7	250.5	0.6891	4.6
Nova	37.78	Nil	983.7	Nil	Nil	7.5	332.3	0.9837	4.4
Mozen	40.40	Nil	1369	Nil	Nil	7.8	278.6	1.369	4.4
Al-gassim	37.74	Nil	4949	Nil	Nil	7.5	511.3	4.949	17.8
Najran	38.31	Nil	798.7	Nil	Nil	7.6	390.4	0.7987	5.6
Hilwa	38.59	Nil	6951	Nil	Nil	7.7	112.4	6.951	13.2
Maeen	41.95	Nil	3068	Nil	Nil	7.1	234.6	3.068	23.5
Haley	38.64	Nil	1054	Nil	Nil	7.4	234.6	1.054	15.6
Dala	38.56	Nil	302.81	Nil	Nil	7.6	327.7	0.3028	12.3
Zamzam	38.63	Nil	961.7	Nil	Nil	6.8	498.3	0.9617	6.9
Manhal	38.41	Nil	798.2	Nil	Nil	6.8	128.5	0.7982	5.3
Juman	38.99	Nil	3818	Nil	Nil	7.6	321.7	3.818	26.6
Safa	38.02	Nil	3168	Nil	Nil	7.9	222.5	3.168	30.5
One	37.91	Nil	6749	Nil	Nil	7.3	443.6	6.749	40.2
Al-wadi	37.76	Nil	724.3	Nil	Nil	6.7	390.0	0.7243	18.8

Key: Nil = Not available in the sample

Table 11: Parameters measured in bottled drinking water of samples collected from supermarkets of different governorates of Jazan city (second group of elements)

Samples	Concentrations (µg/L)				
Brand name	Mn	Co	Ni	Cu	Zn
QatratSahab	Nil	Nil	Nil	Nil	3.395
Hana	Nil	Nil	Nil	Nil	3.591
Pure life	Nil	Nil	Nil	Nil	3.591
Hada	Nil	Nil	Nil	Nil	14.20
Aquqfina	Nil	Nil	Nil	Nil	0.6341
Panda	Nil	Nil	Nil	Nil	3.395
Arwa	Nil	Nil	Nil	Nil	9.484
Fayha	Nil	Nil	Nil	Nil	4.377
Nova	Nil	Nil	Nil	Nil	7.716
Mozen	Nil	Nil	Nil	Nil	12.43
Al-gassim	Nil	Nil	Nil	Nil	6.734
Najran	Nil	Nil	Nil	Nil	8.502
Hilwa	Nil	Nil	Nil	Nil	6.341
Maeen	Nil	Nil	Nil	Nil	13.02
Haley	Nil	Nil	Nil	Nil	12.04
Dala	Nil	Nil	Nil	Nil	23.63
Zamzam	Nil	Nil	Nil	Nil	6.734
Manhal	Nil	Nil	Nil	Nil	6.145
Juman	Nil	Nil	Nil	Nil	21.07
Safa	Nil	Nil	Nil	Nil	31.68
One	Nil	Nil	Nil	Nil	15.97
Al-wadi	Nil	Nil	Nil	Nil	13.61

Key: Nil = Not available in the sample

shown in (Table 10). It is noteworthy that none of the deliberate components in the drinking water tested in this study exceeded their maximum allowable limits. Hence, on the basis the investigation results, one can infer that the drinking water quality in Jazan area is maintained as per the global regulatory standards.

Table 12: Parameters measured in bottled drinking water of samples collected from supermarkets of different governorates of Jazan city (third group of elements)

Samples	Concentrations in (µg/L)				
Brand name	Ca	As	Rb	Sr	Cd
QatratSahab	Nil	Nil	69.43	8.669	Nil
Hana	Nil	Nil	177.7	25.49	Nil
Pure life	Nil	Nil	Nil	Nil	Nil
Hada	Nil	Nil	6.322	Nil	Nil
Aquqfina	Nil	Nil	14.16	2.104	Nil
Panda	Nil	Nil	70.88	8.045	Nil
Arwa	Nil	Nil	40.16	2.765	Nil
Fayha	Nil	Nil	51.77	4.617	Nil
Nova	Nil	Nil	Nil	Nil	Nil
Mozen	Nil	Nil	139.6	20.32	Nil
Al-gassim	Nil	Nil	Nil	Nil	Nil
Najran	Nil	Nil	66.89	8.357	Nil
Hilwa	Nil	Nil	Nil	Nil	Nil
Maeen	Nil	Nil	60.88	10.26	Nil
Haley	Nil	Nil	214.8	32.22	Nil
Dala	Nil	Nil	6.551	Nil	Nil
Zamzam	Nil	Nil	194.2	28.64	Nil
Manhal	Nil	Nil	74.49	9.005	Nil
Juman	Nil	Nil	199.0	29.54	Nil
Safa	Nil	Nil	108.7	14.35	Nil
One	Nil	Nil	46.27	3.323	Nil
Al-wadi	Nil	Nil	Nil	Nil	Nil

Key: Nil = Not available in the sample

Table 13: Parameters measured in bottled drinking water of samples collected from supermarkets of different governorates of Jazan city (fourth group of elements)

Samples	Concentrations (µg/L)				
Brand name	Cs	Ba	Ti	Pb	U
QatratSahab	Nil	Nil	5.172	5.711	Nil
Hana	Nil	Nil	5.172	4.658	22.18
Pure life	Nil	Nil	5.172	4.431	Nil
Hada	Nil	Nil	5.174	4.400	Nil
Aquqfina	Nil	Nil	0.5174	0.4694	Nil
Panda	Nil	Nil	5.173	4.297	82.66
Arwa	Nil	Nil	5.180	4.936	2.016
Fayha	Nil	Nil	5.175	4.572	Nil
Nova	Nil	Nil	5.182	4.356	Nil
Mozen	Nil	Nil	5.172	4.342	Nil
Al-gassim	Nil	Nil	5.172	5.696	Nil
Najran	Nil	Nil	5.174	4.852	Nil
Hilwa	Nil	Nil	5.172	4.332	2.016
Maeen	Nil	Nil	5.175	4.646	Nil
Haley	Nil	Nil	5.172	4.987	42.34
Dala	Nil	Nil	5.178	4.682	Nil
Zamzam	Nil	Nil	5.180	4.955	Nil
Manhal	Nil	Nil	5.181	4.701	42.34
Juman	210.0	277.2	5.181	5.727	2.016
Safa	Nil	16.41	5.173	4.952	Nil
One	Nil	Nil	5.193	4.278	Nil
Al-wadi	Nil	Nil	5.173	5.091	2.016
GSO,2009					
WHO, 2011					

Key: Nil = Not available in the sample

CONCLUSION

The current study determined the concentration of heavy metals and physico-chemical properties of drinking water from different sources (bottled, treated, and tap water) in Jazan area. Our findings showed that the drinking water quality of the investigated sources was within the recommended limits established by WHO. However, to estimate the complete quality of the water samples additional investigations are recommended for determining other kinds of pollutants such as pesticides, polycyclic aromatic hydrocarbons (PAHs), pharmaceuticals and personal care products (PPCPs).

Funding Information

This study was fully funded by the Scientific Research Deanship, Jazan University, under the grant number 36/6/2637.

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