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Toxic (aluminum, beryllium, boron, chromium and zinc) in groundwater: health risk assessment

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Abstract The objective of this study is to determine the seasonal water quality variations of the major springs of the Yarmouk Basin (YB) of north Jordan. A total of 36 water samples were collected in October 2006 (dry season) and in May 2007 (wet season) and analyzed for temperature, hydrogen ion concentration, electrical conductivity, aluminum, beryllium, boron, chromium and zinc. The hydrogen ion concentration was found in the alkaline ranges (7.01–7.87) and (7.01–8.09) for the pre and post-wet season water samples, respectively. Electrical conductivity varied from 300 to 1199 µS/cm and from 424 to 962 µS/cm for the dry and wet season water samples, respectively. The results of heavy metals analysis indicated that some water samples exceeded the Jordanian Standards for drinking water. Overall, the results showed that the water springs of the Yarmouk Basin in north Jordan is contaminated with heavy metals that might affect human health as well as the health of the ecosystem.

Keywords Heavy metals · Human health · Seasonal water quality · Water springs

Introduction

Pollution of the natural environment by heavy metals is a worldwide problem because these metals are indestructible and most of them have toxic effects on living organisms when they exceed a certain concentration. Therefore, monitoring these metals is important for safety assessment

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of the environment and human health in particular. Heavy metals cannot be biologically or chemically degraded, and thus may either accumulate locally or be transported over long distances. The presence of metals in water results from two independent factors. The first involving the weathering of soils and rocks (White et al. 2005; Bozkurtoglu et al. 2006; Yazdi and Behzad 2009; Mahjoobi et al. 2010) with its products being transported by air (Moreno et al. 2006; Duruibe et al. 2007; Giuliano et al. 2007; Zorer et al. 2009) and water (Das and Krishnaswami 2007; Elmaci et al. 2007; Kar et al. 2008), and the second involving a variety of anthropogenic activities that have potential impact on human health (contamination of groundwater aquifers, uptake by vegetation and input into the food chain).

Environmental pollution by heavy metals is very prominent in areas of mining sites and pollution reduces with increasing distance away from mining sites. Other contribution of anthropogenic metals of terrestrial origin is from industrial and urban development and other human practices (Abderahman and Abu-Rukah 2006; Buccolieri et al. 2006; Ip et al. 2007; Ong and Kamaruzzaman 2009). Through mining activities, water bodies are most emphatically polluted. The metals are transported as either dissolved species in water or as an integral part of suspended sediments. They may then be stored in bed sediments or seep into the groundwater, particularly wells and springs; and the extent of contamination will depend on the nearness of the well and spring to the mining site. As a result of these factors, metal concentration in the natural environment changes in space and time. In fact, during the last few decades, industrial and urban activities have contributed to the increase of metals contamination into semi-arid environment and have directly influenced the urban ecosystems causing toxic, mutagenic or carcinogenic effects to the

human health depending on the substances properties. The expected effect of these substances may be illustrated by risk assessment.

The environmental pollution with metals in the water springs of the Yarmouk Basin (YB), north Jordan, has not been previously assessed or investigated. Such an investigation is required if the water springs are to be understood quantitatively and qualitatively. The main objectives of the current study are: (1) to determine if sufficiently high concentrations of any metals exist in the water springs of the Yarmouk Basin of north Jordan, such that they can be considered toxic to the aquatic environment, and (2) to assess the extent and degree of metals and the origin of these metals. The metals considered of concern in the investigation are aluminum (Al), beryllium (Be), boron (B), chromium (Cr) and zinc (Zn).

Study area

The YB is located in the northwestern part of Jordan. Seventy-five percent of this basin lies in Syria. In Jordan, the basin is located between coordinates 32°20′ to 32°45′N and longitudes 35°42′ to 36°23′E, covering an area of about 1,426 km^2 (Fig. 1a).

The north Jordan area between the Zarqa and Yarmouk Rivers (Fig. 1a) is a key area on the hydrological map of the country. The adjacent mountain and height areas (Ajlun Mountains and Golan Heights), which are at 1,200 m above sea level, are the highest uplands in the region east of the Jordan Rift Valley (JRV). These areas receive high rainfall. In addition, the Yarmouk River flows at the borders of Syria and Jordan and delineates the northern boundary of the study area, whereas the Jordan River represents the western boundary (Fig. 1a). In 2006, a major dam (Al-Wehda Dam) between Jordan and Syria was constructed across this river. It is proposed that this dam will supply Jordan with about, 110 MCM/year of potable water. Water quality of the springs, which discharge into the dam, is of great importance to the eventual usefulness of the waters to be stored.

The study area is part of the semi-arid climate of the Mediterranean Sea that has a limited amount of rainfall and high temperatures. Meteorological records collected by Jordan Meteorological Department (JMD) in Irbid station (north Jordan) during the years of 1955–2009 give the mean annual rainfall and temperatures as 420 mm and 18°C, respectively. Most of the rain falls between the months of November and April, with its peak in January (JMD 2009, personal communication).

Geologically, the rock formations of the study area are of Upper Cretaceous to Tertiary age formations (Moh'd 2000). The oldest is the Wadi Es-Sir Limestone (WSL)
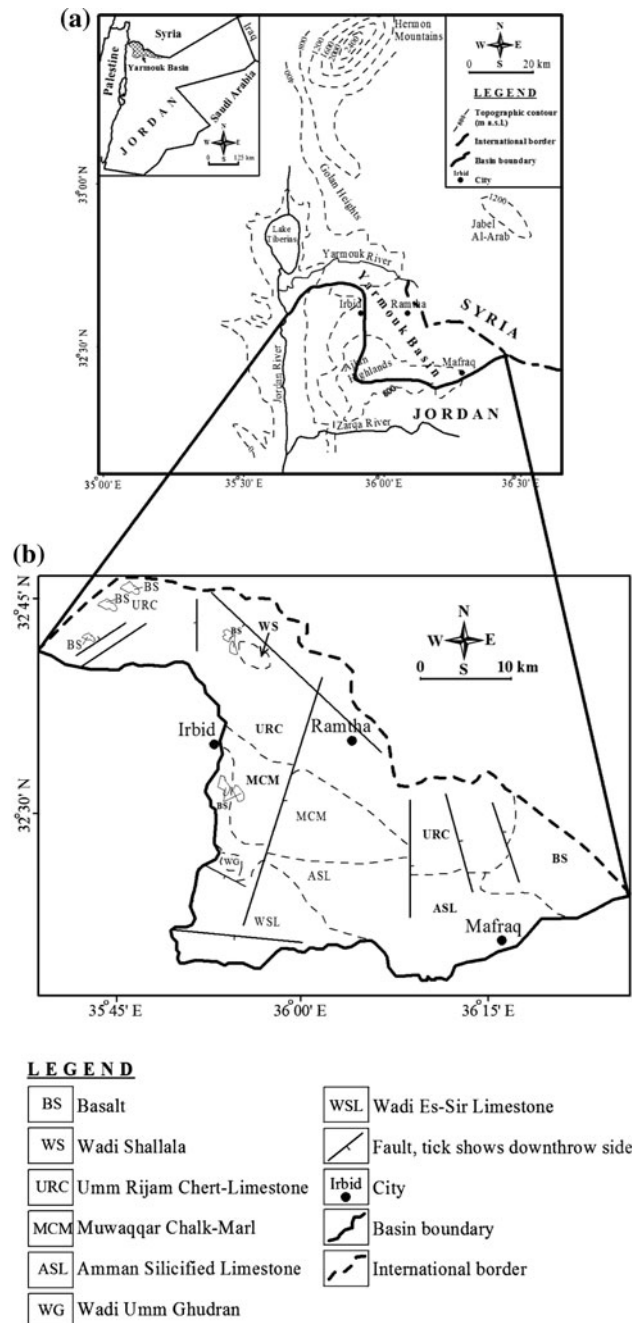

Fig. 1 a Location map of north Jordan showing principal physiographic features. **b** Spring location and generalized geologic map of the Yarmouk Basin, north Jordan

formation of Turonian age, essentially composed of limestone and dolomatic limestone. The WSL formation is exposed on the southwestern part of the basin area (Fig. 1b). The WSL formation is overlain by rocks including in ascending order: Wadi Umm Ghudran (WG), Amman Silicified Limestone (ASL), Muwaqqar Chalk-Marl (MCM), Umm Rijam Chert-Limestone (URC) and Wadi Shallala (WS) formations. The base, WG formation

of Santonian age, comprises marl, marly limestone, chalk and chert. The overlying limestone, chert, chalk and phosphorite beds that exposed in the southern part of the basin area are members of the ASL formation (Campanian age). Bituminous marl and clayey marl of the MCM formation of Maastrichtian age overlies the ASL formation and is exposed in the central part of the basin area (Moh'd 2000). Alternating beds of limestone, chalk and chert of the URC formation of Paleocene age overlies the MCM formation. In the basin area, the URC formation outcrops in the northern part (Fig. 1b). At the site of northeast Irbid; Fig. 1b, chalk and marly limestone with glauconite is present. These belong to the WS formation of Eocene age. In the eastern part of the basin area, basaltic flows (BS formation) of Oligocene age cover the area. In addition, basalts were found as small exposures scattered to the south, north and northwest of Irbid (Fig. 1b).

Sampling and analysis

Water samples were collected twice in October 2006 (dry season) and May 2007 (wet season). A total of 36 water samples were collected from major springs of the Yarmouk Basin in northern Jordan (Fig. 1b). The water samples were collected in 1 L pre-cleaned polyethylene bottles, preserved in a cool place (about 4°C) and transported to the laboratory of the Department of Chemistry, Yarmouk University, Irbid, Jordan for further analysis.

The temperature (T), hydrogen ion concentration (pH) and electrical conductivity (EC) were measured in the field using a mercury thermometer, pH-meter and portable EC-meter, respectively. Measurements and analyses were performed according to American Public Health Association (APHA) standard procedures method (APHA 1998). The evaluated metals were aluminum (Al), beryllium (Be), boron (B), chromium (Cr) and zinc (Zn). Results of chemical analysis are given in Tables 1 and 2.

For quality control, all water samples were analyzed in triplicate and mean values were calculated. Blank samples (acids blank) were also prepared every one or two batches during samples digestion. Acid blank samples were analyzed along with the samples and the average contribution of the added acids and reagents were estimated (Table 3). All results were blank corrected by subtracting the average blank concentration observed for a certain element from the concentration observed for the same element in each samples. Sample-to-blank ratio for most of the measured elements is greater than 5. This means that blank subtraction does not have significant contribution on the observed concentrations. The absorption wavelengths and detection limits of metals were as follows: 396.152 nm and 1.54 ng/mL for Al, 313.042 nm and 0.090 ng/mL for Be,

Table 1 Dry season chemical composition of major springs of the Yarmouk Basin, north Jordan

Serial no.	C (mg/L)				
Allowable concentration level (JISM 2008)	Aluminum 0.5	Beryllium 0.0002	Boron 0.5	Chromium 0.055	Zinc 5.0
1	0.052	0.0003[a]	0.176	0.003	0.010
2	0.040	0.0004[a]	0.126	0.003	0.026
3	0.016	0.0005[a]	0.111	0.002	0.004
4	0.015	0.0004[a]	0.114	0.003	0.004
5	0.016	0.0004[a]	0.110	0.004	0.005
6	0.023	0.0003[a]	0.158	0.004	0.016
7	0.022	0.0003[a]	0.192	0.006	0.015
8	0.142	0.0004[a]	0.100	0.003	0.003
9	0.025	0.0004[a]	0.102	0.002	0.015
10	0.019	0.0005[a]	0.157	0.004	0.005
11	0.022	0.0011[a]	0.201	0.005	0.059
12	0.025	0.0005[a]	0.178	0.005	0.007
13	0.365	0.0006[a]	0.092	0.005	0.017
14	0.018	0.0005[a]	0.098	0.003	0.005
15	0.015	0.0004[a]	0.102	0.003	0.002
16	0.026	0.0004[a]	0.098	0.002	0.007
17	0.253	0.0004[a]	0.106	0.004	0.007
18	0.102	0.0006[a]	0.082	0.003	0.009
19	0.035	0.0005[a]	0.108	0.003	0.006
20	0.024	0.0003[a]	0.102	0.003	0.007
21	0.032	0.0004[a]	0.086	0.001	1.354
22	0.024	0.0004[a]	0.135	0.003	0.006
23	0.022	0.0005[a]	0.085	0.002	0.005
24	0.030	0.0004[a]	0.088	0.002	0.011
25	0.010	0.0006[a]	0.105	0.002	0.007
26	0.014	0.0007[a]	0.126	0.004	0.076
27	0.071	0.0005[a]	0.085	0.002	0.008
28	0.051	0.0005[a]	0.084	0.002	0.010
29	0.107	0.0006[a]	0.086	0.002	0.014
30	0.027	0.0005[a]	0.086	0.001	0.009
31	0.207	0.0006[a]	0.090	0.002	0.015
32	0.007	0.0006[a]	0.120	0.001	0.007
33	0.019	0.0006[a]	0.135	0.002	0.006
34	0.014	0.0005[a]	0.094	0.001	0.004
35	0.027	0.0006[a]	0.094	0.002	0.006
36	0.121	0.0006[a]	0.145	0.001	0.006

[a] Element excess over allowable concentration level

249.772 nm and 3.80 ng/mL for B, 267.716 nm and 0.32 ng/mL for Cr, and 206.200 nm and 0.46 ng/mL for Zn. The accuracy and precision of the analysis resulted were checked by periodic analysis of Standard Reference Materials (SRMs) obtained from the National Institute of

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Table 2 Wet season chemical composition of major springs of the Yarmouk Basin, north Jordan

Serial no.	C (mg/L)				
	Aluminum	Beryllium	Boron	Chromium	Zinc
Allowable concentration level (JISM 2008)	0.5	0.0002	0.5	0.055	5.0
1	0.015	0.0017[a]	0.175	0.005	0.009
2	0.020	0.0006[a]	0.113	0.003	0.011
3	0.027	0.0005[a]	0.098	0.002	0.010
4	0.013	0.0005[a]	0.091	0.002	0.003
5	0.028	0.0005[a]	0.090	0.003	0.004
6	0.018	0.0005[a]	0.138	0.004	0.014
7	0.022	0.0005[a]	0.176	0.006	0.011
8	0.041	0.0005[a]	0.081	0.003	0.007
9	0.018	0.0005[a]	0.083	0.003	0.012
10	0.018	0.0005[a]	0.104	0.004	0.006
11	0.014	0.0005[a]	0.119	0.004	0.038
12	0.027	0.0005[a]	0.111	0.005	0.006
13	0.047	0.0005[a]	0.094	0.002	0.079
14	0.026	0.0005[a]	0.073	0.002	0.006
15	0.024	0.0006[a]	0.079	0.002	0.003
16	0.024	0.0005[a]	0.073	0.002	0.005
17	0.035	0.0004[a]	0.072	0.002	0.003
18	0.027	0.0005[a]	0.073	0.002	0.010
19	0.021	0.005[a]	0.118	0.007	0.006
20	0.031	0.0009[a]	0.119	0.004	0.005
21	0.012	0.0015[a]	0.103	0.003	0.275
22	0.021	0.0012[a]	0.143	0.003	0.005
23	0.019	0.0004[a]	0.087	0.002	0.005
24	0.022	0.0004[a]	0.092	0.001	0.011
25	0.032	0.0004[a]	0.117	0.002	0.004
26	0.011	0.0004[a]	0.151	0.004	0.454
27	0.123	0.0004[a]	0.080	0.002	0.007
28	0.042	0.0003[a]	0.078	0.001	0.011
29	0.037	0.0003[a]	0.082	0.001	0.010
30	0.015	0.0004[a]	0.081	0.001	0.009
31	0.021	0.0004[a]	0.086	0.001	0.006
32	0.022	0.0004[a]	0.116	0.001	0.006
33	0.009	0.0003[a]	0.131	0.001	0.003
34	0.028	0.0003[a]	0.089	0.001	0.002
35	0.013	0.0003[a]	0.082	0.001	0.005
36	0.064	0.0003[a]	0.133	0.001	0.003

[a] Element excess over allowable concentration level

Standards and Technology (NIST). Three SRMs were used: SRM-1646a (Estuarine Sediments), SRM-1633b (Trace elements in Coal Fly Ash) and SRM-2702 (Inorganics in Marine Sediments). Approximately 0.5 g of the SRM was transferred into a Teflon beaker and digested using the

same procedure followed for the samples and analyzed along with samples. The results obtained for SRM analysis were in a good agreement with the certified concentration values within 10% for all measured elements.

Results and discussion

Comparisons of elemental concentration and comparisons with literature data

Statistical analysis on the concentration of the five evaluated metals (Al, Be, B, Cr and Zn) was presented in Table 4. Average concentrations, standard deviations (SD), geometric means (GM), medians, minimum (Min) and maximum (Max) concentration of water samples analyzed are presented. Standard deviations listed in Table 4 are high for most of the measured metals. These observed variations are due to the larger variability of the locations, industrial and human activities, variations in physical and chemical nature of the sampling site, changes in the air mass transport patterns, and the variations in the source strengths.

The result of chemical analysis for the evaluated metals in this study showed variability for both sampling seasons and sampling locations (Tables 1 and 2). To assess whether the mean values of dry and wet water samples are statistically different, T test analysis was used to compare the mean concentrations of each element in both seasons (Table 4). T test is a statistical technique which can be used to compare mean values of two or more samples and estimate the different causes of variation (Keppel and Wickens 2004). Calculated T test values were found to be 0.03, 0.24, 0.10, 0.69, and 0.62 for the Al, Be, B, Cr and Zn, respectively. The computed T test values were compared with the risk level "alpha level" (0.05). Results show that significant differences between the mean values of the dry and wet water samples for the Al element were found ($P < 0.05$), while statistically insignificant differences for the other elements Be, B, Cr and Zn were observed ($P > 0.05$).

In all environmental studies, comparison of the obtained data with the literature is one of the essential steps to know the extent of contamination by these metals. The study area is classified as urban. The urban areas are the ones, which are under the direct influence of the local anthropogenic emissions. Therefore, to roughly know the extent of pollution in the area under study, the results should be compared with literature data in which the pollution level is known. Comparing the data with data obtained from resembling areas helps in finding out the unusual results, which could be due to particular analytical problem. Calculated values of the geometric means in both seasons for

Table 3 Detection limits and sample-to-blank ratios of elements

Element	Dry season			Wet season			Detection limit (ng/mL)
	C^a (ng/mL)	Blank[a] (ng/mL)	Sample-to-blank ratio	C^a (ng/mL)	Blank[a] (ng/mL)	Sample-to-blank ratio	
Al	57	3.26	17.5	27.4	3.26	8.4	1.54
Be	0.5	0.11	4.5	0.7	0.11	6.4	0.09
B	116	6.52	17.8	104	6.52	16	3.8
Cr	2.7	0.32	8.4	2.6	0.32	8.1	0.32
Zn	49.3	0.24	205.4	29.6	0.24	123.3	0.46

[a] Average values were taken

Table 4 Statistical summary of heavy metals concentrations (mg/L)

Element	Dry season						Wet season						T test
	Mean	SD	GM	Median	Min	Max	Mean	SD	GM	Median	Min	Max	
Al	0.0570	0.077	0.0336	0.0248	0.0070	0.3650	0.0274	0.0199	0.0236	0.0222	0.0093	0.1234	0.03
Be	0.0005	0.0001	0.0005	0.0005	0.0004	0.0011	0.0007	0.0007	0.0006	0.0005	0.0004	0.0046	0.24
B	0.116	0.033	0.1117	0.1038	0.0820	0.2010	0.1040	0.0280	0.1003	0.0926	0.0724	0.1760	0.10
Cr	0.0027	0.0013	0.0024	0.0026	0.0007	0.0056	0.0026	0.0015	0.0022	0.0022	0.0006	0.0069	0.69
Zn	0.0493	0.2241	0.0097	0.0073	0.0016	1.3540	0.0296	0.0862	0.0086	0.0062	0.0022	0.4540	0.62

SD standard deviation, *GM* geometric mean, *Min* minimum, *Max* maximum

Table 5 Comparison with geometric means of other studies for metal concentrations (mg/L)

Element	This study		Chihuahua (Mexico)[a]	Asa (Nigeria)[b]	Middle Russia[c]
	Dry season	Wet season			
Al	0.0336	0.0236	–	–	0.0950
Be	0.0005	0.0006	0.0350	–	0.0009
B	0.1117	0.1003	–	–	0.0600
Cr	0.0024	0.0022	0.0700	0.01	0.0490
Zn	0.0097	0.0086	–	0.42	0.0040

[a] Chihuahua, Mexico (Gutierrez et al. 2008)

[b] Asa, Nigeria (Eletta 2007)

[c] Middle Russia (Momot and Synzynys 2005)

the evaluated elements given in Table 4 are compared with those found by other researchers around the world and presented in Table 5.

Table 5 reveals that, geometric mean concentrations of aluminum (Al) element for both season water samples is about 3–4 times lower than level reported for Middle Russia. For beryllium (Be) metal, the geometric concentration for both season water samples is much lower (about 60 times) than the level reported for Chihuahua. In addition, the level of boron (B) metal in the dry and wet season water samples is about 2 times higher than level in Middle Russia (Table 5). On the other hand, the level of chromium (Cr) metal in both season water samples is about 30 times lower than those reported for Chihuahua, 5 times lower than those reported for Asa and 20 times lower than those

reported for Middle Russia (Table 5). For zinc (Zn) metal in this study, the level is about 40 times lower than level reported for Asa and about 2 times higher than those reported for Middle Russia (Table 5).

Temperature, hydrogen ion concentration and electrical conductivity

The average temperature was 18°C ± 3.5. This parameter varied with sampling location, time of collection and season of the year. The range of pH in dry season water samples was 7.01–7.87 with a mean of 7.31 and it was 6.8–8.04 with a mean 7.58 for the wet season water samples. The pH values indicate their alkaline nature of water. The pH values detected in water spring samples were found

Fig. 2 Solubility plots show the relationship between the pH and heavy metal concentrations in water considering season of the year and 36 springs
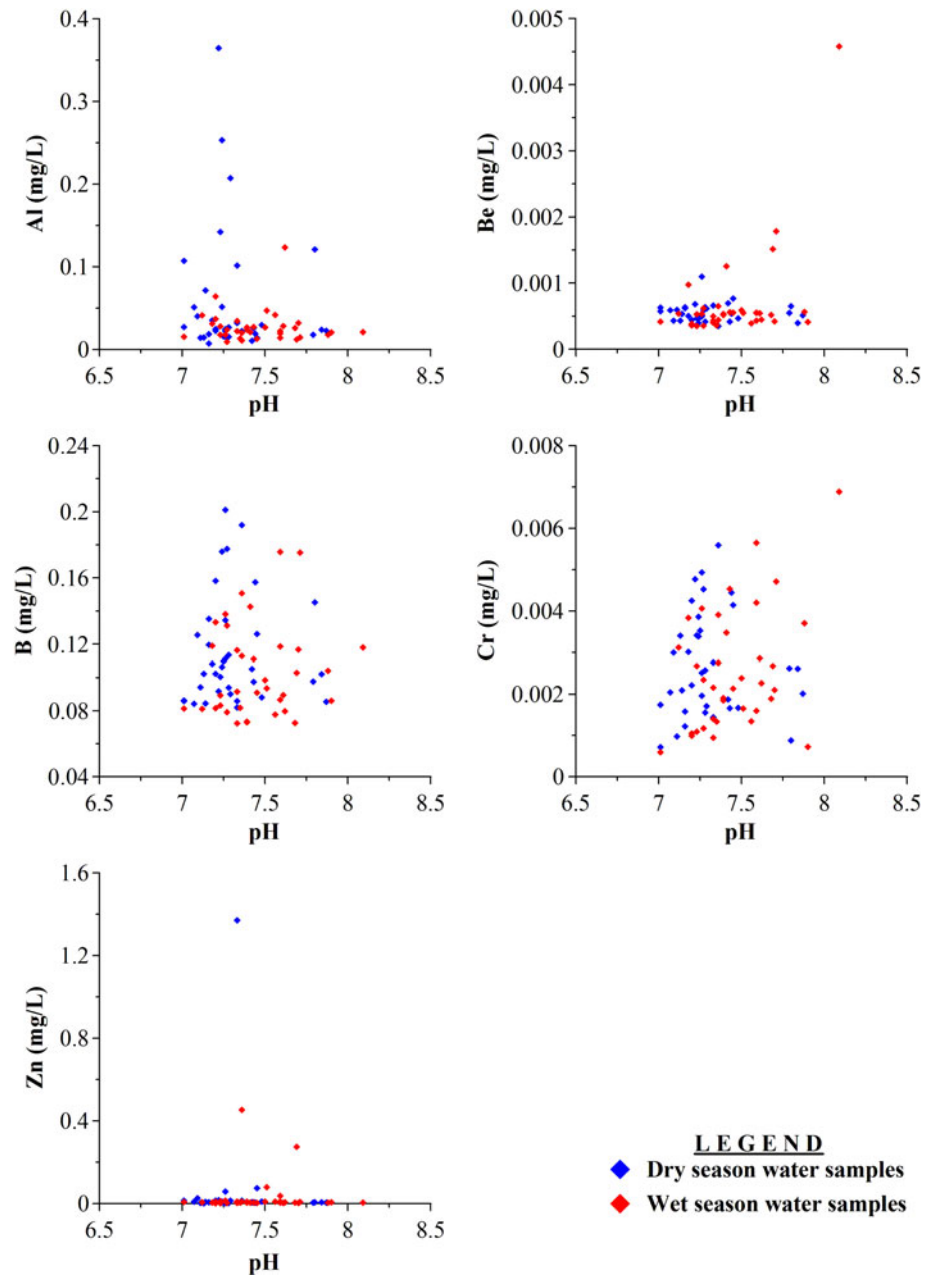
to be in the permissible range of 6.5–8.5 [Jordan Institution for Standards and Metrology (JISM 2008)]. Electrical conductivity (EC) varies from 300 to 1199 μS/cm and from 424 to 962 μS/cm with a mean of 516.1 μS/cm and 614.7 μS/cm for the dry and wet water samples, respectively. These results agree with those reported by Ta'any et al. (2007) and Batayneh et al. (2008) who quantified pH and EC values in groundwater from north Jordan.

Scatter plots (Fig. 2) are used for illustrating how the solubility of heavy metals varies with water pH and with metal concentration. The stability plots indicate a general decrease in heavy metals solubility with increasing pH, which is the usual trend with cationic metals.

Aluminum element

Aluminum is the most abundant metallic element and constitutes about 8% of the earths crust. It occurs naturally in the environment as silicates, oxides, and hydroxides, combined with other elements, such as sodium and fluoride, and as complexes with organic matter. The concentration of aluminum in natural waters can vary significantly depending on various physiochemical and mineralogical factors. Dissolved aluminum concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/L but rise to 0.5–1.0 mg/L in more acidic waters or water rich in organic matter. At the extreme acidity of

waters affected by acid mine drainage, dissolved aluminum concentrations of up to 90 mg/L have been measured (Hicks et al. 1987; Momot and Synzynys 2005).

The range of aluminum concentration in dry season water samples was 0.007–0.360 mg/L (Table 1), while for wet season water samples it was 0.009–0.120 mg/L (Table 2). The levels of aluminum in dry season water samples were significantly higher than those in wet season water samples. In both seasons water samples, aluminum levels were within the safe limit for drinking; lower than the allowable concentration level recommended by the JISM (2008) (0.5 mg/L).

Beryllium element

Beryllium has an oxidation state of $+2$. In addition to forming various types of ionic bonds, beryllium has a strong tendency for covalent bond formation. In most natural waters, the majority of beryllium will be adsorbed to suspended matter or in the sediment, rather than dissolved (Hannah et al. 1977; Gutierrez et al. 2008). Beryllium in sediment is primarily adsorbed to clay, but some beryllium may be in sediment as a result of the formation and precipitation of insoluble complexes. At neutral pH, most soluble beryllium salts dissolved in water will be hydrolyzed to insoluble beryllium hydroxide, and only trace quantities of dissolved beryllium will remain. However, at high pH, water-soluble complexes with hydroxide ions may form, increasing the solubility and mobility of beryllium. Solubility may also increase at low pH; detectable concentrations of dissolved beryllium have been found in acidified waters. At pH 7.5 only a small amount of beryllium will be in a soluble form in water, although solubility is likely to increase to a small extent at lower and higher pH (Lytle et al. 1992; Muller-Quernheim 2005). Beryllium is concentrated in silicate minerals relative to sulfides and in feldspar minerals relative to ferromagnesium minerals. The greatest known naturally occurring concentrations of beryllium are found in certain pegmatite bodies (Lytle et al. 1992). Beryllium is not likely to be found in natural water above trace levels due to the insolubility of oxides and hydroxides at the normal pH range. The passivity of beryllium has been shown to be controlled by a thin surface film of BeO or its hydrate (BeO (H_2O)x) (Gulbrandsen and Johansen 1994). In the presence of highly acidic solutions, hydrogen is evolved as the water decomposes and beryllium anodically reacts to form Be++. In strongly alkaline solutions, hydrogen evolves and soluble Be_2O_3 and BeO_2 anions form. At neutral pH, a protective layer of Be(OH)$_2$ forms on the surface of the beryllium. Gulbrandsen and Johansen (1994) have studied the passive behavior of beryllium in solutions pH (1–15) and concluded that the passive current density was minimum in solution pH 11 and increased logarithmically in more acidic and alkaline solutions. Further, there was some evidence that oxygen evolution on BeO occurred suggesting that BeO is a semiconductor.

The results of chemical analysis show significant differences for the beryllium element concentration due to sampling season and sampling location (Tables 1, 2). Beryllium is not considered an essential element for human and, in fact, is toxic and responsible for the chronic beryllium disease (Muller-Quernheim 2005) caused by beryllium exposure. In this study, the beryllium level was higher than the limits for drinking water (0.0002 mg/L) recommended by the JISM (2008). The range of beryllium concentration in dry season water samples was 0.0004–0.001 mg/L (Table 1) and it was in the range of 0.0004–0.0045 mg/L for the wet season water samples (Table 2). The maximum amount of beryllium concentration was detected in spring no. 19 with 0.0045 mg/L (Table 2).

Boron element

Boron is never found in the elemental form in nature. It exists as a mixture of the ^{10}B (19.78%) and ^{11}B (80.22) isotopes (Cotton and Wilkinson 1988). Boron's chemistry is complex and resembles that of silicon. The natural borate content of groundwater and surface water is usually small. The borate content of surface water can be significantly increased as a result of wastewater discharges, because borate compounds are ingredients of domestic washing agents. Naturally occurring boron is present in groundwater as a result of leaching from rocks and soils containing borates and borosilicates. The amount of boron in fresh water depends on the geochemical nature of the drainage area and inputs from industrial and municipal effluents (Butterwick et al. 1989).

With respect to the element boron, there were statistical differences in concentration due to sampling month and sampling location. The range of boron concentration in dry season water samples was 0.08–0.2 mg/L (Table 1) while for wet season water samples it was 0.07–0.18 mg/L (Table 2). The levels of boron element in both seasons (Tables 1, 2) were within the safe limit for drinking; lower than the allowable concentration level recommended by the JISM (2008) (0.5 mg/L).

Chromium element

Chromium is widely distributed in the earth's crust. It can exist in oxidation states of $+2$ to $+6$. Soils and rocks may contain small amounts of chromium, almost always in the trivalent state. The average concentration of chromium in rainwater is in the range 0.0002–0.001 mg/L. Most surface

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waters contain between 0.001 and 0.010 mg/L of chromium. In general, the chromium content of surface waters reflects the extent of industrial activity (Shiller and Boyle 1987).

The element chromium shows small differences for sampling month and sampling location (Tables 1, 2). The range of chromium concentration in dry season water samples was 0.0007–0.006 mg/L (Table 1) while for wet season water samples it was 0.0006–0.007 mg/L (Table 2). These results were within the safe limit for drinking; lower than the allowable concentration level recommended by the JISM (2008) (0.055 mg/L).

Zinc element

Zinc occurs in small amounts in almost all igneous rocks. The principle zinc ores are sulfides, such as sphalerite and wurzite (Nriagu 1980; Elinder 1986). The natural zinc content of soils is estimated to be 1–300 mg/kg (Nriagu 1980). In natural surface waters, the concentration of zinc is usually below 0.010 mg/L, and in groundwaters 0.010–0.040 mg/L (Nriagu 1980; Elinder 1986).

The range of zinc concentration in dry season water samples was 0.002–1.35 mg/L (Table 1) while for wet season water samples it was 0.002–0.45 mg/L (Table 2). Data from Tables 1 and 2 show that the zinc element concentrations are lower than the allowable concentration level recommended by the JISM (2008) (5.0 mg/L) for drinking water.

Risk assessment

On the basis of heavy metal levels detected in water springs (Tables 1, 2) and distance from anthropogenic activities (mining and old mine sites, industrial, urban development and other human practices), water from spring no. 19 found

to be the worst. Thus, this spring will be used for estimating the risk assessment.

According to the US Environmental Protection Agency (US EPA 2002) technique, the following considerations should be taken. Risk is calculated under the following conditions: (1) the water consumption every day during the whole human lifetime, (2) the water quality is specified for the same period, (3) the average amount of water used every day for drinking is 2 L and (4) the mean body weight is 50 kg. Thus, the dose of a chemical substance taken by a person with drinking water every day is given by:

$$\text{ADDd} = \frac{\text{DW} \times C}{\text{BW}},$$

where ADDd is the dose taken with drinking water; BW is the body weight, 50 kg; C is the substance content in water, mg/L; DW is the mean volume of water drank every day, 2 L.

Calculations of daily mean dose of the individual's uptake of contaminants with water have been performed using analyzed data on spring (No. 19). Table 6 presents the data obtained.

Risk assessment can be expressed by the following formula:

$$\text{Risk} = \text{ADDd} \times \text{UR},$$

where Risk is the risk of adverse health effect estimated as the probability of this effect under given condition; ADDd is the daily substance dose, mg/kg; UR is the risk unit specified as a factor of risk proportion depending on the available concentration (dose).

Table 6 shows the calculated health risk in cases of using springs water for both dry and wet seasons. Water contains many different components and the risk of a combined impact of contaminants can be determined from the formula:

Table 6 Calculated carcinogenic and non-carcinogenic risk of groundwater

Water source	Substance	C (mg/L)	ADDd (mg/kg)	UR$_{cancer}$ (mg/kg day)	Risk	UR$_{non-carc}$ (mg/kg day)	Risk
Dry season (spring no. 19)	Aluminum	0.035	0.0014	–	–	0.1	0.00014
	Beryllium	0.0005	0.00002	4.3	0.000086	0.002	0.00000004
	Boron	0.108	0.0043	0.6	0.00258	0.09	0.000387
	Chromium	0.003	0.0001	0.005	0.0000005	0.1	0.00001
	Zinc	0.006	0.0002	–	–	0.3	0.00006
Wet season (spring no. 19)	Aluminum	0.021	0.0008	–	–	0.1	0.00008
	Beryllium	0.005	0.0002	4.3	0.00086	0.002	0.0000004
	Boron	0.118	0.0047	0.6	0.00282	0.09	0.000423
	Chromium	0.007	0.0003	0.005	0.0000015	0.1	0.00003
	Zinc	0.006	0.0002	–	–	0.3	0.00006

$$\text{Risk}_{sum} = 1 - (1 - \text{Risk}_1) \times (1 - \text{Risk}_2)$$
$$\times \cdots \times (1 - \text{Risk}_n),$$

where, Risk_{sum} is the risk of a combined impact of contaminants; $\text{Risk}_1 \ldots \text{Risk}_n$ is the risk of impact of each isolated contaminant.

As a result, the calculation risk for dry season water samples is 2.67×10^{-4} and that for wet season is 3.68×10^{-4}. In terms of per capita (10,000 persons) it means that three persons would be in danger of oncological diseases in the dry season and four persons would be in danger of oncological diseases in the wet season. In addition, for the non-oncological diseases, the estimated values are 5.97 and 5.93×10^{-5} for the dry and wet season water samples, respectively. In terms of population of (100,000 persons) it means that six persons are of non-oncological diseases in both seasons.

Conclusion

The study generally found that the concentration of heavy metals in wet season was higher than that of dry season. The results showed that the risk of diseases in case of wet season water springs is higher as compared to dry season water springs. Uncontrolled consumption of spring water unfavorable in its composition may be dangerous for human health. According to this study, some spring water is more preferable to people, but some of risk for inhabitants of Yarmouk Basin is also not excluded.

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