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IS RAW SPRING WATER SAFE FOR DRINKING? A CASE STUDY FOR SPRING WATER QUALITY IN JORDAN

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ABSTRACT

Spring water is considered as the purest form of water on earth. Springs are spread in several regions in Jordan, which serves as sources for drinking, by localized people for many years. Although, scarcity of water is one of the major problems in Jordan, no governmental control from the associated authorities has existed on springs. So, detailed investigations for the quality of that water were conducted. Gross alpha and beta activity concentrations were determined by using the Liquid Scintillation Counter, whereas, the concentrations of 13 elements (Ag, Ba, Bi, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Ti, U, and V) were determined by using Inductively Coupled Plasma Mass Spectroscopy. The activity concentrations of gross alpha and beta were <0.045-0.769, and 0.270-3.758 Bq L^{-1}, respectively. Besides, the concentrations of Ba, Cr, Cu, Fe, Mo, Ni, Pb, Ti, U, and V in spring water samples were 24.436-57.698, 1.724-4.948, 0.867-2.353, 110.810-379.915, 0.611-1.774, 1.481-2.811, <0.012-0.035, 0.518-1.644, 0.945-3.364, and 3.307-23.016 µg L^{-1}, respectively. The results showed that all spring waters are safe for drinking except at Jerash, which may pose a threat to consumers. Due to the lack of studies about springs in Jordan, this study could be valuable for future works.

KEYWORDS:
Drinking water, Gross alpha and beta activity concentrations, heavy elements, Jordan, Spring water.

INTRODUCTION

Water is essential for humans and other living organisms. Recently, natural waters including surface water (freshwater, lakes, and rivers) and ground waters (borehole water and springs) are received many pollutants from natural processes and anthropogenic activities. Several studies determined the concentrations of elements and radioisotopes, to draw an overall picture of the status of water sources [1-4]. In Jordan, many researchers investigated the elemental composition of drinking water [3,5], groundwater [6], hot springs [7], springs [8], and rivers [9]. Besides, other studies investigated the radiological status in different drinking water sources in Jordan such as tap water [10,11], hot springs [12,13], and groundwater [14]. Recently, Jordan populations are increased, so there is a demand for more exploitation of natural resources as well as protection. The demand for high-quality drinking water is really increased, although the average domestic water consumption is less than 100 liters/capita/day, which is one of the lowest rates in the world [15]. In Jordan, stress on groundwater resources is related to two factors: 1) Water has traditionally been scarce due to climatic conditions such as low rainfall and high evaporation. 2) Excessive groundwater withdrawal has caused the severe lowering of groundwater table by more than 2m/year in some fields in the central and northern areas of Jordan [16].

Several diseases could affect people due to drinking water containing high concentrations of elements. High levels of Pb can cause decreased IQ in children, hypertension, and damaged red blood cell production. Elevated levels of U cause kidney diseases and decreased fertility, while high Ba concentrations cause intestinal and cardiovascular diseases. On the contrary, elements, like Ca in drinking water, may decrease the negative health effects of a toxic element, so it should not be eliminated [17]. The potentially toxic elements (PTE's) such as Cr and Pb can lead to both non-carcinogenic and carcinogenic effects such as mental diseases, skin lesions, liver and kidney problems, abdominal pain, and cancer [18,19]. Also, exposure to heavy metals such as Ba, Cr, Ni, and Pb can induce cardio-vascular sicknesses, kidney-related disorders, and cancer [5,20]. Additionally, the impacts of Pb exposure include various neurodevelopmental effects, impaired renal function, hypertension, reduced fertility, and adverse pregnancy outcomes and mortality [20]. Although taste and odor of drinking water are related to Cu levels in the water, many symptoms in humans result from excess levels of Cu such as gastrointestinal illness (nausea, abdominal pain, vomiting, and diarrhea) [20].

Recently, the quality of drinking water is of great interest by people in Jordan, which is one of the poor countries by water sources [21-23]. Therefore, monitoring of water sources in Jordan is highly recommended. Natural water sources may have high levels of trace, heavy elements, and radioisotopes or other pathogens. Therefore, consuming raw water directly by people from any water source is undesirable. Generally, spring water is known as the purest form of natural water on earth, since it has the perfect balance of minerals and other essential elements. The absolute faith in the natural spring water that it is the fountain of health over the years by humans produces malpractice affects negatively on their health. In fact, many people prefer to drink raw spring water because its taste is much better than other water sources such as tap water. Tap water is often subjected to contaminations through different means such as tanks and pipes. Generally, tap water contains many useful elements and minerals, but in some cases, high levels of some elements are found. As the spring water keeps on flowing and passes through many hurdles during its journey, it constantly gets agitated by every obstacle and the minimum amount of impurities can be expected in this water form. However, filtration of water from impurities is expected due to the natural purification process, as the spring water keeps seeping and passing through different rock types, which lead to a natural purification process. This technique is being used effectively by many companies making bottled mineral water. In Jordan, many water springs are found in the capital Amman and other governates. The importance of these spring waters has been linked to the fact that they have high water flow all year.

The aim of this study is to assess the quality of spring water by determining the radiological status and the elemental composition of drinking water samples from Amman and neighboring locations. Gross alpha and beta activity concentrations and most of the widely recognized elements (Ag, Ba, Bi, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Ti, U, and V) will be analyzed to evaluate the quality of spring water. In addition, selected physico-chemical parameters were analyzed (Total Dissolved Solids (TDS), Electrical Conductivity (EC), and pH). To our knowledge, few studies investigated the quality of spring water in terms of radionuclides, trace and heavy elements to decide if it is safe for drinking and other domestic uses.

MATERIALS AND METHODS

Study area. Jordan is an arid to semi-arid country, with a land area of approximately 90,000 km^2. The mean annual rainfall in Jordan ranges between 50 mm in the desert region to about 600 mm in the eastern mountains adjacent to the Jordan valley. The total annual rainfall in Amman and its areas was varied between 150 mm and 300 mm [24].

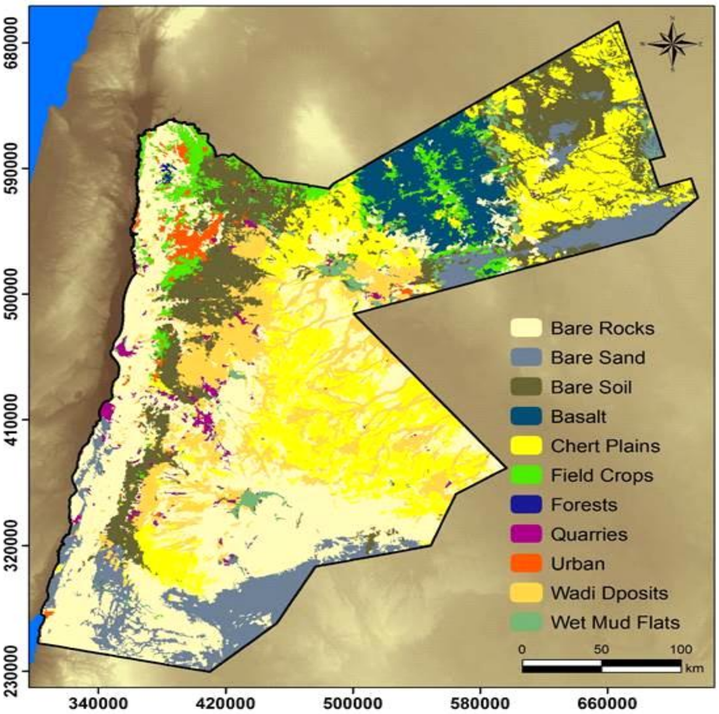

FIGURE 1
Land cover categories in Jordan classified from Landsat 8 OLI images [26].

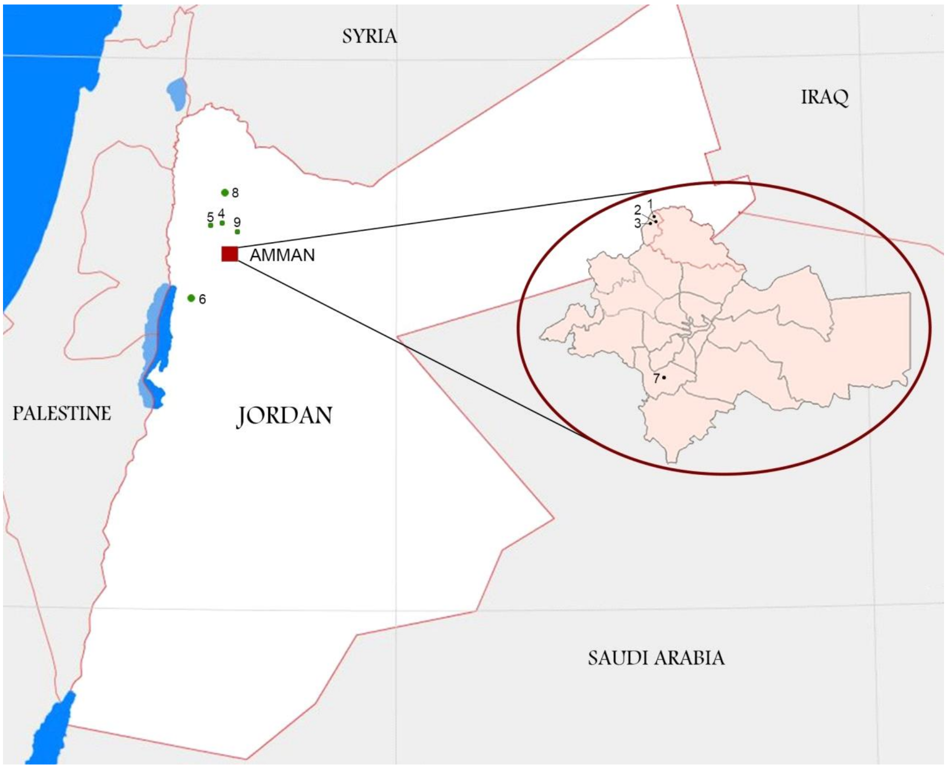

FIGURE 2
The selected locations of natural springs in Jordan
1:SN1, 2: SN2, 3: SN3, 4: SM, 5: SB, 6: SA, 7: SH, 8: SJ, and 9: SY

The main aquifers in the study area are Kurnub Sandstone aquifer (K), Nau'r aquifer (A1/2) and Hummar aquifer (A4). The Kurnub aquifer consists of massive, white and varicolored sandstones with a thickness of 300 m [25]. The Na'ur aquifer consists of limestones interbedded by thick sequences of marl and overlies the Kurnub sandstone aquifer, and the Hummar aquifer comprises a karstified dolomitic limestone, light to dark grey in color, hard, crystalline, coarse-grained and highly fractured. The geologic map of Jordan is shown in Figure 1. The geology in the area for each water spring is a sedimentary rock composed of limestone, marl, chert, marly limestone, and chalky limestone. Generally, the geological nature and rock's type govern the natural radioactivity levels.

The capital Amman and nearby cities are popular with springs. Nine different springs are chosen to represent the study area (Figure 2): Abu Nseir-Village (SN1), Abu Nseir-Housing (SN2), Abu Nseir-Al Habraj (SN3), Moubes (SM), Ein Al Basha-Abu Jalal (SB), Al Adaseya (SA), Marj Al Hamam- Al Bahath (SH), Jerash-Thaghret Asfour (SJ), Yajouz (SY).

Sample collection and preparation. A total of 24 samples of spring water were collected from nine locations as shown in Figure. 2. The spring water samples were collected at the source of the spring, using polyethylene bottles (1 L). These bottles were rinsed several times in spring water at each site during sampling and then filled with water. Physico-chemical parameters including TDS, EC, and pH were determined directly using standard procedures. A known volume of each water sample (50 mL) was evaporated until dryness and then the residue with the glass was weighed after it was weighed alone. The TDS is determined from the difference between both weights. The pH meter and conductivity meter were used easily to determine the pH and conductivity of water samples, respectively. Also, chloride and sulfate ions were determined by Ion Chromatograph (Model; Prominence LC-20A Series) from Shimadzu Corporation.

Gross alpha and beta activity concentrations. All samples were prepared for measurement according to ASTM D7283–17 method [27]. An amount of 100 mL of each water sample was evaporated to dryness under infrared (IR) lamp, the residue was transferred to a glass scintillation vial, washed with 5 mL of 1 M HNO_3, transferred to a liquid scintillation counter (LSC) vial, and evaporated under IR lamp to dryness. The residue was dissolved in 1 mL of 1M HNO_3 and then 15 mL of Ultima Gold^{TM} AB scintillation cocktail was added to the vial. After mixing and set in the dark for approximately an hour, it was cleaned with ethanol before counting; each water sample was counted for 500 min. Gross alpha and beta activity concentrations were performed using LSC from Perkin Elmer Tri-Crab 3170TR/LS analyzer which is equipped with a pulse shape analyzer. The system was calibrated using certified standard solutions of Am-214 and Sr-90. This test method has been ISO-17025 accredited since 2012 at the Jordan Atomic Energy Commission laboratories.

Elemental analysis. According to the recommended method in EPA 200.8, water samples were filtered through 0.45 µm filter at the time of collection and then acidified with HNO_3 (2%) to pH< 2, to preserve metals and to avoid precipitation [28]. Each sample was spiked with 1 µg L^{-1} of indium. The levels Ag, Ba, Bi, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Ti, U, and V were measured using the Inductively Coupled Plasma Mass Spectrometer (ICP-MS) from Perkin Elmer Sciex Company, USA/Canada. Each sample was analyzed with three replicates from which the mean concentration, standard deviation (SD), and relative standard deviation (RSD) were evaluated. It is worth mentioning that the instrument (ICP-MS) has been ISO-17025 accredited since 2012.

RESULTS

Physico-chemical analysis and anions. The mean values of TDS, EC, and pH were determined for all spring water samples (Table 1). Their ranges were 425-776 mg L^{-1}, 714-1292 µS cm^{-1}, and 7.11-8.20, respectively. Additionally, the concentrations of chloride and sulfate in springs were 48.96-115.88, and 16.99- 45.36 mg L^{-1}, respectively.

Gross alpha and beta activity concentrations. The mean values of gross alpha and beta activity concentrations in spring water samples are summarized in Table 2. Their ranges were <0.045-0.769, and 0.270-3.758 Bq L^{-1}, respectively.

Concentrations of elements. The levels of 13 elements in spring water are summarized in Table 3. The concentration ranges of Ba, Cr, Cu, Fe, Mo, Ni, Pb, Ti, U, and V were 24.436-106.626, 1.724-5.246, 0.580-2.353, 110.810-379.915, 0.611-1.906, 0.351-2.811, <0.012-0.315, 0.518-1.644, 0.945-3.364, and 3.307-23.016 µg L^{-1}, respectively. Besides, the levels of Ag, Bi, and Mn were below detection limits (BDL's) for all samples. The detection limits (DLs) for Ag and Bi were 0.040 µg L^{-1}, while it was 0.115 µg L^{-1} for Mn.

Discussion. The TDS in natural waters consists mainly of carbonates, bicarbonates, chloride, sulfate, calcium, magnesium, sodium, and potassium, while dissolved metals and dissolved organic matter represent a small percentage [20]. In this study, the TDS content in spring waters varied from

TABLE 1
Information, physico-chemical parameters, and ions in spring water samples.

Sample ID	TDS (mg L^{-1})	EC (µS cm^{-1})	pH	Cl^- (mg L^{-1})	SO_4^{-2} (mg L^{-1})
SN1	616	1026	8.17	88.96±8.90	28.50±2.85
SN2	702	1173	8.06	91.97±9.20	26.97±2.70
SN3	444	739	8.20	94.95±9.50	28.06±2.81
SM	425	714	7.11	90.00±9.00	29.40±2.94
SB	776	1292	7.59	115.88±11.59	31.83±3.18
SA	460	770	7.65	48.96±4.90	19.82±1.98
SH	580	996	7.56	85.54±8.55	71.25±7.12
SJ	578	946	8.10	55.47±5.55	52.07±5.21
SY	498	837	8.02	63.99±6.40	16.99±1.70
Max.	776	1292	8.20	115.88±11.59	71.25±7.12
Min.	425	714	7.11	48.96±4.90	16.99±1.70

TABLE 2
Gross alpha/beta activity concentrations (Bq L^{-1}) for spring water samples.

Sample ID	Gross alpha	Gross beta
SN1	0.068±0.021	0.270±0.039
SN2	0.051±0.021	0.712±0.063
SN3	< 0.045	0.639±0.060
SM	< 0.045	0.744±0.055
SB	0.080±0.023	0.543±0.047
SA	< 0.045	0.412±0.043
SH	0.048±0.011	0.390±0.030
SJ	0.769±0.022	3.758±0.068
SY	< 0.045	0.725±0.054
Max.	0.769	3.758
Min.	< 0.045	0.270

TABLE 3
Concentrations of elements (μg L^{-1}) expressed as mean value, SD and RSD in spring water samples.

Sample ID		Ba	Cr	Cu	Fe	Mo	Ni	Pb	Ti	U	V
SN1	Mean	57.698	3.523	0.867	305.886	1.774	1.847	<0.012	0.901	1.914	3.307
	SD	0.432	0.146	0.027	4.491	0.010	0.049		0.123	0.010	0.079
	RSD%	0.749	4.142	3.134	1.468	0.565	2.634		13.653	0.523	2.379
SN2	Mean	40.395	2.704	1.099	340.610	0.634	2.811	<0.012	1.257	1.628	7.719
	SD	0.225	0.040	0.004	3.428	0.007	0.085		0.132	0.017	0.107
	RSD%	0.556	1.496	0.381	1.006	1.100	3.027		10.544	1.028	1.391
SN3	Mean	56.793	4.125	1.501	356.123	1.208	2.456	<0.012	1.151	1.943	5.339
	SD	0.178	0.166	0.013	23.016	0.007	0.072		0.177	0.009	0.141
	RSD%	0.314	4.013	0.863	6.463	0.596	2.931		15.377	0.445	2.642
SM	Mean	52.382	3.661	1.108	379.915	0.973	2.613	<0.012	1.192	1.838	6.060
	SD	0.404	0.163	0.004	8.801	0.009	0.042		0.184	0.024	0.125
	RSD%	0.772	4.443	0.404	2.317	0.921	1.599		15.401	1.299	2.069
SB	Mean	53.185	4.948	1.402	352.241	1.177	2.616	<0.012	1.380	2.334	7.917
	SD	0.381	0.255	0.033	8.722	0.006	0.090		0.148	0.009	0.131
	RSD%	0.716	5.159	2.342	2.476	0.507	3.423		10.705	0.384	1.659
SA	Mean	72.368	3.987	0.580	110.81	0.911	0.351	0.315	0.954	1.351	5.349
	SD	1.297	0.175	0.025	8.53	0.004	0.057	0.006	0.197	0.011	0.166
	RSD%	1.792	2.178	4.369	7.7	0.445	2.582	1.906	20.637	0.789	3.099
SH	Mean	106.626	5.246	0.668	270.57	1.906	0.843	0.109	0.712	2.391	3.738
	SD	1.288	0.227	0.016	20.29	0.038	0.218	0.003	0.183	0.017	0.017
	RSD%	1.208	2.229	2.402	7.5	1.976	5.582	2.814	25.694	0.692	0.466
SJ	Mean	24.436	1.724	2.353	281.180	0.948	2.404	0.035	0.518	3.364	23.016
	SD	0.269	0.130	0.026	6.031	0.017	0.084	0.001	0.088	0.052	0.440
	RSD%	1.102	7.527	1.115	2.145	1.747	3.503	2.860	17.053	1.559	1.913
SY	Mean	52.359	2.302	0.891	288.718	0.611	1.481	<0.012	1.644	0.945	14.029
	SD	0.558	0.082	0.015	8.984	0.007	0.087		0.069	0.017	0.297
	RSD%	1.066	3.540	1.735	3.112	1.150	5.882		4.189	1.785	2.114
	Max.	106.626	5.246	2.353	379.915	1.906	2.811	0.315	1.644	3.364	23.016
	Min.	24.436	1.724	0.580	110.810	0.611	0.351	<0.012	0.518	0.945	3.307

RSD: Relative standard deviation.

425 up to 776 mg L^{-1}. These variations in TDS values mainly depends on the solubility of minerals in different geological areas [20]. On the contrary, pH values ranged between 7.11 and 8.20, which indicate that all investigated spring waters were alkaline. Besides, such pH values point toward the identity of having spring water with dissolved metals raised the pH in comparison with ultra-pure water (ASTM I) which has a pH value of 5.5. However, TDS and pH values for all investigated samples were lower than both Jordanian and WHO guidelines, which are 1000 mg L^{-1} and 6.5-8.5, respectively [29,30]. Electrical conductivity (EC) is a measure of the ions present in water, but it does not tell us what specific ions are present. This property is useful for determining the number of treatment chemicals that could be added to a water sample [20]. No threshold value was found for EC (Table 4). Although the permissible levels for chloride and sulfate concentrations by the Jordanian guidelines are double WHO recommended levels, all chloride and sulfate concentrations in this study were much lower than both legislations.

The results showed that gross alpha and beta activity concentrations were below the recommended values (0.5 and 1.0 Bq L^{-1}) except for SJ. Hammouri and El-Naqa found that Jerash area is subjected to contaminants due to the disposal of domestic wastewater and uses of fertilizers for agriculture [31]. So, more investigations for the soil in that area is recommended to determine the main reason/reasons for high radioactivity concentrations in Jerash. No elevated concentrations of gross alpha and beta were found in other spring waters from all sites, which revealed that there is no adverse health effect on people who use spring waters for drinking and domestic uses. However, further analysis is recommended for all spring water sources before using any of them for drinking and cooking.

The concentration values of 13 elements in spring waters were lower than the national and the international recommended limits as shown in Table 4 [29,30]. Based on the results, it is not expected that drinking spring water could cause any health problems for humans. But it is highly recommended to analyze samples from springs periodically to ascertain that they are safe for drinking and free from potentially toxic elements (PTEs). Comparisons between the present study and other studies are also summarized in Table 4. Generally, the concentrations ranges found in the present study were within the values reported by other local or international studies except for Cu, Fe, Mn, and Pb. These variations depend on the natural and/or anthropogenic activities that may affect the area of springs. But, gross alpha and beta activity concentrations from this study were higher than other reported studies for only one spring (SJ). Unfortunately, no available data is found for either elements or radioisotopes content in the selected springs.

TABLE 4
Comparisons between spring waters from the present study and other studies.

Parameter	Turkey-spring water	Turkey-spring water	Serbia-spring water	Jordan-Ma'in hot springs water	Jordan-Yarmouk Basin springs	Jordan-Shoubak basin	JISM Guidelines	WHO Guidelines	The present study
Ag ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	100	100 [a]	<0.040
Ba ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	1000	700	24.436-106.626
Bi ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	ND	ND	<0.040
Cr ($\mu g\ L^{-1}$)	---	---	<0.21-1.57	571 ± 59	NM	2.0-5.3	50	50	1.724-5.246
Cu ($\mu g\ L^{-1}$)	---	---	0.28-3.00	70 ± 23	3.2-6.0	2.5-23.5	2000	2000	0.580-2.353
Fe ($\mu g\ L^{-1}$)	---	---	NM	124 ± 30	4.3-5.4	66.0-193.0	1000	ND [b, c]	110.810-379.915
Mn ($\mu g\ L^{-1}$)	---	---	0.03-25.56	169 ± 16	0.3-6.0	3.5-20.5	400	400 [c]	<0.115
Mo ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	90	70 [d]	0.611-1.906
Ni ($\mu g\ L^{-1}$)	---	---	<0.30-3.52	58 ± 20	NM	7.5-18.5	70	70	0.351-2.811
Pb ($\mu g\ L^{-1}$)	---	---	0.21-0.91	NM	1.0-15.0	17.5-47.0	10	10	<0.012-0.315
Ti ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	ND	ND	0.518-1.644
U ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	ND	30	0.945-3.364
V ($\mu g\ L^{-1}$)	---	---	NM	NM	NM	NM	ND	ND	3.307-23.016
TDS ($mg\ L^{-1}$)	---	---	---	---	---	276.16-768	1000	1000	425-776
EC ($\mu S\ cm^{-1}$)	---	---	---	---	300-1199	432-1200	---	---	714-1292
pH	---	---	---	7.8	7.01-7.87	7.52-7.76	6.5-8.5	6.5-8.5	7.11-8.20
Cl^- ($mg\ L^{-1}$)	---	---	---	---	---	51.1-163.8	500	250	48.96-115.88
SO_4^{-2} ($mg\ L^{-1}$)	---	---	---	---	---	71.04-235.68	500	250	16.99-45.36
Gross α ($Bq\ L^{-1}$)	0.03-0.360	0.005-0.771	---	---	---	---	0.5	0.5	<0.045-0.769
Gross β ($Bq\ L^{-1}$)	0.04-1.940	0.013-0.707	---	---	---	---	1.0	1.0	0.270-3.758
Reference no.	[32]	[33]	[34]	[7]	[35]	[8]	[30]	[29]	

[a]: Available data inadequate to permit derivation of health-based guideline value [29].
[b]: No guideline value for iron in drinking-water is proposed [29].
[c]: Not of health concern [29].
[d]: Occurs in drinking-water at concentrations well below those of health concern [29].
ND: Not determined
NM: Not measured

TABLE 5
Pearson correlation coefficients among elements, SO_4^{-2}, Cl^-, TDS, EC, and pH in spring water

	Ag	Ba	Bi	Cr	Cu	Fe	Mo	Mn	Ni	Pb	Tl	U	V	TDS	EC	pH	Cl^-	SO_4^{-2}
Ag	1																	
Ba	-0.64	1																
Bi	**0.88**	-0.61	1															
Cr	-0.30	**0.78**	-0.29	1														
Cu	**0.98**	**-0.72**	**0.85**	-0.46	1													
Fe	0.34	-0.34	0.48	-0.01	0.37	1												
Mo	-0.21	0.64	-0.28	0.64	-0.23	0.02	1											
Mn	**-0.43**	**0.89**	-0.49	0.57	-0.48	-0.43	0.57	1										
Ni	0.61	**-0.71**	**0.70**	-0.28	0.64	**0.86**	-0.28	**-0.69**	1									
Pb	-0.35	0.47	-0.44	0.25	-0.43	**-0.93**	0.03	0.52	**-0.82**	1								
Tl	-0.26	-0.15	-0.08	-0.01	-0.29	0.33	-0.52	-0.44	0.24	-0.34	1							
U	**0.73**	-0.20	0.48	-0.01	**0.74**	0.19	0.36	0.11	0.31	-0.17	**-0.73**	1						
V	0.66	-0.67	0.44	**-0.76**	**0.75**	-0.02	-0.50	-0.34	0.24	-0.19	-0.16	0.44	1					
TDS	0.13	-0.15	0.01	0.12	0.16	0.24	0.12	-0.06	0.34	-0.30	0.05	0.31	0.05	1				
EC	0.09	-0.10	-0.04	0.16	0.11	0.24	0.15	-0.02	0.31	-0.29	0.06	0.29	0.01	**0.99**	1			
pH	0.25	-0.38	0.39	-0.48	0.31	-0.01	-0.06	-0.33	0.13	-0.24	-0.07	0.04	0.3	0.168	0.14	1		
Cl^-	0.07	0.07	0.18	0.55	0.01	**0.76**	0.32	-0.13	0.59	-0.60	0.34	0.09	-0.48	0.51	0.525	-0.16	1	
SO_4^{-2}	0.2	0.41	0.03	0.28	0.21	0.03	0.61	**0.70**	-0.13	0.02	**-0.71**	**0.74**	0.12	0.19	0.21	-0.15	0.04	1

Bold font means P values below 0.050.

The Pearson correlation coefficients between concentrations of elements in spring water are summarized in Table 5. The correlation matrix revealed strong positive correlations (P<0.05%) between Ag-Bi, Ag-Cu, Ba-Cr, Ba-Mn, Bi-Cu, Bi-Ni, Cu-U, Cu-V, Fe-Ni, Fe-Cl^-, Mn-SO_4^{-2}, and U-SO_4^{-2}. Also, a strong positive correlation was found between TDS and EC as expected. Positive correlation coefficients result when each pair of elements increase together, indicating a similarity in their natural or artificial sources. Conversely, strong negative correlations (P<0.05%) were found between Ba-Cu, Ba-Ni, Cr-V, Fe-Pb, Mn-Ni, Ni-Pb, Tl-U, and Tl-SO_4^{-2}. It can be seen that Ag, Bi, and Mn were reported with values less than the detection limits. Hence, a positive trend of elements in comparison with Ag, Bi, and Mn would show a positive correlation and vice versa. Therefore, the redox cycling and dissolution or precipitation processes might affect the behavior of elements. Also, the variation in element concentrations among the spring waters is strongly related to the proportion of terrestrial recharge contributing to spring water sources. Furthermore, adsorption onto sediments in the route of spring water could highly impact the elements' concentrations. Moreover, it is worth mentioning that the seasonal hydrologic events would dilute the spring water sourced metals and flush metals from sediments alongside the spring water passages.

CONCLUSIONS

Clean water is essential for a healthy human life. Since natural water sources including groundwater are subjected to pollution, risk assessment and monitoring are highly required to prevent many diseases such as cancer. Gross alpha and beta activity concentrations, as well as concentrations of heavy elements, were determined in the present study. The results revealed that all investigated spring waters are radiologically safe for drinking and domestic uses except SJ at Jerash, due to high gross alpha and beta concentrations. Besides, all elements in spring waters were below the recommended limits by national and international legislations. Generally, people are not advised to drink water directly from springs without analyzing that water at laboratories. However, the quality of spring waters is generally very good. Extra analyses are recommended for other elements to ensure that spring waters are free from any kind of toxins, impurities, and pathogens. It is also to study the microbiological status in the future. Also, studying other springs in Jordan should be conducted especially since they are out of governmental control by the water authority.

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