

Monitoring and Assessing of Spring Water Quality in Southwestern Basin of Jordan

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Abstract

This study was undertaken to assess the physical, chemical and hydrochemical quality of spring water in the southwestern basin of Jordan during a 60-month follow up monitoring study (April 2009 to April 2014). The samples were analyzed for temperature, conductivity, dissolved oxygen, pH, major cations, major anions and trace metals. The results show that there were considerable variations among the analyzed samples with respect to their physical and chemical parameters, which lie below the maximum permissible levels of the Jordanian and World Health Organization (WHO) drinking water standards. This study shows that the trace metals of spring water in the study area do not generally pose any health or environmental issues. The assessment of water samples indicates that groundwater, in general, is chemically suitable for drinking and agricultural uses.

Keywords

Water Quality, Springs, Hydrochemistry, Metals, Jordan

1. Introduction

1.1. The Study Area: An Overview

Water demand for industrial, domestic and agricultural uses increases with population growth. When the demand exceeds the naturally renewable supply, water shortage occurs in the area. However, excessive groundwater withdrawals lead to water shortage, and to decline in the water quality due to saltwater intrusion [1]. Groundwater sustainability may refer to the development and use of the resource in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences [2]. Surface

and groundwater represent an important source for drinking and irrigation purposes and the quality is currently threatened by the combination of over-abstraction and physical, chemical and microbiological contamination [3] [4].

The scarcities of freshwater in Jordan and the continuous increase in demand and hence supply play a major role in the development of water quality in Jordan. The groundwater resources in Jordan consist of both renewable and fossil waters which extend in aquifers at different depths throughout the country [5]. Groundwater in Jordan represents the major source of drinking water and therefore, leaching of agricultural and industrial pollutants is a growing concern, hence groundwater quality monitoring is an essential step in characterizing groundwater systems [6].

The pollution and scarcity of water resources are the most important challenges facing the country, while pollution of water is attributed to high population growth (the average population growth is around 3.5% per year), agricultural activities, industrialization and arid to semiarid climate [7]. These Factors resulted in infiltration of wastewater into spring and groundwater resources. In towns and villages of Jordan, wastewater from septic tanks and cesspools infiltrating into the groundwater accelerates the pollution problems. This increases the pressure on the water resources by increasing the salinity, nitrate, sulfate, ammonia, phosphate and organic materials contents.

The study area is considered as a very arid to semiarid area (Figure 1). The area is marked by sharp seasonal variation in both temperature and precipitation. The area extends 10 km east the Dead Sea from Karak to Wadi Musa including Wadi Araba with an annual rainfall of about 60 mm/year in Ghore Safi area to 350 mm/year in Petra area [8].

This area is selected because it extends along the southwestern basin which is an important water basin in Jordan. The area is influenced by industrial activities, such as potash and cement industries, in addition to agricultural and vehicles activities.

Spring water within the study area is one of the major sources for drinking water and irrigation activities. The average discharge in the springs ranges from 0.2 m³/h in Jghaileyeh spring to 147.7 m³/h in El-Ghweir spring (Table 1). The surface water is composed of ephemeral wadis that drain their water during winter. Approximately 89% of the total amount of the rainfall water precipitation over the area evaporates into the atmosphere [10]. The rest flows into wadis as flood flow and partly recharges the groundwater aquifers.

The study area is subdivided into several sub-drainage areas. Some of these drainage areas are perennial and the others are intermittent depending on the intensity and duration of the rainfall as well as the topography and geology of the area. In time of extensive rainfall, runoff concentrates in the wadis and flow out of the recent sediments (alluvial fans). Part of the runoff reaches to Wadi Araba and the rest infiltrates into the wadis sediments and feeds the groundwater [10] [12]. The groundwater resources in the investigated area consist of 15

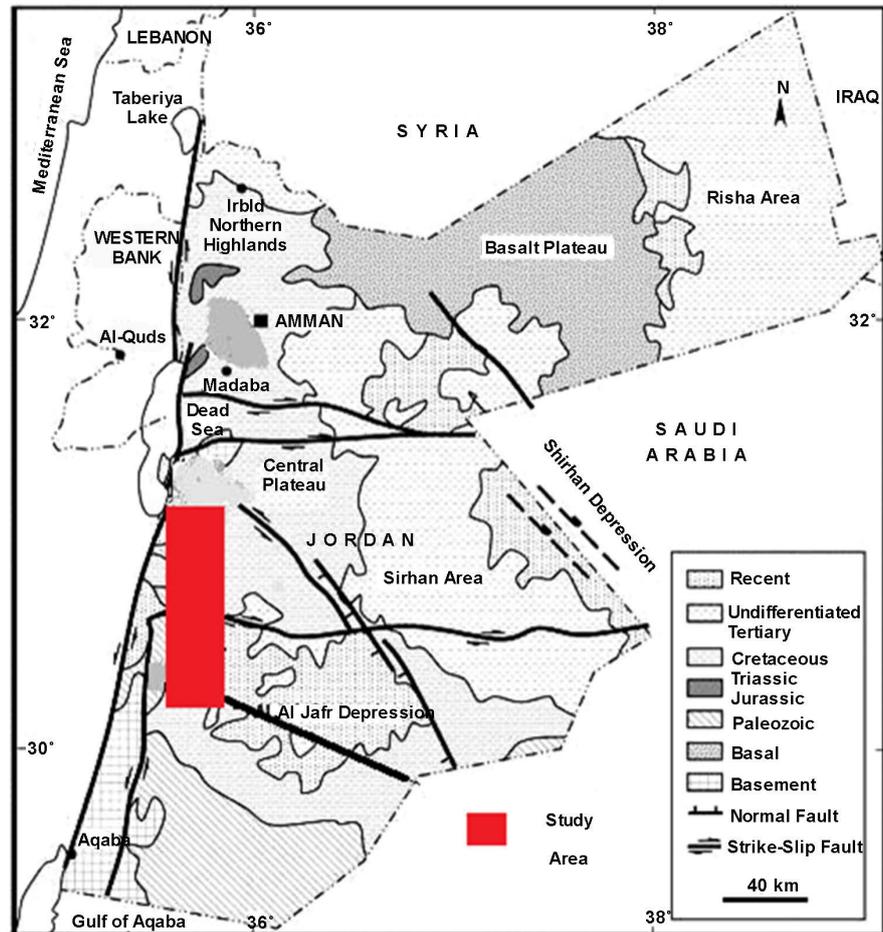


Figure 1. Geological setting map of Jordan [9]. The study area is highlighted.

springs emerging from Upper Cretaceous aquifers. The goals of the present research is to study the chemical, physical and biological characteristics of spring water and to determine the deterioration in water quality, identify sources of pollutants and characterize the suitability of the springs water for drinking and agricultural purposes. One of the objectives for this work is to characterize the present status of water resources and to determine if the resources are changing over time. This work is part of a long-term program designed to establish the inventories of groundwater quality in the study area.

1.2. Geology of the Study Area

The geology of the investigated area is built of a series of rock units ranging in age from Cambrian to recent with missing of carboniferous to Jurassic [5] [13]. The Kurnub group composed primarily of sandstones cropping out along the rift side at Tafila, Karak and Shoubak [14]. The group is more or less consistent in lithology throughout Jordan, although it becomes slightly more terrestrial southward and eastwards of the study area [13] [15]. The groundwater in the study area is derived entirely from precipitation that falls over its entire catchment area [5] [10]. This is considered as the main water resource, which can be

Table 1. Major springs with their average discharge at Northern Wadi Araba basin [11].

No.	Code	Spring name	Coordinate/PG		Altitude (m)	Discharge m^3h^{-1}	Aquifer type
			North	East			
1S	DG 0556	Shalha	1027.900	207.500	900	6.8	A1-A2
2S	DB 0562	Unsur	1027.700	207.700	1000	6.7	A1-A2
3S	DB 0556	Um-Garyah	1027.900	208.500	995	2.6	A7-B2
4S	DB 0610	Karma	1032.000	210.000	870	3.1	A7-B2
5S	DC 0564	Reah	1015.300	210.100	870	1.6	A7-B2
6S	DB 0614	Marwan	1035.200	213.700	850	2.3	A7-B2
7S	DB 0548	El-Hasdeh	1028.800	204.100	1020	2.2	K
8S	DB 0546	El-Balad	1028.000	204.100	1000	2.4	K
9S	DB 0582	Um Ruweim	1026.100	205.800	1005	3.3	A1-A2
10S	DC 0602	El-Mour	1025.100	204.200	1200	1.1	A7-B2
11S	DB 0572	Um-Keis	1028.300	206.500	1280	13.8	A1-A2
12S	DC 0566	El-Ubour	1016.400	208.500	930	8.0	K
13S	DC 0562	Gharandel	1014.100	212.700	1340	32.8	A1-A2
14S	DC 0542	El-Rahadiya	1012.900	210.700	1440	3.2	A1-A2
15S	DC 0540	Lahdha	1012.300	207.000	1414	1.3	A1-A2
16S	AE 22	Al-Ghweir	200.950	2.750	660	147.7	K
17S	EA 23	Al-Dathneh	201.000	2.770	680	40.4	K
18S	DE 0584	Zubeidiya	208.300	10.500	1210	2.7	A1-A2
19S	DE 0586	Khalid	209.300	10.500	1140	4	A7-B2
20S	DE 0550	Ifjeij (Fouqa)	208.000	993.700	1240	3.8	B4
21S	DE 0552	Ifjeij (Tehta)	208.200	994.000	1180	2.4	B4
22S	DE 0554	Liwainat	203.500	996.800	1220	0.9	B3
23S	DF 0546	Jenania	197.000	988.200	1330	3.2	A1-A6
24S	DF 0548	Hawalah	198.000	988.200	1340	4.2	A7-B2
25S	DE 0548	Essider	204.200	996.300	1125	11.4	B3
26S	DE 0546	Mugarayyeh	203.700	995.600	1250	6.7	A7-B2
27S	DE 0544	Aqeel	205.300	993.700	1145	10.7	B3
28S	DF 0540	Shammakh	198.800	989.000	1320	4.2	A7-B2
29S	DE 0558	El-A'Asi	203.800	993.600	1300	4.2	A7-B2
30S	DE 0556	Jghaileyeyeh	202.800	996.900	1300	0.2	A7-B2
31S	DG 20	Musa	197.700	970.600	1310	25.8	A7-B2
32S	DG 21	Boi'Bo	197.500	970.800	1275	4.8	A7-B2
33S	DG 22	Jilwack	197.600	971.300	1275	7.1	A7-B2
34S	DG 23	Ras Jilwack	197.800	971.500	1350	2.5	A7-B2
35S	DG 24	Sakeeneh	197.700	971.300	1320	4.3	A7-B2
36S	DG 26	Shallaleh	197.300	970.900	1250	2.6	A7-B2
37S	DG 27	Es-Sarab	196.300	970.200	1185	0.9	A7-B2
38S	DG 30	Zarraba	195.700	970.800	1085	3.4	A1-A6
39S	DG 56	Ammun	194.200	968.200	1300	1.6	A1-A6
40S	DH 36	Saboor	194.200	964.100	1540	0.5	A1-A6

developed in the area. The groundwater flow direction within the study area is from the east and west toward the central part of Wadi Araba. It is governed by the two base levels of the Dead Sea in the north and the Red Sea in the south [16]. The lithological units are composed of the 40 - 480 m thick sedimentary rocks including Cretaceous and Tertiary formations [5] [13]. Those formations are composed of limestone, marl, chert, marly limestone and chalky limestone with chert intercalation [9].

Structurally, the area is intensively faulted and folded as a result of various tectonic activities. The basin is affected by many major faults and complicated fault zones. These faults trend E-W, WNW-ESE, N-S, NNE and NE-SW directions. Most of the folds in the basin are found in the Upper Cretaceous and Tertiary carbonate rocks. These folds were affected by compression forces, which produced folding deformation [16].

1.3. Hydrogeology of the Study Area

Groundwater is considered as the main water resources in the study area, discharged mainly from precipitation to the entire catchment area. The groundwater is the most common developed source among the various water resources in the country because it is reliable in yield and of good quality. The main aquifer system in the investigated area is of Cretaceous [5] [10] and consists of the following subsystems:

1) Lower aquifer systems: this system is composed of sandstone and party limestone of lower Cretaceous age together with older sandstones of Silurian and Ordovician. It consists of massive, white and varicolored sandstone reaching in total thickness about 300 m [5] [9] [15]. Aquifer systems are found along the rift side within the investigated area. The sequences are jointed and well cemented to friable and highly permeable; therefore possess good aquifer properties (**Table 2**).

2) Middle aquifer systems: This system is composed of Upper Cretaceous rock unit that comprises Amman, Wadi Al-Sir and Hummar hydraulic complex [16]. This aquifer system is part of the main aquifers (A1/A2, A3, A4, A5/A6, A7/B2, B2 and B4). Table 2 shows the geological and hydrogeological classification of these units into aquifer and aquiclude [15] [17]. The A1/A2 is composed of marl, limestone, dolomitic limestone and grey mudstone containing plant remains and gypsum lamina and marl stone forming a fair aquifer [9] [18].

The A3 is composed of marl inter-bedded with limestone and mudstone with beds of laminated fibrous and locally nodular gypsum and is considered as a poor aquifers. Whereas, the A4 consists of crystalline dolomitic limestone and grey limestone. The later is rich in micrite and chert nodules. This formation is considered as highly permeable, when fractured and jointed, forming a good aquifer [5] [15] [19]. The A5/A6 consists of marly limestone and marl with few bands of dolomitic limestone, dolomite, and limestone forming a good aquifer because of high jointing nature. The A7/B2 formation is considered to be one of the most important groundwater reservoirs in the investigated area. It is

Table 2. Hydrogeological classification of rock types in the study area [17].

Period	Group	Formation	Symbol	General Lithology	Hydrogeological Classification
Quaternary		Alluvial deposits	JA	Sand, gravel, clay, lacustrine sediments, marl	Aquifer-aquiclude
		Basalts	BS	Basalt, tuff, clay	Aquifer
		Sirhan	S1 S2	Sandy marl, sandstone, clay, marl	Aquifer-aquitard
Tertiary		Basalts	B4-B1	Basalt, tuff, clay	Aquifer
		W. Shallaha	B5	Marl, clay, limestone, chert	Aquitard
		Balqa Rijam B4		Chalky limestone with chert	Aquifer
		Muwaqqa	B3	Bituminous marl, chalky chert, shale	Aquitard
		Amman	B2	Marly limestone, phosphates, chert	Aquifer
		Umm Ghudran	B1	Marl, shale	Aquitard
	Late Cretaceous		Wadi Es Sir	A7	Marly limestone
		Shueib	A5-A6	Argillaceous dolomite and limestone.	
		Ajlun Hummar	A4	Limestone, dolomite limestone.	Aquitard
		Fuheis	A3	Shale, sandstone	
		Na'ur	A1-2	Dolomitized carbonate.	
Early Cretaceous		Kurunb	K	Sandstone	Aquifer
Jurassic		Huni		Sandy silt sand, shale	Aquiclude-aquifer
Triassic		Ma'in		Siltstone, mudstone	Aquiclude
Cambrian-Silurian				Sandstone, dolomite limestone	Aquifer

composed of limestone, marly limestone with chert bands, chalk, and dolomite limestone.

2. Materials and Methods

Water samples were collected monthly using polyethylene bottles from 40 springs covering the area over the period from April 2009 to April 2014. Samples numbers and samples names are shown in **Table 1**. A total of 1800 samples were collected during a five years monitoring program. The water samples were analyzed for their physical and chemical parameters according to the methods that suggested by Rand *et al.* [20] and Al-Khashman [21]. Monthly samples were collected to monitor changes in the water quality caused by the seasonal hydrological cycle.

All glassware and polyethylene bottles were soaked in 20% HNO₃ for one day

and rinsed several times with deionized water before use. During sampling, polyethylene sample bottles were rinsed in clear spring water several times and then filled to the top to minimize entrapment of air in water spring samples [22]. On the other hand, the samples for metals determination were preserved with nitric acid. On-site measurements included temperature, pH, and electrical conductivity (EC) and dissolved oxygen (DO). Conductivity measurements were carried out with 470 JENWAY conductivity meter with temperature compensation, while the pH values were measured in the field using 370 JENWAY pH-meters. Calibration was always carried out before measurement using standards buffer solutions of pH 4.00 and 7.00 respectively. Dissolved oxygen values were measured in the field using DO-meter (WTW equipment). The total dissolved solids (TDS) were measured by TDS meter (Oakton Control Co, USA). Major anions (F^- , Cl^- , NO_3^- , PO_4^{3-} , SO_4^{2-}) were analyzed by 100 Dionex Ion Chromatography instruments equipped with AG4A-SC guard column, AS4ASC separating column, SSR1 anion self-generation suppresser and conductivity detector. Major cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+) were measured by 800 Varian Flame Atomic Absorption Spectrophotometer. The concentrations of cations were determined using a CS12 analytical column, CG 12 guard column, using 20 μ $CH_4SO_3^-$. The concentration of bicarbonate was measured by titration with 0.01 hydrochloric acid using methyl orange as indicator. Trace metals (Fe^{2+} , Al^{3+} , Mn^{2+} , Cu^{2+} , Ni^{2+} , Zn^{2+} , Pb^{2+}) were analyzed with Graphite Furnace using GTA 100 instruments. The GF-AAS was calibrated using the method of the standard addition. The standard solutions of the anions, cations, and trace metals as well as blank samples were prepared with different concentrations. All standard solution were made daily by diluting the stock solutions with 0.01 M HNO_3 [23], which was prepared from analytical grade HNO_3 solution that obtained from Merck. A quality control procedure, including, recalibration of the instruments, analysis of triplicate samples and recovery test of standard reference material was used to control data quality [20]. All chemicals and reagent used were of the analytical grade unless otherwise stated. Deionized water (Milli-Q 18.2 μ s/cm) was used for all dilutions.

To prevent the sample contamination with trace metals, all the glassware, pyrex and plastic containers were washed several times with soap, deionized water and treated with 0.01 M HNO_3 and finally rinsed with ultra-pure water. After analysis the accuracy of these standards were within $\pm 7\%$. The numerical simulation model PHREEQ was used to set up the hydrological components of the groundwater, especially the saturation indices of minerals (calcite, dolomite, gypsum and anhydrate) to test the saturation of minerals in water samples.

3. Results and Discussion

3.1. Chemical Characteristics of Water

A Total of 1800 water samples were collected from forty representative springs in southwestern part of Jordan during the studying period, April 2009 to April 2014. The statistical summaries of volume-weighted mean concentrations of

physical and chemical parameters are presented in **Table 3**. The ratio of total anions to that of cations ($(\Sigma\text{anions})/(\Sigma\text{cations})$) was used as an indicator for the completeness of measured parameters [24]. The average equivalent sum of cations to that of anions $(\Sigma\text{anions})/(\Sigma\text{cations})$ was found to be 0.83 ± 0.21 . Also, for the set of samples considered in this study, linear regression of cation sum on anion sum resulted in a variance R^2 of 0.89, indicating that the quality of the data was satisfactory. The in-situ measured temperature for the water samples ranges between $16.31^\circ\text{C} \pm 1.73^\circ\text{C}$ in Sakeeneh spring in the wet season to $24.30^\circ\text{C} \pm 3.28^\circ\text{C}$ in Jghaileyyeh spring in the dry season, with a median value of $19.57^\circ\text{C} \pm 1.94^\circ\text{C}$. The variation in the recorded temperature for all springs in the study area was mainly a result of varying elevation above sea level from which the springs emerged [10].

The pH values in all sampling sites were in the range of 6.69 in El-Rahadiya spring to 8.23 in Jilwack spring, with a median value of 7.73 ± 0.35 . The variations in the measured pH values of different springs were mainly caused by increases in the bicarbonate concentration in the water. The median values of pH in spring water samples were found to comply with the Jordanian standards for drinking water [25] and WHO [26] [27] drinking water standards (**Table 4**).

Electrical conductivity (EC) of spring water ranges from 510 $\mu\text{s}/\text{cm}$ in Hawalah spring to 1215 $\mu\text{s}/\text{cm}$ in Sakeeneh spring with a median value of 761 ± 177.2 $\mu\text{s}/\text{cm}$ at 25°C . The high conductivity of the water samples in Tafila basin was corresponding to the high concentrations of dominant ions, which result from ion exchange and solubility of rocks in aquifer [23] [28]. Dissolved Oxygen (DO) varied in the range from 3.25 mg/l to 6.70 mg/l.

Total Dissolved Solid (TDS) values in the spring water varied from 323 mg/l in Hawalah spring to 728 mg/l in Sakeeneh spring (**Figure 2**). In general, all TDS values of the spring water fall within the permissible limit of Jordanian standards for drinking water [25]. The results showed that there is an increasing tendency in the TDS values in the dry seasons compared to the wet seasons except for April as TDS is higher than that of June.

The calcium concentration varied from 50 mg/l in Hawalah spring to 140 mg/l in Al-Ghweir spring in the wet season, with a median value of 81.27 ± 21.0 mg/l. The high values of calcium in the dry season in Al-Ghweir spring are due to the dissociation of calcium from the sedimentary carbonate rocks and soils. The concentration of sodium in the water samples ranges from 17 mg/l in Um-Keis spring to 44.65 mg/l in El-Hasdeh spring, with a median value of 26.53 ± 7.31 mg/l (**Table 3**). The high concentration of sodium in water samples in the summer season resulted from wastewater infiltration and uses of fertilizers in agricultural activities around the water springs. The decrease in sodium concentrations from dry to wet seasons reflects the dilution of groundwater by rainwater. Sodium ion makes a relatively medium contribution compared to calcium and magnesium.

Anions such as chloride, sulfate and nitrate were the major inorganic components deteriorating the drinking-water quality of the groundwater. The spring

Table 3. Statistical analysis of physical, chemical and biological parameters of spring water samples, n = 1440 samples.

Parameters	Units	Minimum	Maximum	Mean	St.Dev
T	(°C)	16.31	24.30	19.57	1.93
pH	-	6.69	8.23	7.73	0.35
EC	µS/cm	510.00	1215.00	761.00	177.00
DO	mg/l	3.25	6.70	4.63	0.79
TDS	mg/l	323.28	728.47	482.00	110.00
TH	mg/l	199.00	475.00	306.00	63.61
Ca ²⁺	mg/l	50.00	140.00	81.27	21.00
Mg ²⁺	mg/l	16.00	36.00	25.23	5.05
Na ⁺	mg/l	17.00	44.65	26.53	7.31
K ⁺	mg/l	1.20	13.50	5.03	2.78
HCO ₃ ⁻	mg/l	120.00	301.00	187.66	49.48
Cl ⁻	mg/l	52.00	158.00	87.63	23.60
NO ₃ ⁻	mg/l	27.00	130.00	79.05	24.55
SO ₄ ²⁻	mg/l	42.00	163.50	85.38	26.82
F ⁻	mg/l	0.66	4.32	1.88	0.94
PO ₄ ³⁻	mg/l	0.63	6.35	3.16	1.58
SAR	-	0.43	1.85	1.63	0.17
% Na		9.86	27.65	18.76	4.72
RSC	meq/l	-5.89	-1.55	-2.89	1.07
PI	%	20.43	33.51	28.83	3.29
SI calcite	-	0.13	0.43	0.26	0.09
SI dolomite	-	1.05	1.37	1.24	0.10
SI gypsum	-	-3.42	-1.44	-2.23	0.43
SI anhydrate	-	-2.95	-2.65	-2.80	0.11

water samples from three sites in the southwestern basin have shown nitrate contents greater than the Jordanian standards [25] which set a maximum permissible nitrate content of 70 mg/l as NO₃⁻ (Figure 3). Especially, samples in the Shalha, Karma, Marwan and El-Hasdeh springs were highly contaminated with NO₃⁻ (above 100 mg/l). Nitrate likely comes from pollution sources such as atmospheric fallout, sanitation facilities, domestic effluents and excess use of fertilization [29] [30]. The increasing number of scattered residences and the high population growth increase the pollution potential of water resources in the study area. The springs were directly influenced by pollution sources through the fissures and fractures associated with the carbonate aquifers. The sulfate, nitrate and chloride contents of the springs have increased sharply during the study period, indicating that pollution, if continued, of springs in the study area in the future would prevent the intended domestic use of these water resources.

Table 4. Jordanian Standards and WHO guidelines for drinking water quality.

Parameters	Units	Jordanian standards [25]	WHO standards [27]
T	(°C)	12 - 25	12 - 25
pH	-	6.50 - 9.0	6.5 - 8.5
EC	µs/cm	-	400
Na ⁺	mg/l	200 - 400	200
Ca ²⁺	mg/l	75 - 200	100
Mg ²⁺	mg/l	50 - 150	50
K ⁺	mg/l	10 - 50	20
HCO ₃ ⁻	mg/l	100 - 500	125 - 350
Cl ⁻	mg/l	200 - 500	250
SO ₄ ²⁻	mg/l	200 - 500	250
NO ₃ ⁻	mg/l	70	50
TDS	mg/l	500 - 1500	500 - 1000
TH	mg/l	500	500
Fe ²⁺	mg/l	0.3 - 1.0	0.3
Mn ²⁺	mg/l	0.1 - 0.2	0.1 - 0.5
Zn ²⁺	mg/l	5 - 15	0.01 - 3
Al ³⁺	mg/l	0.2 - 0.3	0.2
Pb ²⁺	mg/l	0.05	0.01
Cu ²⁺	mg/l	-	2
Cd ²⁺	mg/l	-	0.003

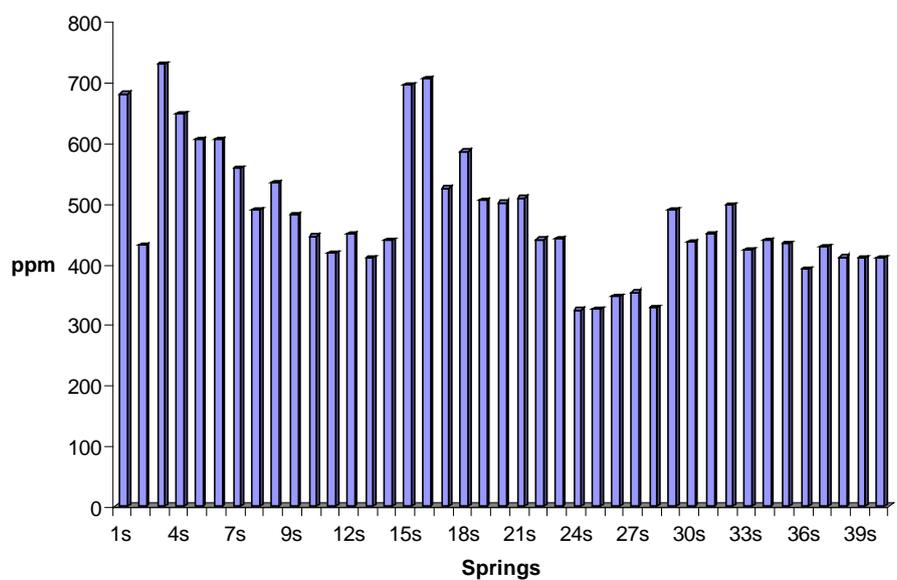


Figure 2. Mean value of TDS levels in spring water samples.

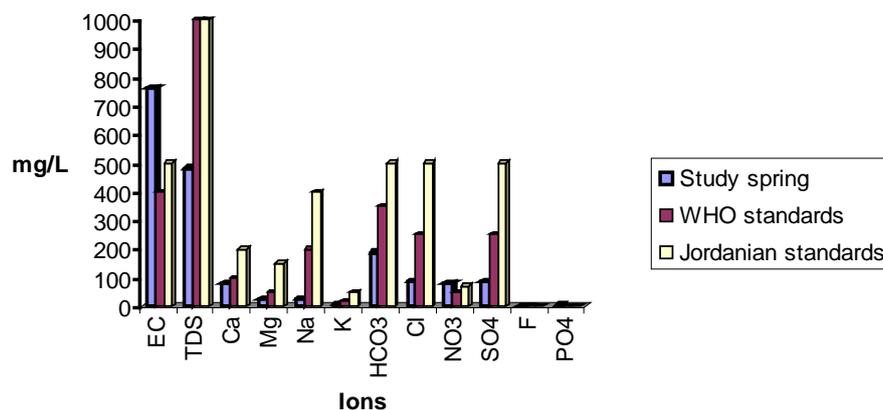


Figure 3. Mean value of ionic compared with Jordanian standard and WHO.

Springs that are located next to the residential areas have been more affected by these points source pollution than other springs. These springs are directly recharged with water. High concentrations of nitrate in the water samples were found in springs located also far away from the cesspools, which indicate that pollution is mainly caused by fertilizers and manure and plant decomposition (**Figure 3**). Sulfate concentration in the spring's water varied between 42 mg/l in Mugarayyeh spring and 163.5 mg/l in Um-Keis spring, with a median value of 85.38 ± 26.3 mg/l. The high concentration of sulfate in these springs is mainly attributed by anthropogenic activities around the springs.

Chloride concentrations varied from 52 mg/l in Shammakh spring to 158 mg/l in Sakeeneh spring (**Figure 4**). However, high value of chloride in the water samples likely originated from pollution sources such as; domestic effluents, fertilizers, septic tanks and natural sources dissolution of fluid inclusions and Cl⁻ bearing minerals [21] [29] [30].

In the collected spring-water samples, the highest concentration of bicarbonate was found in Shalha, Um-Garyah, Um-Keis and El-Balad springs. The bicarbonate concentration ranges from 120 mg/l in Es-Sarab spring to 301 mg/l in Um-Garyah spring. It seems to be that the increasing pH values in the spring season was mainly attributed to the increasing of bicarbonate value in spring water samples. The increasing tendency of salinity from summer season (dry season) to the winter and summer season (wet season) was also clearly seen for Na⁺, K⁺, Cl⁻, NO₃⁻ and PO₄³⁻. It's related to the concentration of these elements in water springs.

Correlation coefficient is commonly used to measure the relationship between two variables. The statistical analysis showed that Ca²⁺ has a positive and good correlation with Mg²⁺, Cl⁻ and SO₄²⁻ ($R^2 = 0.814, 0.662,$ and 0.721 respectively). Mg²⁺ was strong positive and significantly correlated with Cl⁻ and SO₄²⁻ ($R^2 = 0.824$ and 0.710 respectively), sodium was positively correlated with Cl⁻ and SO₄²⁻ ($R^2 = 0.751$ and 0.665 respectively). Furthermore, Cl⁻ ions show more significant correlation with SO₄²⁻ and HCO₃⁻ ($R^2 = 0.823$ and 0.801 respectively). Phosphate and fluoride ions were not significantly correlated with any of ions studied.

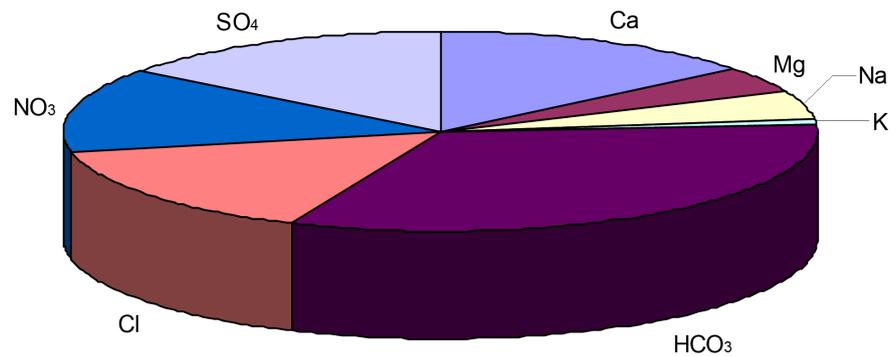


Figure 4. Mean value of ionic composition of springs water samples.

3.2. Water Chemistry

Groundwater exchanges ions with the various minerals and gases of the aquifer matrix, which results in dissolution and precipitation of minerals [31]. Saturation indices are used to evaluate the degree of equilibrium between minerals and water. The saturation index of a mineral is obtained by the Equation (1) [32] (Aghazadeh *et al.*, 2010).

$$SI = \log\left(\frac{IAP}{Kt}\right) \quad (1)$$

where IAP is the ion activity product of the dissociated chemical species in solution, Kt is the equilibrium solubility product for the chemical involved at the same temperature. When $SI < 1$ the minerals will dissolve, on the other hand, the minerals will precipitated when $SI > 1$ [12]. The saturation indices for the minerals in the spring water can be expressed by the saturation index (SI). The minerals either dissolve or precipitate when $SI < 1$ and $SI > 1$ [31] [33]. The summary of statistical analyses of the saturation indices of water samples are presented in **Table 3**. In all samples, the SI of calcite and dolomite are positive. On the other hand, all of the water samples gave negative values for gypsum and anhydrate indices, which means that all of samples are under saturated with respect to the gypsum and anhydrate and are able to dissolve additional amount of these minerals.

The ion proportions in the samples are shown on the trilinear diagram [34] and then interpreted depending on the classification given by Langguth [35] (**Figure 5**). The water of springs classifies into two groups: alkaline earth waters with prevailing bicarbonate and alkaline earth waters with prevailing bicarbonate and chloride. The chemistry of water samples shows the following ionic ratio: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-} > F^{-}$. Water chemistry originates from dissolution of carbonate rocks. However, the water was generally classified as Ca- HCO_3 with low salinity.

3.3. Drinking and Irrigation Water Quality

The analytical results have been evaluated for the suitability of spring water in the investigated area for drinking and agricultural purposes (**Table 3**). The drinking water quality was evaluated by comparing with the specification of TDS

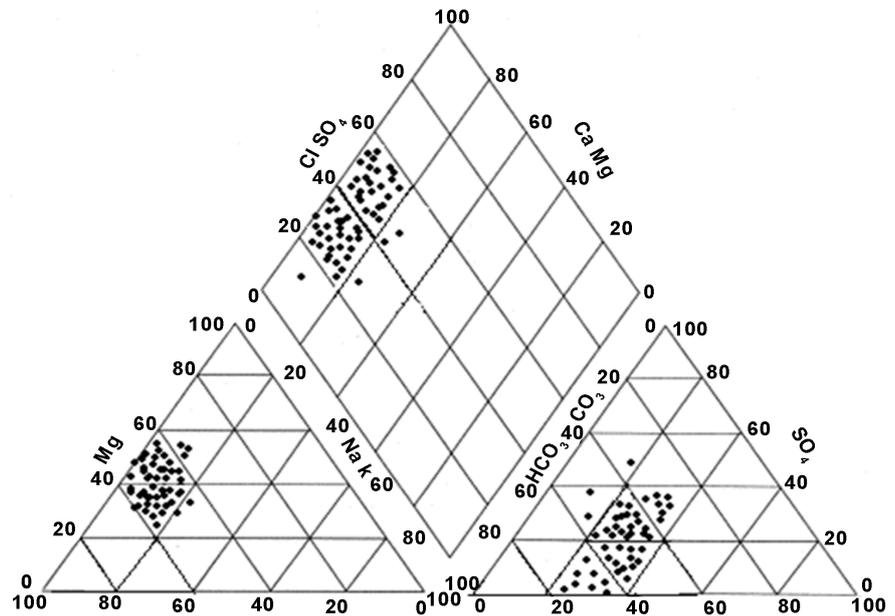


Figure 5. Piper diagram of spring waters in studied area (Values in % meq/l).

and TH set by the World Health Organization [27] and Jordanian standards [25] (Table 4). In general, all the TDS values of the spring water fall within the permissible limit of Jordanian standards for drinking water [25]. In order to know the suitability of the water for drinking and domestic purposes, the classification of water springs according to Sawyer and McCarty [36] was used. Results show that almost all the samples fall in the category of hard to very hard (Table 5). To solve the water hardness problem, several treatment options can be considered. Among these options are the use of chemical softeners, water filters, and mechanical softeners.

Electrical conductivity is a good measure of salinity in water as it reflects the TDS in groundwater which high concentration causes hazard to crops. The excess of salinity in water reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil [37] [38]. The Sodium Adsorption Ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation purposes, as it is a measure of alkali or sodium hazard to crops. The SAR is defined by the following equation [39].

$$SAR = \frac{Na^+}{(Ca^{2+} + Mg^{2+})^{0.5}} / 2 \quad (2)$$

All the concentrations are reported in meq/l.

The SAR values for the analyzed samples range from 0.43 to 1.85 with a mean value of 1.63, therefore groundwater samples of the study area fall in the low sodium class (S1). The analytical data plotted on the US salinity diagram [40] shows that most of the groundwater samples fall in the field of C₃S₁, indicating a low sodium hazard which can be used for irrigation on almost all types of soil.

The residual sodium carbonate (RSC) represents the excess of carbonate (CO₃²⁻ + HCO₃⁻) over the calcium ion (Ca²⁺ + Mg²⁺). The quality of water

Table 5. Classification of the water samples on the basis of the total hardness.

Hardness (mg/l)	Water class	No. of samples
0 - 75	Soft	-
75 - 150	Moderately hard	4
150 - 300	Hard	450
Over 300	Very hard	986

samples has been determined according to the scale of *RSC* [40]. The *RSC* is represented in the following equation:

$$RSC = (\text{CO}_3^{2-} + \text{HCO}_3^-) - (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (3)$$

All the concentrations are reported in meq/l.

The classification of irrigation water according to the *RSC* values was shown in **Table 3**, where the category of groundwater was good. Organic matter is important for the agricultural productivity, the high concentration of HCO_3^- leads to an increase in the pH values causing the dissolution of organic material in the soil. The *RSC* is used to distinguish between the different water classes for irrigation purposes [41]. The higher value of HCO_3^- in irrigation water leads to an increase in its toxicity and affects the element nutrition of plants.

On the other hand, the permeability index (*PI*) values for groundwater samples indicated that the water samples are suitable for irrigation [32] [42]. It is defined as follows (Equation (4)):

$$PI = 100 \times \left[\frac{([\text{Na}] + [\text{HCO}_3^-]^{1/2})}{([\text{Na}] + [\text{Ca}] + [\text{Mg}])} \right] \quad (4)$$

All the ions are expressed in meq/l.

WHO [43] used a criterion for assessing the suitability of water for irrigation based on permeability index. In this study, the *PI* range from 20.4% to 33.5% with an average value of about 28.8%. According to *PI* values, the groundwater in the investigated area can be classified as class II (25% - 75%) which shows that the water is suitable for irrigation uses.

3.4. Trace Metals

Trace metals present in both surface water and groundwater, while the sources of these metals are associated with either natural processes or human activities. Chemical weathering and soil leaching are the two important natural sources contributing to the increase in trace metals concentration in water [12] [44]. Many factors affect the release of trace metals from primary materials and soil, and consequently their stability in water. These factors are pH, adsorption characteristics, hydration and co-precipitation [32] [44]. The statistical analyses of metal contents in the study area are presented in **Table 6**.

Most of the water samples show low content of trace metals which could be attributed to the high pH value (higher than pH = 7) which enhances the deposition of these metals or retarding their dissolution from the rock matrix [10]

Table 6. Statistical analysis of trace metals of groundwater samples.

Parameters	Units	Minimum	Maximum	Mean	St.Dev
Fe ²⁺	µg/l	66.35	208.00	132.70	43.19
Al ³⁺	µg/l	56.40	195.00	90.53	30.82
Cu ²⁺	µg/l	8.50	35.80	19.41	6.58
Ni ²⁺	µg/l	8.65	32.00	17.95	5.60
Pb ²⁺	µg/l	11.00	60.00	26.53	12.13
Zn ²⁺	µg/l	10.50	48.00	25.07	8.83
Mn ²⁺	µg/l	8.00	28.00	16.58	5.46

[45]. The maximum concentration of iron in water samples was found to be 208 µg/l at Mugarayyeh spring. The iron concentration generally is low in spring water with strong correlation between oxygen and iron as the latter is mobilized under anoxic conditions. The iron content in the springs is much below the WHO [27] set limit for drinking water (Figure 6). The highest value of lead was measured at Um-Ruweim spring, and the lowest value was recorded in Ifjeij (Fouqa) spring. Most of the springs in the investigated area contain an amount of lead below the tolerance limits (0.05 µg/l) according to the Jordanian standard for drinking water [25]. The mean value of Mn in the springs ranges from 8 µg/l in Shammakh spring to 28 µg/l in Um-Ruweim spring. The highest value of Mn was found in Um-Ruweim spring of 28 µg/l. This can be explained by point source pollution for municipal waste and septic tanks. However, Mn concentrations in all water samples were found to be lower than the permissible limits for drinking water quality. Zinc concentration in the water springs ranges from 10.50 µg/l in El-Mour spring to 48 µg/l in Shalha spring. All spring water samples contained zinc concentrations that do not exceed the recommended limit according to the Jordanian standard [25] (Figure 6). Other trace metals showed lower concentrations in the collected water samples, indicating lower value than the recommended limit for drinking water.

Finally, the results of this study show that there were considerable variations among the analyzed samples with respect to their physical and chemical parameters, which lie below the maximum permissible levels of the Jordanian standards [25] and World Health Organization [27] drinking water standards. Such variations are attributed to many factors. Among these factors are the variation in depths, aquifers and their physical properties, and samples locations.

4. Conclusions

The physical and chemical composition of spring water was studied over a five-year period in the southwestern part of Jordan. The results indicate that spring water is typically alkaline. The chloride, sodium, calcium, bicarbonate and magnesium are the major sources of salinity in the water, while the ion values increased compared with precipitation water due to dissolution of carbonate rocks

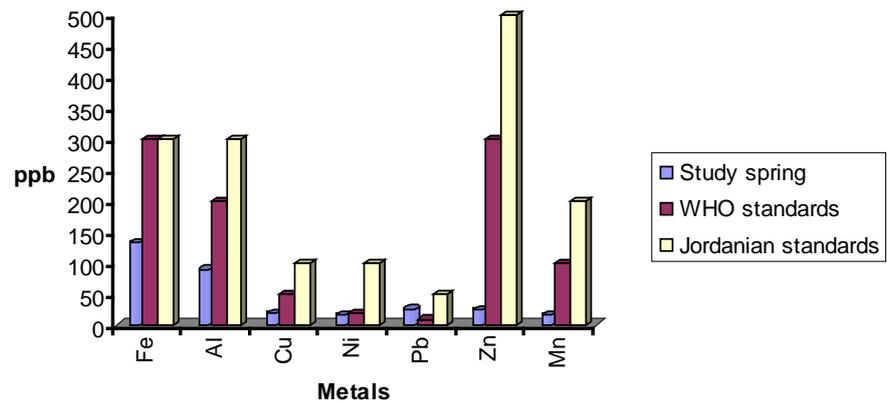


Figure 6. Mean value of metal compared with Jordanian standard and WHO.

and ion exchange processes with rock matrix minerals. The results of this study indicate that the concentration of ions of water are influenced by natural and anthropogenic sources, and indicate that some of the springs are highly polluted with nitrate and sulfate. Point and non-point source pollution of springs are agricultural activities and wastewater recharge from cesspits and septic tanks. Springs located near residential areas have been affected by waste water disposal more than other springs. These springs are directly fed with wastewater through fractures, joints, faults and fissures associated with carbonate aquifers. The water of springs is classified into two groups, alkaline earth waters with prevailing bicarbonate and alkaline earth waters with prevailing chloride. The chemistry of investigated water indicate the ionic ratios of water to be $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > Cl^{-} > SO_4^{2-} > NO_3^{-} > PO_4^{3-} > F^{-}$. Trace metals content in the spring water samples are low due to slightly alkaline water. The study concluded that the trace metals concentrations of the spring waters are much lower than the Jordanian standards and WHO guidelines for drinking waters.

Based on the results of this study, it is highly recommended that the groundwater in the area should be continuously monitored and protection measures must be implemented to alleviate the effects of municipal refuse, wastewater and chemical fertilizers used in agricultural activities. Further studies are also warranted to identify the physical, chemical, biological and organic parameters that are important in monitoring spring and groundwater quality.

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