

Water quality evaluation of Qunayya Spring- Jordan

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Abstract

Qunayya Spring, a catchment covers an area of about 111 km² with a total discharge of about 4.3 Million Cubic Meter (MCM)/year, where water flows from the Ajloun Group Formation located at the lower part of the Upper Cretaceous to the outlet of spring. Qunayya Spring is considered a major source of drinking water for many villages in the governorates of Zarqa and Mafraq, and a major source of irrigation for farms, nurseries, livestock, and poultry farms. Because of septic tanks in populated areas, and because of the use of chemical and natural fertilizers on farms, this led to pollution and deterioration of the quality of the Qunayya Springwater. Therefore, the physical, chemical and biological properties of the Qunayya Spring were studied to determine the water quality and assess its suitability for human and agricultural uses. The total number of samples collected from Qunayya Spring reached 84 samples distributed over 14 sites, with a total of 6 samples for each site over 9 months. The physical and chemical properties of 74 samples were evaluated to verify the hydrogeochemical processes and the background environment of ion concentration. In addition to 10 samples were taken for bacterial biological analysis of the cultivation faecal coliforms and total coliform bacteria. The biological consumed oxygen (BOD) and chemically (BOC) values were also calculated for all water samples. The hydrochemical of ionic relations show that the higher concentrations of Na⁺ and Cl⁻ ions are due to ion exchange and evaporation processes. Anthropogenic sources are the other reason for increasing Mg²⁺, Na⁺, Cl⁻, SO₄²⁻, PO₄³⁻, and NO₃⁻ ions. Besides, Piper's diagram shows an increased ratio of the normal earth alkaline with an increase in the content of bicarbonate and chlorine, or earth alkaline with an increase in bicarbonate. Thus, the groundwater quality is distinguished by Ca²⁺ > Mg²⁺ > Na⁺ > K⁺: HCO₃⁻ + CO₃²⁻ > Cl⁻ > NO₃⁻ > SO₄²⁻ > PO₄³⁻ facies, while the predominate of hydrochemical types are Ca²⁺-HCO₃⁻, Ca²⁺-Mg²⁺-HCO₃⁻, and Ca²⁺-Mg²⁺-Cl⁻. Based on the concentrations of TDS and TH, the majority of groundwater samples are not suitable for drinking. According to EC versus SAR, the most dominant categories are C2-S1 and C3-S1, which have medium to high salinity hazards and low sodium hazards, and in a consideration of irrigation water, the quality is medium to low. The major ion concentrations are below the acceptable level for drinking water. Therefore, it is necessary to eradicate the high toxic salt concentration from the drainage system. Furthermore, the biological results showed that the water spring was highly polluted with total coliforms and faecal coliforms. Also, the spring water was shown to be free from biological contamination after treatment.

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1. Introduction

Jordan is located within the arid to semi-arid climate zone, this plays a big role in decreasing the rainfall and thus recharge groundwater reservoirs with water, which makes daily groundwater withdrawals for daily uses more than feedback, and this, in turn, leads to total depletion for groundwater basins. This is one of the biggest environmental challenges facing the country. Besides, the water resources in Jordan flow around a constant volume annually, unlike the population, which increases continuously from year to year, due to natural increases, the high annual flow of immigrants from neighbouring countries, and the return of workers from abroad. This situation disturbs the balance of water between supply and demand (Abboud, 2018a). Whereas, in 2025, if the situation continues as such, it is expected that the Jordanian per capita share of water will decrease from 170 m³/year to 91 m³/year (Tabieh and Al-Horani, 2010). This will place Jordan among the countries that suffer from severe water shortages.

The water crisis in Jordan is represented in a scarcity of water resources and inefficient administration, the decline in quality because of agricultural development, groundwater pollution, and over pumping, which causes salination (Salameh, 1996; Abboud, 2018a; b). Also, there are many hydrogeochemical studies conducted on different areas of Jordan in an attempt to monitor the geological, hydrological, and hydrochemical conditions of the groundwater basins to identify the quality of water, the impact of pollution on it, and the level of the depletion (Al Kuisi et al., 2009; Abboud, 2014; Abboud, 2018a; b).

Water resources in Jordan were divided into surface and subsurface sources, as well as unconventional sources as treated wastewater (Abed, 1982; MWI, 2000). The developed available annual surface water quantity in Jordan is about 295 MCM in 2007 and is expected to reach 365 MCM in 2022 (UNESCO, 2012). Most of this water comes from Syria in the form of floods and surface flow (Abed, 1982; WAJ, 1995; 1996). Groundwater is considered the main water source in

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Jordan; there are 12 water basins, these water sources are renewable or nonrenewable. Some basins are classified as fossil aquifer, meaning that water is not renewed in them if it is extracted, such as the Al-Disi basin (Wardam, 2004). In 2000, more than 412 MCM renewable groundwater sources and 62 MCM non-renewable water resources were used in Jordan, although the total annual recharge for groundwater resources is about 275 MCM, which means that more than 199 MCM were over-pumped in 1997, and this quantity increases with time (Tabieh and Al-Horani, 2010). Treated wastewater is considered one of the most important non-conventional resources of water in Jordan. It is continuously increasing, and its treatment limits environmental pollution and provides water for use in agriculture (MWI, 2000).

Qunayya Spring water is a primary source of drinking water for ten villages in the governorates of Zarqa and Al-Mafraq, and also a main source of irrigation for many nearby farms, Mashtal, watering livestock, and poultry farms. Pollution water quality deterioration has been a noticeable problem at Qunayya Spring during the previous years since 2001 (CDM, 2002), resulting from septic tanks in the populated areas around it, and the use of chemical and natural fertilizers in the nearby farms. As a result, water pumping from the Qunayya Spring was stopped many times, since 2001 (MWI, 2004). The physical, chemical and biological features of Qunayya Spring were studied to define the water quality and compare it with the Jordanian and international standards, also evaluated the suitability for human and agricultural uses. Besides, the water pollution of Qunayya Spring and the leakage occurring in the spring channel were studied, with the quantity of discharge calculated to determine the water quality.

2. Study Area

2.1. Location and Physiography

The Qunayya Spring is located in the Amman-Zarqa Basin in northern Jordan, in Wadi Qunayya, northwest of Zarqa city with attitudes: $35^{\circ}59'52.3''\text{N}$ and $32^{\circ}12'53''\text{E}$. The elevation of the Qunayya area is about 500 m above the mean sea level, as a trapezoidal shape, with a total catchment area of about 111 km^2 (Figures 1-2). The climate of the study area is of a Mediterranean type which is characterized by dry and hot summers, and mild wet winters with fluctuating rainfall during the years. The average annual rainfall is very low and ranges from 110 mm to 355 mm. While, the absolute monthly temperatures range from 2°C in January to 45°C in July (Elemat, 2012).

Physiographically, The morphology of the Amman-Zarqa Basin shows a gradual slope from east to west, where the elevation above the mean sea level varies, between 500 m in the east at Qunayya Spring 1000 m at the northwest part of the Qunayya area. The texture of the soil is mostly friable red soils in the west to clay, silty loam, and sandy soil in the east. The Amman-Zarqa Basin extends from the Ajloun mountains in the west to the Azraq Basin in the east and south, while to the north, the study area extends to the Yarmouk Basin (Figures 1-2). The catchment area is drained by many different wadis: Al-Dajanyeh, Um Rumana, Hammam Al-Eleimat, Um Kharrouba, and Dahal. Irrigation

in the study area has used both surface and subsurface water, giving rise to the recirculation of groundwater. Where the area of Qunayya Spring and other surrounding areas are used for agriculture, greenhouses, poultry farms, grazing lands, and olive farms.

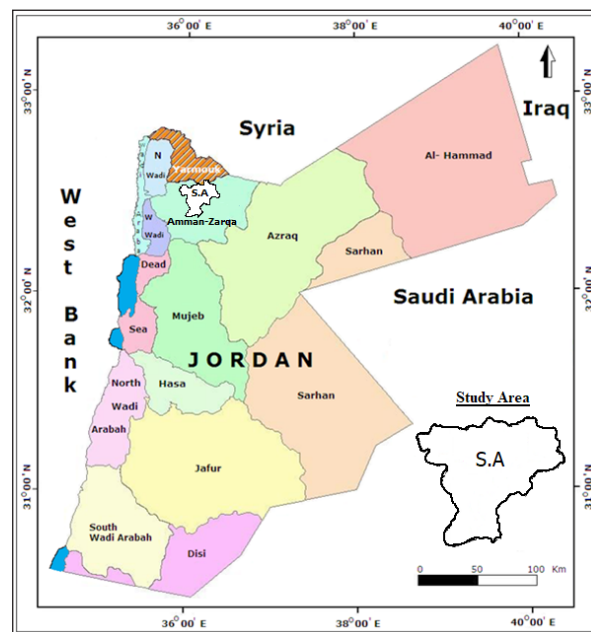


Figure 1. Jordan map showing the 15 surface water basins and Qunayya catchment areas as a study area (after MWI, 2010).

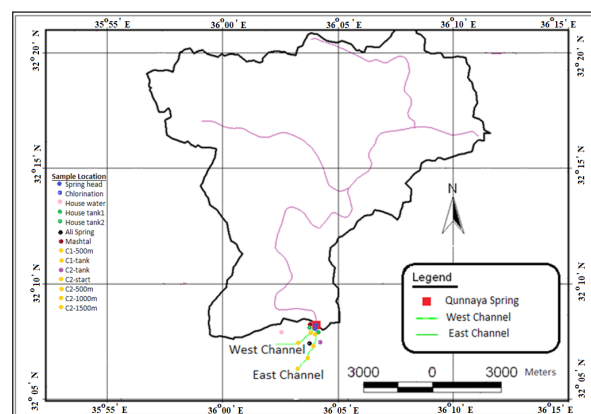


Figure 2. The catchment area of Qunayya Spring and locations of water samples.

2.2. Geological and Hydrogeological Setting

The geological setting of the study area shows that it is from tectonism type causing the appearance of heights, cracks, and severe folds in the rock layers, especially from west to east (Brunke, 1997). Figure 3 shows the geological formations of the study area and the most important geological structures of the rock units spread in the study area. Most outcrops in the study area mostly trace the Triassic to Recent age through the dominance of the Cretaceous deposits. Upper Cretaceous was divided according to Quennel (1951) into the Ajloun and Belqa Groups, which consist of limestones, chert, phosphorite marl, and porcellanite (Abed et al., 2008). The rocks of the Lower Cretaceous Kurnub Group are distributed along the axis of the Suweileh structure and the Zarqa River Valley, while the northeastern part of the basin is largely covered by basalt flows (Figure 3).

Table 1 shows the geological and hydrogeological classification of the rock units in the Amman-Zarqa Basin based on Rimawi (1985) since the area of Qunayya Spring is considered a part of the Ajloun Group, which consists of five geological formations. Na'ur Formation (A1-2) consists of limestone interbedded with thick sequences of marl and marly limestone with a thickness of about 130 m. This formation is considered as one of the oldest hydrogeological units in the Ajloun Group at the Qunayya area, and this formation is considered a poor aquifer; Fuheis Formation (A3) consists of soft gray and green marl, marly limestone, and limestone with a thickness of about 70 m. This formation forms an excellent and distinct aquifer in the study area. Al-Hummar Formation (A4) consists of hard dense limestone and dolomitic limestone with a thickness of about 50 m. This formation together with Na'ur Formation contributes to the discharge of the Qunayya Springwater. Shu'eib Formation (A5-6) consists of gray limestone interbedded with marl and marly limestone with a thickness of about 60 m and forms a fair to poor aquiclude. Wadi Sir Formation (A7) consists of limestone, dolomitic limestone, dolomite, chert, and marl with a thickness of about 70 m and was considered the main

aquifers in the study area (Abed, 1982; Rimawi, 1985; Abed, 2000). The recent sediments in the Qunayya area, consist of silt, sands, and mud and their thickness ranges between 5 m to 15 m (Brunke, 1997).

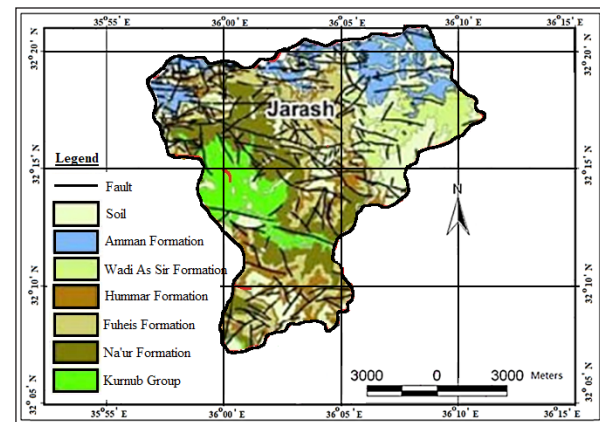


Figure 3. Geological and structural map of the study area (Catchment area of Qunayya Spring)

(Modified after the Natural Resources Authority (NRA), 2004 and Al Kuisi et al., 2014).

Table 1. Geological and hydrogeological classification of the rock units in Amman-Zarqa Basin (after Rimawi, 1985).

Epoch	Group	Formation	Symbol	Rock type	Thickness (m)	Aquifer potentiality
Tertiary	Balqa	Wadi fill		Soil, sand, gravel	10-40	Good
		Basalt	V	Basalt, clay	0-50	Good
Upper Cretaceous	Balqa	Muwaqqar	B3	Chalk, marl, chalky limestone	60-70	Poor
		Amman	B2	chert, limestone with phosphate	80-120	Excellent
		Ghudran	B1	Chalk, marl, marly limestone	15-20	Poor
	Ajloun (Qunayya area)	Wadi Sir	A7	Limestone, dolomite, chert	90-110	Excellent
		Shu'eib	A5-6	Gray limestone interbedded with marl and marly limestone	75-100	Fair to poor
		Al-Hummar	A4	Hard dense limestone and dolomitic limestone	40-60	Good
		Fuheis	A3	Soft gray and green marl, marly limestone, and limestone	60-80	excellent
		Na'ur	A1-2	Limestone interbedded with a thick sequence of marl and marly limestone	150-220	Poor
Lower Cretaceous		Kurnub	K	Massive white and varicolored sandstone with layers of reddish silt and shale	300	Good

3. Methodology

3.1. Samples Collection

Eighty-four samples were collected from Qunayya Springwater, from more than 14 sites (Figure 2), with a total of 6 samples from each site, as listed in Table 3, for a period from December to August. Ten water samples placed in a suitable medium for biological bacterial analysis, for growing the Qunayya Spring is considered a major source of drinking water for many villages in the governorates of Zarqa and Mafraq, and a major source of irrigation for farms, nurseries, livestock, and poultry farms. Because of septic tanks in populated areas, and as a result of the use of chemical and natural fertilizers on farms, this led to pollution and deterioration of the quality of the Qunayya Spring water.

3.2. Chemical Analyses

The physical, chemical and biological properties of the Qunayya Spring were studied to determine the water

quality and assess its suitability for human and agricultural uses. The total number of samples collected from Qunayya Spring reached 84 samples distributed over 14 sites, with a total of 6 samples for each site over 9 months. The physical and chemical properties of 74 samples were evaluated to verify the hydrogeochemical processes and the background environment of ion concentration. Forty-seven samples were taken for chemical analyses to determine the type and concentrations of the major ions using the standard methods book (APHA, 1998). Then, all samples were analyzed in the laboratories of Al al-Bayt University to determine the geochemical characteristics and groundwater quality of the Qunayya Springwater.

Hydrogen ion concentration (pH), specific electrical conductivity (EC), and temperature (T) were measured to all samples directly in the field, using pH and EC meters. Total dissolved solids (TDS) were measured in the field

and computed by multiplying the specific EC by a factor of 0.55 to 0.75, depending on the relative concentrations of ions. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were estimated by titrating with HCl. The total hardness (TH) as CaCO_3 was calculated using Equation 1, while Ca^{2+} was analyzed by titration using standard EDTA. Magnesium (Mg^{2+}) was calculated from the TH and Ca^{2+} . Sodium (Na^+) and potassium (K^+) were measured by a flame photometer. Chloride (Cl^-) was estimated by standard AgNO_3 titration. Sulphate (SO_4^{2-}), nitrate (NO_3^-), and phosphorate (PO_4^{3-}) were analysed using a spectrophotometer. Finally, the error for the chemical analyses results was calculated with a percentage that doesn't exceed (5-10%) according to the Gibbs equation (Gibbs, 1972).

$$\text{TH as CaCO}_3 = 2.5(\text{Ca}^{2+}) + 4.1(\text{Mg}^{2+}) \dots\dots\dots(1)$$

The percentage of sodium ($\%\text{Na}^+$) was measured related to the sodium hazard for judging the quality of water for irrigation, according to Equation 2, taking the ionic concentrations in milliequivalents per liter (meq/l). To determine the soil zone and quality, this is usually expressed in the process of ion exchange in the soil zone by using the concept of sodium adsorption ratio (SAR), as summarized in Equation 3, and the ion concentrations were taken in meq/l.

$$\%\text{Na}^+ = (\text{Na}^+ + \text{K}^+) * 100 / \text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+ \dots\dots\dots(2)$$

$$\text{SAR} = \text{Na}^+ / ((\text{Ca}^{2+} + \text{Mg}^{2+}) / 2)^{0.5} \dots\dots\dots(3)$$

3.3. BOD and COD

The biological oxygen demand (BOD) and chemical oxygen demand (COD) were determined for all water samples. The value of BOD was defined by using an Oxytop device which was installed in a special container made for this purpose. After taking 432 ml of water sample in this container and putting two pills of NaOH in the plastic container, the device was put in a special incubator at 20°C for 5 days with taking care to continuously stir the sample by using a magnetic stirrer. At the end of the period, the reading was taken directly from the device which represents the value of BOD (John and Holum, 1986; APHA, 1998). The value of COD was determined by titration after preparing the sample by adding 2.5 ml of water sample to 1.5 ml of potassium dichromate solution and 3.5 ml of sulfuric acid. Then put into a COD reactor for 2 hours at 150°C . After cooling, 3 drops of ferriox detector were added. Then the titration was made by using ferriox ammonium sulphate solution until a reddish-brown color appears. The COD value is calculated using Equation 4 after John and Holum (1986) and APHA (1998).

Where: B: consumed volume of FAS solution at blank titration; S: The consumed volume of FAS solution at sample titration; M: The concentration of FAS.

3.4. Bacteriological Analyses

Ten samples were taken for bacterial biological analysis of the cultivation faecal coliforms and total coliform bacteria.

Bacterial tests were performed in the form of two tests per sample to determine the type and number of bacterial colonies of total coliform and faecal coliform bacteria. The number of bacterial colonies was determined for the total coliform after filtering 100 ml of the spring water sample to be tested using sterilized filtration paper ($0.45 \mu\text{m}$) and a Partial Vacuum device. The filtration paper was then placed on a medium of Endo Broth in a Petri dish placed in an incubator at 35°C for 22 hours. The bacterial colonies were counted in a colony-forming unit (CFU) for every 100 ml (CFU/100 ml). Each red or metal gold-colored colony was considered to be of the total coliform count (TCC). The number of bacterial colonies of the total of faecal coliform bacteria was defined after filtering the water sample and putting the filtration paper in a medium of multiple fermentation tube test for coliforms (MFC) Broth in a Petri dish previously placed in a water bath at 44.5°C for 24 hours. Each blue-colored colony was considered to be a part of the faecal coliform group.

4. Results and Discussion

4.1. Discharge

The discharge quantity of the Qunayya Spring fluctuates according to the years and the amount of rainfall, so the maximum drainage of the Spring in recent years reached about $337.2 \text{ m}^3/\text{hr}$. The permanent discharge quantities vary between $237 \text{ m}^3/\text{hr}$ to $268 \text{ m}^3/\text{hr}$, and the highest discharge level is 45-60 days after rainfall, with an annual of 2.95 Mm^3 in the period from 1960 to 2003. The discharge was calculated according to Equation 5 after Margane and Almomani (1995). The maximum discharge rate of Qunayya Spring water in the period from 1983 to 2004 was in April-1992 when it was $2142 \text{ m}^3/\text{hr}$. The minimum discharge was in November-2002 and it was $134.5 \text{ m}^3/\text{hr}$, while the maximum monthly rate of discharge was in the period between 1983-2004 in April, and it was $407.2 \text{ m}^3/\text{hr}$. The minimum monthly discharge rate for the same period was in September at about $251.7 \text{ m}^3/\text{hr}$ (Table 2). The monthly rate of discharge for every 5 years was between $(181.1 - 758.8) \text{ m}^3/\text{hr}$ and the highest annual discharge was in 1991-1992 at about 8.47 MCM which equals $966.68 \text{ m}^3/\text{hr}$. The highest annual discharge rate for every 5 years ranged from $1.93 \text{ mm}^3/\text{year}$ to $4.34 \text{ mm}^3/\text{year}$ which equals $(220.4 - 495.44) \text{ m}^3/\text{hr}$. The total discharge in the catchment area was about $4.3 \text{ MCM}/\text{year}$ (Table 2). Based on the available data at the Ministry of Water and Irrigation, it appears that water discharge peaks after 45-60 days of rainfall which is $288 \text{ ml}/\text{day}$, and that equals $32 \text{ MCM}/\text{year}$. The stored water is about $1.25 \text{ MCM}/\text{year}$ since the unstored spring water into the spring is $4.5 \text{ MCM}/\text{year}$, this value equals the discharge at the catchment area which forms 14% of the total amount of rainfall (Brunke, 1997).

$$Q = A * V \dots\dots\dots(5)$$

Where: Q: Discharge rate; A: Surface area; V: Velocity of water (depends on distance and time).

Table 2. Monthly discharge of Qunayya Spring for the period (1983-2004) in (m³/hr).

Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Average	MCM
1983/1984	360	591	434	484	-	418	265	380	435	285	250	-	390.2	3.42
1984/1985	266	317	328	266	300	558	386	310	298	282	271	245	318.9	2.79
1985/1986	240	231	258	293	308	248	212	358	240	236	270	223	259.8	2.28
1986/1987	213	292	279	328.5	309.3	432	213	225.8	171	272	200	217	262.72	2.30
1987/1988	208	235	246	302	431	334	416	276	389	454	237.8	253	315.2	2.76
Avr (83-88)	257.4	333.2	309	334.7	269.7	398	298.4	310	306.6	305.8	245.8	234.5	309.4	2.71
1988/1989	294	516	378	555	385	324	250	238	188	159	198	171	304.7	2.67
1989/1990	251	246	227	312	332	393	314	140	303	-	190	303	273.7	2.40
1990/1991	197	182	191	205	335	226	329	-	282	226	316	221	246.4	2.16
1991/1992	197	205.8	330	1288	605	-	2142	1468	923	1194	1314	-	966.7	8.47
1992/1993	891	801	857	1048	-	-	-	594	288	205	979	509	685.8	6.01
Avr (88-93)	366	390.2	396.6	681.6	414.3	239	758.8	610	396.8	446	599.4	301	495.4	4.34
1993/1994	-	-	-	-	473	-	-	-	-	339	-	330	380.7	3.33
1994/1995	298	309	-	264.5	-	-	-	415	-	-	285	-	314.3	2.75
1995/1996	287	376	322	362	239	341	-	288	323	281.3	227	347.6	308.5	2.70
1996/1997	240	302.2	-	-	-	268	288.2	-	278.1	-	210	219.4	258.0	2.26
1997/1998	224	244	279	230	274.3	361.8	-	282.8	195	272.4	237	255.8	259.7	2.27
Avr (93-98)	262.3	307.8	300.5	285.5	328.8	323.6	288.2	328.6	265.4	297.6	239.8	288.2	304.2	2.67
1998/1999	208.2	198.4	-	-	223.5	279	-	179.6	195.4	-	190.8	180.5	206.9	1.81
1999/2000	-	166.4	184.6	-	221	263.3	-	189.5	162.8	176.3	166.8	176.2	189.7	1.66
2000/2001	167.7	181.4	202.2	186.9	189.2	-	155.1	175.5	140.1	160.1	142.6	142.7	167.6	1.47
2001/2002	125.6	168	-	174.6	210.8	222.5	256.3	174.6	180	144.8	-	150.6	180.8	1.58
2002/2003	136.8	134.5	-	174.3	-	308.6	265.3	-	419.2	-	-	-	239.8	2.10
2003/2004	266.9	300.9	334.7	388.8	384.8	336.9	457.1	374.3	285.1	324.3	331.8	266.3	337.7	2.95
Avr (98-2004)	181.1	191.6	240.5	231.2	245.9	282.1	283.4	218.7	230.4	201.4	208	183.3	220.4	1.93
Avr (83-2004)	266.7	305.7	311.7	383.2	314.6	310.7	407.2	366.8	299.8	312.7	323.2	251.7	332.4	2.91

4.2. Field Measurements

The maximum, minimum, and average results of the field tests (pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), and Temperature (T)) are summarized in Table 3. The pH values of groundwater varied from 6.7 to 9.4 with an average of 7.8, indicating an alkaline condition of groundwater. This is caused by the inflow of carbonates in the groundwater aquifer due to the percolation of water through fractures, joints, permeability, and porosity of carbonate rocks (Hummar Formation-A4). The concentration of TDS, a measure of quality, values ranged from 300 to 788 mg/l with a mean of 383.4 mg/l in the spring water. There were no significant variations between TDS values in the house tank water or along the two channels and the spring water values. So, according to the TDS classification, all

of the water samples of the groundwater belonged to the freshwater type (TDS<1,000 mg/l). The values of EC in the spring water varied between 728 and 749 $\mu\text{S}/\text{cm}$ and in the house water varied between 700 and 789 $\mu\text{S}/\text{cm}$, which is directly linked to the concentrations of ions existing in the groundwater and its higher values that contribute to higher salinity. While the rest of the samples along the two channels varied between 446 and 848 $\mu\text{S}/\text{cm}$ with an average of 738.4 $\mu\text{S}/\text{cm}$. Commonly, the slight variations in EC reflect a low variation in geochemical processes present in an area. The temperature of the spring water varied between 20 and 26°C while in the water of the channel it varied between 20 and 27°C. In general, the temperature of all the samples varied between 15.6 and 32.8°C with an average of 25°C, corresponding to the seasonal temperature variation.

Table 3. Physical properties results of Qunayya Springwater samples in the field.

Sample Location See Figure 2	pH			TDS (mg/l)			EC (μ S/cm)			TH (mg/l)			Temperature (C°)			Coordinates		Elv. (m)
	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	N	E	
Springhead	7.3	7.5	7.4	361	390	371.5	728	749	737.0	357	403	370	20.4	26.0	24.1	35° 59 52.3"	32° 13 53"	475
Chlorination	7.2	7.8	7.4	352	398	383.3	667	800	761.8	329	368	346	20.3	26.8	24.3	35° 59 51.9"	32° 13 53.2"	497
House water	7.1	7.4	7.2	349	420	386.3	700	802	762.7	301	342	325	23.4	27.9	25.9	35° 59 49.4"	32° 13 52.7"	477
House tank1	7.3	8.5	7.9	300	395	366.4	700	789	751.6	306	346	330	15.6	32.8	25.8	35° 59 44.7"	32° 13 20.3"	479
House tank2	7.5	8.7	8.2	369	391	379.5	739	768	754.2	298	340	317	24.2	31.7	28.9	35° 59 57.3"	32° 13 44.4"	475
Ali spring	6.7	7.6	7.3	349	470	431.8	667	943	834.6	254	276	265	19.3	24.5	21.5	35° 59 53.8"	32° 13 32.5	462
Mashtal	7.8	8.3	8.1	310	419	382	603	883	765.0	245	278	259	17.7	26.1	22.8	35° 59 29.3"	32° 13 23.5"	473
C1-500m	7.2	8.1	7.6	348	395	365.7	705	786	742.7	313	384	350	21.4	25.7	24.4	35° 59 53.4"	32° 13 49.6"	470
C1-tank	7.0	8.4	7.8	355	385	368.8	705	765	734.8	314	376	329	19.2	28.6	25.1	35° 59 53.4"	32° 13 49.6"	470
C2-tank	8.4	8.9	8.8	300	514	359.4	446	669	597.6	296	353	314	20.3	29.4	26.5	35° 59 25.7"	32° 13 23.1"	474
C2- start	7.2	8.1	7.5	352	588	463	470	835	703.2	336	391	351	22.2	26.6	24.9	35° 59 53.4"	32° 13 49.6"	467
C2-500m	7.7	8.5	7.9	355	401	370	712	800	738.5	322	379	344	18.7	26.5	24.1	35° 59 25.7"	32° 13 23.1"	446
C2-1000m	7.1	8.3	7.9	352	395	375	690	788	729.5	314	368	334	17.4	28.4	25.0	35° 59 53.9"	32° 13 29.9"	470
C2-1500m	7.9	8.9	8.5	331	419	365.1	662	848	724.5	299	359	325	20.0	31.0	26.7	35° 59 45.2"	32° 13 26.8"	450
Mean			7.8			383.4			738.4			326			25.0			

4.3. Water Chemistry

The total hardness (TH) is between 176 and 412 mg/l (Table 3). This is because of the alkaline earth metals (Calcium: Ca^{2+} and Magnesium: Mg^{2+}) of weak acidic anions (Bicarbonates: HCO_3^- and Carbonates: CO_3^{2-}) and the strong acidic anions (Chlorides: Cl^- , Sulfates: SO_4^{2-} , and Nitrates: NO_3^-). According to Sawyer and McCarty (1967) for TH classification, about 30% of the total groundwater samples from the study area were classified as hard water (150 – 300 mg/l) and the other water samples (70%) in the category of very hard (>300 mg/l; Table 4). The results of the chemical analysis of Qunayya Spring groundwater are presented in Table 5. The table shows the minimum, maximum, and mean values for the ions concentration of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , HCO_3^- , SO_4^{2-} , NO_3^- , and PO_4^{3-} , and also shows a comparison between the results of water analysis of the two channels with the water from the Qunayya Springhead.

After analysing the water samples of the spring head, it appeared that there is a fair variation in the concentration of some ions, while others were more and some of them have a fixed rate. In the groundwater samples, the concentrations of Na^+ , K^+ , Ca^{2+} , and Mg^{2+} ions vary from 30.8 to 44.9, 4 to 6, 43 to 65.2, and 43.4 to 58.4 mg/l, respectively (Table 5). In general, the aquifer rocks of the study area are the main source of Na^+ , K^+ , Ca^{2+} , and Mg^{2+} ions in the groundwater, the differences in the concentrations of ions are probability to differences in their sources. The mean concentration of Ca^{2+} (53.1 mg/l) is mostly closer to the mean of Mg^{2+} (49.6 mg/l; Table 5), despite the Ca^{2+} generally exceeds the Mg^{2+} , depending on their relative abundance in rocks. This shows that the anthropogenic activities could be the source of increased concentration of Mg^{2+} than Ca^{2+} in normal conditions; thereby the Mg^{2+} shows the comparable concentration of the Ca^{2+} in the groundwater (Rao et al., 2012). The high concentration of Ca and Mg indicates that they are both derived from the same source, that is, from the dissolution of calcite and dolomite from the rocks of the B2/A7 Formation. Finally, the analysis of Ca^{2+} and Mg^{2+} didn't show any changes in their concentrations overall months of the year.

The mean concentration of Na^+ (37.15 mg/l) is much higher than that of K^+ (4.63 mg/l; Table 5). The high concentration of Na^+ among the other cation concentrations reflect a rock weathering process and/or dissolution of salts stocked in soil by the impact of evaporation (Stallard and Edmond, 1983) and also indicate higher solubility conduct (Rao et al., 2012), while the lower concentration of K^+ (less than 5 mg/l) is because of its compatibility at clay minerals (Hem, 1991). Mainly, the appearance of any anomalies in the concentration of K in the water is due to the addition of K in the groundwater coming from potassium fertilizers and clay minerals associated with the reservoir rocks. Also notice the decrease in the concentration of Na^+ in the summer months (32 mg/l) in comparison with the winter months (42 mg/l), while the K^+ didn't show any changes in the concentration (Table 5). As a result, the order of cationic abundances is, $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$.

Given the anions, the concentrations mean of HCO_3^- , Cl^- , NO_3^- , SO_4^{2-} , and PO_4^{3-} ions distributed as thus 233.53, 73.61, 38.27, 25.13, and 0.662 mg/l, respectively (Table 5). So, carbonates (HCO_3^-) are the common ion in the groundwater. The concentration of HCO_3^- in groundwater is caused by the presence of CO_2 in the soil zone which is formed from the weathering of origin materials, or may also be coming from the dissolution of silicate minerals from country rocks (Rao, 2002). Therefore, the high concentration of bicarbonate in the water is attributed to the natural weathering processes of the basin rocks. As a result of the decay of organic matter and the root respiration process in the soil zone works to launch carbon dioxide, which reacts with water to produce HCO_3^- , which in turn converts to CO_3^{2-} as a result of rocks weathering through the infiltration of recharge water (Jacks, 1973; Berner and Berner, 1987). The excess content of carbonates indicates a strong weathering of rocks, which favors a vigorous mineral dissolution (Stumm and Morgan, 1996).

In general, chloride (Cl^-) is mainly derived from non-lithological sources (Hem, 1991), as well as nitrates- NO_3^- (Ritzi et al., 1993). Also, the possibility contributes to Cl^- in the groundwater maybe depends on the country rocks (shale) (Rao et al., 2012). Another source of Cl^- in the groundwater of the study area represented in the influences of irrigation practice, use of natural and chemical fertilizers, solid waste of the poultry farms and barns cattle and cows, waste of olive mills, and septic tanks. The solubility rate of Cl^- is also high (Rao et al., 2012) becomes the next dominant ion after HCO_3^- in the groundwater (Table 5). Therefore, the increase in chloride concentration is often attributed to excessive irrigation and overexploitation of groundwater aquifers in the study area. Excess concentration of NO_3^- more than 10 mg/l in the water reflects man-made pollution (Rao et al., 2012). However, under natural conditions the NO_3^- concentrations do not exceed 10 mg/l (Cushing et al., 1973). So, the concentration of NO_3^- in the study area varies from 10 to 72.8 mg/l with a mean of 38.27 mg/l (Table 5). The high concentration of nitrates in the study area is attributed to the extensive agricultural activities and the intensive use of chemical fertilizers, also, to the use of treated wastewater effluents in irrigation of crops. Relatively, the higher concentration of SO_4^{2-} (mean 25.013 mg/l; Table 5) reflects the influence of the country rocks (Rao et al., 2012), and it may also be related to some agricultural activities (ammonium sulfate fertilizer) widely spread in the study area. The order of abundance is $\text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{SO}_4^{2-} > \text{PO}_4^{3-}$. Generally, the concentration of dissolved ions in groundwater controlled by; lithology, soil type and texture, velocity and proportion of groundwater flow, type of aquifer, nature of geochemical reactions, solubility ratio of salts, and human activities (Hem, 1970; 1991; Karanth, 1991; 1997; Ritzi et al., 1993; Bhatt and Saklani, 1996; Stumm and Morgan, 1996; Eraifej and Abu-Jabber, 1999; Rao, 2002; Al Kuisi et al., 2009; 2014; 2015; Pazand et al., 2012; Rao et al., 2012; Abboud, 2014; 2018a; 2018b).

Table 4. Distribution of groundwater samples based on the classification of TH (after Todd and Mays, 2005).

Classification of TH (mg/l)	Sample numbers	Percentage of samples	Water type
<75	-	-	Soft
75-150	-	-	Moderately hard
150-300	1, 6-9, 11, 12, and 14	44.44	Hard
>300	2-5, 10, 13, and 15-18	55.56	Very hard

Table 5. Chemical analysis results of Qunayya Springwater samples during 6 months.

Sample	Na ²⁺			K ⁺			Ca ²⁺			Mg ²⁺			Cl ⁻			HCO ₃ ⁻			SO ²⁻ ₄			NO ₃ ⁻			PO ³⁻ ₄		
	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean
Springhead	30.8	44.8	37.1	4	5	4.7	59.1	65.2	57.6	50.8	58.4	55.0	67.4	77.4	71.6	235	257	244	23.5	26.3	24.6	35.7	66.7	47.4	0	2.8	0.90
Chlorination	30.8	44.8	37.1	4	5	4.6	48.0	60.1	54.5	48.5	53.0	51.0	76.0	82.5	78.7	205	257	237	22.7	28.2	24.9	35.0	66.7	46.9	0	0.1	0.06
House water	30.8	44.9	37.1	4	5	4.7	44.0	53.0	49.8	46.3	51.0	48.8	77.2	79.4	77.9	195	251	226	19.5	25.8	23.7	10.0	15.4	12.8	0	0.1	0.05
House tank1	30.8	44.8	37.1	4	5	4.6	45.1	55.1	50.7	47.0	50.6	49.5	77.7	83.5	80.5	191	251	222	21.4	30.2	25.6	10.0	14.5	12.5	0	0.1	0.02
House tank2	30.8	42.2	36.9	4	6	4.9	43.0	53.0	49.6	46.3	50.5	47.6	72.8	80.4	77.8	191	251	224	19.3	34.3	25.5	12.4	30.0	16.1	0	0.3	0.08
C1-500 m	30.8	44.8	37.0	4	5	4.5	53.0	62.0	55.4	43.9	55.7	51.4	66.3	76.5	70.9	234	257	242	12.1	36.6	24.4	35.1	66.7	47.2	0	2.5	0.86
C1-tank	30.8	44.9	37.5	4	5	4.5	49.0	60.0	54.8	46.6	54.9	46.7	67.4	82.5	72.9	232	255	240	22.9	42.7	29.6	31.2	65.7	45.0	.1	2.6	0.91
C2-tank	30.8	44.8	37.1	4	6	5.0	47.0	57.9	50.7	43.4	50.7	45.4	65.7	80.2	71.6	220	256	237	23.3	30.6	25.7	37.5	68.7	48.3	0	2.5	0.85
C2-start	30.8	44.8	37.6	4	5	4.5	52.0	64.0	56.3	50.0	56.1	51.1	65.5	76.8	70.6	220	256	238	22.1	28.7	24.8	37.8	70.5	49.4	0	3.0	1.05
C2-500 m	30.8	44.8	37.1	4	5	4.5	50.5	64.1	54.1	47.5	53.2	50.8	66.2	74.1	70.3	208	256	235	21.1	29.5	24.5	37.2	72.8	49.9	0	3.5	1.16
C2-1000 m	30.8	44.8	37.2	4	6	4.8	49.0	61.0	52.7	46.5	52.3	49.2	66.8	73.5	70.3	208	256	234	21.1	26.5	24.0	31.5	65.1	45.7	0	3.0	1.06
C2-1500 m	30.8	44.8	37.0	3	5	4.3	46.0	58.0	50.7	44.7	51.9	48.1	66.4	73.7	70.2	195	256	227	21.3	31.5	24.3	12.9	66.7	38.0	0	2.8	0.95
Mean			37.15			4.63			53.1			49.6		73.6			234			25.1			38.3				0.66

4.4. Water Type

The distributions of the dissolved ions in Qunayya Springwater and modifications in water character using Piper's trilinear diagram (Piper, 1944) were shown in Figure 4 to determine the type of water and its potability over six months and to determine the geochemical processes. Waters in the study area are characterized by the dominance of carbonates, chloride, calcium, magnesium, sodium, and sulfate. The percentages of Ca^{2+} (28.2–38.1%), Mg^{2+} (44.3–52.5%), $\text{Na}^+ + \text{K}^+$ (17.2–29.4%), $\text{HCO}_3^- + \text{CO}_3^{2-}$ (50.7–62.5%), Cl^- (29.8–40.2%), and SO_4^{2-} (4.8–11.4%) are calculated for all groundwater samples they are plotted in the Piper's diagram (Table 6; Figure 4). One hundred percent of the groundwater sampling points are fall in zone 5. This indicates that alkaline earth and weak acids are occupied over the alkalies and strong acids. So, the groundwater quality is characterized by carbonate hardness exceeds 50%. Based on dominant cations and anions in the Qunayya Springwater, one water type was found for the water samples that analysed: $\text{Ca}^{2+}\text{--HCO}_3^-$, $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--HCO}_3^-$, and $\text{Ca}^{2+}\text{--Mg}^{2+}\text{--Cl}^-$. The first two characters are to connect with the mineral processes (limestone–dolomite weathering, dissolution, and precipitation) and to the aquifer recharge. While the third characteristic is related to groundwater pollution, as it is associated with ion exchange processes, rock weathering, and halite solution. Consequently, depending on the results of Piper's diagram, the geochemical classification of groundwater indicates that the origin of salts and other dissolved solids in the groundwater came of during infiltration of recharge water which loaded of the influences of anthropogenic sources.

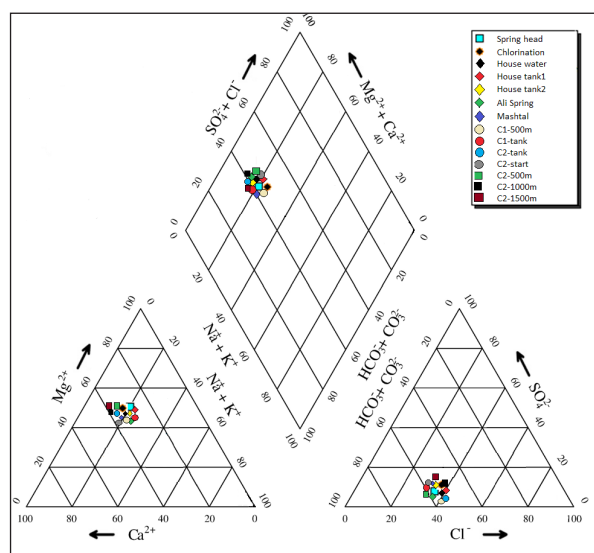


Figure 4. Piper's trilinear diagram of water chemistry in the study area (after Piper, 1944).

Table 6. Particulars of various parameters after Piper's diagram.

Particulars	Minimum	Maximum	Mean
Ca^{2+} (%)	28.2	38.1	34.2
Mg^{2+} (%)	44.3	52.5	49.4
$\text{Na}^+ + \text{K}^+$ (%)	17.2	29.4	25.1
$\text{HCO}_3^- + \text{CO}_3^{2-}$ (%)	50.7	62.5	58.1
Cl^- (%)	29.8	40.2	36.6
SO_4^{2-} (%)	4.8	11.4	8.2

4.5. Water Quality

Water types depend on several factors to become suitable for several purposes: drinking, agriculture, and industrial purposes. These factors are codified into minimal standards required for the use of water. So the Jordanian standards (JS) (1997), World Health Organization (WHO) (1998, 2004, 2011), and the Environmental Protection Agency (EPA) have issued to set physical, chemical, and biological standards. A maximum and a minimum value have been given for each quality. Table 7 shows the analytical results of physical and chemical parameters of spring water in the study area, which were compared with the Jordanian standards, specifications, and values as recommended by the Ministry of Water and Irrigation (MWI) (2000, 2004) and the WHO for drinking and public health purposes. It appears that all the results fall within the permissible limits for using water for drinking and irrigation purposes. The analytical results of the physical parameters (TDS, pH, EC, and T) for Qunayya Springwater show that it follows the Jordanian and World Standards. Table 8 shows how to identify the taste of drinking water since there is a relationship between water quality and the total amount of dissolved solids (TDS) in the solution. The values of TDS were varied between 300–788 mg/l with an average of 383.4 mg/l, where the TDS concentration in 92.7 % of the samples was good while 7.3 % was acceptable. According to the Jordanian Standard (JS) and WHO guidelines, the range of eligible pH values of water specified for drinking purposes is between 6.5–9.2. The values of pH for the groundwater in the study area vary between 6.7 to 8.9 with a mean of 7.8 (Table 8).

Water type varies from one area to another and from time to time because of the geology of the aquifers and because of pollution sources (septic tanks, chemicals, and natural fertilizers...etc). Looking at the chemical analysis results along different periods, there are not any significant differences in the water quality. The hardness of water depends mainly upon the amounts of divalent cations, especially Ca^{2+} and Mg^{2+} which are the more abundant in groundwater. The acceptable limit of TH for drinking water is ≤ 300 mg/l as per WHO guidelines. Through the TH values of the groundwater samples in the study area, about 55.56 % of the total samples were classified under the category of very hard water, and they are not suitable for drinking (Table 4). Excess concentration of TH in water affects the formation of gallstones and bladder stones (Abboud, 2008), as well as affects the water's taste for drinking and the use of household items.

The most important ions that are used to determine the water suitability for drinking or irrigation are K^+ , Na^+ , Ca^{2+} , Mg^{2+} , HCO_3^- , Cl^- , SO_4^{2-} , NO_3^- , and PO_4^{3-} . So, any increase or decrease in the concentrations of these ions is attributed to several factors; lithology, structural setting, aquifer type, water flow, land uses, and human pollution. The concentrations of the ions of K^+ , Mg^{2+} , and HCO_3^- are determined by the aquifer type and temperature (Gibbs, 1972). So, the concentrations of these ions will be increased through limestone or dolostone aquifers (Table 7). The analytical results of these ions in the groundwater

of the study area fall within the allowed limits according to Jordanian and international standards (Table 7). The relative increase in the concentrations of some of these ions in the

groundwater may result from an increase in dissolution rate caused by an increase in the temperature in summer and the passage of water in the carbonate rocks.

Table 7. Specifications of Qunayya water depending on Jordanian Standard (JS), EPA, and WHO guidelines.

Variable (mg/l)	Spring rate	JS	WHO	EPA	Cause/Origin
pH	7.8	6.5 – 9	6.5-8.5	-	Acids, decrease CO ₂ Pressure, bicarbonates increase pH
TDS	383.4	500-1500	500-1500	-	Dissolving rocks and soil, wastewater
TH	234–294	300–500	500	-	Calcium and Magnesium concentration total
Na ⁺	30–45	200–400	200	-	Dissolving all rocks and soil, connection with seawater and wastewater
K ⁺	4–6	12	12	-	Sediment rocks, man and cattle remnants
Ca ²⁺	43–65	75–200	75	-	Dissolving limestones and soil
Mg ²⁺	43–58	50–150	< 125	-	Dissolving all rocks and soil, connection with seawater and wastewater
Cl ⁻	65–83	200–500	250	250	Dissolving some rocks and soil, connection with seawater and wastewater
HCO ₃ ⁻	190–256	100–500	125–350	-	In all water types
CO ₃ ²⁻	0	-	-	-	Limestones and soil
SO ₄ ²⁻	12–42	200–500	250	250	Dissolving rocks and soil that contains sulfide and sulfates
NO ₃ ⁻	10–73	50–70	50	10	Dissolving the organic substances, wastewater, and fertilizers leftovers
PO ₄ ³⁻	0.01–3.5	0.2	0.2	-	Organic and chemical fertilizers, penetration of house wastewater, phosphate rocks

The decrease of Na⁺, NO₃⁻, and PO₄³⁻ concentration in the groundwater during the summer months (Table 7), may be the result of an increase in temperature which works to decrease the dissolution rate of the ions, which causes the decline in precipitation of ions to the aquifer. The water of Qunayya Spring that is pumped to the houses, has a decrease of K⁺ rate in the summer months (Table 7). That may be caused by the lack of water discharge in the aquifer. Moreover, The dissolution rate of K⁺ becomes less during the winter months. Excessive sodium may lead to high blood pressure, heart disease, and kidney infection. Potassium is also important for maintaining fluid balance in the human body. While, the remarkable increase in the concentration of NO₃⁻ in the spring water over the allowed level may be caused by several reasons (Table 7), such as the use of natural and chemical fertilizers near the source of water, wastes which comes from the poultry farms and the cattle barns, wastes of olive mills, and finally, distribution of a large number of septic tanks in the area. Finally, the concentration of Ca²⁺ in the spring water has been higher than the permissible level according to the drinking water guidelines in the WHO, where it varies between 47 to 270 mg/l. Calcium and magnesium are two major components for building and healthy bones for a human and they are also essential in the metabolism process. Calcium is essential for preventing heart problems, while a deficiency of magnesium leads to protein deficiency and malnutrition (WHO, 2011). While the concentration means of Cl⁻, NO₃⁻, and SO₄²⁻ were within the permissible limit according to WHO (1998), and the water of Qunayya Spring was classified as being calcium bicarbonate water (alkaline water).

Table 8. Water classification depending on TDS in groundwater of Qunayya Spring (after WHO guidelines, 2004).

Type	TDS mg/l	% of samples
Very good	<300	-
Good	300 – 600	92.7 %
Acceptable	600 – 900	7.3 %
poor	900 – 1200	-
Unacceptable	>1200	-

4.6. Quality of Irrigation Water

4.6.1. Sodium percentage (Na%) and SAR Analyses

The suitability of water for irrigation was determined by the total amount of salt present and by the kind of salt and minerals in water (Wilcox, 1948; Todd, 1980). Increasing the total level of salts content in agricultural soil leads to the emergence of new problems in the growth and quality of different crops, so there may be an urgent need to impose special administrative and legal practices to maintain acceptable crop yields. The most important salts in this context are sodium, calcium, and magnesium concerning other cations and anions (Todd, 1980; Hem, 1991). The most harmful effects of water are the excessive accumulation of dissolvable salts and the concentration of sodium in the soil, which makes it difficult for plants to absorb water. Soils containing a high content of sodium with dominant carbonate anion are named alkaline soils; otherwise, if predominant of chloride or sulfate anion it develops to saline soil (Hem, 1991). Finally, the soil enriched in sodium will not support plant growth (Todd, 1980). The water at the study area was titrated and evaluated by studying values of %Na⁺, TDS, EC, and SAR, where the irrigation water has been

divided into groups to be compared with the international standards (Tables 9, 10, 11). Salinity is the total of inorganic solid material dissolved in water, and water salinization assigns to an increase of TDS and total chemical content of water (Ritcher and Kreidler, 1993). The percentage of sodium

(%Na⁺) was measured related to the sodium hazard for judging the quality of water for irrigation, taking the ionic concentrations in meq/l. The content of sodium is commonly obvious in terms of sodium percent as summarized in Equation 2.

Table 9. Results of sodium ratio (Na%) analysis of Qunayya water.

Sample	December-2005	March-2006	May-2006	June-2006	July-2006	August-2006	Mean
Springhead	20.6	21.9	21.0	16.6	15.9	17.8	18.97
Chlorination	20.9	22.9	22.4	18.1	16.8	18.9	20.00
Bump water	21.9	24.1	22.7	18.7	17.6	19.5	20.75
House water1	21.8	24.4	23.3	19.0	18.1	19.5	21.02
House water2	-	-	18.9	19.1	18.1	19.7	18.95
C1-500 m	21.0	23.1	18.9	16.7	16.6	18.4	19.12
C1-tank	-	23.1	18.6	17.3	16.8	18.9	18.94
C2	-	22.3	17.6	16.9	16.3	18.6	18.34
C2-500 m	21.5	23.5	22.4	17.1	16.6	19.2	20.05
C2-1000 m	22.1	23.6	18.5	18.0	17.6	19.5	19.88
C2-1500 m	22.2	24.2	19.2	17.7	18.3	19.7	20.22
C2-tank	-	24.1	19.4	18.8	18.1	20.2	20.12
Mean	21.5	23.4	20.2	17.8	17.2	19.2	19.70

Table 10. Classification of irrigation water depending on sodium content (Na%) (after Glover, 1996).

Type	Na%	EC $\mu\text{S}/\text{cm}$
Excellent	20>	250>
Good	20 – 40	250 – 750
Acceptable	40 – 60	759 – 2000
Bad	60 - 80	2000 – 3000
Unacceptable	80<	3000<

Table 11. Results of sodium adsorption ratio (SAR) for Qunayya Springwater (meq/l).

Samples	December-2005	March-2006	May-2006	June-2006	July-2006	August-2006	Mean
Springhead	0.01	0.011	0.011	0.007	0.008	0.008	0.0092
Chlorination	0.01	0.011	0.011	0.008	0.008	0.009	0.0095
Bump water	0.011	0.012	0.011	0.008	0.008	0.009	0.0098
House water1	0.011	0.012	0.011	0.008	0.008	0.009	0.0098
House water2	-	-	0.008	0.008	0.008	0.009	0.0083
C1-500 m	0.01	0.012	0.008	0.008	0.008	0.008	0.0090
C1-tank	-	0.012	0.008	0.008	0.008	0.009	0.0090
C2	-	0.012	0.008	0.008	0.008	0.008	0.0088
C2-500 m	0.011	0.012	0.011	0.008	0.008	0.009	0.0098
C2-1000 m	0.011	0.012	0.008	0.008	0.008	0.009	0.0093
C2-1500 m	0.011	0.012	0.009	0.008	0.008	0.009	0.0095
C2-tank	-	0.012	0.009	0.008	0.008	0.009	0.0092
Mean	0.011	0.019	0.0094	0.008	0.008	0.0088	0.0093

The results of the percentage of sodium (%Na⁺) at Qunayya Springwater over 6 months are shown in table 9, where the increase in the percentage of sodium in the water harms the type of water and its suitability in agriculture or its usefulness for crops. Also, saline water, which contains high levels of sodium, reduces the permeability of agricultural soil due to the ion exchange processes between it and different soil ions such as calcium, potassium, and magnesium. The water classification in the study area in which the %Na⁺

varied between 15.9 to 24.4 with a mean of 19.7 (Table 9), came under an excellent classification in December, March, and May, while in the summer months, water was good and the classification varied between good to excellent (Table 10). The values of EC varied have between 446–943 $\mu\text{S}/\text{cm}$ (Table 3), and all samples were classified as good and acceptable (Table 10). Thus, the groundwater quality is suitable for irrigation. Sodium is adsorbed on clay surfaces by substitution of alkaline earth that destroys the soil structure

(Todd, 1980). The ion exchange process at the soil zone is commonly expressed in sodium adsorption ratio (SAR), the sodium hazard of water is mostly described by the SAR. The concentration of ions is taking in milliequivalents per liter (meq/l). This is computed by Equation 3. The effect of EC and (SAR) on water quality is shown graphically by the United States Salinity Laboratory (USSL: Richards, 1954). Table 11 shows the results of sodium adsorption ratio (SAR), which was determined from a chemical equation that relates the dissolved sodium concentration with the double valency cations dissolved in water. By using the results we can predict the rate of sodium between water and the soil which is saturated with the other double ions to make a balance. Thus, we can determine the water type to be used for irrigation and agriculture. The SAR values computed from the groundwater of the study area are in between 0.007 – 0.011 meq/l with a mean of 0.0093 meq/l, (Table 11).

Classification of groundwater quality for irrigation purposes depends on SAR versus EC (after Richards 1954). Therefore, we notice that the types of irrigation water in the study area based on that classification were concentrated in the medium (C2) and the high (C3) classifications (Richards, 1954; WHO, 1998), where the values of TDS ranged between 300–788 mg/l, and this indicates that the quality of the water of Qunayya Spring for agriculture uses is threatened by salinity and not suitable for irrigation. This places the spring water in the medium salinity range that can be used in the medium sediment soil for irrigating plants without any special efforts for controlling salinity. According to the Wilcox salinity diagram (Figure 5) for the classification of sodium hazard, the zones of groundwater samples fall in two classes of water types; i.e., C2-S1 (57%) and C3-S1 (43%) which has medium to high salinity hazards and low sodium hazard. Besides, the zone of C2-S1 comes under the good water quality category, the zone of C3-S1 comes under the moderate water quality category for irrigation, with increasing salinity hazard from C1 to C4 and sodium hazard from S1 to S4 for irrigation processes (Figure 5). Finally, the distribution of Qunayya Springwater samples on Wilcox's salinity diagram by drawing the relationship between SAR and EC shows that the spring water is a low soda and medium salinity water. As spring water quality and its suitability for agriculture is a concern, it appears that the sodium concentration, which varies between 30–40 mg/l (Table 10) is within the permissible limit for agriculture. Whereas, the water is considered good according to the Todd classification (Todd, 1980).

4.6.2. Water Quality for Poultry and Cattle Uses

The high rates of ions in water may cause health problems and the death of animals. The high salinity of water used for poultry may harm the animals and cause them to die. The water type in the study area was evaluated for poultry and cattle based on issues of the National Academy for Science, 1972 (NRC, 1974). Comparing the results it appears that, the total dissolving salts (TDS) values vary between 300–788 mg/l (Table 3), and thus did not exceed the 1000 mg/l (Table 8) limit set by the recommendations of the National Academy for Science, 1972 (NRC, 1974). Hence, Qunayya Spring water is suitable for all purposes (drinking, agriculture, industry, poultry, and livestock).

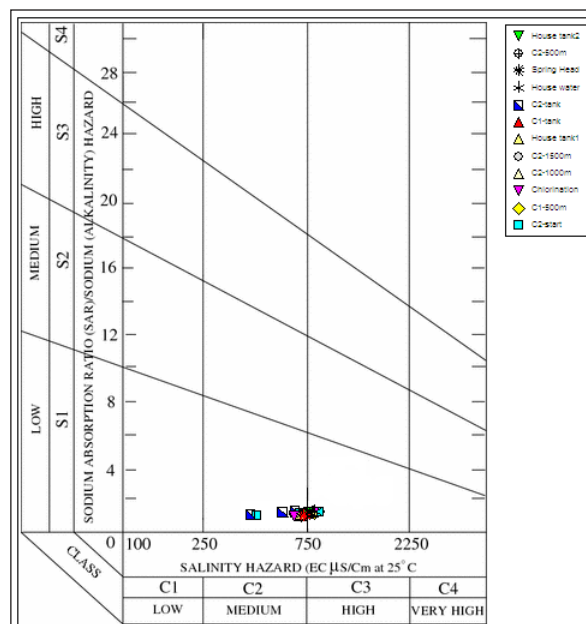


Figure 5. Classification of groundwater quality for irrigation purposes depends on SAR versus EC (after Richards, 1954).

4.6.3. Microbiological Water Quality

Qunayya Spring water has been used for drinking because of its high quality, since 1960 (WAJ, 2004). Recently different pollution cases have been reported as a result of the increase in bacillus coliforms above the permissible limits in the Jordanian Standards 286/2001 (WAJ, 2001). This has been attributed to leaking from septic tanks and the use of natural fertilizers in nearby farms (WAJ, 2004; MM, 2003). The existence of cattle and poultry farms at the northeast and northwest of the spring head is the main threat to the Qunayya spring water. The use of natural and chemical fertilizers in the surrounding farms and the existence of olive mills at the high areas northeast of the spring cause the residual of chemicals and olives oil leftovers to leak into the spring source. The burial of the poultry consumed cars, and detergent remnants in the spring water zone can pollute the groundwater, especially when the water moves through it. Moreover, the overpumping of the groundwater and leakage of the wastewater from the septic tanks in the area lead to pollution of groundwater of Qunayya Spring.

The results of the bacterial analyses show the degree of water pollution by total coliform and faecal coliform bacillus. Table 12 shows the microbiological specifications for the water samples where the most probable number (MPN) of the bacterial colonies are less than one for every 100 ml of the sample is drinkable water, while the samples where the most probable number of the bacterial colonies are more than one is polluted water and not suitable for drink according to the Jordanian Standards Specifications (286/2001). Most of the results show that Qunayya Spring water is polluted in colon bacillus where the MPN for every 100 ml of total coliform vary between (15–100 MPN/100 ml), i.e it is undrinkable water except for the samples taken in March where the bacterial analysis results have been good and the water has not been polluted. But the faecal coliform bacteria' most probable number for every 100 ml varied between (10-35 MPN/100 ml). As a final result

of microbiological contamination in the study area; The results of faecal coliform culture indicate the risks of water pollution in the area of Qunayya Spring due to the spread of septic tanks in the area, in addition to the extensive use of chemical and natural fertilizers in agriculture. Therefore, the Ministry of Water and Irrigation (MWI) reported the

pollution caused by organic substances in the Qunayya Spring waters in the period between 1980-1996, and it did not report the inorganic pollution present in the water. Thus, constant analyses in addition to the regular and periodical analyses for water quality before and after treatment of the spring is highly recommended.

Table 11. Results of microbiology analysis for Qunayya water during 6 months.

Sample	Decem.-2005		June-2006		March-2006		July-2006		May-2006		August-2006	
	F.C/MPN/100ml	T.C MPN/100ml	F.C MPN/100ml	T.C MPN/100ml	F.C MPN/100ml	T.C MPN/100ml	F.C MPN/100ml	T.C MPN/100ml	F.C MPN/100ml	T.C MPN/100ml	F.C MPN/100ml	T.C MPN/100ml
Spring head	20	42	35	100	1>	1>	16	17	10	50	14	15
Chlorination	1>	42	60	84	1>	1>	19	33	14	40	1>	1>
Bump water	1>	1>	1>	1>	1>	1>	1>	1>	1>	1>	1>	1>
House water1	1>	3	1>	1>	1>	1>	1>	1>	1>	1>	1>	1>
House water2	1>	1>	1>	1>	1>	1>	21	31	1>	1>	1>	1>
C1-500 m	17	41	21	33	1>	17	-	-	5	22	5	7
C1-tank	-	-	25	50	1>	1>	1>	22	23	44	1>	1>
C2	-	-	9	11	1>	3	10	43	3	5	25	27
C2-500 m	67	79	24	30	1>	16	20	35	1>	12	19	30
C2-1000 m	2	52	1>	1>	1>	2	26	51	1>	2>	22	33
C2-1500 m	17	31	1>	1>	1>	16	9	17	1>	8	24	35
C2-tank	-	-	1>	1>	1>	1>	1>	3	1>	1>	1>	1>

5. Conclusions

This study has highlighted the hydrochemical regime of the Qunayya Springwater as well as identified the quality of the water in the Amman-Zarqa Basin. So, the rainfall amount at the study area along 22 years ranged between 100-355 mm, and during this period the total discharge in the catchment area was about 4.3 MCM/year. The quality of groundwater in the study area was characterized by moderately high to high pH and TH because of the high concentrations of carbonates. The TH is in between 176 and 412 mg/l and classified as hard to very hard categories. The major cations in the groundwater were arranged as follows $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$, while the anions are also arranged as $\text{HCO}_3^- > \text{Cl}^- > \text{NO}_3^- > \text{SO}_4^{2-} > \text{PO}_4^{3-}$. Based on dominant cations and anions in the groundwater of Qunayya Spring, the main types of hydrochemical facies were found for the water samples are $\text{Ca}^{2+}\text{-HCO}_3^-$, $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^-$, and $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-Cl}^-$. The facies also propose that the ion exchange and evaporation factors are the secondary processes for higher concentrations of Na^+ and Cl^- ions. The influences of country rocks, weathering process, dissolution of salts stocked in soil, irrigation practice, natural and chemical fertilizers, solid wastes, and anthropogenic actions are the other reasons for increasing Mg^{2+} , Na^+ , Cl^- , SO_4^{2-} , NO_3^- , and PO_4^{3-} ions in the groundwater. Thus, the results of groundwater quality plotted on Piper's diagram, the geochemical classification of groundwater chemistry indicates that the origin of dissolved solids in the groundwater came of during infiltration of recharge water which loaded of the influences of anthropogenic sources. The distribution of groundwater samples on Wilcox's salinity diagram shows that the spring water is low soda and medium salinity water. The salinity hazard is considered as low to medium, which that the sodium concentration is between 30–40 mg/l, is within the permissible limit for agriculture. The groundwater quality is characterized by carbonate

hardness exceeds 50%, and also suitable for drinking. The major element concentrations of all samples have lower content than the acceptable limits for drinking water. Finally, the reason for microbiological pollution hazards of water at Qunayya Spring area refers to the existence of leakage of the septic tanks in homes, and the use of chemical and natural fertilizers by farmers.

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References

- Abboud, I.A. (2008). Mineralogy and chemistry of urinary stones, patients from North Jordan. *Environmental Geochemistry and Health* 30(5):445-463. DOI: 10.1007/s10653-007-9128-7.
- Abboud, I.A. (2014). Describe and statistical evaluation of hydrochemical data of karst phenomena in Jordan: Al-Dhaheer Cave Karst Spring. *Journal of Applied Geology and Geophysics* 2(3):23-42.
- Abboud, I.A. (2018a). Geochemistry and quality of groundwater of the Yarmouk basin aquifer, north Jordan. *Environmental Geochemistry and Health* (2018) 40:1405-1435. DOI: 10.1007/s10653-017-0064-x.
- Abboud, I.A. (2018b). Statistical analysis of the hydro-geochemical evolution of groundwater in the aquifers of the Yarmouk basin, North Jordan. *Arabian Journal of Geosciences* 11: 111. DOI: 10.1007/s12517-018-3448-z.

- Abed, A.A. (1982). *Geology of Jordan*. Publications of Islamic Progress Library, Amman-Jordan (in Arabic).
- Abed, A.A. (2000). *Geology of Jordan, environment and water*. Jordan Geological Association, 571 pp. (in Arabic).
- Abed, A., Sadaqa, R., Al Kuisi, M. (2008). Uranium and Potentially Toxic Metals during the Mining, Beneficiation, and Processing of Phosphorite and Their Effects on Ground Water in Jordan. *Mine Water and the Environment* 27: 171-182. DOI: 10.1007/s10230-008-0039-3.
- Al Kuisi, M., Abed, A., Mashal, K., Saffarini, G. (2015). Hydrogeochemistry of groundwater from karstic limestone aquifer highlighting arsenic contamination: a case study from Jordan.
- Arabian Journal of Geosciences (2015) 8:9699–9720. DOI: 10.1007/s12517-015-1919-z.
- Al Kuisi, M., Al-Qinna, M., Margane, A., Aljazzar, T. (2009). Spatial assessment of salinity and nitrate pollution in Amman Zarqa Basin: a case study. *Environmental Earth Sciences* 59(1):117-129. DOI: 10.1007/s12665-009-0010-z.
- Al Kuisi, M., Mashal, K., Al-Qinna, M., Abu Hamad, A., Margane, A. (2014). Groundwater Vulnerability and Hazard Mapping in an Arid Region: Case Study, Amman-Zarqa Basin (AZB)-Jordan. *Journal of Water Resource and Protection*. 6(4):297-318. DOI:10.4236/jwarp.2014.64033.
- APHA (1998). Analytical methods for determining chlorine dioxide and chlorite in environmental samples by American Public Health Association. In Hofmann et al.
- Berner, E.K., and Berner, R.A. (1987). *The global water cycle, geochemistry and environment*. Prentice-Hall, New Jersey.
- Bhatt, K.S., and Saklani, S. (1996). Hydrogeochemistry of the Upper Ganges River. *Journal of The Geological Society of India* 48:171-182.
- Brunke, H.P. (1997). Groundwater resources of northern Jordan. V5 Part 1: Three-dimensional groundwater flow model of northern Jordan. Unpublished report prepared by Federal Institute of Geosciences and Natural Resources (BGR) and Water Authority of Jordan (WAJ). Technical cooperation project "Groundwater resources of northern Jordan". BGR archive No 118705: Amman and Hannover.
- CDM, Camp Dresser and McKee International Inc. (2002). *Jordan Water Quality Management Program: Compilation of technical Memoranda*. USAID Report, December 2002.
- Cushing, E.M., Kantrowitz, I.H., Taylor, K.R. (1973). *Water resources of the Delmarva Peninsular*. US Geological Survey Professional, Paper 822, Washington DC.
- Elemat, M. (2012). *Climate in Jordan*, Jordan Meteorological Department. Third MEDARE Workshop On Building Mediterranean Long-Term And Homogenized Climate Datasets. Istanbul, Turkey, 27-28 September 2012.
- Eraifej, N., and Abu-Jaber, N. (1999). Geochemistry and pollution of shallow aquifers in the Mafraq area, North Jordan. *Environmental Geology* 37(1-2): 162-170.
- Gibbs, R.J. (1972). Mechanism of trace metal transportation rivers. *Science* 180:71-73.
- Glover, C.R. (1996). *Irrigation Water Classification Systems*. Cooperative Extension Service College of Agriculture and Home Economics. Guide A-116, 4p.
- Hem, J.D. (1970). Study and interpretation of the chemical characteristics of natural water. 2nd, US Geological Survey Water-Supply Paper 1483, p 269.
- Hem, J.D. (1991). Study and interpretation of the chemical characteristics of natural water: USGS Professional Paper Book 2254. 3rd edn. Scientific Publishers, Jodhpur.
- Jacks, G. (1973). Chemistry of groundwater in a district in southern India *Journal of Hydrology* 18:185–200.
- John, R., and Holm (1986). *Fundamentals of general organic and biological chemistry*, 3rd edition.
- (JS) Jordanian Standards (1997). *Jordanian Drinking Water Standards*. JS 286/1997.
- Karanth, K.P. (1991). Impact of human activities on hydrogeological environment. *Journal of the Geological Society of India* 38:195-206.
- Karanth, K.P. (1997). *Groundwater assessment, development and management*. Tata McGraw-Hill Publisher, New Delhi.
- Margane, A., and Almomani, M. (1995). Groundwater resources of northern Jordan, V2 Part 1: Groundwater abstraction in northern Jordan. Unpublished report prepared by Federal Institute for Geosciences and Natural Resources (BGR) and Water Authority of Jordan, (WAJ), Technical cooperation project 'Groundwater Resources of Northern Jordan', BGR-archive No. 118702; Amman and Hannover.
- MM (2003). Ministry of Municipal: Village and environment affairs, Qunayya village organization plan-capital governorate (in Arabic).
- MWI (2000). Ministry of Water and Irrigation (MWI), Central Laboratories for Water Type, Amman, Bayadir Wadi Al-Seer, Jordan (in Arabic).
- MWI (2004). Ministry of Water and Irrigation (MWI) and German Technical Cooperation (GTZ); National water master plan. German Technical Cooperation, Amman.
- MWI (2010). Ministry of Water and Irrigation (MWI), Water Information System. Hydrological, Geological and Hydrogeological Data Bank. MWI, Water Resources and Planning Directorate, Amman, Jordan.
- NRA Natural Resources Authority, Geology Directorate, (2004). *Geology Map of Amman Zarqa Basin*. Scale 1:50,000. Natural Resources Authority Geology Directorate, Amman.
- NRC National Research Council (1974). *Nutrients and toxic substances in water for livestock and poultry*. National academy of Sciences, Washington, Dc.
- Pazand, K., Hezarkhani, A., Ghanbari, Y., Aghavali, N. (2012). Groundwater geochemistry in the Meshkinshahr basin Ardabil province in Iran. *Environmental Earth Science* 65:871-879. DOI: 10.1007/s12665-011-1131-8.
- Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water analyses. *American Geophysical Union Transactions* 25:914–923.
- Quennel, A. (1951). *The Geology and Mineral Resources of Trans-Jordan*. Colonial Geology and Mineral Resources 2: 85-115.
- Rao, N.S. (2002). Geochemistry of groundwater in parts of Guntur district, Andhra Pradesh, India. *Environmental Geology* 41:552-562. DOI: 10.1007/s002540100431.
- Rao, N.S., Subrahmanyam, A., Ravi, S.K., Srinivasulu, N., Babu, G.R., Surya, P.R., Venkatram, G.R. (2012). Geochemistry and quality of groundwater of Gummanampadu sub-basin, Guntur District, Andhra Pradesh, India. *Environmental Earth Sciences* 67(5):1451-1471. DOI: 10.1007/s12665-012-1590-6.
- Richards, L.A. (1954). *Diagnosis and improvement of saline and alkalis soils*. US Department of Agriculture Handbook 60, ed. Washington; United States Salinity Laboratory Staff, 159p.
- Rimawi, O. (1985). *Hydrochemistry and isotope hydrology of groundwater and surface water in the northeast of Mafraq, Dhuleil, Hallabat, Azraq Basin*. PhD dissertation, Technical University of Munich.

- Ritcher, B.C., and Kreitler, W.C. (1993). *Geochemical techniques for identifying sources of groundwater salinization*. CRC, New York. ISBN 1-56670-000-0.
- Ritzi, R.W., Wright, S.L., Mann, B., Chen, M. (1993). Analysis of temporal variability in hydrogeochemical data used for multivariate analyses. *Ground Water* 31:221–229.
- Salameh, E. (1996). *Water quality degradation in Jordan, Amman*. The Higher Council of Science and Technology, Ebert, Fredrich.
- Sawyer, G.N., and McCarty, D.L. (1967). *Chemistry of sanitary engineers*, 2nd edn, McGraw Hill, New York, 518 pp.
- Stallard, R.E., and Edmond, J.M. (1983). Geochemistry of Amazon River: the influence of the geology and weathering environment on the dissolved load. *Journal of geophysical research* 88:9671–9688.
- Stumm, W., and Morgan, J.J. (1996). *Aquatic chemistry*. Wiley-Interscience, New York.
- Tabieh, M.A.S. and Al-Horani, A. (2010). An Economic Analysis of Water Status in Jordan. *Journal of Applied Sciences* 10(16): 1695-1704.
- Todd, D.K. (1980). *Groundwater hydrology*. 2nd edition. John Willey and Sons, New York.
- Todd, D.K., and Mays, L.W. (2005). *Groundwater Hydrology*, third Edition, 2005. Larry W. Mays (Author). Publisher NG.
- UNESCO (2012). *Managing Water under Uncertainty and Risk*. The United Nations World Water Development, Report 4, Chapter 39.
- WAJ (1995). Water Authority of Jordan. Groundwater resources of northern Jordan. Project No. 89.2105.8. V2 Groundwater abstraction groundwater monitoring. Part 1, report and appendix 1-4, Amman, Jordan.
- WAJ (1996). Water Authority of Jordan. Groundwater resources of northern Jordan. Project No. 89.2105.8. V1 Rainfall, Spring discharge and baseflow. Part 2, report and appendix 1-4, Amman, Jordan.
- WAJ (2001). Water Authority of Jordan, Jordanian standards. Guidelines for drinking water.
- WAJ (2004). Water Authority of Jordan. Hannover and Natural Resources (BGR) and Water Authority of Jordan (WAJ), Technical cooperation project 'Groundwater Resources of Southern Jordan', Report No. 108652 and 107375; Southern Jordan, V1-5, Unpublished report prepared by Federal Institute for Geosciences.
- Wardam, B. (2004). *More politics than water: Water rights in Jordan*. Global Issue Papers (11). Published by the Heinrich Böll Foundation, © Heinrich Böll Foundation: 60-107.
- WHO (1998). World Health Organization. Guidelines for drinking water quality. V3, Drinking water quality control in small community supplies, Geneva.
- WHO (2004). World Health Organization. Guidelines for drinking water quality, Geneva.
- WHO (2011). World Health Organization. Guidelines for drinking water quality, Geneva.
- Wilcox, L.V. (1948). *Water quality for agriculture*, Annex I Water analyses of 250 selected irrigation supplies from various locations in the world, FAO Irrigation and drainage paper 29 Rev., 1, Reprinted 1989, 1994, California, USA.