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CHARACTERISTICS OF THE AQUIFER SYSTEMS IN WADI KAFRAIN CATCHMENT AREA, JORDAN

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This paper describes the characteristics of the aquifer systems in Wadi Kafrain Catchment Area, Jordan. The investigated area lies within Longitudes 210 E and 235 E, and Latitude 135 N and 160 N according to Palestine Grid System, covering an area of about 243 square kilometers. The geology of the study area consists of arenaceous deposits of lower Cretaceous and carbonate rocks of Middle to Upper Cretaceous. The main aquifer systems are the Kurnub Sandstone (K) Formation and Naur Formation (A1/2); they are considered among the principal sources of groundwater in Jordan. The main objectives of this research were to determine the spatial and temporal distribution of hydrogeologic characteristics of the groundwater aquifer systems in Wadi Kafrain catchment area and evaluate the water chemistry of the major water sources located in the study area. Data related to existing boreholes, geology, hydrology, hydrogeology, water level and the essential maps needed were collected and evaluated. Water samples were collected from the water resources available in the catchment area. The specific capacity of Naur Formation (A1/2) is determined to be in the range of 0.01 to 12 m^2/hr, with a transmissivities ranges between 4-10 m^2/d and storage coefficient: 0.0006. The specific capacity of the Hummar Aquifer is determined to be in the range of 1.1 to 8.8 m^2/day and the hydraulic conductivity range from 0.59 to 6.7 m/day. According to the Piper diagram, classification the water chemistry is classified as alkaline earth water with prevailing bicarbonate and alkaline earth water with prevailing bicarbonate chloride. The chemistry of the analysed water showed the following ionic ratio Ca > Na > Mg > K and HCO3 > Cl > SO4 > NO3. The water chemistry originates from dissolution of carbonate rocks. However, the water is generally classified as Ca-HCO3 water with low salinity.

INTRODUCTION

The gravest environmental challenge that Jordan faces today is the scarcity of water. Indeed, water is the decisive factor in the population/resources equation. Whereas water resources in Jordan have fluctuated around a stationary average, the country's population has continued to rise. A high rate of natural population growth, combined with periodic massive influxes of refugees, has transformed a comfortable balance between population and water. On a per capita basis, Jordan has one of the lowest levels of water resources in the world. Most experts consider countries with a per capita water production below 1,000 cubic meters per year to be water-poor countries.

Jordan falls in a region that suffers from water scarcity and shortage. The area of Jordan is about 90.000 km^2 with more than 71% of the land area receives an annual average rainfall of less than 100 mm. Rainfall distribution varies with spatial annual rainfall ranges from more than 600 mm in the northwest of Jordan at Ajlun areas to less than 50 mm in the eastern part of southern desert, (JICA and MWI, 2001).

Groundwater is considered as the major source of water in Jordan, and the only source of water in some areas of the country. Twelve groundwater basins have been identified in Jordan, (MWI, 2008). Furthermore, due to the increasing demand, the withdrawal from these aquifers is almost double that of the safe yield. This will eventually lead to the depletion of water resources and deterioration in the water quality (Abdulla and Al-Assa'd, 2006). Due to water scarcity, it is believed that water resources can be developed through adaptation of non-conventional water such as wastewater treatment technologies to provide extra water recourses and it is considered as part of the country's water supply-demand budget. In Jordan, the volume of treated wastewater produced in 2005 reached 82 MCM per year of which about 95% is reused for irrigation, however, it was reported that around two MCM of treated wastewater produced from Kherbit Essamra recharge the groundwater resources in Zarqa basin (Haddadin and Bdour, 2005).

This study was carried out to determine the spatial and temporal distribution of the hydrogeologic characteristics of the groundwater aquifer systems in Wadi Kafrain catchment area and to evaluate the water chemistry of the major water sources located in the study area. In the process of meeting the above objectives, aquifer characteristics such as aquifer thicknesses and depth to water table as well as static water level, would be defined. Aquifer parameters such as hydraulic conductivity (K) and transmissivity (T) would be established within the limits of the available data and information collected.

MATERIALS AND METHODS

Climate and Physiography

The climate of the study area characterized by a hot dry summer and cool wet winter with two short transitional periods in between. The first starts around mid-October and the second starts around the mid of May. High temperatures, low relative humidity and high evapotranspiration also characterize the dry period. In addition, moderate temperatures and high relative humidity of about 80 to 90% characterize the wet period, while high temperatures and lower relative humidity ranging from 45% to 66% characterize the dry period. The mean temperature value ranges from 12 to 30 ^{o}C, with daytime temperature range of 10 to 29 ^{o}C, (JMD, 2010). The prevailing wind direction is westerly-northwesterly winds in summer, shifting to the east in winter season. Westerly and southwesterly winds also occur. They are cold dry in winter, but hot, scorching and consequently harmful to the vegetation in summer.

The physiography of the study area is made up of the residual hills, lowlands and intermittent valleys. According to Palestine Grids, the study area lies between 210 to 235 E and 140 to 160 N, Figure 1. Wadi Kafrain drains an area west of Amman with an extent of 243 km^2 lying at elevations ranging from 1200 m ASL (above mean sea level) down to areas lying below sea level in the Jordan Valley. The geological and hydrological as well as the geotechnical and hydro-geochemical characteristics of the area and possibly human activities have contributed to gulley development and growth. Heavy rainfall (between 250 mm to more than 550 mm) could also be a factor that causes a rise in the water table.

The geologic materials underlying a watershed are one of the most salient features influencing the hydrologic flow regime .The rate of flow of both surface and subsurface water are dependent upon the nature of the material in the path of flow. It will be worthwhile to note that vegetation cover affects the rate of erosion. In most part of the study area, disparity in the vegetation-cover exists. The vegetation is dense in the low-lying marly terrains thus hindering erosion. However, in the hilly area, there are sparse vegetations, making them more prone to erosion.

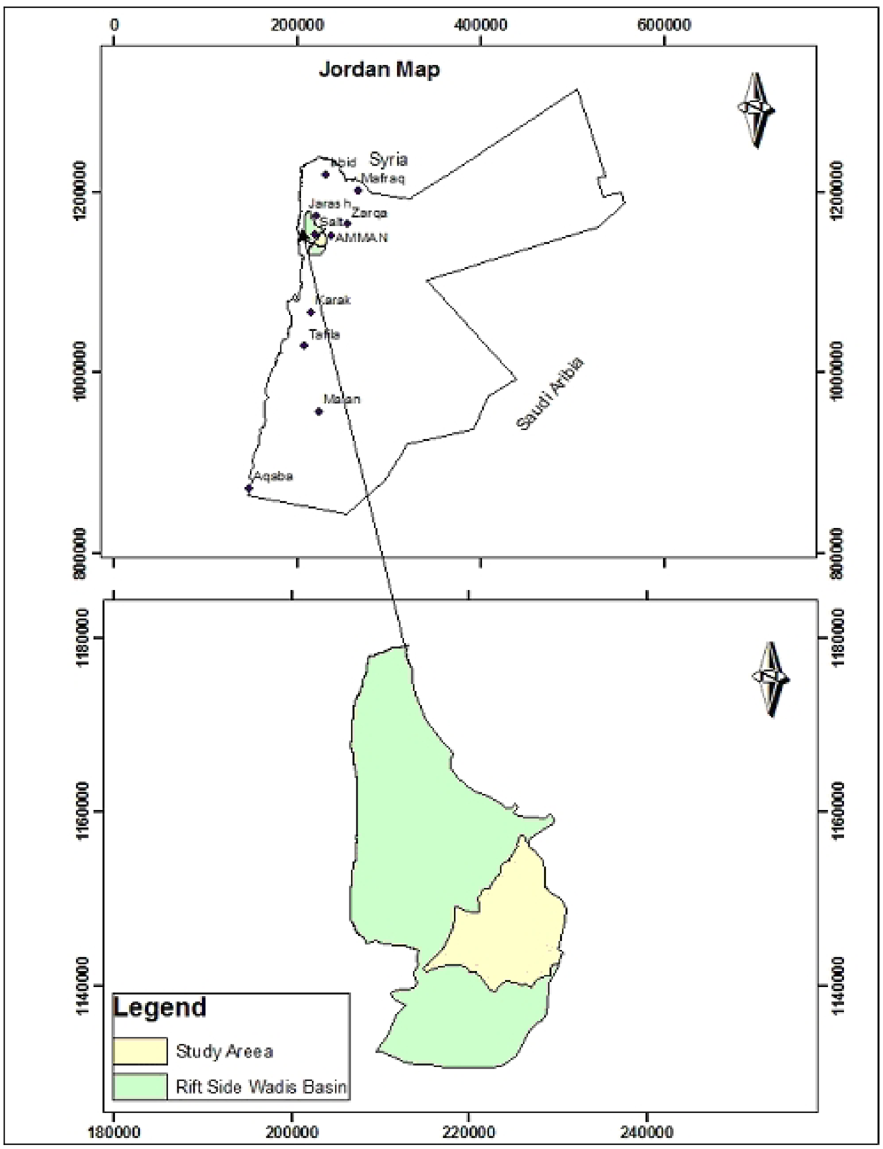

Figure 1. Location map of the study area.

Geology of the Study Area

The study is covered by the Cretaceous rocks, which are subdivided into two main sequences. The Lower Cretaceous sandstone sequence (Kurnub) which is overlain by marine Upper Cretaceous limestone, dolomites, marls and cherts. The stratigraphy of the study area is tabulated in Table 1, and the areal distribution of the outcropping formation is shown in Figure 2.

Lower Cretaceous

The Lower Cretaceous sequence of varicolored sandstone (K2) crops out at the lower limit of the study area particularly to the south west of Fuhais town and west of Mahis town. This sequence composed of fine, medium, and coarse-grained sandstone alternating with shales, yellow, reddish and greenish marls. The uppermost part is characterized by the gradual increase of fine sandy to silty shales and fine- grained sandstone, (Abed, 2000).

Upper Cretaceous

Generally, Cretaceous rocks in Jordan are mainly subdivided into two main sequences: the Early Cretaceous rocks and the Late Cretaceous rocks, which are further subdivided into Ajlun and Balqa Groups, (JICA and MWI, 2001).

Ajlun Group consists of marine sediments of Cenomanian-Turonian Age. The Ajlun group overlies the Kurnub sandstone and consists of about 350-460 m of alternation limestone, marly

Table 1. Lithological sequence and aquifer potential in Wadi Kafrain, (JICA and MWI, 2001).

System	Group	Formation	Symbol	Lithology	Thickness (m)	Aquifer Potential
Upper Cretaceous	Balqa	Amman-Al Hias	B2	Limestone , chert , chalk and Phosphorite	25-60	B2/A7 (Aquifer)
		W.Umm Ghudran	B1	Dolomitic marly limestone , marl and chert	30-40	
	Ajlun	Wadi Es sir	A7	Dolomitic limestone, limestone ,chert and marl	100-220	
		Shueib	A5/6	Marl , limestone	60-80	A5/6(Aquitard)
		Hummar	A4	Limestone , dolomite	50-60	A4 (Aquifer)
		Fuheis	A3	Marl , limestone	55-80	A3 (Aquitard)
		Naur	A1/2	Limestone , dolomite and marl	60 -90	A1/2 (Aquifer)
Lower Cretaceous	Kurnub	Subeihi	K2	Sand and shale ,clay and sandy and limestone	120-350	K2 (Aquifer)
		Aarda	K1	Sandstone marl and shale		K1 (Aquifer)

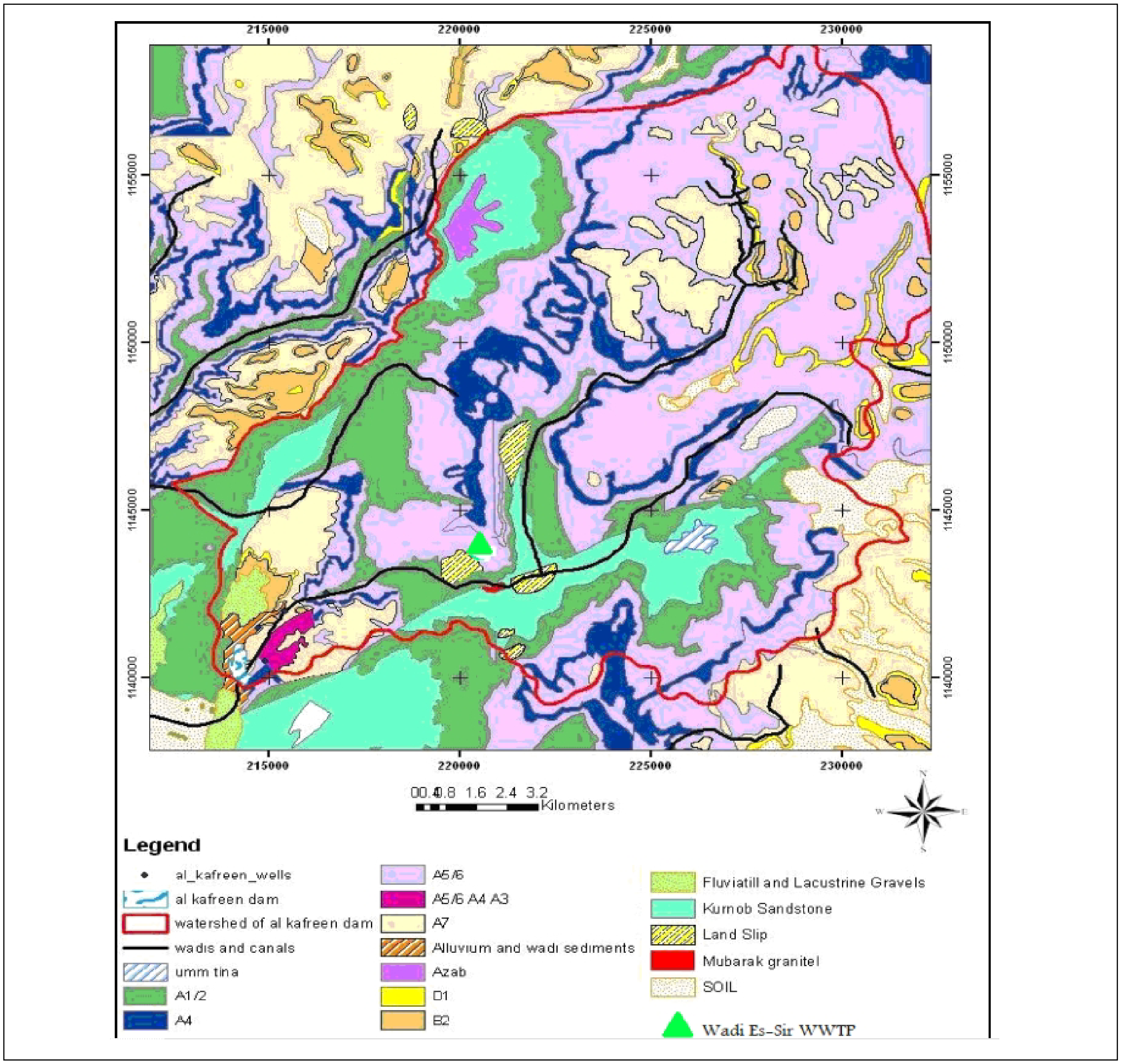

Figure 2. Geological map of Wadi Kafrain catchment area.

limestone and dolomitic limestone layers. This group has been distinguished over most of the area from A4-A7, (Al Sawarieh, 2005).

Belqa group comprises a predominantly Pelagic sequence of sediments including chalk, marl, chert, phosphate, coquina, limestone, and silicate sand overlaying the Ajlun Group. It ranges in age from Cenomanian to Eocene. MacDonald et al (1965) subdivided the group to five units (B1-B5). Parker (1970) named the units as Wadi Umm Ghudran, Amman, Muwaqqar, Umm Rijam and Wadi Shallala formations.

Field Study and Data Acquisition

This research was carried out in three stages; these are office work, fieldwork and laboratory work. During the implementation of this study, geological, hydrogeological and hydrological data were collected from Water published reports. Rainfall Isohyethal map was drawn using AutoCAD whereas Flow-net mas was drawn using Surfer 8.

Mean annual rainfall

The average depth of the rainfall over the study area was determined using the Isohyethal method and Thiessen method. The Isohyethal method involves the measurement of the areas between each two rainfall contour lines, multiplying this by the average precipitation between them, and then by dividing the summation of these products by the total area of the catchment as in the following formula (Chow and Mays, 1990):

$$P_m = \Sigma(A_i * P_i) / A$$

Where: P_m: mean areal rainfall in (mm), A_i: sub area, Pi: average precipitation between two successive contour lines and A: total area. The mean annual rainfall in the normal water year condition ranges between less than 350 mm to more than 525 mm, Figure 3.

Hydrogeologic Setting of the Study Area

The aquifer systems in Wadi Kafrain catchment area are subdivided into the Lower Cretaceous Aquifer Complex (Kurnub Sandstone-K), and Upper Cretaceous Aquifer Complex, (Naur-A1/2), (El-Naqa and Al-Shayeb, 2008).

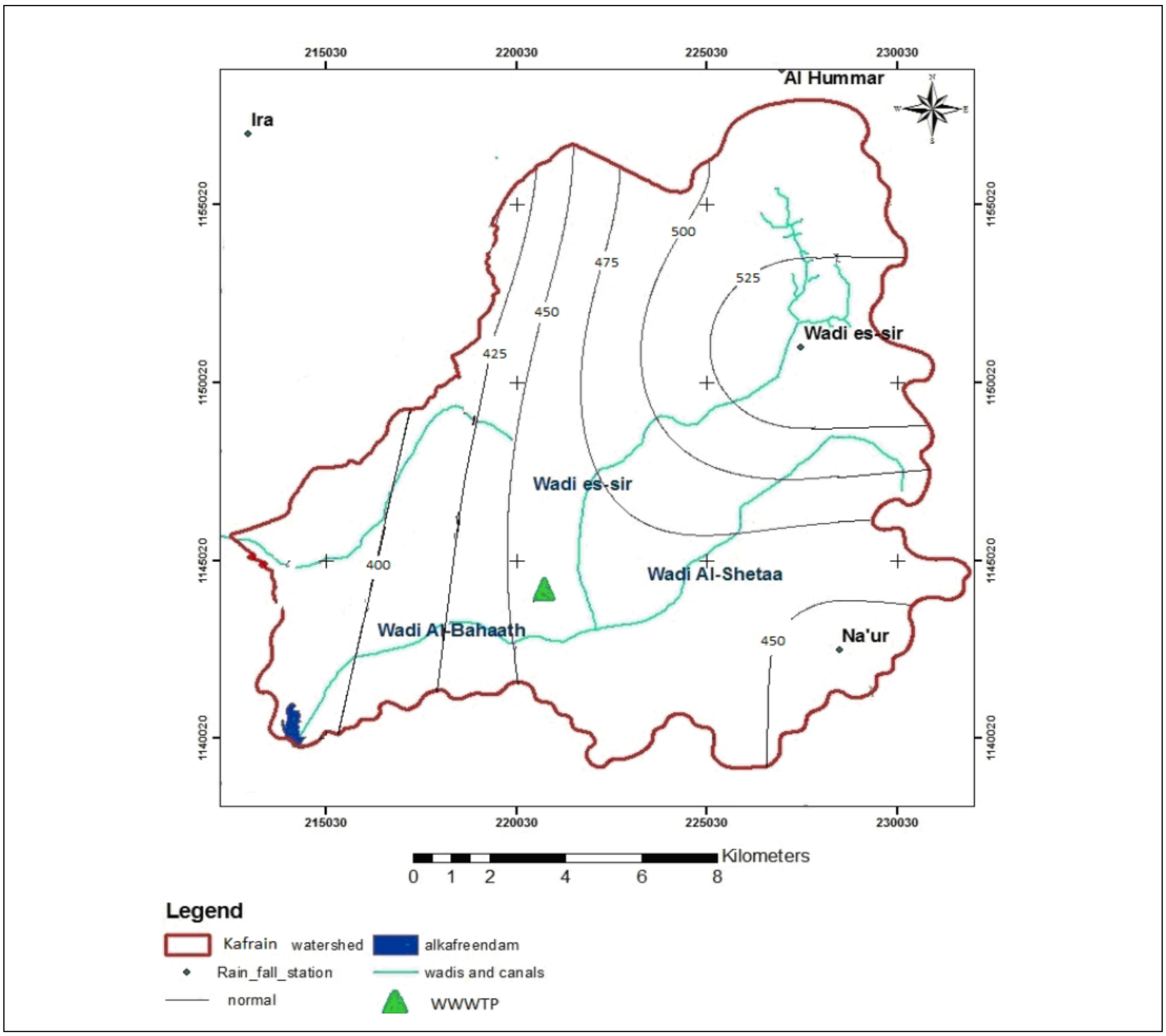

Figure 3. Isohyethal map of the study area average year, (Ta'any, 2012).

Lower Cretaceous aquifer Complex (Kurnub Sandstone-K)

The Kurnub sandstone of Lower Cretaceous is a regional aquifer in Jordan and consists of massive, white and varicolored sandstone reach a maximum thickness of about 300 m (JICA and MWI, 2001). It outcrops out in the west and extremely southwest of Wadi Kafrain Catchment area. The Kurnub sandstone aquifer is described as a semi-confined aquifer underlaying the carbonate aquifers and separated from them by the marls and shales of Nau'r Formation (A1/2) with a thickness range between 120 - 350m. In general, the transmissivities of this aquifer range between 3.0-1700 m^2/d and the Hydraulic conductivity ranges between (1-2.6) m/d while the storage coefficient ranges between 0.001-0.10, (JICA and MWI, 2001).

Upper Cretaceous Aquifer Complex (Nau'r-A1/2)

This formation is of Lower Cenomanian age, its thickness ranges between 200-300 m, Balawi, 2003. It is composed of dolomitic limestone, sandy-marl, shale and alternation of marls and limestone. This formation outcrops in most parts of the study area except the southern part.

The permeability of this aquifer is low and the recharge is limited to the exposed area. The total recharging area is about 4.5 MCM/Y (WAJ, 1989). The specific capacity of the aquifer system is determined to be in the range of 0.01 to 12 m^3/hr, with transmissivities range between 4-10 m^2/d and storage coefficient 0.0006. The hydraulic conductivity of this aquifer is between (0.003-3) m/s.

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Water Sampling

Water samples were collected from Kafrain catchment area in June for summer season in the year 2009 and in January 2010 for winter from downstream groundwater wells; Kafrain 4, 8, 10, 12 and from three private wells. Effluent of Wadi Es-Sir WWTP samples and Kafrain dam were collected in the same period. In the upper stream of the plant, samples were taken from Dalia, Wadi Es-Sir, Kursi and Bahhath springs in September 2010 and in January 2011 for summer and winter respectively. Standard procedures used in Water Authority of Jordan (WAJ) were followed for the collection of water samples for physical and chemical analysis. Polyethylene bottles were used for water sampling collected for determination of its inorganic content while Dark glass bottles were used for sampling of water for determination of its organic content.

RESULTS AND DISCUSSION

Groundwater flow and Aquifer Parameters

Infiltration is controlled by the steep slopes, but is quite good due to relatively high rainfall in the area. The limestone of the A1 Formation is a good aquifer. Facies changes with the A4 limestone formation limit its potential. The marls and marly limestones of the remainder of the Ajlun Group (A5/6) must be considered as aquicludes. The groundwater flow pattern in the upper aquifer system within the study area is strongly governed by several features. The most important features are; the recharge mounds, the geological structural setting, the presence of Wadi Al Kafrain. Table 2, represents the aquifer properties in the catchment area.

The Kurnub Aquifer Complex of the Lower Cretaceous consists of massive, white sandstones and varicolored sandstones reaching a total thickness of about 300 m. The specific capacity of Naur Formation (A1/2) is determined to be in the range of 0.01 to 12 m^3/hr, with a transmissivities range between 4-10 m^2/d and storage coefficient: 0.0006, while hydraulic conductivity of this aquifer is between (0.003-3) m/s.

Table 2. Aquifer properties according to the main wells drilled in the catchment area.

Location (IDN)	Coordinates		Altitude	Well Depth(m)	Aquifer type	Yield(m^3)	Salinity (ppm)
	E	N					
AN1019	1141477	214727	-72	700	K	78	544
AN1029	1141991	215448	-100	620	K	80	663
AN1018	1140500	214900	-100	550	A1/A2	400	524
AN3003	1142550	216500	-75	475	A1/A2	100	396

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Hydrological characteristics

Four rainfall stations exist in and around the study area these are: (Wadi Es-Sir, Hummar, Ira and Nau'r station). All stations measure the daily rainfall and one of them have also rainfall recorder, giving hourly rainfall events. Table 3, represents the rainfall stations, their locations, type of gauges, and their approximate altitudes. The density of the stations is about 61 km²/station. This density is sufficient for the evaluation of regional distribution and the determination of annual averages, according to the World Meteorological Organization Guide, (WMO, 1994).

Generally, the mean annual rainfall decreases across the catchment area from northeast to southwest (Figure 2). The coefficient of variation ranges from 0.35 to 0.49. The minimum variation coefficient was found for the Wadi Es-Sir rainfall station, whereas the highest variation coefficient was found for Nau'r rainfall station. This implies that the distribution of rainfall is much better in the northeastern and eastern part of the catchment (Wadi Es-Sir rainfall station) than in the western and southwestern part of the catchment (Nau'r rainfall station).

The water balance was performed using the water budget approach. The average annual evapotranspiration (ET) according to Penman equation was found to be 127.78 MCM, 107.29 MCM and 80.43 MCM in the wet, normal and dry conditions, respectively. The rate of evaporation

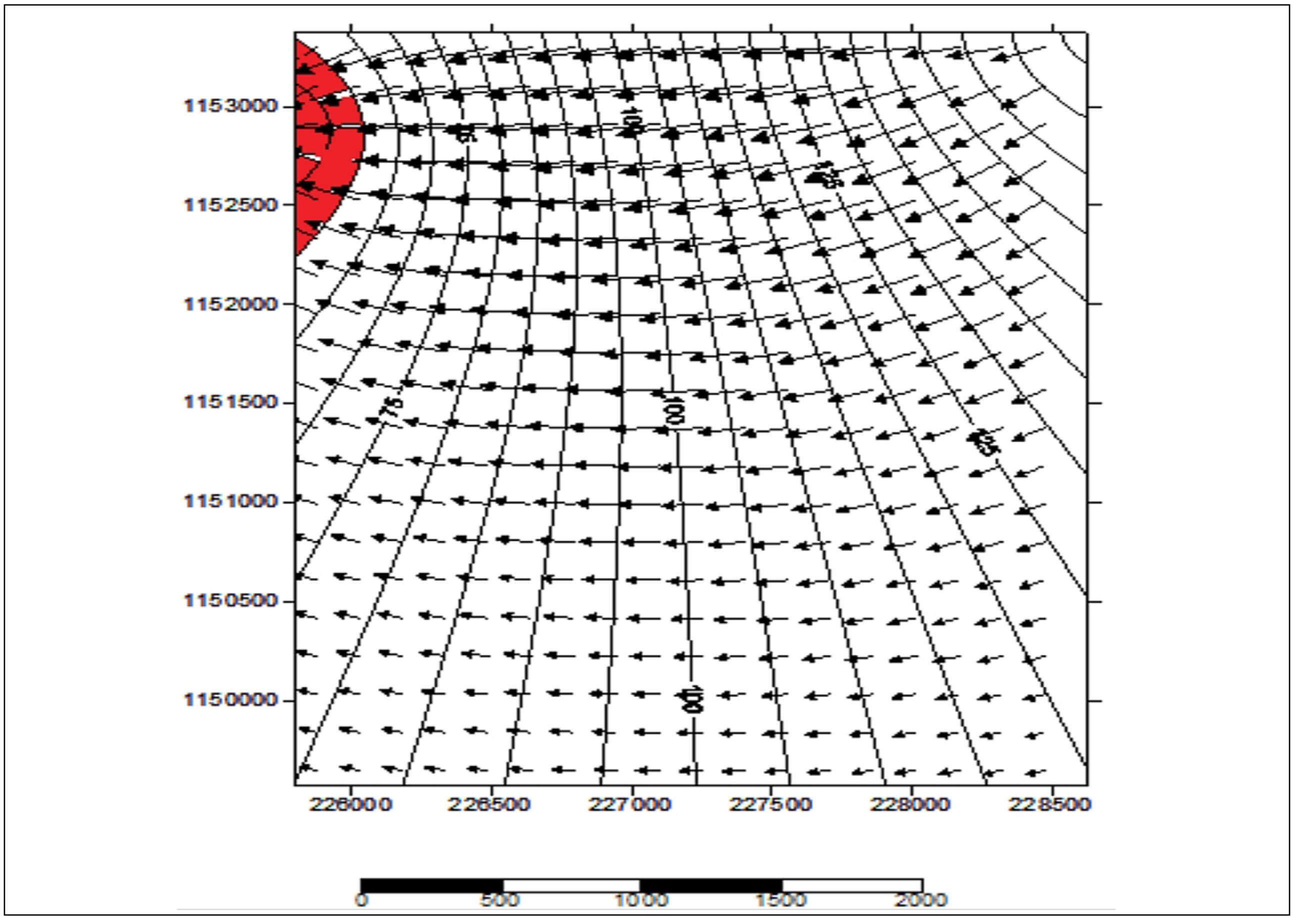

Figure 4. Groundwater movement in the catchment area.

ranges between 83.30% in the wet year and 99.00% in the dry water year, while average annual recharge of the upper aquifer of Wadi Kafrain catchment was found to range between 0.00 and 13.65 MCM in dry and wet water years representing an infiltration rate of 0.00% and 8.9%, respectively. The results of the water balance calculations for the whole catchment area are presented in Table 4.

Hydrochemical analysis

Water samples were collected from Kafrain catchment area in June to represent summer season in the year 2009 and in January 2010 to represent the winter season from downstream groundwater

Table 3. The Rainfall Stations Exist in the catchment area

Name of Rainfall Station	Coordinates		Altitude (m)	Type of station	Average annual Rainfall(mm)
	East	North			
Wadi Es-Sir	227.50	115.100	720	Daily and Hourly	480.9
Hummar	227. 0	115.880	925	Daily	540.3
Nau'r	228.50	114.250	800	Daily	354.1
Ira	213.00	115.700	280	Daily	277.7

Table 4. Calculated water balance for Wadi Kafrain catchment area.

Water Year	Rainfall (MCM)*	Runoff (MCM)	Evaporation (MCM)	Infiltration (MCM)	Runoff (%)	Evaporation (%)	Infiltration (%)
Wet	153.33	11.96	127.78	13.65	7.80	83.30	8.90
Norma l	116.64	4.90	107.29	3.73	4.20	92.60	3.20
Dry	81.43	0.81	80.43	0.00	1.00	99.00	0.00

wells; Kafrain 4, 8, 10, 12 and from three private wells. Effluent of Wadi Es-Sir WWTP samples and Kafrain dam were collected in the same period. The chemical and physical analyses were performed on the collected samples to determine concentrations of: (HCO_3^-, Cl^-, NO_3^-, SO_4^{-2}, Ca^{+2}, Mg^{+2}, Na^+ and K^+). All analyses were carried out at the Ministry of Water and Irrigation (Jordan). The samples were analyzed according to the standard methods for the examination of water and wastewater, Table 5 shows the major ionic compositions, pH and EC in summer and in winter season for the collected water samples.

Water quality evaluation

Naturally, water is never pure; it always contains at least small amounts of dissolved gases and solids. The quality of any type of water reflects its potential use for domestic, industrial and irrigation purposes. The quality of water depends on its chemical, physical and biological constituents. Due to the long residence time of groundwater in the invisible subsurface environment, the effects of pollution may first become apparent tens to hundreds of years afterwards, (Appelo and Postma, 1996).

Several parameters such as hardness, soluble sodium percentage (SSP) and sodium adsorption ratio (SAR) were calculated to determine the suitability of the collected water samples in the study area use. So, the suitability of the water for any particular use is determined by comparing the calculated and measured parameters with standards of particular use. The quality of the water samples in the study area can be evaluated as follows:

Domestic Water

The suitability of water for domestic purposes was determined by comparing the constituents with the Jordanian standards (286/2008) and the World Health Organization (WHO) standards (1995) for drinking water. According to Jordanian standards, water with total dissolved solids (TDS) less than 1500 mg/L is acceptable for human consumption, while the WHO standards water

Table 5. Chemical compositions, and physical parameters for the collected samples.

	Site	Descriptive Statistics	pH	EC (µs)	HCO3 (meq/l)	Cl (meq/l)	NO3 (meq/l)	SO4 (meq/l)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)
Summer	GW Downstream	Min	6.75	709	3.592	1.592	2.142	1.826	4.092	2.082	1.761	0.120
		Max	9.57	1885.0	7.921	10.290	4.248	4.451	5.888	3.983	8.526	0.420
		Mean	7.62	1109.9	5.672	4.523	1.607	2.733	3.836	2.936	4.181	0.256
	Kafrein Dam	Min	7.91	699	4.805	2.059	3.884	0.449	4.030	1.831	1.171	0.070
		Max	8.29	784	5.390	2.309	4.357	0.504	4.520	2.054	1.313	0.079
		Mean	8.12	738.7	5.078	2.175	4.105	0.475	4.258	1.935	1.237	0.074
	Wadi Sir WWTP	Min	7.5	815	5.822	2.397	3.213	0.666	5.763	2.058	1.958	0.079
		Max	7.6	840	5.904	2.679	3.927	0.728	5.998	2.222	2.175	0.102
		Mean	7.55	827.5	5.863	2.538	3.570	0.697	5.881	2.140	2.066	0.091
	GW Upstream	Min	6.91	754	4.772	1.962	0.129	0.549	3.468	1.852	1.421	0.060
		Max	7.32	979	6.708	27.608	3.406	2.288	5.350	2.832	3.292	0.180
		Mean	7.18	882.8	5.642	14.050	2.090	1.442	4.473	2.411	2.156	0.103
Winter	GW Downstream	Min	6.85	735	4.772	1.962	0.129	0.549	3.468	1.852	1.421	0.060
		Max	8.27	1825	6.708	27.608	3.406	2.288	5.350	2.832	3.292	0.180
		Mean	7.56	1280	5.642	14.050	2.090	1.442	4.473	2.411	2.156	0.103
	Kafrein Dam	Min	7.54	997	4.822	4.616	1.214	2.454	2.789	3.086	3.802	0.271
		Max	8.34	1330	6.134	6.159	1.621	3.274	3.723	4.115	5.072	3.356
		Mean	7.89	1185.7	5.565	5.491	1.444	2.919	3.318	3.671	4.521	1.329
	Wadi Sir WWTP	Min	7.85	1141	5.592	4.346	3.570	2.226	4.261	3.415	3.612	0.166
		Max	8.1	1308	7.921	5.316	5.712	2.808	4.765	4.362	4.785	0.230
		Mean	7.95	1218	6.719	4.724	4.522	2.475	4.490	3.827	4.176	0.199
	GW Upstream	Min	7.42	701	4.432	1.452	2.327	0.469	4.050	1.641	1.151	0.020
		Max	8.43	831	4.752	2.222	3.666	0.559	5.010	1.841	1.401	0.070
		Mean	7.93	766	4.592	1.837	2.997	0.514	4.530	1.741	1.276	0.045

with TDS less than 1000 mg/L is acceptable for human consumption.

The total hardness was calculated as mg/l as $CaCO_3$ according to the following relation:

$$TH = (2.5^* Ca^{2+} + 4.1^* Mg^{2+}) \ldots\ldots\ldots\ldots \text{(Todd, 1980)}$$

where: Ca^{2+} and Mg^{2+} concentration in mg/L, and TH = is the total hardness in mg/L as $CaCO_3$

According to Sawyer and McCarty, 1967 water are classified as soft, moderately hard, hard and very hard, Table 6. The classification of the Kafrain dam, Wadi Sir WWP and groundwater samples hardness in the study area is shown in Table 7.

Generally, all of the analyzed water and groundwater wells water are classified as very hard water, and this is due to the nature of limestone aquifer.

Evaluation of water quality for irrigation uses

The suitability of water for irrigation is determined by its mineral constituents and the type of the plant and soil to be irrigated. The successful growth of the plants depends on the quality of the water for irrigation. The hydrochemical parameter of the water limited the irrigation water suitability, with other criteria's such as the soil properties, irrigated crops, local climate and management of irrigation and drainage (Gadjalska, 1994).

Due to that more generalized criteria, which represent combinations of the different water parameters, were adopted worldwide (i.e. salinity (EC), SAR, SSP and RSC) for the evaluation of water quality for irrigation purposes.

Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) that expresses the relative activity of sodium ions in the exchange reactions with the soil. This ration measures the relative concentration of sodium to calcium and Magnesium**.** It is used in determining the suitability of water for irrigation purpose.

High sodium ions in water affects the permeability of soil and causes infiltration problems, Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops. The SAR equation can be represented as follows:

Table 6. Classification of water based on hardness (Sawyer and McCarty, 1967).

Site	Hardness as$CaCO_3$	Class
GW- Downstream	0-75	Soft
Kafrain Dam	75-150	Moderately Hard
Wadi Sir WWP	150-300	Hard
Gw- Upstream	>300	Very Hard

Table 7. Classification of hardness for water samples, based on Sawyer and McCarty (1967).

Season	Site	Hardness as$CaCO_3$	Class
Summer	GW- Downstream	338.4	Very hard
	Kafrain Dam	309.7	Very hard
	Wadi Sir WWP	401.2	Very hard
	GW- Upstream	344.2	Very hard
Winter	GW- Downstream	344.2	Very hard
	Kafrain Dam	349.1	Very hard
	Wadi Sir WWP	415.6	Very hard
	GW- Upstream	313.7	Very hard

$$SAR = Na / \sqrt{(Ca + Mg) / 2}$$

The availability of sodium in the soil in exchangeable form replaces calcium and magnesium adsorbed on the soil clays and cause dispersion of soil particles, this dispersion leads to breakdown of soil aggregates. The soil becomes hard and compact when dry and reduces infiltration rates of water and air into the soil affecting its structure.

The collected water samples during this study belong to S1 group with SAR values and range between less than 1 and 2.42. Most of the analyzed water samples have low sodium hazard and high salinity range between 738.67 and 1218 (µS/cm) and classified as C_3-S_1, except Kafrain dam water have low sodium and medium salinity hazard (< 750 µS /cm) and classified as C_2 - S1. Classification of irrigation water based on SAR values is shown in Table 8 and Figure 5.

Soluble sodium percentage

Soluble sodium percentage (SSP) is an estimation of the sodium hazard of irrigation water like SAR and SSP is an important factor for classifying the irrigation water. Lloyd and Heathcoat, (1985) defined the SSP of water by the following equation:

$$SSP = ((Na + K) * 100) / (Ca + Mg + Na + K)$$

where the ionic concentrations are in milliequivalent per liters. Table 9, shows the classification of irrigation water according to the soluble sodium based on Todd 1980, Table 10, represents the classification of the water samples collected in summer and winter season in the study area, based on the sodium percentage. Water samples from four sites are classified as permissible and two sites are good water for irrigation purposes, as shown in Table 10.

Classification of water samples according to Langguth

The analyzed water samples from different sites are firstly plotted on Trilinear Diagram of Piper (Piper, 1997), thereafter, they assessed depending on Langguth Classification (1966), The classification is based on the concentration of the milliequivalent percentages of the four major actions (calcium, magnesium, sodium and potassium) and anions (bicarbonate, sulfate, chloride and nitrate), Figure 6.

The water chemistry is classified as alkaline earth water with prevailing bicarbonate and alkaline earth water with prevailing bicarbonate chloride. The chemistry of the analysed water showed the following ionic ratio Ca ? Na ? Mg ? K and HCO3 ? Cl ? SO4 ?NO3. , Water chemistry originates from dissolution of carbonate rocks. However, the water is generally classified as Ca-HCO3 water

Table 8. Classification of water for irrigation based on salinity and Sodium Adsorption Ratio (SAR).

Season	Site	SAR	EC (µs/cm)	Class
Summer	GW- Downstream	2.27	1109.86	C3-S1
	Kafrain Dam	0.70	738.67	C2-S1
	Wadi Sir WWP	1.03	827.50	C3-S1
	Gw- Upstream	1.16	882.75	C3-S1
Winter	GW- Downstream	2.16	1280.00	C3-S1
	Kafrain Dam	2.42	1185.67	C3-S1
	Wadi Sir WWP	2.05	1218.00	C3-S1
	Gw- Upstream	0.72	766.00	C3-S1

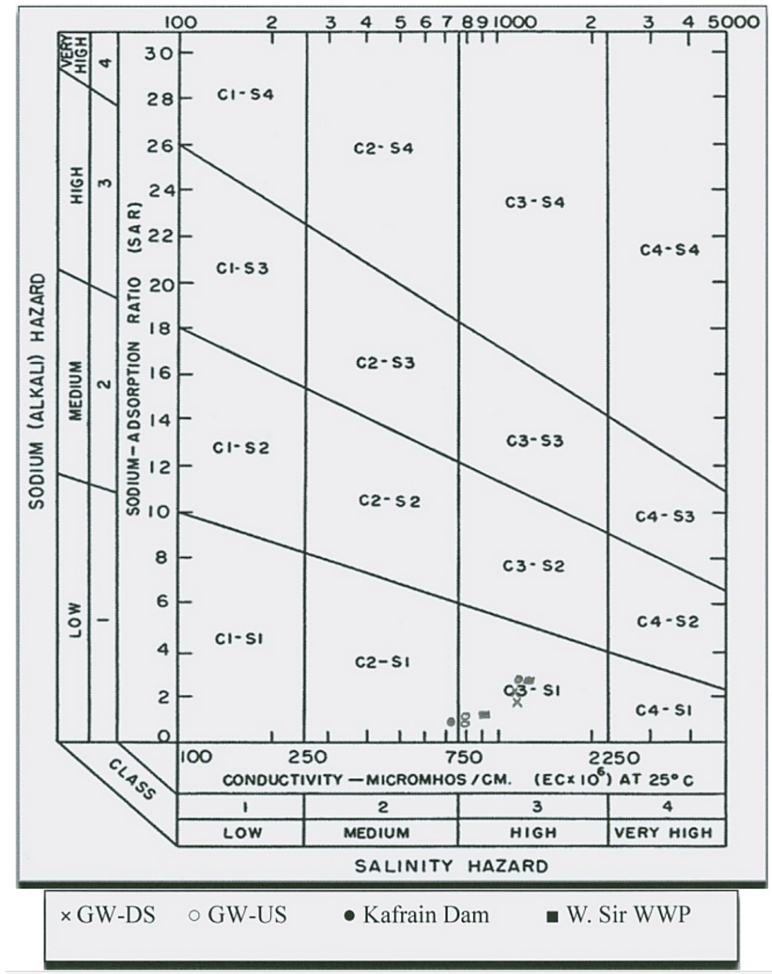

Figure 5. Wilcox diagram illustrating the chemical analyses of the collected water samples.

Table 9. Classification of the irrigation water based on Sodium Percentage (Todd, 1980).

Water Class	Sodium Percentage	EC (µs/cm)
Excellent	< 20	<200
Good	20-40	250-750
Permissible	40-60	750-200
Doubtful	60-80	2000-3000
Unsuitable	>80	>3000

Table 10. Classification of water samples for irrigation based on Sodium Percentage, (Todd, 1980).

Season	Site	Sodium Percentage	EC (µs/cm)	Class
Summer	GW- Downstream	40	1109.86	Permissible
	Kafrain Dam	17	738.67	Good
	Wadi Sir WWP	21	827.50	Permissible
	Gw- Upstream	25	882.75	Permissible
Winter	GW- Downstream	25	1280.0	Permissible
	Kafrain Dam	46	1185.67	Permissible
	Wadi Sir WWP	34	1218.00	Permissible
	Gw- Upstream	17	766.00	Good

with low salinity.

CONCLUSIONS

· The mean annual rainfall decreases across the catchment area from northeast to southwest and the coefficient of variation ranges from 0.35 to 0.49. The minimum variation coefficient was found for Wadi Es-Sir rainfall station, whereas the highest variation coefficient was found for Nau'r rainfall station. This implies that the distribution of rainfall is much better in the northeastern and eastern part of the catchment (Wadi Es-Sir rainfall station) than in the western and southwestern part of the catchment (Nau'r rainfall station).

· The rate of evaporation ranges between 83.30% in the wet year and 99.00% in the dry water year, while average annual recharge of the upper aquifer of Wadi Kafrain catchment was found to range between 0.00 and 13.65 MCM in dry and wet water years representing an infiltration rate of 0.00% and 8.9%, respectively.

· The transmissivity of the Kurnub (K) Sandstone aquifer ranges between 3.0-1700 m^2/d and the hydraulic conductivity ranges between (1 - 2.6) m/d while the storage coefficient ranges between 0.001-0.10.

· The specific capacity of the Naur (A1/2) aquifer system is determined to be in the range of 0.01 to 12 m^3/hr, with a transmissivities range between 4-10 m^2/d and storage coefficient: 0.0006, while hydraulic conductivity of this aquifer is between (0.003-3) m/s.

· The Flow-net map showed that, the groundwater flow direction is mainly from east to west and the most promising area for the extraction of groundwater is the extremely northwest area.

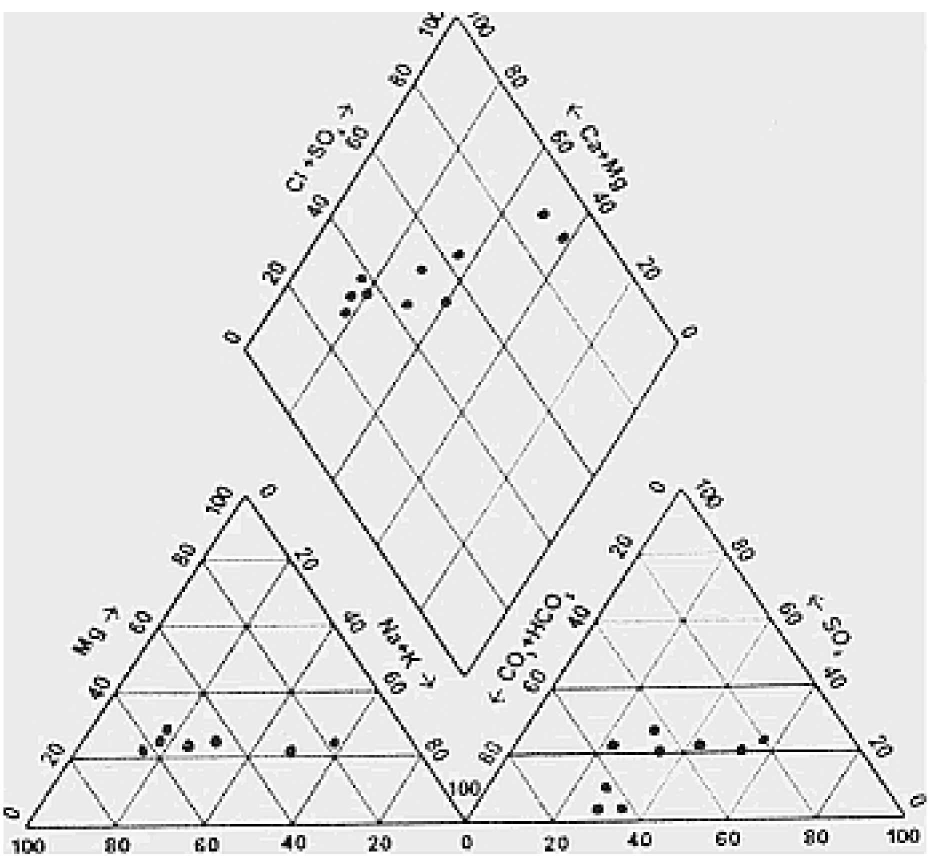

Figure 6. Piper Diagram used for water classification based on the percentage of meq/l.

· According to Sawyer and McCarty, the analyzed water from the collected sites are classified as very hard water, and this is due to the nature of limestone aquifer.

· According to USA Salinity diagram, the water samples were classified into two main groups according Wilcox classification: C2-S1 and C3-S1. Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. Water of medium salinity (C2) can be used if a moderate amount of leaching occurs. Crops having moderate salt tolerances, such as potatoes, corn, wheat, oats, and alfalfa, can be irrigated with C2 water without special practices. Water of high salinity (C3) cannot be used on soils having restricted drainage.

· The chemistry of the analysed water showed that, the following ionic ratio Ca > Na > Mg >K and HCO3 > Cl > SO4 >NO3. The water chemistry originates from dissolution of carbonate rocks. However, the water is generally classified as Ca-HCO3 water with low salinity.

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