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EVALUATION OF GROUNDWATER QUALITY IN THE YARMOUK BASIN, NORTH JORDAN

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The groundwater resources of the Yarmouk Basin were evaluated to aid in their planning, development and management. The principal sources of groundwater in this basin are classified as Shallow and Upper Cretaceous Aquifers. Groundwater levels in this basin vary from zero at the Mukheiba area, where aquifers are under water table conditions, to 250 m below the ground surface near Irbid, where the aquifers are confined. Water table fluctuation between the wet and dry seasons is high; with a mean of about 9 m. Directions of groundwater flow are due north and northwest. Calcium and magnesium are the dominant ions in the groundwater in this basin, while bicarbonate is the most abundant of the anions. Concentrations of the major cations and anions are low compared with their permissible levels in potable water. The total dissolved solids is 1,069 mg l^{-1} and below, which indicates fresh water. The water has low to moderate electrical conductivity (424-1,670 mS cm^{-1}) and pH below 8.12. The concentration of total iron exceeds the recommended optimum limit for drinking water and some industrial usage, but falls below the maximum permissible limit of 1 mg l^{-1}. The low sodium adsorption ratio (0.6-5.27) coupled with low electrical conductivity, gives the water low sodicity and salinity hazards. Thus, the groundwater is generally of suitable chemical quality for domestic, agriculture and most industrial uses.

INTRODUCTION

Jordan's primary sources of water are aquifers and basins fed and recharged through annual rainfall. The groundwater resources of Jordan are subdivided into groundwater basins on the bases of natural boundaries (such as structural features, aquifer extent, and groundwater divides) and administrative boundaries. The Yarmouk Basin (hereafter denoted YB) in the northern part of the Jordan highlands is the largest. The basin lies approximately within latitudes 32° 20' to 32° 45' N and longitudes 35° 42' to 36° 23' E, and covers an area of about 1,426 km^2 (Figure 1).

The North Jordan area between the Zarqa and Yarmouk Rivers is a key area on the hydrological map of the country. The adjacent mountains and height elevations (Ajlun Highlands and Golan Heights), which are 1,200 m above sea level (m asl), are the highest uplands east of the Jordan Rift Valley (JRV) (Figure 1). These areas receive a high rainfall of about 500 mm/yr. The Yarmouk River flows at the borders of Syria and Jordan and is the northern boundary of the study area. The Jordan River is the western boundary (Figure 1). The Yarmouk River originates from Jabel Al-Arab (Syria) and drains from Jordanian and Syrian territories. The discharge of the Yarmouk River is 7,200 $m^3\ h^{-1}$, of which 2,005 $m^3\ h^{-1}$ is from the Mukheiba wells (Jordan Valley Authority 2006, personal communication). They contribute about 57% of the flow in the King Abdullah Canal, which supplies the Jordan River area with irrigation water, and potable water in the summer for the capital Amman.

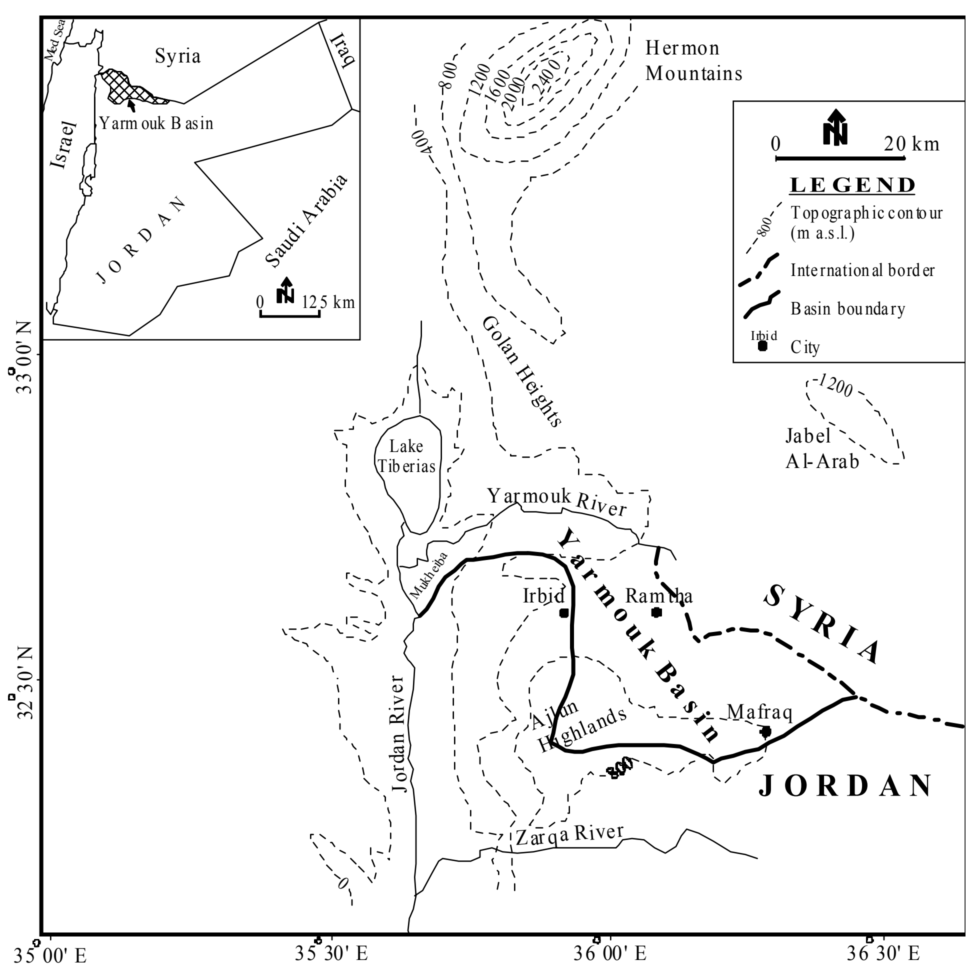

Figure 1. Location map of north Jordan showing principal physiographic features.

The study area has the semiarid climate of the Mediterranean Sea region with a limited amount of rainfall and high temperatures. Meteorological records collected by the Jordan Meteorological Department (JMD) at the Irbid station (north Jordan) during the years 1963 to 2006 give the mean annual rainfall and temperatures as 410 mm and 18 °C, respectively. Most of the rain falls between the months of November and April, with a peak in January (JMD 2006, personal communication).

As a result of the increasing popularity of the study area, its population is growing and an increased demand for water resources is expected. The objectives of this study include studying the occurrence, movement, availability, quality and uses of groundwater in the basin. The study is intended to aid in planning, development and management of the groundwater resources. The scope of the study included collection and analysis of groundwater samples, water levels and water use to describe the water resource status of the basin.

GEOLOGY AND HYDROGEOLOGY

Geological setting

Geologically, the rock formations of the study area are classified as the Ajlun Group, Balqa Group and Jordan Valley Group of Upper Cretaceous to Tertiary ages (Makhlouf et al., 1996; Moh'd, 2000). The oldest is the Wadi Es-Sir Limestone (WSL) formation of Turonian age belonging to the Ajlun Group, essentially composed of limestone and dolomitic limestone. In northern Jordan, and locally in the basin area, the upper 100 m thickness of the WSL formation is exposed on the southwestern part of the basin area (Figure 2). The WSL formation of the Ajlun Group is overlain by the rocks of the Balqa Group and include, in ascending order: Wadi Umm Ghudran (WG), Amman Silicified Limestone (ASL), Muwaqqar Chalk-Marl (MCM), Umm Rijam Chert-Limestone (URC) and Wadi Shallala (WS) formations. The base of the Balqa Group, WG formation of Santonian age, comprises marl, marly limestone, chalk and chert, up to 40 m thick exposed in Wadi Umm Ghudran Ed Dibab, south Irbid (Figure 2). The overlying limestone, chert, chalk and phosphorite beds that are exposed in the southern part of the basin area are members of the ASL formation (Campanian age). At the site this formation is about 60 m thick. Bituminous marl and clayey marl of the MCM formation of Maestrichtian age overlies the ASL formation and is exposed in the central part of the basin area. These are about 200 m thick (Parker, 1970; Makhlouf et al., 1996; Moh'd, 2000). Alternating beds of limestone, chalk and chert of the URC formation of Paleocene age overlie the MCM formation. In the basin area, the URC formation outcrops at the north (Figure 2). The thickness of this formation is 200 m at the outcrop. At the site of Wadi Shallala (northeast Irbid; Figure 2), a 35 m thickness of chalk and marly limestone with glauconite is present. These are of WS formation of Eocene age. In the eastern part of the basin area, basaltic flows (BS formation) of the Jordan Valley Group (Oligocene age) cover rocks of the Balqa Group. In addition, basalts were found as small exposures scattered at areas south, north and northwest of Irbid (Figure 2). Table 1 shows a stratigraphic column of the geology of northern Jordan.

Hydrogeology

Generally, the groundwater aquifers of Jordan are divided into three main hydraulic complexes (Salameh, 1996), i.e., the Deep Sandstone Aquifer Complex, the Upper Cretaceous Aquifer Complex, and the Shallow Aquifer Complex (Table 1). Although this study is concentrated on the Upper Cretaceous and Shallow Aquifers, it is important to indicate the significant role of the Deep Sandstone Aquifer Complex where it occurs in the adjacent highlands. It may contribute to the

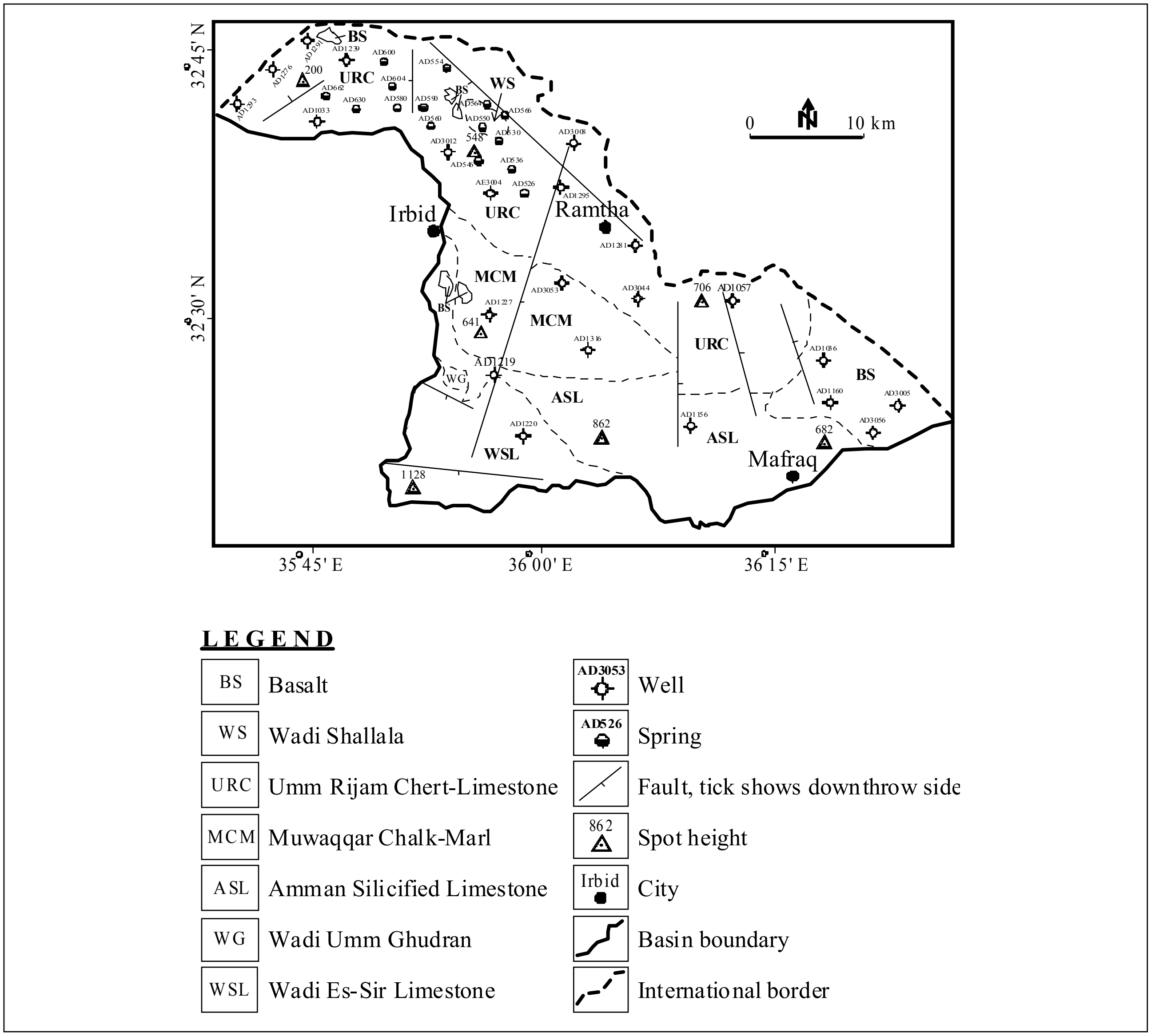

Figure 2. Geological map of the Yarmouk Basin. Location of the sampled springs and wells are also shown.

recharge of the Upper Cretaceous and Shallow Aquifers by upward leakage, as suggested by El-Naser (1991), or through lateral groundwater flow directed from the mountain foothills toward the Jordan River (Rimawi et al., 1992).

The Shallow and Upper Cretaceous Aquifer Systems are the principal aquifer systems providing the water requirements of almost all households in the YB. The Shallow Aquifer System, namely (B4/5), consists of the URC, WS and BS formations, while the Upper Cretaceous Aquifer System, namely (B2/A7), consists of the WSL, WG and ASL formations (Table 1).

The B4/5 aquifer system is recharged either along the elevated areas of Jabel Al-Arab, Golan Heights and Ajlun Highlands (Figure 1), which are believed to have great water-bearing potential (Hawi, 1990; Abderahman and Awad, 2002; Abu-Jaber and Ismail, 2003), or due to local surface water infiltration through the URC and WS outcrops in the northern and northwestern parts of the basin. But their small outcrop area and steep slopes limit the amount of recharge. Accordingly, most groundwater the emerges from the B4/5 aquifer appears as spring discharge in several locations. A total of 46 springs, yielding about 491 m^3 h^{-1} are encountered throughout the basin.

Table 1. Stratigraphic column for the geology of northern Jordan.

Period	Epoch	Formation	Symbol	Group	Aquifer
Tertiary	Oligocene	Basalt (BS)	BS	Jordan Valley	Shallow Aquifer Complex
	Eocene	Wadi Shallala (WS) (Limestone and Chalky Limestone)	B5	Balqa	
	Paleocene	Umm Rijam Chert-Limestone (URC)	B4		
Upper Cretaceous	Maastrichtian	Muwaqqar Chalk-Marl (MCM)	B3		B3 Aquitard
	Campanian	Amman Silicified Limestone (ASL)	B2		Upper Cretaceous Aquifer Complex
	Santonian	Wadi Umm Ghudran (WG) Marl and Marly Limestone	B1		
	Turonian	Wadi Es-Sir Limestone (WSL)	A7	Ajlun	
	Cenomanian	Shua'yb (Echinoidal limestone)	A5/6		
		Hummar (Echinoidal Limestone)	A4		
		Fuheis (Nodular Limestone)	A3		
		Na'ur (Nodular Limestone)	A1/2		
Lower Cretaceous	Albian	Subeihi (Vary Colored Sandstone)	K2	Kurnub Sandstone	Deep Sandstone Aquifer Complex
	Aptian-Neocomian	Arda'a (White Sandstone)	K1		

The most regionally extensive aquifer, and the most important for water resources in north Jordan, is the Upper Cretaceous Aquifer (B2/A7), because of the extended outcrop catchment areas located in the Ajlun Highlands and on the uplands of the Hermon Mountains (see Figure 1).

The drainage systems in the YB are shown in Figure 3. This map is based on topographic sheets of scale 1:100,000 produced by the Royal Jordanian Geographic Center. The map shows three distinctive drainage patterns. First, areas in the north and northwest parts of the basin consisting mainly of URC formation exposures and areas in the eastern parts of BS formation exposures are dominated by a NW drainage trend. Second, a NE trend dominates areas in the southwest that consist mainly of Ajlun Group rocks. Finally, the central part of the basin dominated by ASL and MCM rock exposures has a N-S drainage trend.

The water table map shows the elevation of the zone of saturation in the basin for the B2/A7 aquifer system (Figure 3). The map was based on the water table levels measured by the Water Authority of Jordan (WAJ, 2005, personal communication) in 89 wells tapping the B2/A7 aquifer system throughout the study area. The water table contours indicate that the direction of groundwater flow is from south and east to the north and northwest and strongly coincides with topography and drainage patterns. Depth to water table with reference to sea level varies from artesian flow in the Mukheiba area, to about 250 m below land surface near Irbid (Figure 1). Seasonal water table fluctuations recorded from monitoring wells are moderately high, with a mean of about 9 m. Declining water levels start in June and reach maximum in September to October. This is due to low rainfall and heavy groundwater withdrawals for domestic, industrial and irrigation purposes from government wells estimated to be as high as 60 x 10^6 m^3 y^{-1} (WAJ, 2006, personal communication).

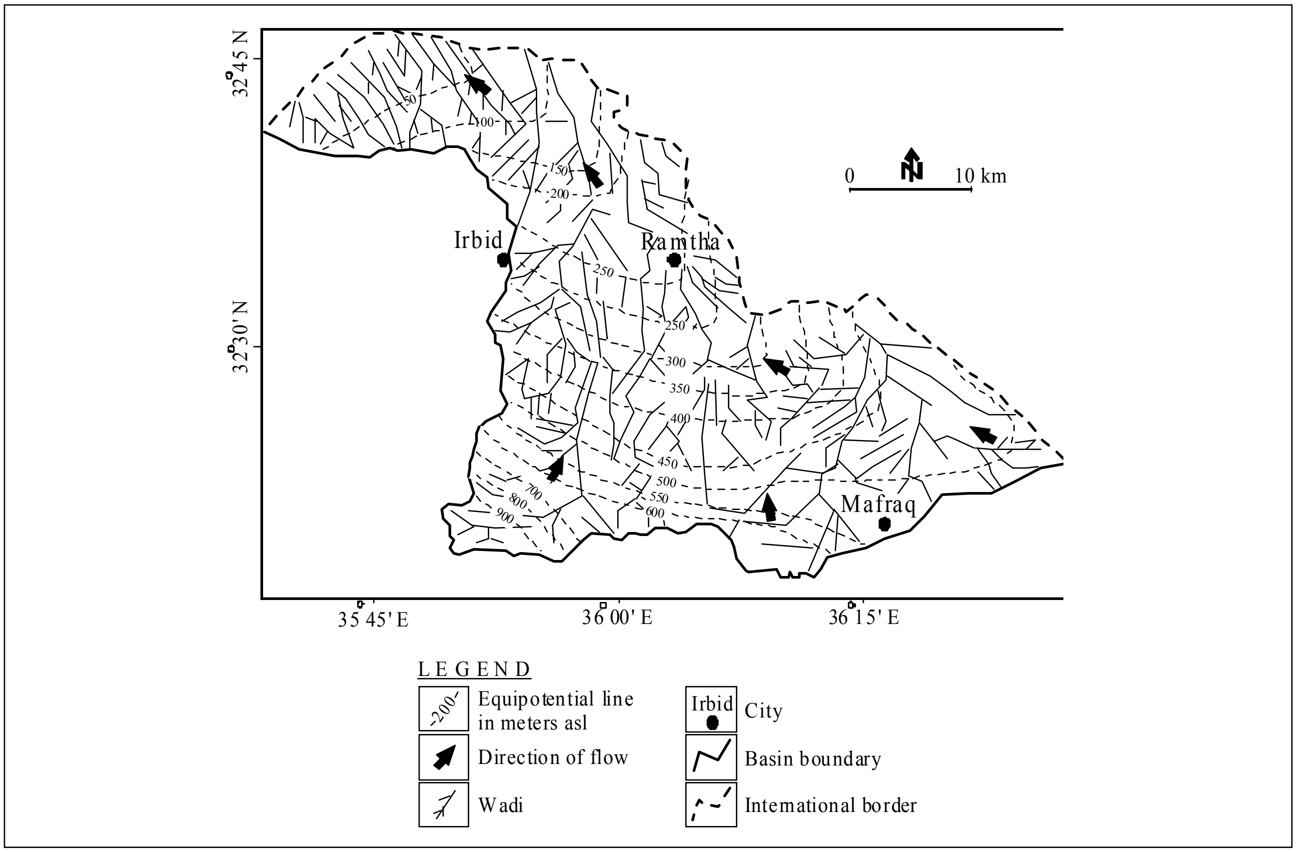

Figure 3. Drainage systems of the Yarmouk Basin. Map of the B2/A7 aquifer water table level and directions of groundwater flow are also shown.

SAMPLING AND ANALYTICAL PROCEDURE

Sampling

Sampling of groundwater within the study area was carried out in 2004. Fifteen samples were collected from the main springs emerging from the B4/5 aquifer and 22 samples were collected from wells tapping the B2/A7 aquifer (Figure 2). The samples were collected in polyethylene bottles; the bottles were previously washed with distilled water and diluted hydrochloric acid. After they were rinsed before filling to minimize sample contamination. These samples were then transported to the laboratory with care to prevent possible evaporation effects.

Analytical methods

The hydrogen ion concentration (pH), electrical conductivity (EC, $\mu S\ cm^{-1}$ at 25 °C) and total dissolved solids (TDS) were measured in the field by using a pH-meter, portable EC-meter and TDS-meter, respectively. Chemical analysis for the cations calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and iron (Fe) was accomplished in the laboratory using an atomic absorption spectrophotometer. The anions nitrate (NO_3) and sulfate (SO_4) were measured by spectrophotometric techniques. Titration methods were used to determine the concentrations of chloride (Cl) and bicarbonate (HCO_3); Cl was measured by using potassium chromate (K_2CrO_4) as an indicator and silver nitrate ($AgNO_3$) as a titration solution; HCO_3 was measured by titrating the samples with 0.02 NH_2SO_4, using methyl orange as an indicator. Sulfate was determined using a spectrophotometric method by measuring turbidity caused by adding $BaCl_2$, resulting in the precipitation of $BaSO_4$. These analyses were performed at the North Jordan laboratories and Quality Control Department of the WAJ. Results of chemical analysis are given in Tables 2 and 3.

RESULTS AND DISCUSSION

Classification of groundwater

Groundwater in the YB area is classified on the basis of the TDS and the dominant ions (Tables 2 and 3). Within the B4/5 aquifer water samples (Table 2), the values of TDS are low, lower than the maximum permissible level (MPL) recommended by the World Health Organization (WHO, 1996) (Table 4) for most domestic uses. They vary from 286 to 630 mg l^{-1} with a mean of 406.6 mg l^{-1}. Likewise specific conductance varies from 424 to 962 µS cm^{-1} with a mean of 614.7 µS cm^{-1}. This low mineralization indicates that the weathered zone has been highly leached of soluble minerals and/or groundwater is likely derived from relatively recent recharge. Hence, the low levels of mineralization with TDS of less than 1,000 mg l^{-1} show that the groundwater from the B4/5 aquifer can be classified as fresh using the classification scheme of Davis and De Wiest (1996). Analysis of water samples on a piper diagram (Figure 4) constructed using RockWare Scientific Software shows that the groundwater from the B4/5 aquifer is dominated by a Ca + Mg - HCO_3 geochemical facies. The concentration of Ca + Mg ions ranges between 71.3 and 115 mg l^{-1}, whereas that of bicarbonate (HCO_3) is between 172.6 and 342 mg l^{-1}. The pH of the groundwater ranges between 6.8 and 8.04 with a mean of 7.58, indicating their alkaline nature. High pH waters are typical of recharge water. The chemical composition, as shown by the low mineralization associated with slow groundwater circulation, also suggests that the basin is of recharged waters. Groundwater is of Ca + Mg - HCO_3 facies of recharge water rather than the predominant Na - HCO_3 of recharge area.

Within the B2/A7 aquifer water samples (Table 3), the values of TDS vary from 348 to 893 mg l^{-1} with a mean of 552 mg l^{-1} (except for AD3056 well where the concentration is 1,069 mg l^{-1}). These values are generally below the WHO (1996) limit of 1,000 mg l^{-1}. The values of EC vary from 543 to 1,670 µS cm^{-1} with a mean of 909.8 mS cm^{-1}. The low levels of mineralization, less than 1,000 mg l^{-1}, indicate that the groundwater from the B2/A7 aquifer is suitable for domestic use. Analysis and plot on a piper diagram (Figure 4) shows that the groundwater from the B2/A7 aquifer is of Ca + Mg - HCO_3 geochemical facies. The concentration of Ca + Mg ions ranges

Table 2. Results of chemical analysis of groundwater of main springs emerge from the B4/5 aquifer.

Spring no. (Fig. 2)	pH	EC (µS cm^{-1})	Concentration (mg l^{-1})										
			TH ($CaCO_3$)	TDS	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}	NO_3^{-}	Fe
AD550	7.89	464.0	210.0	297.0	68.1	9.7	27.0	2.0	217.8	17.3	40.6	22.7	0.14
AD566	7.66	930.0	292.0	595.0	86.6	18.5	49.0	48.0	236.6	117.1	80.3	36.6	0.18
AD564	7.46	486.0	267.0	370.0	73.9	4.6	15.6	0.4	209.2	19.7	24.5	23.6	0.23
AD560	7.30	534.0	283.0	342.0	97.4	9.6	20.5	3.9	289.1	26.4	31.9	30.0	0.68
AD554	7.76	581.0	234.0	372.0	70.5	14.1	31.0	1.4	238.9	30.7	48.2	10.7	0.37
AD546	7.45	615.0	246.3	454.0	82.8	8.15	28.9	9.4	225.7	14.4	46.9	49.7	0.11
AD536	7.37	592.0	226.0	379.0	68.9	13.1	36.3	2.0	232.8	18.5	57.0	31.8	<0.05
AD526	7.62	962.0	285.6	630.0	74.5	20.7	77.0	10.2	172.6	54.2	121.4	99.5	<0.05
AD604	7.72	424.0	263.4	323.0	64.9	6.4	12.9	1.2	201.3	8.2	19.9	21.4	0.0
AD600	7.40	844.0	317.0	540.0	90.2	22.0	54.5	14.8	278.0	48.0	83.7	41.9	0.45
AD630	7.70	506.0	218.0	324.0	70.5	10.2	15.5	2.0	212.9	36.5	27.3	24.0	0.09
AD580	7.70	476.0	218.0	305.0	71.0	9.0	14.0	1.1	240.0	6.0	28.0	26.0	0.0
AD662	7.89	776.0	329.0	496.0	90.0	25.0	22.0	0.7	342.0	21.0	34.0	9.6	0.0
AD590	8.04	447.0	205.5	286.0	65.7	10.0	15.0	1.2	208.0	22.1	23.6	21.9	0.59
AD530	6.80	580.0	287.5	386.0	62.2	15.1	38.6	1.6	222.7	24	54.3	24.4	0.41

Table 3. Results of chemical analysis of groundwater of wells tapped the B2/A7 aquifer.

Well no. (Fig. 2)	WL (m)	pH	EC ($\mu S\ cm^{-1}$)	Concentration ($mg\ l^{-1}$)										
				TH ($CaCO_3$)	TDS	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	Cl^{-}	NO_3^{-}	Fe
AD1160	295.0	7.60	1185.0	455.0	758.0	110.4	43.5	77.0	8.2	399.6	86.4	145.7	0.6	0.14
AD1276	33.4	7.28	1470.0	331.5	893.0	115.2	42.6	127.4	14.9	317.2	213.6	189.6	0.5	0.01
AD1291	42.3	7.41	817.0	343.9	553.0	74.9	24.3	43.0	3.9	323.3	27.4	59.6	0.6	0.02
AD1293	24.7	7.93	890.0	352.0	514.0	61.1	52.5	40.7	4.3	430.1	33.1	56.1	0.2	0.00
AD1295	254.1	7.43	816.0	279.7	522.0	59.2	32.1	55.0	1.8	259.3	39.3	106.0	1.1	0.09
AE3004	373.4	7.27	897.0	348.0	574.0	68.9	42.8	70.0	0.1	336.2	53.0	109.0	2.8	0.49
AD1281	278.6	7.44	824.0	301.4	527.0	63.2	34.9	60.0	1.4	316.4	26.6	97.0	2.18	2.32
AD1219	162.4	7.68	543.0	254.2	348.0	63.9	23.0	20.0	1.1	264.1	12.7	32.0	28.3	0.05
AD1057	148.5	7.24	943.0	285.6	603.0	69.5	27.3	89.0	6.0	316.0	77.0	133.0	0.8	0.05
AD1036	103.8	7.86	944.0	208.8	604.0	41.8	25.4	108.0	6.1	232.5	56.1	142.0	5.6	0.05
AD1220	192.7	7.30	636.0	284.0	407.0	75.4	23.3	23.0	4.4	287.3	13.0	43.0	25.9	0.05
AD3053	214.8	7.53	988.0	352.6	632.0	71.8	42.1	75.0	2.4	352.1	82.0	116.0	1.0	0.80
AD3044	314.0	7.52	770.0	275.8	493.0	58.4	31.6	53.0	1.5	271.8	43.8	82.0	0.8	0.09
AD3008	25.0	8.12	827.0	267.9	529.0	56.9	30.6	68.0	2.7	242.7	48.5	114.0	2.39	0.05
AD3056	196.0	8.02	1670.0	432.0	1069.0	63.3	66.6	178.0	4.7	175.9	81.0	410.0	40.8	0.05
AD3005	178.0	7.98	900.0	198.0	576.0	28.9	30.6	113.0	6.5	155.2	76.8	160.0	19.6	0.05
AD3012	364.0	7.23	815.0	347.3	521.6	75.7	38.4	43.5	2.9	354.3	39.1	67.0	28.0	0.00
AD1156	236.0	7.41	665.0	-	-	31.62	21.28	62.56	5.87	143.4	41.28	96.21	16.27	0.01
AD1227	208.0	7.45	661.0	278.5	423.0	67.4	26.8	20.5	1.8	255.6	30.1	48.5	26.4	0.02
AD1316	198.2	7.30	1180	-	-	76.09	51.07	96.37	7.04	374.5	98.88	146.6	-	-
AD1239	134.4	7.22	737.0	337.0	472.0	70.6	38.1	37.0	1.9	362.3	52.3	42.8	0.89	0.30
AD1033	178.4	8.04	838.0	368.0	536.3	95.2	31.6	41.5	3.0	366.4	63.4	63.1	8.02	2.10

between 52.9 and 157.8 mg l^{-1}, whereas that of bicarbonate (HCO_3) is between 143.4 and 430.1 mg l^{-1}. The pH of the groundwater ranges between 7.22 and 8.12 with a mean of 7.58, indicating their alkaline nature.

Major components, contents and ratios

- Groundwater chlorinity and water types

Most of the water sources in the YB area, which drain carbonate aquifers, are fresh, with chlorinities between a few to several tens of mg l^{-1}. Variations in chlorinity within the carbonate aquifers (water of the Ca + Mg - HCO_3 type) are caused by changes in lithology, residence time of water and pollution. The basalt aquifer water sources are also of the bicarbonate type with expected higher amounts of Na as compared with the carbonate aquifers.

Brackish water sources with higher chlorinities between a several tens to few hundred of mg l^{-1} of the B4/5 aquifer (i.e., AD526 spring; Figure 2, Table 2) are considered, in general, as mixtures of a fresh water component with a saline end member. In this spring, the water tends to be a Na-chloride type. In addition, wells in the eastern side of the YB (i.e., AD1036, AD1160, AD3005 and AD3056; Figure 2, Table 3) and wells in the northwestern side (i.e., AD1276; Figure 2, Table 3) show a high amount of chloride of the B2/A7 aquifer. Again, those are considered as mixtures of fresh-brackish water. In these wells, the water tends to be a Na-chloride type.

- rNa/rCl and Q (rCa/[$rHCO_3$+rSO_4]) ratios

Most of the B4/5 aquifer waters in the study area exhibit rNa/rCl values (0.77-1.1) around the normal marine and rainfall (0.82-0.86) values. Q values lie between 0.68 and 1.03 (Figures 5 and 6). Higher rNa/rCl values exceeding 1 were found within the B4/5 aquifer waters at (AD550, AD530, and AD600 springs; Figure 2) and are attributed to volcanic sources (0.9-2.5) because of the abundance of Na in basalt.

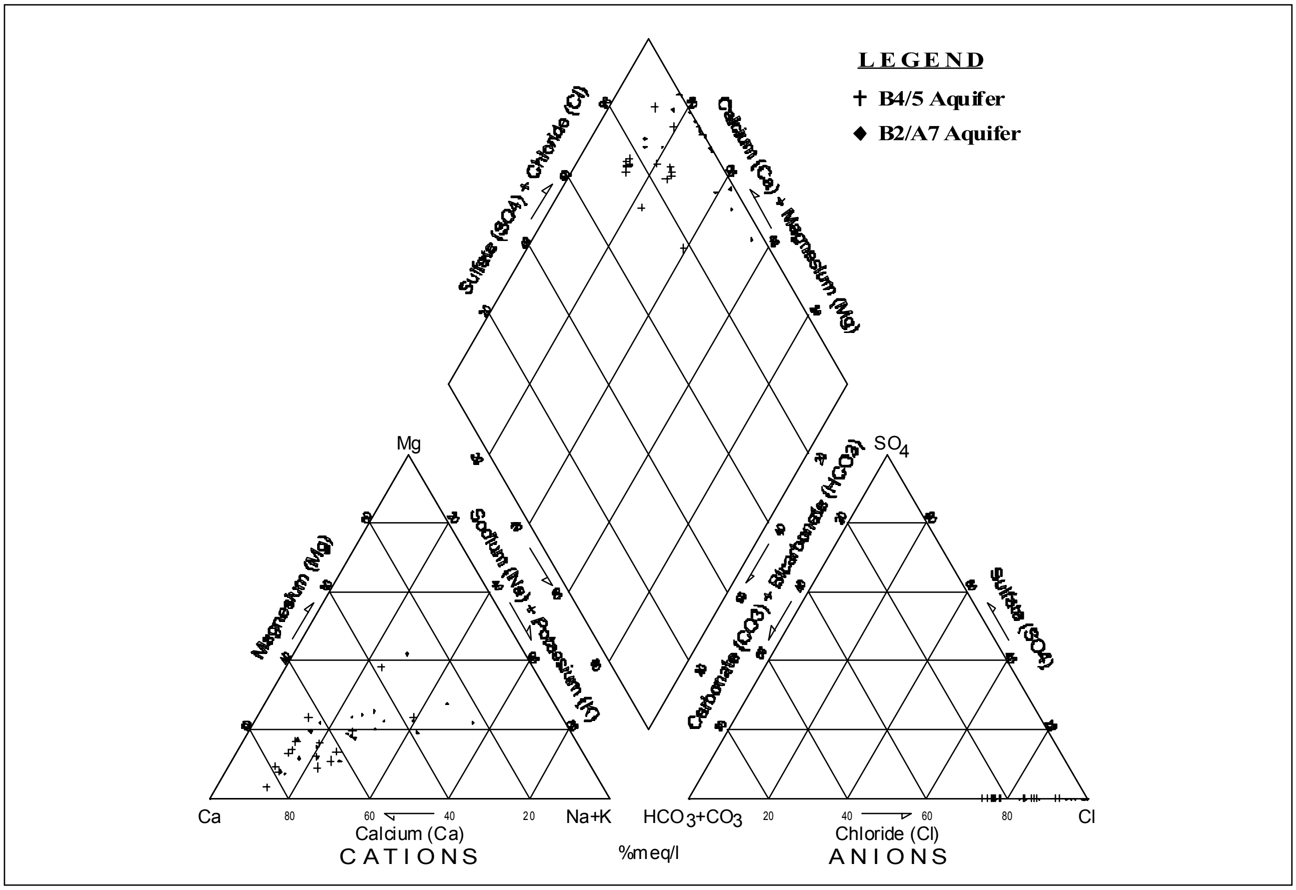

Figure 4. Piper trilinear diagram used for water classification based on the percentage of milliequivalents per liter.

Within the B2/A7 aquifer, the waters exhibit rNa/rCl values (0.65-1.33) and Q values between 0.35-0.76 (Figures 5 and 6). Higher rNa/rCl values exceeding 1 were detected at wells located in the northwestern and eastern parts of the YB, where basaltic flows outcrop.

- rSO_4/rCl and rCa/rMg ratios

The B4/5 aquifer water exhibits relatively low rSO_4/rCl ratios, between 0.16 and 0.69, and higher (1.08) in the AD566 spring (Figure 7). The B2/A7 aquifer waters, basically exhibit similar rSO_4/rCl ratios, mostly between 0.15 and 0.65 (Figure 7). The high rSO_4/rCl ratio (1.08) detected at the AD566 spring was associated with considerably high Total Organic Carbon (TOC) that is typical of fresh groundwater (values of TOC are not shown here). The TOC originates from the high kerogen and bitumen content of the Balqa Group sequences (MCM and URC formations). The high sulfide content detected may also of surface origin, and derived from the same source as the high EC salinity (930 $\mu S\ cm^{-1}$) in these waters (Table 2).

The rCa/rMg ratios of water reflect the lithology of the relevant hosting aquifers that can be summarized as follows (Figure 8): Within the B4/5 aquifer, the rCa/rMg ratios range between 2.18 and 9.75 because of the abundance of dolomites in its mineralized intake area. It seems that springs draining the upper part of the B4/5 aquifer, which include chalk and limestone in their intake area (e.g., AD564, AD560, AD546 and AD604 springs) have high rCa/rMg ratios (6.15-9.75) as compared with those (2.18-4) found in the lower massive limestone aquifer (e.g., AD662 and AD600 springs; Figure 2). The B2/A7 aquifer waters exhibit low rCa/rMg ratios between 0.57 and 1.96, reflecting the marine contribution of Mg to the water.

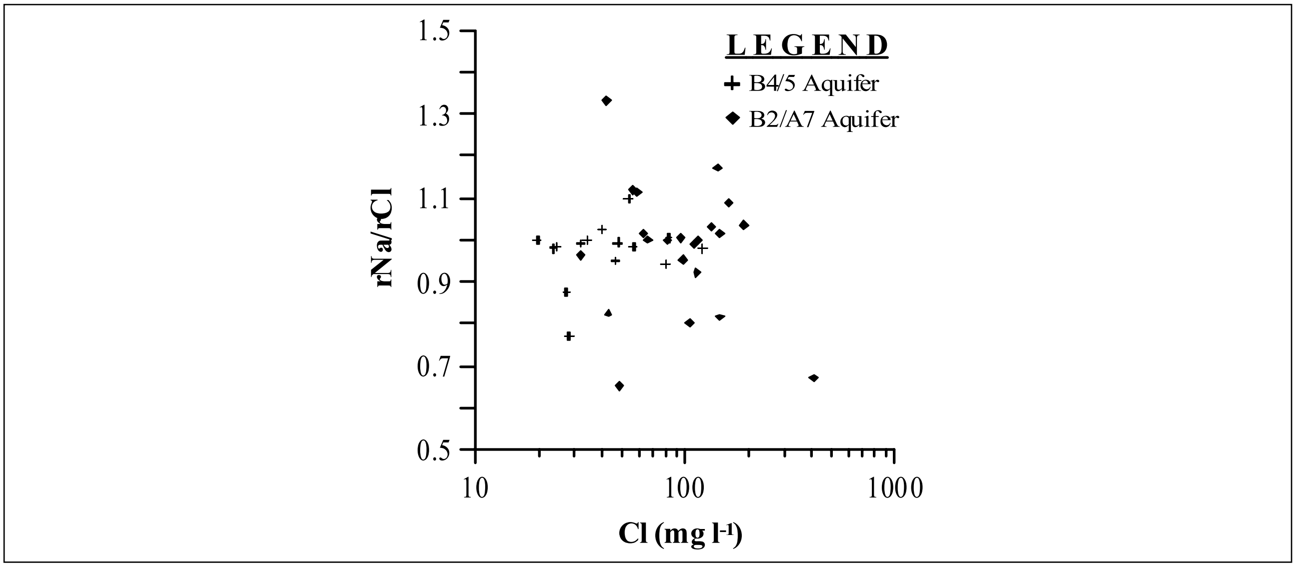

Figure 5. rNa/rCl ratio versus Cl (mg/l).

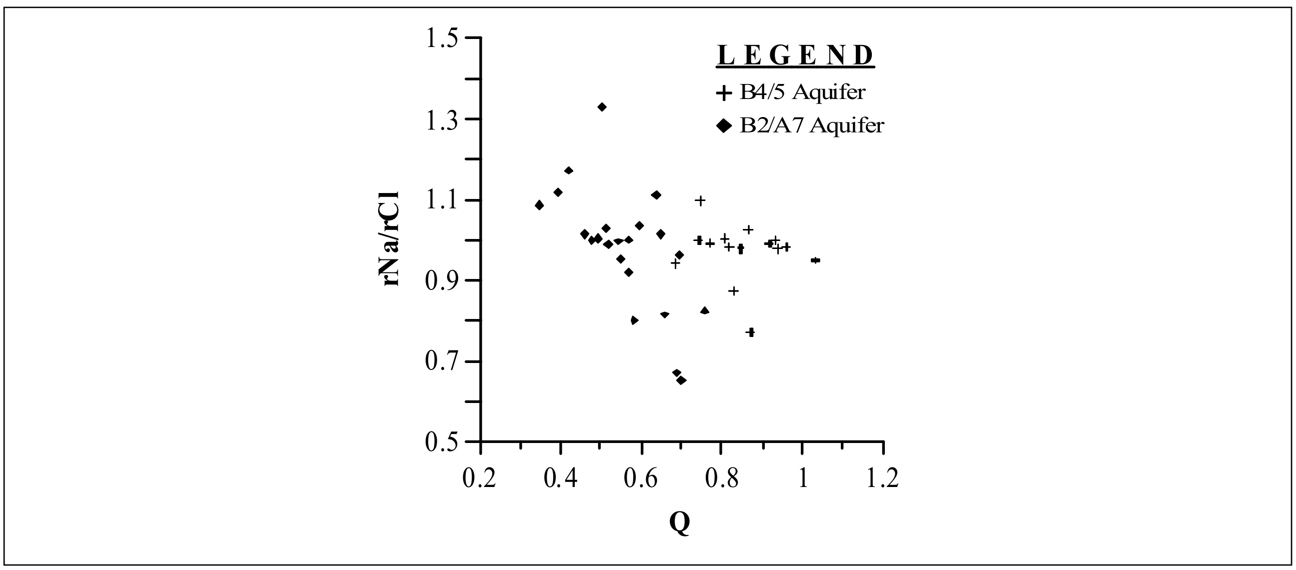

Figure 6. rNa/rCl ratio versus Q.

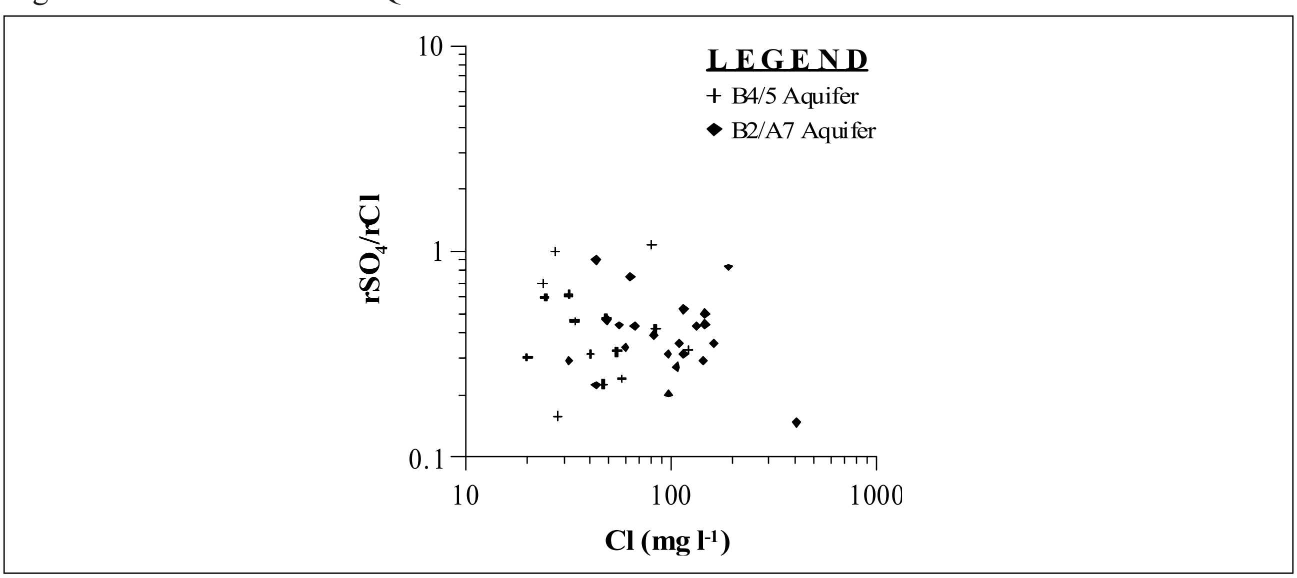

Figure 7. rSO_4/rCl ratio versus Cl (mg/l).

- NO_3 and Fe contents

NO_3 detected in the aquifer waters is either natural, by decomposition of organic matter found in the rock sequence or overlying soil, or by anthropogenic pollution. The NO_3 content ranged between 9.6 and 99.5 mg l^{-1} within the B4/5 aquifer water (Table 2), and between 0.2 and 40.8 mg l^{-1} within the B2/A7 aquifer water (Table 3). Higher values exceeding the MPL of WHO (1996) (Table 4) of 50 mg l^{-1} for most domestic use can be attributed to anthropogenic contribution in the form of agricultural fertilizers or to the seepage of domestic wastewater of the villages located in the basin.

Fe detected in the aquifer waters is either derived from the solution of lateritic topsoil or from dissolution of ferromagnesian minerals during weathering (Appelo and Postma, 1996). The Fe content in the B4/5 aquifer water is generally low (Table 2). Its concentrations range between trace and 0.68 mg l^{-1}. These values are below the WHO (1996) limit of 1.0 mg l^{-1}. Within the B2/A7 water samples (Table 3), the total iron content is generally low compared with their MPL in potable water (Table 4). Its concentrations range between trace and 0.8 mg l^{-1}. High Fe values were detected in the two boreholes AD1033 and AD1281 (Figure 2) where the concentrations are 2.1 and 2.32 mg l^{-1} (Table 3), respectively. The high Fe content in these two boreholes may be attributed to the upward leakage from the Deep Sandstone Aquifer Complex.

Groundwater use

Physical qualities such as odor, taste and color were absent in the YB groundwater, although a few samples were slightly cloudy. The temperature range of water from this basin (24-32 °C) is higher than the permissible range of 15-22 °C for fresh potable water. These temperature variations are probably caused by seasonal changes as data are from shallow groundwater. The groundwater tends to be slightly acidic and this could pose a problem of corrosion and slime formation in some industrial uses. The TDS is low; lower than the MPL of 1,000 mg l^{-1} for domestic use (Tables 2 and 3). Groundwater from the YB, therefore, is good for domestic use.

For an agrarian community like the study area, the groundwater was evaluated for irrigation using the sodium absorption ratio (SAR) and EC values to determine its suitability. The SAR was computed using the expression developed by the US Salinity Laboratory Staff (1954):

$$SAR = \frac{Na}{\sqrt{(Ca)+(Mg)}/2} \tag{1}$$

where ionic concentrations of Na, Ca, and Mg are given in milliequivalents per liter. This gave values for the B4/5 aquifer water ranging between 0.58 and 2.88 with an average of 1.19, whereas in the B2/A7 aquifer water samples it varies from 0.76 to 5.27 with a mean of 2.39. According to the US Salinity Laboratory Staff (1954), water with SAR values less than 10 offer little or no danger of creating sodium problems. Therefore, by these low SAR and EC (salinity) values, it is deduced that the salinity and sodicity hazards of the YB groundwater is low, which confirms its suitability for irrigation purposes.

Contaminated sources

As stated before, part of the present study focused on springs emerging from the shallow aquifer whose water is in contact with man made systems and installations. Most of the springs are managed, pumped and flow through pipes, all of which introduce artifacts into the natural systems.

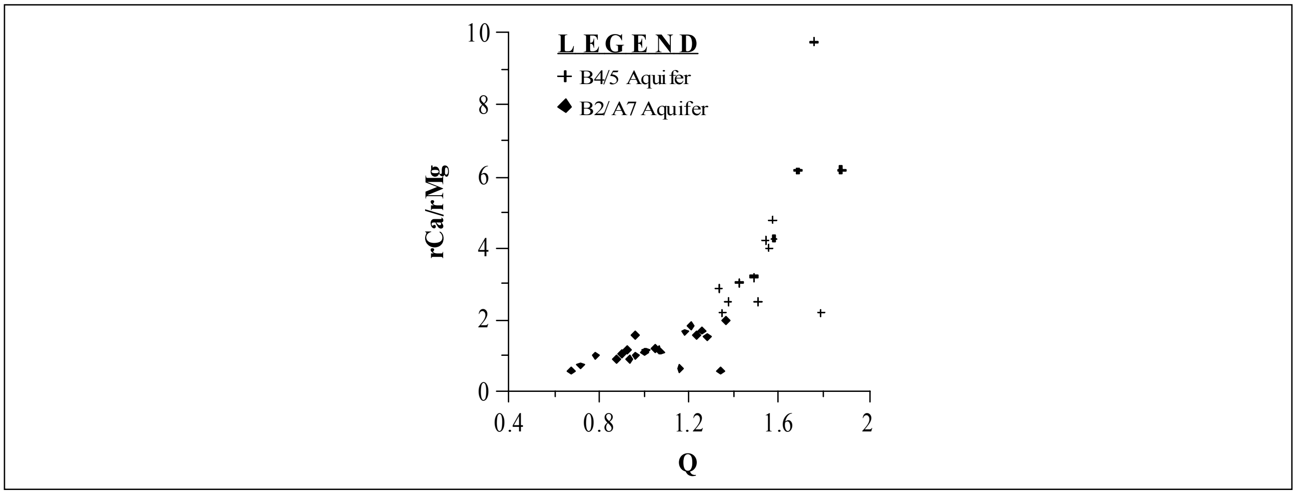

Figure 8. rCa/rMg ratio versus Q.

A high NO_3 value, exceeding the MPL of 50 mg l^{-1} for domestic use, was detected in the AD526 spring (99.5 mg l^{-1}; Table 2) and raised suspicions of surficial contamination. The contamination can be attributed to cattle grazing in the north Jordan catchment area or local contamination upstream of the spring.

High NH_4 contents were detected in 4 wells (Salameh, 1996) located in the northwestern part of the YB, which is dominated by thick Balqa Group organic-rich sequence. They are explained by the fact that reducing conditions (oil shale, H_2S) keep most of the nitrogen in the intake area in the form of NH_4, and not NO_3.

CONCLUSIONS

The groundwater resources of the YB, Jordan were evaluated and studied to aid in planning, development and management. The principal sources of groundwater in this basin are classified as Shallow and Upper Cretaceous Aquifer Systems. Groundwater levels in this basin vary from zero to 250 m below the ground surface. Water table fluctuation in the wet and dry seasons is high; with a mean of about 9 m. Directions of groundwater flow are due north and northwest. The chemical quality of groundwater in this basin is good, with low mineralization. Within the Shallow Aquifer System, the highest TDS value is 630 mg l^{-1} and the lowest is 286 mg l^{-1}, whereas within the Upper

Table 4. WHO guidelines for drinking water and range of values of chemical species in the groundwater of the Yarmouk Basin, north Jordan.

Parameter	WHO standard (1996)		B4/5 Aquifer		B2/A7 Aquifer	
	Acceptable Level	MPL	Range	Mean	Range	Mean
Ca (mg l^{-1})	75.0	200.0	62.2-97.4	75.81	28.9-115.2	68.16
Mg (mg l^{-1})		50.0	4.6-25.0	13.08	21.3-66.6	35.48
Na (mg l^{-1})	20.0	175.0	12.9-77.0	30.50	20.0-178.0	68.25
K (mg l^{-1})			0.4-48.0	6.66	0.1-14.9	4.21
Fe (mg l^{-1})	0.3	1.0	0.0-0.68	0.263	0.0-2.32	0.46
HCO_3 (mg l^{-1})			172.6-342.0	235.17	143.4-430.1	297.1
SO_4 (mg l^{-1})		250.0	6.0-117.1	30.94	12.7-213.6	58.88
NO_3 (mg l^{-1})		50.0	9.6-99.5	31.59	0.2-40.8	11.11
Cl^- (mg l^{-1})		300.0	19.9-121.4	48.11	32.0-410.0	111.78
TH (mg l^{-1}) ($CaCO_3$)	100.0	500.0	205.5-329.0	258.8	198.0-455.0	315.06
TDS (mg l^{-1})		1,000.0	286.0-630.0	406.6	348.0-1069.0	577.75
pH	6.5	8.0	6.82-8.04	7.59	7.22-8.12	7.56

Cretaceous Aquifer System it varies from 348 to 1069 mg l^{-1}. The dominant ions in the basin are calcium and magnesium while bicarbonate is the most abundant of the anions. Hence, groundwater from this basin is of the Ca + Mg - HCO_3 type. The groundwater is alkaline, has a low electrical conductance and SAR and hence low salinity hazard. Based on this chemical quality, the groundwater of the YB is good for domestic, industrial and agricultural purposes.

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