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Sources of Water Salinities in the Jordan Valley Area/Jordan

Review

Due to its history, development of its hydrologic regime, recharge-discharge mechanisms, geologic formations, and development of its hydrodynamic pattern, the groundwater resources of the Jordan Valley show a very wide range of chemistries.
In this paper the groundwater hydrochemistries are studied along profiles extending N-S along the Jordan Valley escarpment and the Jordan Valley itself and along profiles extending from the eastern escarpment to the Jordan River. Hydrochemical end members are identified and the sources of water salinization are defined. It was found that the evaporites within the Jurassic and Triassic rocks are the main contributors to the salinization of groundwater entering the Jordan Valley laterally, from its eastern side, and that the deposits of the ancestors of the Dead Sea; the Lisan Lake (Lisan deposits) are the main contributors to water salinities within the Jordan Valley itself.
The Jurassic and Triassic evaporites contribute with NaCl and $CaSO_4$ salts to the groundwater. Whereas, the Lisan deposits contribute with NaCl, $CaSO_4$ and moderately, in a few localities with Ca^{2+} and Mg^{2+} chlorides.

Herkunft der Wassersalinität im Jordantal/Jordanien

Die Grundwasservorräte des Jordantals weisen große Unterschiede in ihrem Chemismus auf, die in der Entstehungsgeschichte, der Entwicklung des hydrologischen Regimes, den Zufluss-/Abflussmechanismen, den geologischen Formationen und der Entwicklung des hydrodynamischen Musters dieses Tals bedingt sind. In der vorliegenden Arbeit wird die Hydrochemie der Grundwässer untersucht, und zwar entlang von Profilen in Nord-Süd-Richtung an der Abbruchkante des Jordantals und im Jordantal selbst sowie entlang von Profilen von der östlichen Abbruchkante in Richtung des Flusses Jordan. Die hydrochemischen Endglieder und die Quellen für die Aufsalzung des Wassers werden ermittelt.
Es zeigte sich, dass Evaporite in den Felsen aus Jura und Trias die Hauptursache für die Aufsalzung des Grundwassers sind, das seitlich von Osten ins das Jordantal einströmt. Die Jura- und Trias-Evaporite geben NaCl und $CaSO_4$ ans Grundwasser ab.
Die Versalzung des Grundwassers im Jordantal selbst hingegen geht auf den Vorläufer des Toten Meers, den Lisan-See (Lisan-Ablagerungen) zurück. Aus den Lisan-Ablagerungen lösen sich NaCl, $CaSO_4$ und in geringerem Maße an einigen Stellen Calcium- und Magnesiumchlorid.

Keywords: Jordan River, Groundwater, Hydrochemistry, Salinization, Hydrochemical End Member

Schlagwörter: Jordan, Grundwasser, Hydrochemie, Versalzung, Hydrochemisches Endglied

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1 Introduction

1.1 Topography

The Jordan Valley extends from Lake Tiberias at an elevation of 212 m below sea level (bsl) southward to the Dead Sea at an elevation of more than 400 m bsl. Its width just to the north of the Dead Sea is around 20 km. In its northern part the width is around 10 km with a minimum width in its central part of 4 km. On the east side of the Jordan River this width varies between 2 km and 10 km (Fig. 1). The length of the Jordan Valley is 105 km. It is bordered on both sides; east and west by high, steep escarpments with differences in elevations between the valley floor and the surrounding mountains of 1200 m going up to 1700 m.

The lower Jordan River flows longitudinally through the valley. It takes its water from Lake Tiberias and from the side wadis to its east and west. The river has eroded its way through the valley to form a secondary trough, some 60 m deeper than the Jordan Valley (henceforth, JV) proper. The river meanders in very large loops in the alluvial plain. The difference in elevation between Lake Tiberias and the Dead Sea is around 200 m. The overall slope of the valley is 1.81 %. Due to meandering, the length of the river itself is around 220 km with an average gradient of 0.86 % or about half the slope of the valley.

This river gradient is still a steep one with erosion capabilities. The strong and violent floods of the river erode along its entire course from the north to the south. The main features of the Jordan Valley area are the relatively flat terraces on both sides of the River Jordan, which constitutes the bed of the valley.

1.2 Climate

The prevailing climate in the Jordan Valley area is unique. It differs totally from the climate of its surroundings, which to the east and west lie at elevations of more than 1000 m rising within a few kilometers from the valley floor (at elevations of 200 to 400 m bsl). The climatic information was obtained from publications of the Department of Meteorology/Ministry of Transport.

1.2.1 Temperature

The mean maximum monthly temperature in the JV is 31.5° C, whereas the mean annual temperature is 23.6 °C. The mean maximum monthly temperature in summer is 38.8 °C and the highest temperature ever registered is 52 °C. In winter, night temperatures may drop to a few degrees centigrade or even reach the freezing point.In the northern part of the valley the average temperature is 1.8 °C less than in the southern part with the highest registered temperature of 51.2 °C and the lowest of –2 °C.

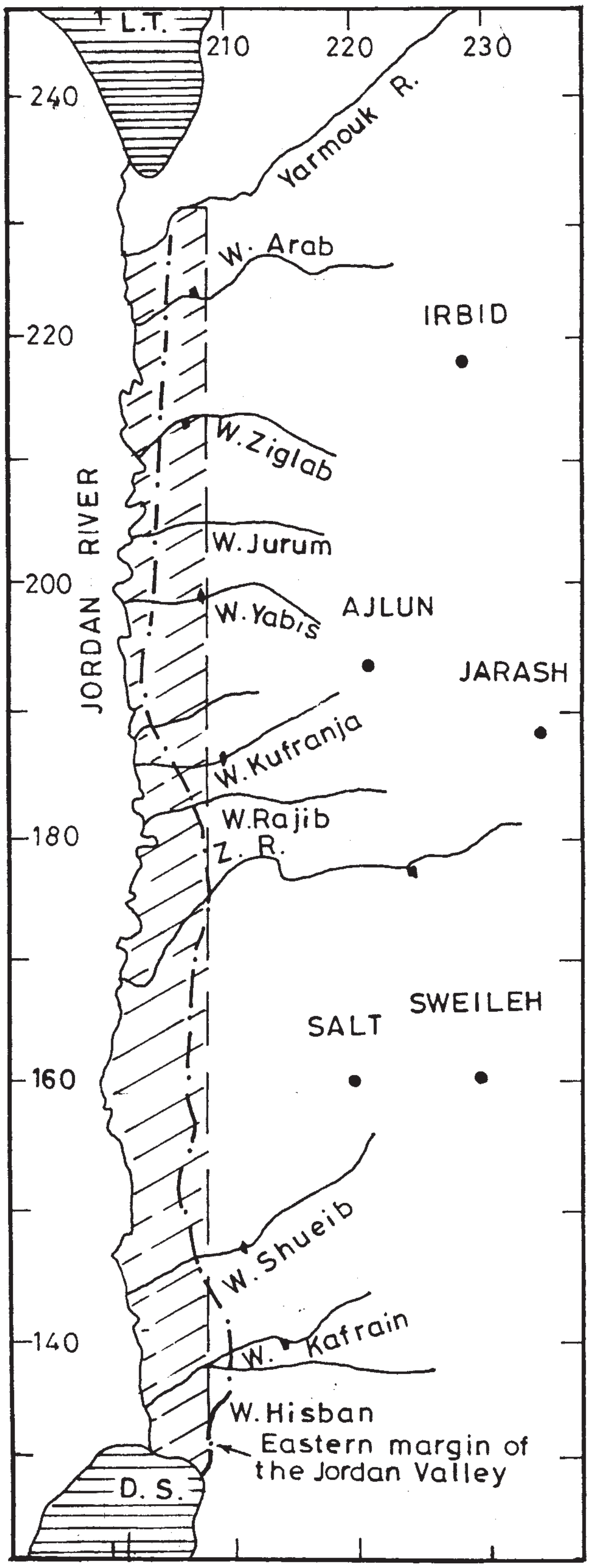

Fig. 1: Location map of the study area.
Lageplan des Untersuchungsgebietes.

1.2.2 Relative humidity

Generally the relative humidity is very low in the southern part with a long term daily mean of 64 % in the coldest period of the year (Jan. + Feb.) going down to 27 % in the hottest summer months at 14.00 o'clock. In the northern part the humidity ranges from 30 % during hot summer days to 70 % in the cold winter.

1.2.3 Rainfall

The rainfall period starts in October and ends in May. Most precipitation occurs from December to March. The northern area close to Lake Tiberias receives a long term average of around 400 mm/a. The annual variations in precipitation are quite remarkable. In dry years the amount of precipitation in the northern part, reaches 200 mm/a whereas at the shores of the Dead Sea, it may decrease to merely 40 mm/a. In rain rich years these values may reach 650 mm/a in the north and 250 mm/a in the south.

Rain falls in violent events, resembling cloudbursts with 40...60 mm of rainfall per day. Snow falls very infrequently mostly in the northernmost part of the valley.In the rain-rich northern parts of the valley rain-fed crops are grown, but further to the south rain is not sufficient for rain-fed agriculture.

1.2.4 Evaporation

Due to the high temperatures in the valley and the low values of relative humidity the evaporation force of the climate is very high. The potential evaporation in the north is around 2100 mm/a increasing to about 2400 mm/a at the shores of the Dead Sea.

2 Geology

2.1 Triassic to Tertiary

The valley floor consists mainly of nonconsolidated alluvial sediments of gravels, sands, shales marls, and clays. In addition evaporites which precipitated from the precursors of the present Dead Sea are found in the form of extensive deposits and lenses, especially in the southern and western parts of the valley [1–3]. Basalts are found in different areas of the JV such as Adasiya, North-Shunah, Mukheiba, in its northern part, and Kattar in its southern part.

Underlying, and laterally bordering the unconsolidated valley sediments are rocks of Triassic to Recent ages. In the different parts of the foothills different rock types of the geologic column from Triassic onward crop out with their western extensions covered by the more recent valley deposits (Fig. 2). Table 1 contains the relevant information about the escarpment foothills formations.

Volcanic rocks: Upper Tertiary and Quaternary basalts cover large extents in northeast Jordan. Bender [2] recognized six phases of basalt flow in northeastern Jordan. The northern part of the study area is covered by basaltic rocks forming the west extensions of Jabel Druz basalts. The thickness reaches few tens of meters covering recent, Tertiary and Cretaceous rocks in the study area.

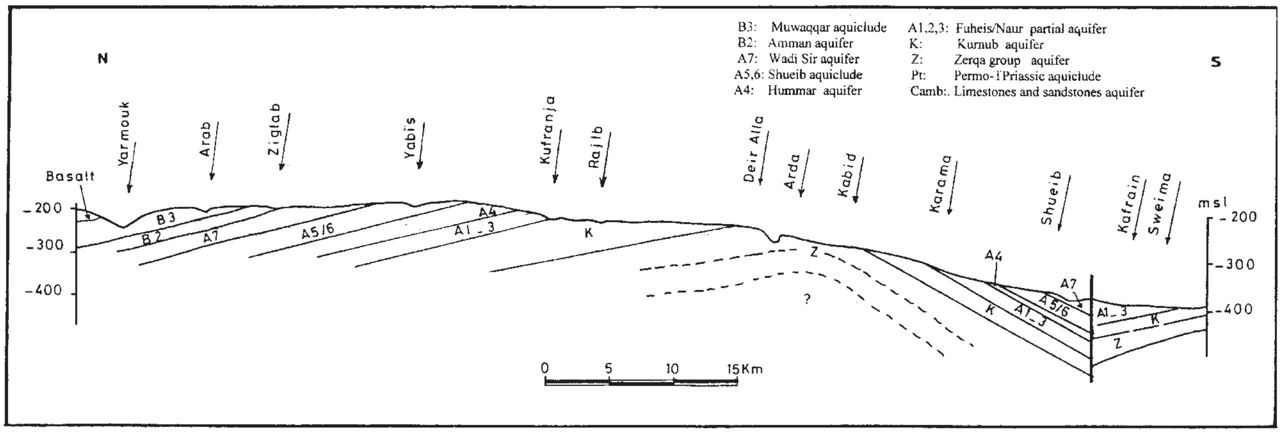

Fig. 2: Geologic cross-section along the eastern Jordan Valley escarpment.

Geologischer Querschnitt entlang der Abbruchkante des Jordantals.

Table 1: Geologic formations along the foothills of the eastern Jordan Valley escarpment.

Geologische Formationen entlang dem Vorgebirge der östlichen Abbruchkante des Jordantals.

Tertiary	
– Wadi Shallala Formation (B5)	Chalky and marly limestones. 250 m in thickness: medium aquifer.
– Rijam Formation (B4)	Chalks, cherts, and limestones. Thickness: 40 m, only locally an aquifer.
– Upper Muwaqqar Formation (B3)*	Chalk, marl, chalky limestones with chart nodules. Thickness: 200...240 m, aquiclude.
Upper Cretaceous	
– Lower Muwaqqar F.(B3)* + Amman Formation (B2)	Silicified limestones, charts, phosphates. Thickness: 30...120 m, excellent aquifer.
– Wadi Ghudran Formation (B1)	Chalks and marls. Up to 70 m in thickness, in same places missing, aquiclude.
– Wadi es Sir Formation (A7)	Hard massive karstified limestone. Thickness: 180 m, very good aquifer.
– Shueib Formation (A5,6)	Thick marls alternating with thin bedded limestones. Thickness: 50...100 m, aquifuge.
– Hummar Formation (A4)	Hard crystalline limestone and dolomitic limestone. Thickness: 60...120 m, excellent aquifer.
– Fuheis Formation (A3)	Marls and chalks only locally limestones. Thickness: 70...90 m, aquiclude.
– Naur Formation (A1,2)	Sandy marls, shales, dolomitic limestones. Thickness: 230 m, aquiclude, except some carbonates forming medium aquifer.
Lower Cretaceous	Mainly sandstones, some silts and shales, glauconite, locally with some gypsum, minor; dolomites and limestones. Thickness: 140 m, good aquifer.
Jurassic	Sandstones, calcareous sandstones, shales oolithic marls, dolomite, and limestones. Total thickness: 130 m, medium aquifer.
Triassic	Sandstones siltstone, shales, marls thin limestones and evaporites, especially gypsum. Thickness: around 490 m, good aquifer.

B3*: Personal Communication, Prof. Dr. Saad Basha, Univ. of Jordan, Amman

Basalts are either directly recharged by rainfall or they receive laterally groundwater from the wadis, like the basalt aquifer of Adasiya which receives its water from the Yarmouk River or from the alluvial fans of this river.In the southern part of the Jordan Valley basaltic outflows are covered by the recent sediments of the ancestors of the Dead Sea and those originating from the surrounding mountains.

2.2 Quaternary deposits in the Jordan Valley

Jordan Valley 1 (JV1, Ghor el Kattar Formation): This formation consists of well cemented conglomerates with low porosities and permeabilities. It was deposited in the Jordan Valley floor, accompanying the faulting and the formation of the Jordan Valley structure. The JV1 deposits normally cover bedrock of different ages at the slopes to the Jordan Valley. These deposits possess secondary porosities in some restricted locations, but they contain saline water. Their thickness may reach 350 m (Table 2, Fig. 3).

Jordan Valley 2 (JV2, Ubeidiya and Samra Formation): This formation consists of conglomerates, sands, silts, and clayey marls and overlies the JV1 with a total thickness of some 100 m. It corresponds to another tectonic activity of the Jordan Valley formation and it overlies the JV1 with a certain unconformity.Water in this formation is generally saline, but in areas close to the slopes of the highlands it contains fresh water originating from lateral flows.

Table 2: Geologic formations in the Jordan Valley area [2].

Geologische Formationen im Jordantal [2].

Thickness, m	Formation Name
0...100	Alluvial fans and recent deposits
40...few hundred	Lisan
35	Samra
100	Kufranja gravels
100	Abu Habil series
ca. 350 m	Ghor El Kattar and Shagur Conglomerates

Jordan Valley 3 (JV3, Lisan Formation): This formation was deposited in the Lisan Lake, the ancestor of the Dead Sea, which extended to Lake Tiberias in the north. It consists of thinnly bedded aragonites and marls (a few millimeters in

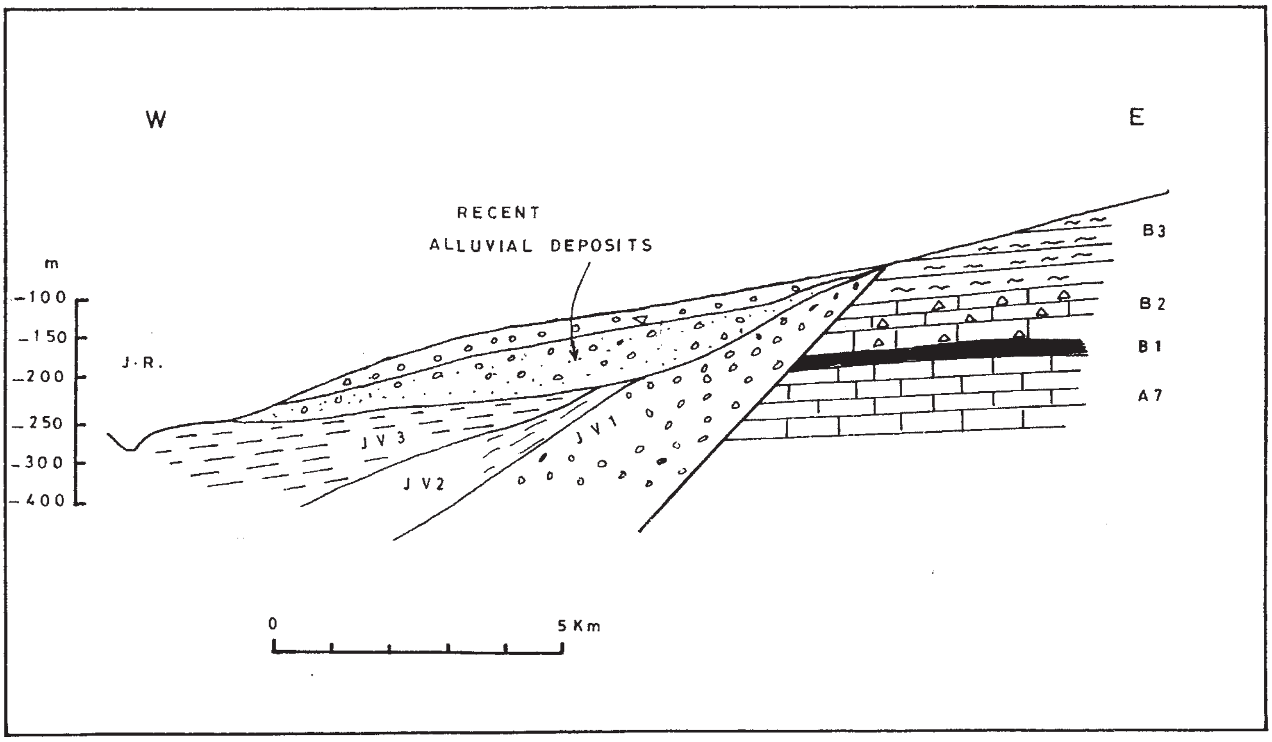

Fig. 3: Cross-section along latitude (195 PG).

Querschnitt in West-Ost-Richtung.

thickness). The thickness of the whole formation ranges from 40 to more than a few hundred meters.The deposit is highly gypsiferous and its salt content is very high. The water in this formation is saline. Old alluvial fans interfinger with the Lisan Formation and contain fresh water in few areas. The primary permeability of the formation is very low but the secondary one due to fracturing and dissolution of salts may be in places high.

Quaternary alluvial fans: These are of post Lisan age and have been formed by the different rivers and wadis as they enter the Jordan Valley area (Fig. 4). These alluvial fans consist of gravels at their apexes and silt and fine sands at their toes, which means that they fine up towards the Jordan River. They posses very high porosities and permeabilities in the upstream areas and low permeabilities in the downstream ones. Water in these alluvial fans flows fast in the upgradient areas and very slow in the down gradient areas. Their thickness as encountered by drilling and geoelectric sounding may reach 100 m. Neighboring and overlapping these fans are slope debris which originate from the escarpment foothills. They were transported and deposited by gravitational forces.

2.3 Structures

The major structure affecting the JV deposits is the strikeslip fault [4, 5] which runs along the central part of the JV in its southern area (Dead Sea to Deir Alla) and at the foothills of the mountain chain in the JV northern area (Deir Alla to Yarmouk). Because of the strikeslip sinistral movement along this fault alluvial fans and slope debris became gradually separated from the wadis and from the mountains feeding them. This situation superimposed by erosion/deposition processes makes the mapping and recognition of the aquifers by using conventional field methods very complicated and sometimes impossible. Only indirect methods such as drilling, geophysics, and water balances may assist in locating groundwater bodies.

The smaller structures are associated to the major fault. They are manifested in offsprings of the major fault and some tensional and compressional east-west trending faults. These may enhance the movement of groundwater. But since the sediments in the JV area are generally unconsolidated or semi consolidated, fractures do not develop properly as openings. They are closed soonly after opening by local land and rock slidings, minimizing herewith any acceleration of groundwater movement.

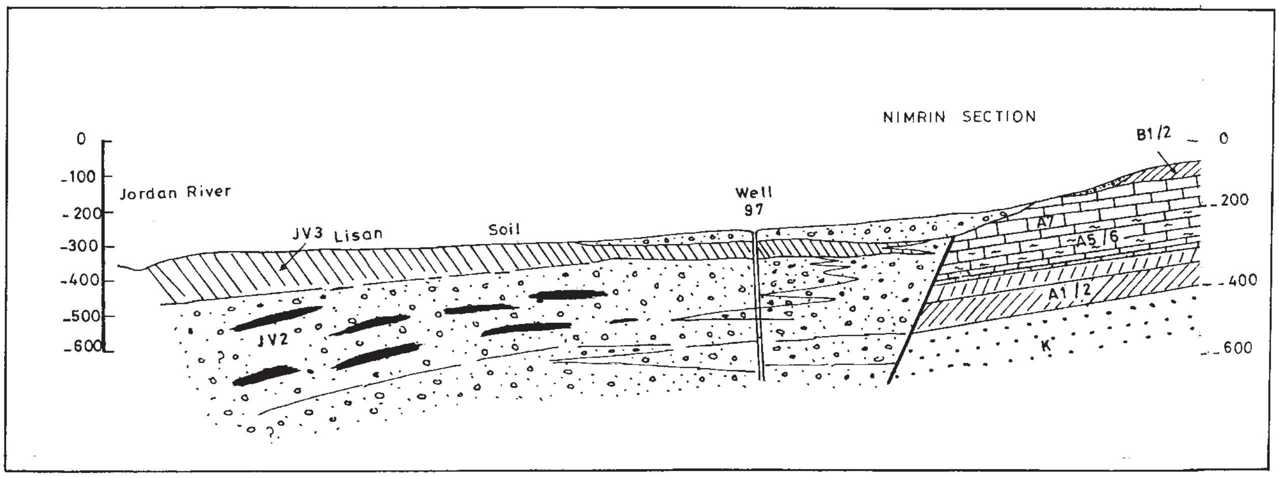

Fig. 4: Jordan Valley deposits and their relations to escarpment formations.

Ablagerungen im Jordantal und ihre relative Lage zu den Formationen der Abbruchkante.

3 Hydrology

3.1 Surface water

As stated above (under precipitation) the average annual amount of rainfall along the Jordan Valley ranges from 400 mm in its northern part to 100 mm at the shores of the Dead Sea, in the southern parts. Surface flows due to precipitation are negligible in that area because of the porous nature of the alluvial deposits. Only in places covered by fine-grained sediments with very low permeabilities does surface runoff take place.

The Jordan Valley receives the surface water from the Jordan River tributaries which drain the catchments extending into the highlands. Infiltration into the aquifers and aquifer lenses of the Jordan Valley takes place along the wadi courses and in the alluvial fans, through which surface runoffs to the Jordan River pass. The discharges of the different side wadis are given in Table 3. The average discharges of intercatchments is given in Table 4. On some of these wadis dams were established and others are planned. Table 5 shows the sites, capacities, and year of construction of these dams. The water of the dams is mainly used for irrigation in the Jordan Valley area.

Table 3: Average discharges of side wadis into the Jordan Valley (Water Authority of Jordan).

Mittlere Abflüsse aus den Seitentälern ins Jordantal (Water Authority of Jordan).

Source	Flow, Mio m^3/a
Yarmouk (at Adasiya)	140
El-Arab	6.2
Ziqlab	7.9
Yabis	4.3
El-Jurum	10.5
Rajib	4.7
Kufranjeh	6.9
Shueib	7.6
Kafrain	17
Hisban	5.3
Zerka	65

3.2 Groundwater

Groundwater in the Jordan Valley area is mainly found in the Quaternary deposits composed of friable sediments which were brought in from the surrounding mountains [6, 7]. The depositional environment of these sediments and especially the decreasing gradients from the mountain foothills to the Jordan River course led to rapidly declining permeabilities towards the Jordan River course. Hence, water infiltrating into the alluvials only very slowly finds its way to the Jordan River.

As mentioned in the geology chapter sediments of the precursors of the Dead Sea cover different parts of the Jordan Valley, especially in its southern and western reaches. These sediments e.g. Lisan Deposits consist of salty marly aragonites. Therefore, the groundwater (Fig. 5) infiltrating into the various rock types of the Jordan Valley or that flowing laterally into them from the older rocks of the eastern escarpment be-

Table 4: Average discharge of inter-catchments between each two neighboring side-wadis of the Jordan River (Water Authority of Jordan).

Mittlerer Abfluss aus den Wassereinzugsgebieten zwischen zwei benachbarten Seitentälern des Jordans (Water Authority of Jordan).

	Flow, Mio m^3/a		
Intercatchment between:	Flood	Base	Total
Arab and Ziqlab (AB21)	5	1	6
Ziqlab and Jurm (AB22)	3	1.5	4.8
Jurm and Yabis (AB23)	1.5	0.0	1.5
Yabis and Kufranje (AB24)	0.1	1.3	1.4
Kufranje and Rajib (AB)	0.2	1.2	1.4
Rajib and Zerka (AB10)	0.1	0.3	0.4
Zerka and Shueib (AB25)	3.5	0.0	3.8
Shueib and Kafrain	2	0.4	2.4
Kafrain and Hisban (AB26)	0.0	1.3	1.3
Hisban and Udheimi (AP2)	0.34	0.3	0.64
Catchment in the downstream of:			
Wadi Arab Dam	Negligible	0.0	0.00
Ziqlab Dam	0.5	0.0	0.5
King Talal Dam	7	0.0	7
Shueib Dam	Negligible	0.0	0.00
Kafrain Dam	Negligible	0.0	0.00

comes salty once it contacts the salt bearing deposits of the precursors of the Dead Sea.

Freshwater is only present in the uppermost gravels, sands, limestones, and fluviatile deposits. These fluviatile sediments interfinger with the salt bearing beds, therefore, the groundwater bodies are not extensive. They are lens-type groundwater bodies mostly present in the alluvial fans of the side wadis.

In the Jordan Valley basin, designated the Ghor area (the higher terrace bordering the mountain chains) the available amount of extractable groundwater is estimated at 21 Mio m^3/a, whereas, in the Jordan River basin, designated the Zoor area (the lower terrace of the Jordan River) the amount of extractable groundwater is around 15 Mio m^3/a [8, 9].

Generally, the salinity of the Jordan Valley basin groundwater ranges from 600...1500 mg/L, and that of the Jordan River basin from 3000 to 30 000 mg/L indicating the effects of the salt bearing beds.The area in between has salinities of 1500...6000 mg/L.

The extracted amount of groundwater in the Jordan Valley is around 35 Mio m^3/a. But this extraction is not uniformly distributed. Hence, some groundwater bodies are overexploited and others underutilized.In addition to the natural recharge along the Jordan Valley area leakages from irrigation facilities and irrigation return flows contribute with different water amounts and qualities to aquifer recharge.

3.3 General hydrochemical characteristics

Different mechanisms and genetic pathways govern the chemical composition of the waters in the Jordan Valley area. Dust in the atmosphere, high evaporation rates, salt deposits, remnants of ancient salt lakes, formation water, and human activities are some of the factors affecting the water quality.

3.3.1 Precipitation water

The location of the rainwater collection site for chemical analyses lies in Deir Alla, in the central part of the Jordan Valley.The measurements on 25 samples with precipitation

Table 5: Dams on side wadis of the Jordan River (Water Authority of Jordan).

Staudämme in den Seitentälern des Jordans (Water Authority of Jordan).

Dam	Capacity, Mio m^3/a	Year of Construction
El Arab	20	1989
Ziqlab	4.3	1966
King Talal Dam (Zerka River)	89	1977 Raised in 1989
Shueib	2.5	1968
Kafrain	7.5	1968 Raised in 1996
Yabis	7	Under Study
Unity (Yarmouk)	225	Under Study
Karamah (in the Jordan Valley)	55	1995
Kufranjeh	7	Under Study

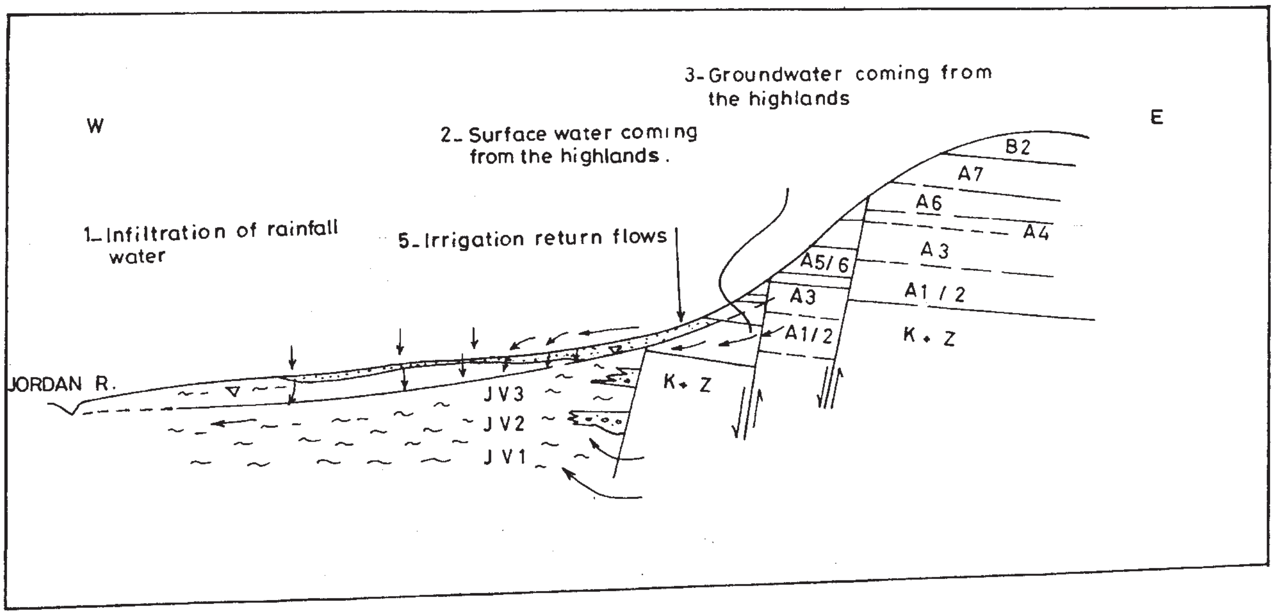

Fig. 5: Upward movement of deep groundwater.

Aufwärtsströmung des Tiefengrundwassers.

amounts ranging from 0.1 mm to 29 mm show that the electric conductivity of the samples ranged between 41 µS/cm and 500 µS/cm with a weighted average of 160 µS/cm [10]. The pH of the rain samples ranged from 7 to 8.7, only one out-raining sample had a value of 6.5. The dominant cations are calcium, sodium, magnesium, and potassium and the dominant anions are chloride, carbonate, and sulfate respectively (Table 6).The concentration of nitrate ranged from 2 to 12 mg/L. The dust in the atmosphere consisting of carbonates, sulfates and other mineral components is responsible for the relatively high pH of the water and general prevalence of calcium carbonate and calcium sulfate.

Table 6: Composition of precipitation water for Salt and Deir Alla areas (3 years average sample each).

Zusammensetzung des Niederschlagswassers in den Gebieten Salt und Deir Alla (Dreijahresmittel).

Variable	Salt Minimum	Salt Maximum	Salt Weighted Av.	Deir Alla Minimum	Deir Alla Maximum	Deir Alla Weighted Av.
Quant., mm	0.2	67.0	10.21	0.1	29.2	9.6
Temp., °C	6.2	16.7	10.81	11.2	00.1	18.5
pH	6.39	6.74	7.607	9.80	9.28	7.49
EC, μS/cm	18.0	372.0	98.67	41.0	800.0	159.8
Na^+, mmol/L	0.000	2.245	0.32	0.022	1.210	0.37
K^+, mmol/L	0.004	0.322	0.046	0.000	0.140	0.037
Mg^{2+}, mmol/L	0.000	0.912	0.32	0.000	3.756	0.612
Ca^{2+}, mmol/L	0.202	2.066	0.94	0.200	5.086	1.762
Cl^-, mmol/L	0.045	2.205	0.422	0.078	1.564	0.471
NO_3^-, mmol/L	0.004	0.214	0.057	0.071	0.128	0.08
SO_4^{2-}, mmol/L	0.062	1.800	0.376	0.002	2.000	0.70
HCO_3^-, mmol/L	0.095	0.719	0.318	0.109	2.599	0.71
Br^-, mg/L	0.000	0.390	0.066	0.000	7.820	0.318

3.3.2 Surface water

The surface water of the Jordan Valley which originates from the eastern side wadis and the Jordan River itself consists of two components; flood and base flow.The flood flows have normally electric conductivity values ranging from 180 to 350 µS/cm with pH values of 7.5 to 8.5 and a nitrate content of 10 to 40 mg/L. The major components are calcium carbonate and sulfate whereas sodium chloride ranks at the second stage of dominance. The chemistry of the flood waters differs very widely along the Jordan Valley and it is highly affected by landuse and human activities, in addition to the effects of the country rocks. The baseflow water quality depends largely on the aquifers from which the water issues. The upper aquifers belonging to the Upper Cretaceous and younger aquifers produce an intermediate water in relation to their salinity which ranges from 500 to 900 µS/cm. The pH of these waters range from 7.5 up to 8.4 and the nitrate content from 15 to 80 mg/L generally the water of this aquifer complex is yearly replenished and its water is of earth alkaline type with prevailing bicarbonates.

Along the lower reaches of the southern Jordan Valley side wadis baseflows originating from the lower aquifers (Lower Cretaceous and older rocks) are discharged. These waters have generally higher salinities which can go as high as a few thousand mg/L. The high salinity is caused by the dissolution of evaporates within the rock sequences or as relicts of the ancestors of the Dead Sea. One extreem example of that is the base flow of wadi Mallaha which has an electric conductivity value of 29 000 µS/cm. The high salinity of these baseflows is a result of the high contents of sodium chloride.

3.3.3 Groundwater

Due to the large extent of the Jordan Valley area, its climatic variability, different surface water resources, mechanisms of flow and water rock interactions in addition to landuse practices which differ from one area to another the groundwater qualities show a wide spectrum of types, characteristics, and salinities.Therefore, it is not easy to convey a detailed picture of the situation of the groundwater qualities. None-the-less the general situation is given below:

a. Water in the alluvial fans and slope debris: This groundwater is generally replenished by flood waters originating in the highlands and flowing into the Jordan Valley.The EC of these waters ranges from 700 up to 1000 µS/cm [11–13]. The pH value lies between 7.5 and 7.9 and the water is of alkaline earth type with prevailing carbonates or chlorides. If not affected by agricultural practices and infiltrations from cesspools the water can be used for drinking purposes after chlorination. Generally, the nitrate concentration is less than 20 mg/L. Only in polluted areas with irrigation return flows this value may reach 100 mg/L. But due to the high throughout capacity of the alluvial fans it is not impractical to flush such aquifers.The salinity of the water in the alluvial fans increases in a westerly direction, towards the Jordan river course, due to mixing processes with more salty waters of different origins.

b. Water in the Lisan Formation (JV3) unit: The permeability of the Lisan Formation is very low and can be considered as an aquiclude. But, since the unit contains thin sand and silt beds of 20 to 30 cm thickness and due to its high salt content (mainly composed of gypsum and rock salt, which may reach 10 % of the volume of the total rock), pathways for the water have developed resulting in higher porosities and permeabilities.The water which seeps from this unit to the surface is highly saline with salinities reaching 50 000 µS/cm.

Other aquifers and rocks in direct contact with the Lisan Formation receive seepages from the latter which leads to increases in their salinities. Generally, the Lisan Formation is a major source of soil and water salinity in the Jordan Valley area. Where it crops out or is in contact with other water bodies high salinity values are expected. Soils covering the Lisan Formation are also highly saline because of upward leaching of salts and restricted drainage. Especially severe are the conditions in the westerly and south westerly quarter of the Jordanian part of the Jordan Valley extending from the Yarmouk River to the Dead Sea and extending 2...5 km to the east of the Jordan River course.

c. Groundwater in the Jordan Valley 2 (JV2) unit: In this aquifer a variety of water types is found. The quality depends on the source of the groundwater and the mixing ratios with other water types (compare Fig. 5):

– Pure JV2 water originating from flood flows, direct recharge by precipitation or lateral flows from the surrounding Upper Cretaceous aquifers have qualities which resemble those of the alluvial fans water discussed under “a” above.

  Mixed, pure JV2 water with upward moving more saline water originating from deep Lower and Upper Cretaceous rocks. The salinity of these waters range from 1500 to 4500 µS/cm. The main components are sodium chloride in areas where the second component comes from Lower Cretaceous and older rocks and calcium carbonates where it comes from Upper Cretaceous rocks. The closer to the foothills of the escarpment the more fresh is the water. The closer to the Jordan River course the less probable to encounter water with salinities of less than 3000 µS/cm in this type of aquifer.

d. Tertiary and Cretaceous rocks: The water in these rock units originates from precipitation over the highlands of Jordan which infiltrates and percolates under a variety of conditions which results also in different water qualities which may be summarized in the following:

– Water naturally discharged from aquifers at elevations of –200 up to 800 m altitude.Such waters are generally fresh and directly recharged by precipitation water. They do not percolate deep into the country rocks but discharge through springs at the mountain slopes to the Jordan Valley (from formations such as B2, A7, A4). The salinity of these springs ranges 700 to 1000 µS/cm with slightly alkaline pH 7.5...7.9 and a nitrate content of 20 to 60 mg/L. This type of groundwater may flow laterally into the Jordan Valley units JV1, 2 or 3.

– Water in the Upper Cretaceous rocks under confined conditions.The Upper Cretaceous rock units are mainly composed of limestones, dolomites, marls, chalks, and chert. The recharge to these aquifers takes place along the highland outcrops or from percolation through the overlying aquifers. At the slopes to the Jordan Valley the water becomes confined and a variety of oxidation/reduction processes takes place resulting in water types of different reducing stages ranging from oxygen free water, to nitrate free water, to waters with reduced sulfate contents with CO_2, H_2S, N_2, and even radon gases. Due to reduction processes and CO_2, H_2S production such waters have capabilities of carbonate dissolution. Therefore, they react with the carbonate rock matrix and produce a groundwater which is oversaturated with carbonate minerals, free of oxygen and nitrates, with reduced sulfate contents, and containing H_2S, CO_2, N_2, and radon gases (Mukheiba and Wadi Arab wells in the northern part of the Jordan Valley producing from the B2/A7, aquifer). This type of water may flow laterally into the Jordan Valley units JV1, 2 and 3 or it may seep upwards through faults, joints, or fissures developed in the confining layers into other units, especially those of the Jordan Valley alluvials.

– Water in the Lower Cretaceous, Jurassic, and Triassic aquifer complex. The rocks of these ages are mainly composed of sandstones and siltstones. The Jurassic and Triassic rocks contain some Gypsum and dolomite beds. Also here two types of groundwater are found; confined and unconfined. In the unconfined portions of the aquifer the water is slightly saline with EC values of 1500 to 3000 µS/cm, containing oxygen and nitrates. The salinity is mainly a result of the sodium chloride content. If not directly affected by human activities the nitrate contents is ± 15 mg/L. Along its flow in a westerly direction the water in these rocks meets the more recent rocks of the Jordan Valley Formations JV1, 2 and 3 and recharge them laterally.

– The confined portions of the aquifer complex contain water with a salinity which is higher than that of the unconfined portions. It ranges from 3000 µS/cm up to few ten thousand µS/cm. The water is oxygen and nitrate free and discharges CO_2, H_2S, N_2, and radon gases. The confined water finds it way laterally and upwards into more recent formations such as Upper Cretaceous rocks or JV1, 2 and 3, to the earth surface.

4 Characterization of water chemistries along profiles

4.1 End members

In this chapter the composition of the end members which contribute to the composition of the groundwaters in the Jordan Valley are briefly discussed.

4.1.1 Precipitation water

The composition of precipitation water along the highlands of Jordan and in the Jordan Valley area was measured for three successive rainy seasons [10]. For the present study Salt and Deir Alla, stations' measurements are used to characterize the precipitation water chemistry along the highlands and in the Jordan Valley area. Along the highlands bordering the JV area measurements of 3 stations are available but their measurement, maximum, minimum, and weighted average of the composition of these stations are similar.

Table 6 gives the average weighted composition of precipitation for Deir Alla and Salt, which represent the types of precipitation in the area. The average EC value for Salt station is around 99 µS/cm, whereas that of Deir Alla is 160 µS/cm, for an average precipitation 500 mm/a and 250 mm/a. The increase in salinity between the two stations is mainly caused by carbonates and gypsum minerals as can be indicated by the unproportional increases in Ca^{2+}, Mg^{2+}, SO_4^{2-} and HCO_3^- of around 2 fold compared to a salinity increase of 1.6 fold. The increase in the concentrations of Na^+, Cl^-, K^+, and NO_3^- are very minor.

This fact may result from carbonate and gypsum dusts in the Jordan Valley which are blown from the exposed friable Lisan Formation. The ionic ratio reflect also that fact. The Na^+/Cl^- of 0.7 to 0.8, and the Mg^{2+}/Ca^{2+} of 0.35 (Table 7a) are normal for precipitation water in Jordan. Precipitation water is strongly undersaturated with respect to anhydrite, calcite, dolomite gypsum and halite (Table 7b). The water is of earth alkaline type with increased portion of sulfates and bicarbonates; $Ca^{2+} >< HCO_3^- > SO_4^{2-}$.

Table 7a: Ionic ratios of water chemistries of the Jordan Valley area.

Chemismus der Wässer im Jordantal – Ionenverhältnisse.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-} + HCO_3^-)$	HCO_3^-/Cl^-
Salt	0.75	1.10	0.37	0.54	2.48	0.45	0.68	0.11	0.92	0.75
Deir Alla	0.79	1.87	0.65	0.35	2.51	0.74	0.42	0.08	0.83	1.51
Um Qeis	0.75	5.13	1.29	0.25	22.00	0.23	0.15	0.08	0.86	5.73
Ziglab	0.70	5.30	2.10	0.40	9.85	0.54	0.13	0.06	0.76	6.41
Hizzir	0.68	1.00	1.90	1.91	2.81	0.35	0.68	0.17	0.44	1.89
Kurnub	0.88	1.00	0.75	0.87	1.24	0.84	1.16	0.08	0.56	0.84
Zerqa Av.	0.93	0.52	0.25	0.51	1.28	0.45	1.95	0.09	0.58	0.45
Lisan Leaching Av.	0.54	0.15	0.23	1.71	3.80	0.05	4.26	0.05	3.67	0.04
Well 5 Karama Av.	0.53	0.21	0.27	1.31	3.85	0.055	2.62	0.03	2.18	0.03

Table 7b: Saturation indices of the end members of water chemistries in the Jordan Valley area.

Chemismus der Wässer im Jordantal – Sättigungsindizes der hydrochemischen Endglieder.

Phase	Salt	Deir Alla	Um Qeis	Ziglab	Hizzir	Kurnub	Zerqa Av.	Lisan Leaching Av.	Well 5 Karama Av.
Anhydrite	–1.67	–1.09	0.44	0.066	–0.4	0.2	0.52	–0.1	0
Calcite	–4.51	–3.16	–0.19	–0.42	–1.02	0.01	0.24	–0.4	–0.45
Dolomite	–3.48	–3	–2.72	–2.27	–2.47	–2.2	–0.3	–1.54	–1.5
Gypsum	–3.22	–2.75	–2.49	–2.05	–2.23	–2.2	–0.13	–1.1	–1
Halite	–8.46	–8.37	–7.86	–7.79	–7.09	–7.3	–3.3	–3.6	–3.6

4.1.2 Water in the Upper Cretaceous rocks

Generally, three aquifers are found along the highlands within the Upper Cretaceous rock sequence; The B4, 5, the B2/A7 and the A4. The salinity of water in these aquifers is less than 1000 µS/cm.

The ionic ratios of Na^+/Cl^-, Mg^{2+}/Ca^{2+}, K^+/Cl^-, and $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$ resemble those of precipitation water of around 0.7, 0.3, 0.07 and 0.8 (Table 7). Their Ca^{2+}/Cl^- and Mg^{2+}/Cl^- show far higher values than precipitation water as an indication of carbonate dissolution. In addition the constance of the $Ca^{2+}/(HCO_3^- + SO_4^{2-})$ ratio and the strong increase of Ca^{2+}/SO_4^{2-} ratio from around 2.5 for precipitation water to 10...22 in the Upper Cretaceous aquifers shows that only little gypsum and halite are being dissolved from these aquifers because they are already strongly leached. The HCO_3^-/Cl^- ratio is very high $\mp$ 6 which shows also the CO_2 contributions of the soil and aquifer and the stronger dissolution of carbonates relative to chlorides.

The groundwater in the Upper Cretaceous aquifers is of normal earth alkaline type with prevailing bicarbonates. The lower aquifer of the Upper Cretaceous sequence; the A4 shows slightly elevated chloride contents. Generally $Ca^{2+} > Mg^{2+} > Na^+$ and $HCO_3^- > Cl^- > SO_4^{2-}$. All the waters in this end member are strongly undersaturated with respect to halite and gypsum (SI 7.92 to –6.48 and –2.49 to –1.43), and are slightly over or undersaturated with respect to calcite and dolomite.

4.1.3 Kurnub and Zerka groups water

Water in these rocks originates from percolation through Upper Cretaceous rocks and to a lesser extent from infiltration of precipitation water. These react with the rock matrices to produce special types of groundwater which flows laterally westward and feed the Jordan Valley aquifers.

With increasing salinity a decrease in the Ca^{2+}/Cl^- ratio is observed from 2.56 to 0.42 in the Kurnub water and from 0.8 to

0.4 in the Zerqa group. The higher ratios are found along the recharge areas or areas where the groundwater is not affected by dissolution of evaporites. This shows that higher amounts of chlorides are dissolved in the water along its pathway from the recharge to the discharge areas than calcium. The Mg^{2+}/Cl^- ratios which also decrease with increasing salinity have a value of 1.29 to 0.3 in the Kurnub water and 0.48 to 0.2 in the Zerqa group water, which also shows higher rates of dissolution of chlorides than magnesium.

The Na^+/Ca^{2+} ratio in the Kurnub water ranges from 0.35 to 2.24 with the majority of samples having a ratio of around 0.8, whereas those of the Zerqa group range from 1.24 to 2.74 and an average of 2. With increasing salinity the ratio increases as a result of cation exchanges or weathering of feldspar remains present in the in the sandstones.

The SO_4^{2-}/Cl^- ratios of the Kurnub water range from 0.51 to 1.55 with an average of around 0.7...0.8, whereas in the Zarka water the values range from 0.17 to 0.69 with an average of around 0.45. The Ca^{2+}/SO_4^{2-} ratio of the Kurnub water ranges widely between 2.43 and 0.57 decreasing with increasing salinity. In the Zarka water this ratio ranges from 0.79 to 1.76 although the salinity of the Zarka water is 2 to 4 times higher than that of the Kurnub water.

The above indicates that the increasing salinity is mainly caused by dissolution of chlorides; mainly calcium chloride and to a lesser extent magnesium chloride. More sulfate becomes also dissolved in the water on its way from the Kurnub group through the Zerqa group but relatively higher amounts of chlorides including earth alkaline chlorides are dissolved than sulfates.

The Kurnub water is of earth alkaline type with increasing portions of alkalies and prevailing bicarbonates with tendencies to prevailing bicarbonates and sulfates. It is of Ca^{2+} + Mg^{2+}, HCO_3^- type with $Na^+ > Ca^{2+} > Mg^{2+}$ and $Cl^- > SO_4^{2-} \geq HCO_3^-$. The Zerqa group water is of alkaline type with prevailing sulfates and chlorides. It is of $Na^+ + K^+$, Cl^- type with $Na^+ > Ca^+ > Mg^{2+}$ and $Cl^- > SO_4^{2-} \geq HCO_3^-$.

4.1.4 Water in the Lisan Formation

Leaching tests of the Lisan Marls, 5 samples from each subformation reveal the results given in Table 7a. They are compared with the results obtained from a well drilled in the Lisan Marls during the investigations of Karama dam site (No. 5). These results are considered to represent one of the major end members for water chemistry in the Jordan Valley. The slight differences in the averages and ranges of data obtained from the leaching experiments and those from the well are attributed to different chemistries of the water reacting with the Lisan Marls. In the case of leaching experiments distilled water was used, whereas the original water reaching the well (site 5) is groundwater with an original salinity of a few thousand µS/cm salt content.

The Na^+/Cl^- ratio is around 0.54 compared to 0.75 in precipitation water and around 0.9 in Kurnub and Zerqa group waters. This indicates dissolution of other chlorides than halite. The Ca^{2+}/SO_4^{2-} ratio is for beyond unity, 2.4 to 6.24 which due to the relatively low ratio of bicarbonate content to salinity shows also the dissolution of a calcium rich source [14]. The magnesium concentration (mmol/L) is even higher than that of calcium which may result from magnesium evaporites; mainly chlorides dissolution.

The water of the Lisan Marls is of alkaline type with prevailing chlorides and sulfates, with $Na^+ > Mg^{2+} > Ca^{2+}$ and $Cl^- > SO_4^{2-} \gg HCO_3$. It is undersaturated in respect to calcite, dolomite,

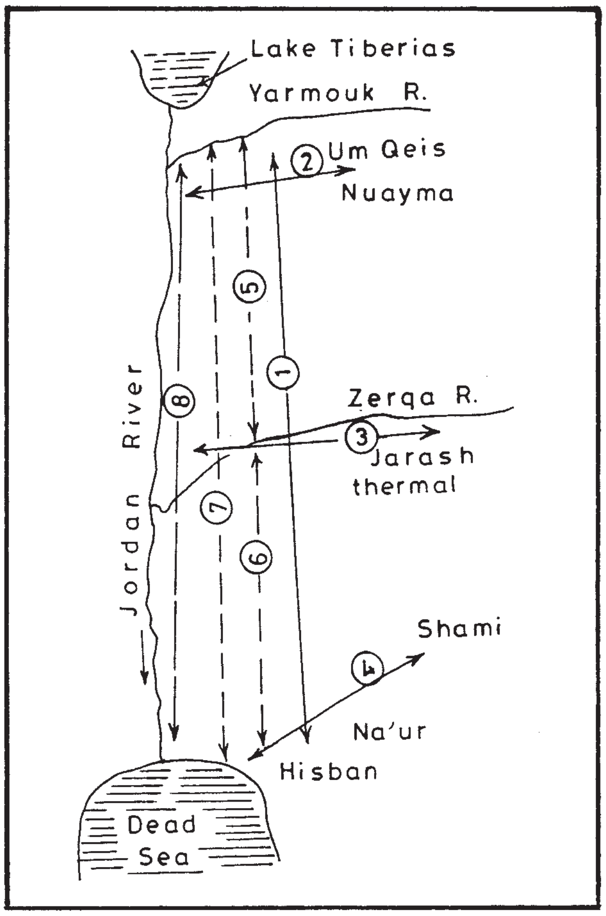

Fig. 6: Location map of hydrochemical profiles.

Übersichtskarte zu den untersuchten hydrochemischen Profilen.

anhydrite, gypsum, and halite but it is less undersaturated than the other waters in respect to halite gypsum and anhydrite.

4.2 Hydrochemical profiles

In the following chapters the hydrochemical variations along profiles extending from the highlands into the Jordan Valley and along the highlands bordering the Jordan Valley and the Jordan Valley itself are discussed. This will allow the understanding the evolution of the water chemistries along the pathways of the groundwater flows in the different aquifers. In addition to own analyses, the results of which are given in the Appendix, some information was taken from [12, 13, 15–17]. Figure 6 shows the locations of the different profiles and sites.

4.2.1 Groundwater along the escarpment (profile 1)

Figure 2 shows the different aquifers cropping out at the slopes to the Jordan Valley. The groundwater in these aquifers flows generally westwards and feeds laterally the groundwater bodies within the Jordan Valley floor. In the northern most area it is the B4, B5 composite aquifer along the Yarmouk and Wadi El-Arab which crops out. The deeper lying confined B2/A7 aquifer contributes also appreciable amounts of water to the Jordan Valley floor aquifers [18]. Along Wadi El-Arab, Ziglab, Yabis, and Kufranja contributions to the JV groundwater bodies originate mainly from the B2/A7 aquifer with minor contributions of the A4 aquifer especially along Wadi Yabis. Along Wadi Zerka and its surroundings and along Wadi Hisban the water originates from the Kurnub and Zerka aquifers. In the area west of Salt City some groundwater of the A4 laterally feeds the JV aquifer. Along the slopes, west of the area extending from Salt to Wadi Sir the groundwater is found in the B2/A7 aquifer. It feeds the JV groundwater bodies lying to its west.

Table 8 gives the results of water analyses of the escarpment aquifers on the examples of springs issuing from them. Generally the salinities expressed in EC units is less than 1000 mS/cm which is considered from this point of view as of the best waters found in Jordan, pH values are normal, the calcium, magnesium, sodium, and potassium equivalent concentrations range from: 2.36 to 5.56, 1.16 to 4.51, 0.63 to 3.78, and 0.02 to 0.41 mmol/L respectively. The equivalent concentrations of anions Cl^-, SO_4^{2-}, and HCO_3^- range from: 0.85 to 4.2, 0.21 to 3.5, and 2.51 to 6.92 mmol/L respectively. All the above parameters show very normal concentrations for surface aquifers feed directly by precipitation water in Jordan.

The nitrate equivalent concentration in surface aquifers which are not affected by human activities range from 0.16 to 0.33 mmol/L [19]. Along the escarpment, only in Subeihi (Al Husan spring), this value exceeds the normal concentrations and reaches 0.520 mmol/L due to animal husbandry in that area.

All these waters are strongly under saturated with respect to halite and gypsum with SI –7.92 to –6.48, and –2.49 to –1.43 (Table 9). Calcite shows a SI ranging from –0.84 up to +0.52 (Table 10). Generally there is a decrease in the saturation indices of calcite from north to south somehow coinciding with the ages of aquifers. The highest SI of +0.521 and +0.439 are found in the youngest aquifer B4, B5 decreasing in the B2/A7 and K/Z to slightly undersaturated to undersaturated water. This fact can be explained by stronger leaching of recent aquifers than that of the older already leached ones. The SI of dolomite show no pattern of increase or decrease; the same aquifer water in neighbouring wadis are either over or undersaturated in respect to dolomite. All samples, from all aquifers are strongly undersaturated with anhydrite, –1.66 to –2.72.

The ionic ratio (Table 9) of Na^+/Cl^- ranges from 0.42 to 1.15 with the majority of samples receiving direct recharge and or only slightly affected by the aquifer matrix having ratios of 0.70 to 0.95. The Azarq sample with a ratio of 0.42 indicates that exchange processes are taking place. The water of this spring issues from the A4 and may be affected by the overlying shales and marls during its down percolation. Subeihi sample with a Na^+/Cl^- ratio of 1.15 reflects recent water infiltrating into the Kurnub sandstone aquifer. The Ca^{2+}/Cl^- and Mg^{2+}/Cl^- are generally above unity and ranges from 1 to 5.3, for Ca^{2+}/Cl^- and from 0.81 to 2.39 for Mg^{2+}/Cl^-. The Mg^{2+}/Ca^{2+} ratio is generally low; less than 0.85. The HCO_3^-/Cl^- ratio is generally higher than 1 and ranges from 0.91 to 6.41 which resembles precipitation water with defferent degrees of contacts and reactions with carbonate rocks.

The water along this profile is of normal earth alkaline type with prevailing bicarbonates (Fig. 7). Hizzir sample has a slightly elevated chloride component and Wadi Arab water tends to become of earth alkaline type with increasing portions of alkalies. This type of water resembles recent recharge water over the highlands of Jordan.

4.2.2 Evolution of water chemistry along profiles extending from the highlands westwards into the Jordan Valley area

4.2.2.1 Northern profile: Nuayma-Jordan Valley (profile 2)

The aquifer here is the B2/A7. Its water becomes confined along its down-gradient direction. The salinity of the groundwater along this profile extending from the highlands to the Jordan Valley shows gradual increases from 590 µS/cm in

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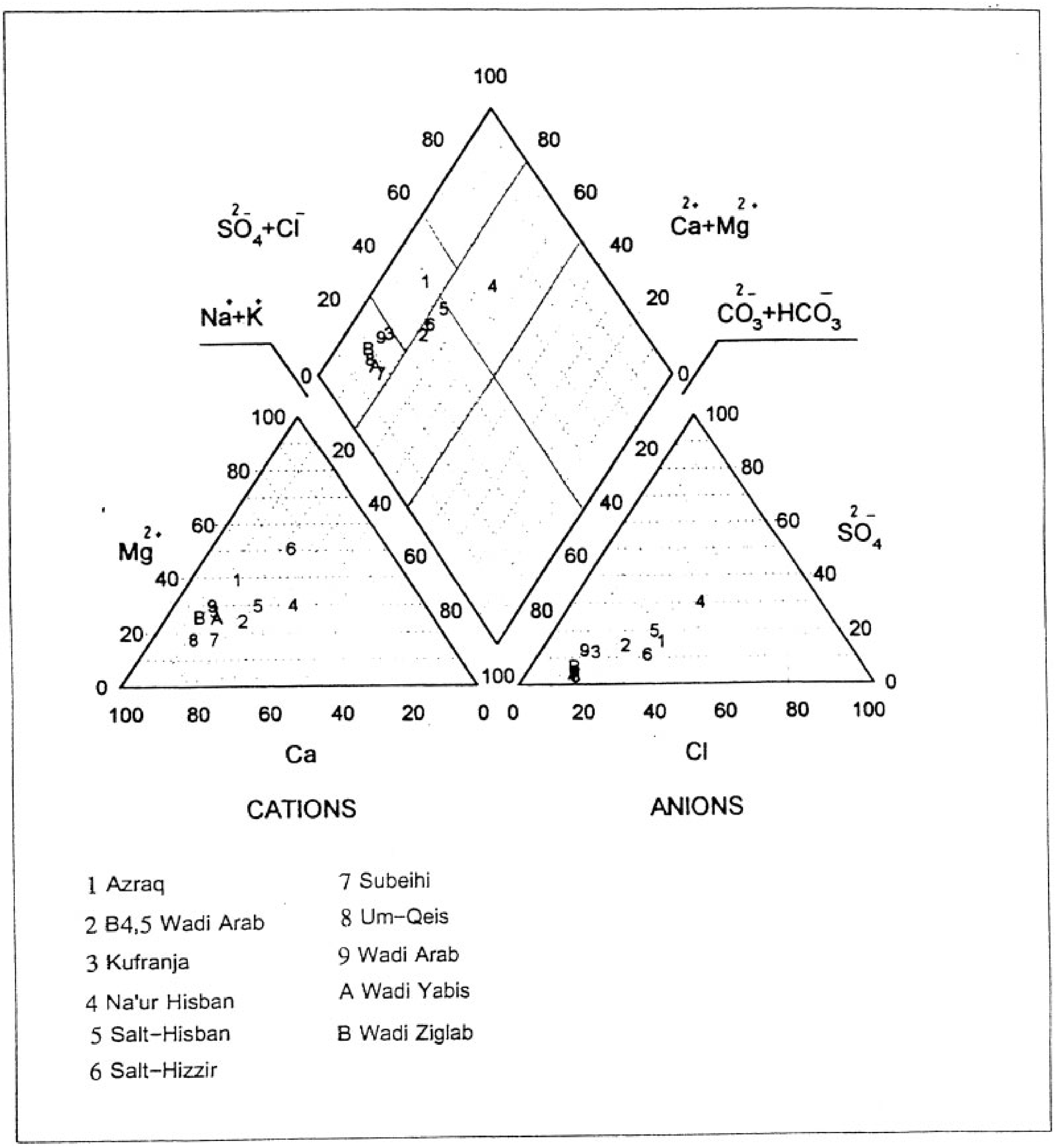

Fig. 7: Piper diagram for profile 1.

Piperdiagramm für Profil 1.

the highlands to 1378 µS/cm in Himma spring. Further west; in the JV area the water becomes mixed with other groundwaters and its salinity shows a relatively high range of variations; Al Shwahin well has an EC value of 1078 µS/cm and Ali Wahid well of 2320 µS/cm (Table 11).

The Na^+ and Cl^- equivalent concentrations increase very rapidly along this profile from around 0.4 to 5.7 mmol/L and 0.8 to 5.7 mmol/L respectively. Potassium and sulfate show also the same trends. Calcium and magnesium increase but at a moderate. The bromide concentration increases rapidly from

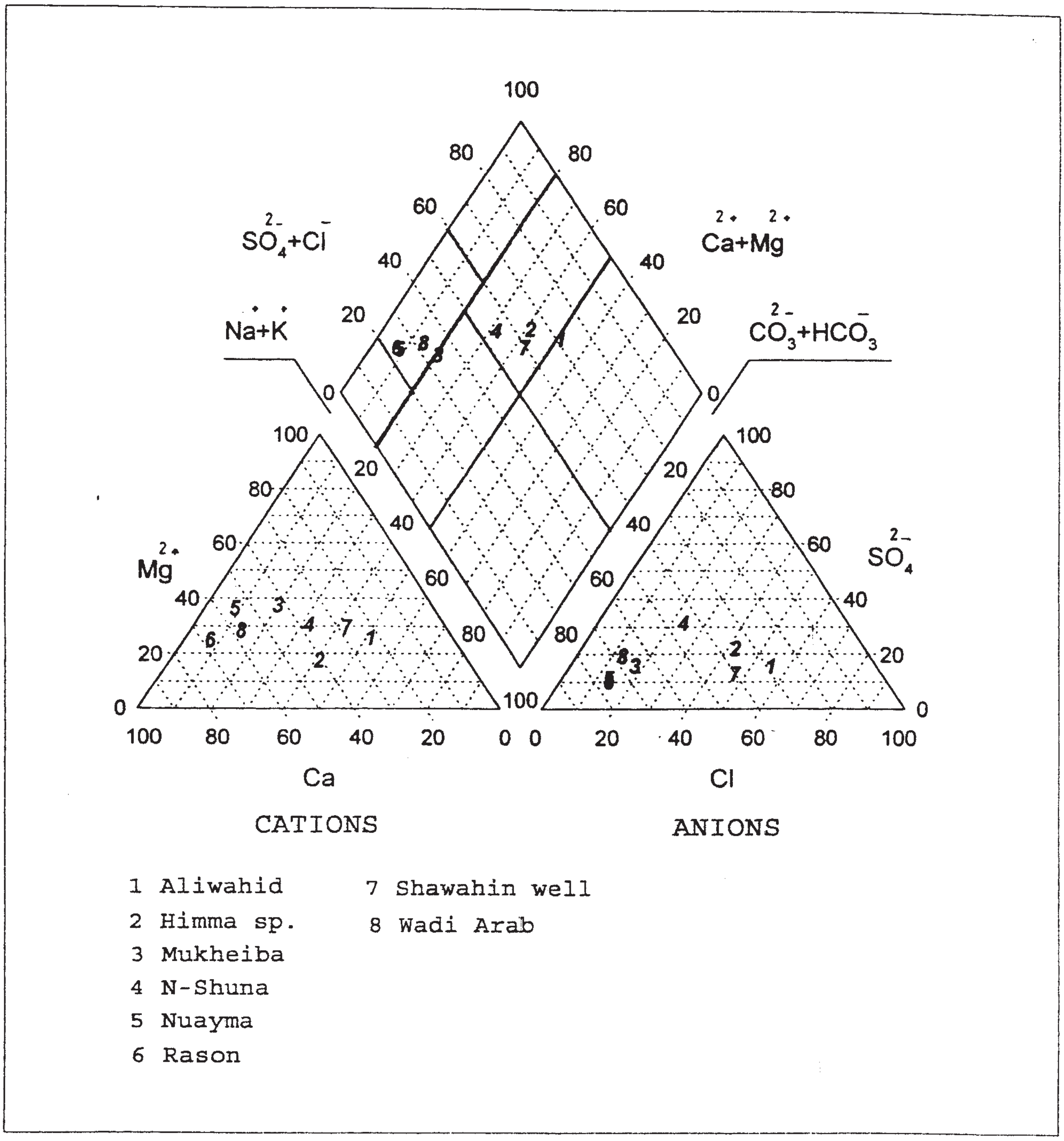

Fig. 8: Piper diagram for profile 2.

Piperdiagramm für Profil 2.

about 0.16 to 4.7 mg/L in Himma spring. In the Jordan Valley area this water mixes with other waters and shows generally increases in all parameter concentrations.

The Na^+/Cl^- ratio is low along the highlands 0.38...0.61 and increases rapidly to ± 1, certainly as a result of halite dissolution in ares covered by basaltic rocks (Table 12). The Mg^{2+}/Cl^- and Ca^{2+}/Cl^- ratios decrease along this profile from 3 to less than 0.5 and from 4.7 to less than 1 respectively. This behavior is also valid for HCO_3^-/Cl^- which decreases from 5.94 to 0.84 and to lower values in the Jordan Valley area itself. The Na^+/Ca^{2+} shows rapid increases from 0.08 to around unity.

This behavior is a result of NaCl-dissolution from the aquifer rocks, partly consisting of basalts covering some wadi courses and the northeastern parts of the study area (Jabel Arab El Druz). Such a Na^+/Cl^- ratio was also given for the basalt water of the surrounding areas [14].

In the highlands the groundwater is of normal earth alkaline type with prevailing bicarbonates. Along its down-gradient path the water dissolves more sulfates and chlorides and the water type changes to earth alkaline with increasing portions of alkalies and prevailing sulfates and partly chlorides (Fig. 8).

The groundwater is strongly undersaturated in respect to halite (–8.1), but it gradually becomes less undersaturated in a down-gradient direction where it becomes around –6. This same behavior is valid for gypsum which SI increases from –2.13 to –1.4 along the same gradient (Table 13).

The water in the recharge area is slightly undersaturated with respect to calcite and dolomite. In a down-gradient direction it becomes gradually oversaturated on these minerals. In the confined parts of the aquifer, Mukheiba, Shuna, and Himma the water is strongly oversaturated in respect to calcite and dolomite and the produced water precipitates these minerals upon release from the aquifer. The water is also undersaturated with respect to anhydrite but less undersaturated in the down-gradient area due to additional dissolution of gypsum minerals from the rock matrix.

The water along this profile is of normal earth alkaline type with increasing bicarbonates in the highlands changing to earth alkaline with increased portions of sulfates and chlorides in the Jordan Valley area.

4.2.2.2 Middle profile: Jarash (Thermal Spring) to Deir Alla (profile 3)

The aquifer here consists of the Kurnub and Zerqa groups. The salinity along this profile increases rapidly from 3420 µS/cm in Jarash thermal spring to 8850 µS/cm and 8550 µS/cm in Deir Alla thermal spring and JICAI well, in the Jordan Valley. Rapid increases in the concentrations of all salinity parameters are found along this profile. Whereas, nitrate does not show any certain pattern of change in its concentrations (Table 14).

The Na^+/Cl^- ratio (Table 15) is around 1 indicating dissolution of halite. Also the Ca^{2+}/SO_4^{2-} ratio fluctuates at around 1 as a result of gypsum dissolution. Ca^{2+}/Cl^-, Mg^{2+}/Cl^-, and SO_4^{2-}/Cl^- ratios decrease along the groundwater gradient which indicate a higher rate of dissolution of halite compared to gypsum. The K^+/Cl^- ratio is almost constant which indicates that the dissolution of halite and sylvite go hand in hand.

All samples are undersaturated with respect to halite, but their undersaturation decreases in a down-gradient direction. In general they are less undersaturated than the groundwater of the recharge area along the escarpment or along the northern profile chapter (4.2.2.1). Except the Mallaha spring in the Jordan Valley area all the samples are slightly undersaturated on gypsum –0.56 to –0.15. But they are less undersaturated than those of the recharge area (1) or those of the northern profile (4.2.2.1) extending from Um Qeis to the JV. The evaporite beds, especially the gypsum beds which crop out along Wadi Zerka are the source of the gypsum, halite, and sylvite of the water.

The saturation status on calcite, dolomite, and anhydrite do not show any pattern of changes. The water is slightly over- or undersaturated in respect to them (Table 16). This is a result of the pathway of the groundwater and its interaction with the evaporite lenses within the Zerqa group formations.

The Zerqa and Kurnub groups seem here to dictate the chemistry of the groundwater, because of their matrices contents on soluble minerals, especially evaporites and easy-weathering feldspars. The groundwater along this profile is of alkaline type with prevailing sulfates and chlorides. In the down-gradient area chlorides are more prevalent as a result of sulfate reduction and H_2S production (Fig. 9).

4.2.2.3 The southern profile Baqqa (Shami well) to the Dead Sea (profile 4)

The aquifer along this profile consists of the Kurnub group in the upper and middle parts and Kurnub and Zerqa group in the lower parts, along the foothills of the Jordan Valley. The groundwater shows here a gradual increase in salinity in a down-gradient direction; from around 700 mS/cm in Shami and Kafrain wells to 7919 µS/cm in JICA6 well and to 6540 µS/cm at the shores of the Dead Sea (Table 17). A general increase in the concentrations of the salinity parameters of Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-}, and to a lesser extent K^+ takes place along this profile. The nitrate concentration is very low.

The Na^+/Cl^- ratio (Table 18) fluctuates around unity which indicates dissolution of halite. The K^+/Cl^- is almost constant which means simultaneous dissolution of sylvite. Along the same profile, the Na^+/Ca^{2+} as well as the Ca^{2+}/SO_4^{2-} ratios increase and the Mg^{2+}/Cl^- and Ca^{2+}/Cl^- decrease which means that the main source of salinity is halite and to a lesser extent gypsum.

The groundwater is strongly undersaturated on halite, but along the flow direction the water becomes less undersaturated in respect to this mineral. This same behavior is also valid for gypsum (Table 19). The groundwater is undersaturated

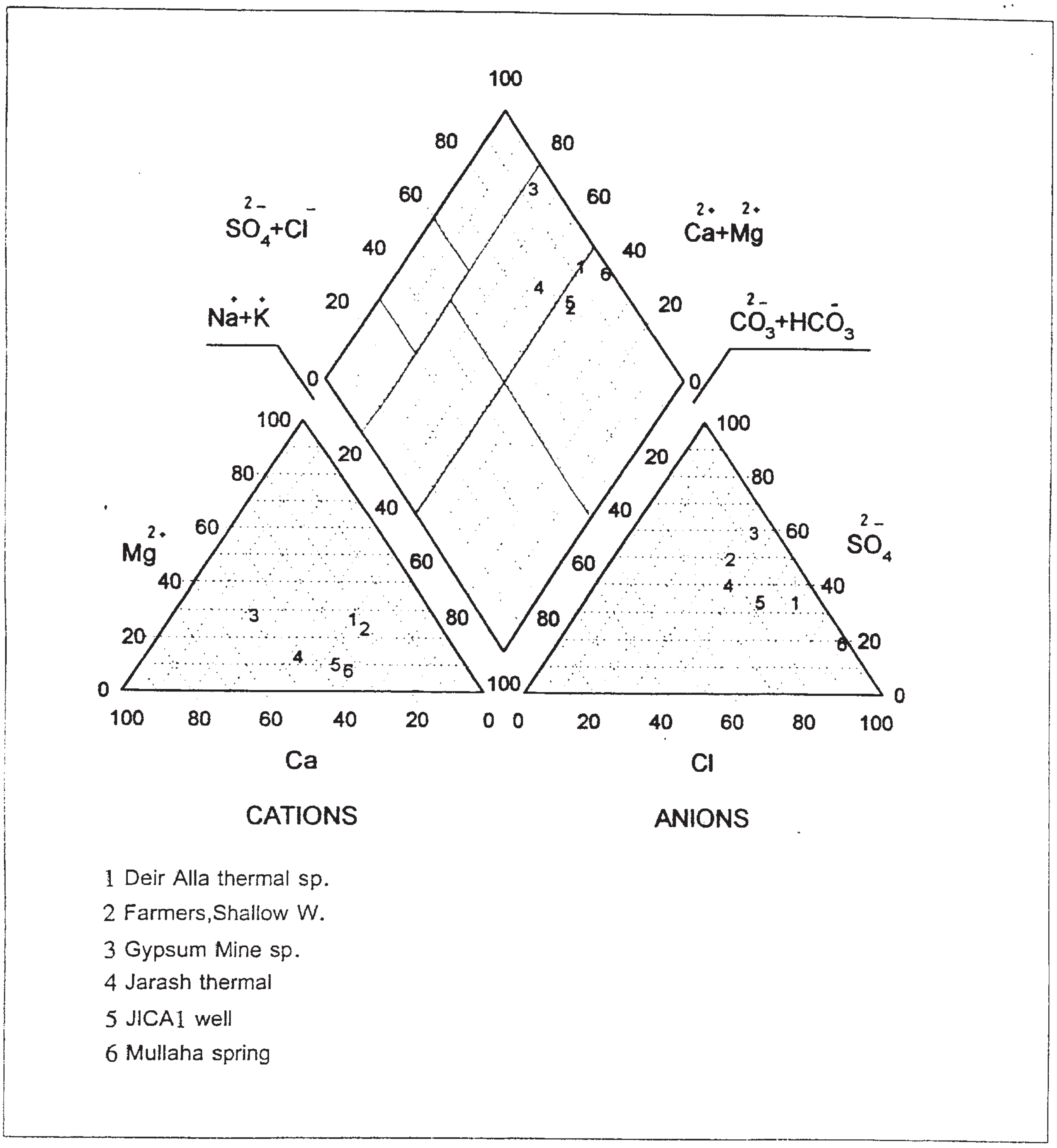

Fig. 9: Piper diagram for profile 3.

Piperdiagramm für Profil 3.

with respect to calcite, dolomite and anhydrite but in a down-gradient direction the water becomes less undersaturated on these minerals.

The Dead Sea well water becomes slightly oversaturated in respect to dolomite and calcite, may be as a result of pressure releases and CO_2 escape.

The groundwater in the up-gradient area is of earth alkaline type with increasing portions of alkalies and prevailing sulfates (Fig. 10). In a down-gradient direction it becomes of alkaline type with prevailing chlorides as a result of additional dissolution of halite and reduction of sulfates accompanied by the formation of H_2S.

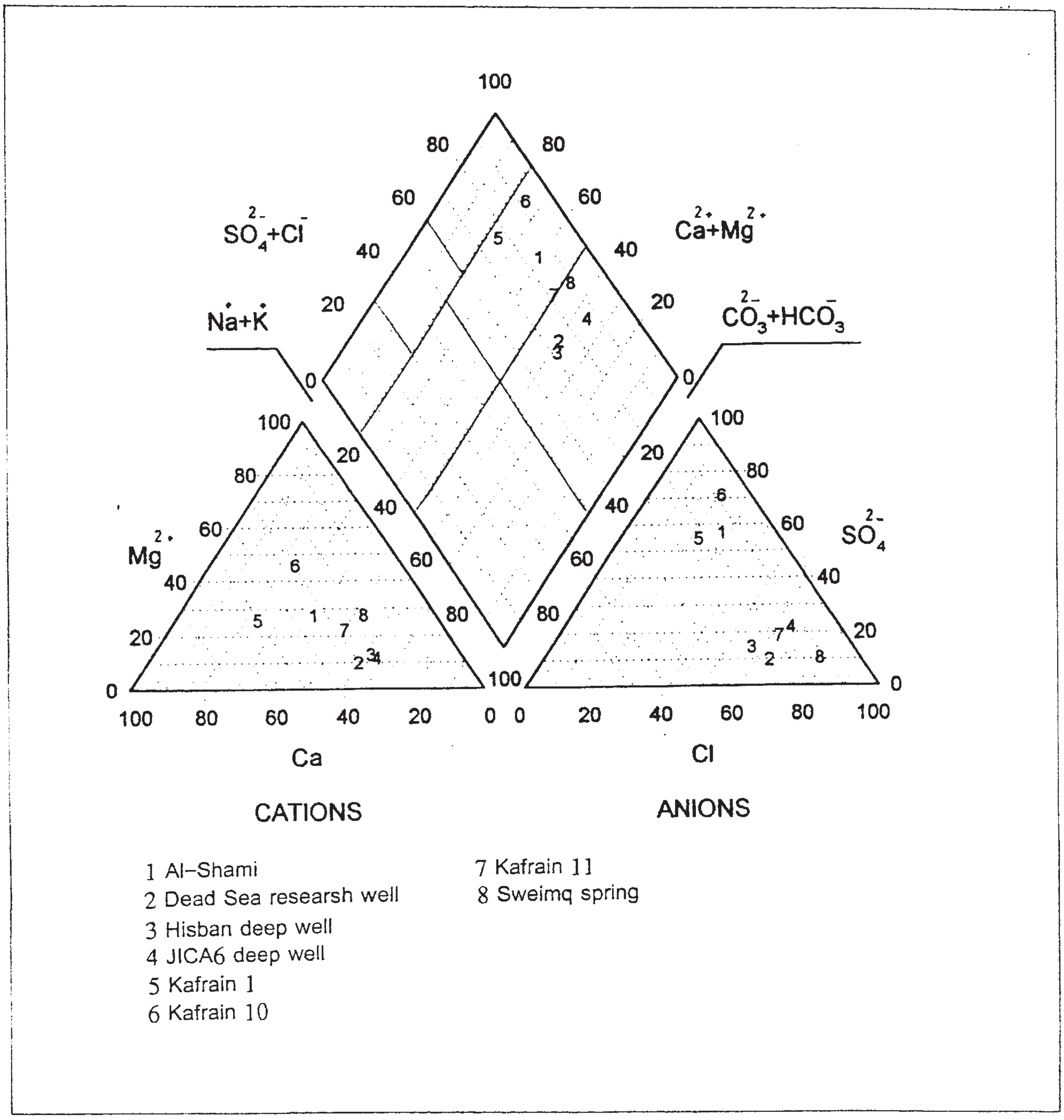

Fig. 10: Piper diagram for profile 4.

Piperdiagramm für Profil 4.

4.2.3 Groundwater along the foothills of the escarpment (profile 5 and 6)

This is the groundwater which enters the Jordan Valley area in the form of a lateral groundwater current feeding the aquifers of the Jordan Valley from its eastern side.

4.2.3.1 The northern area extending from the Yarmouk River to the Zerka River (Mukheiba wells to Deir Alla thermal spring) (profile 5)

In this area the water is found in the B2A7 aquifer. But it may in some portions originate from the deep Kurnub water which

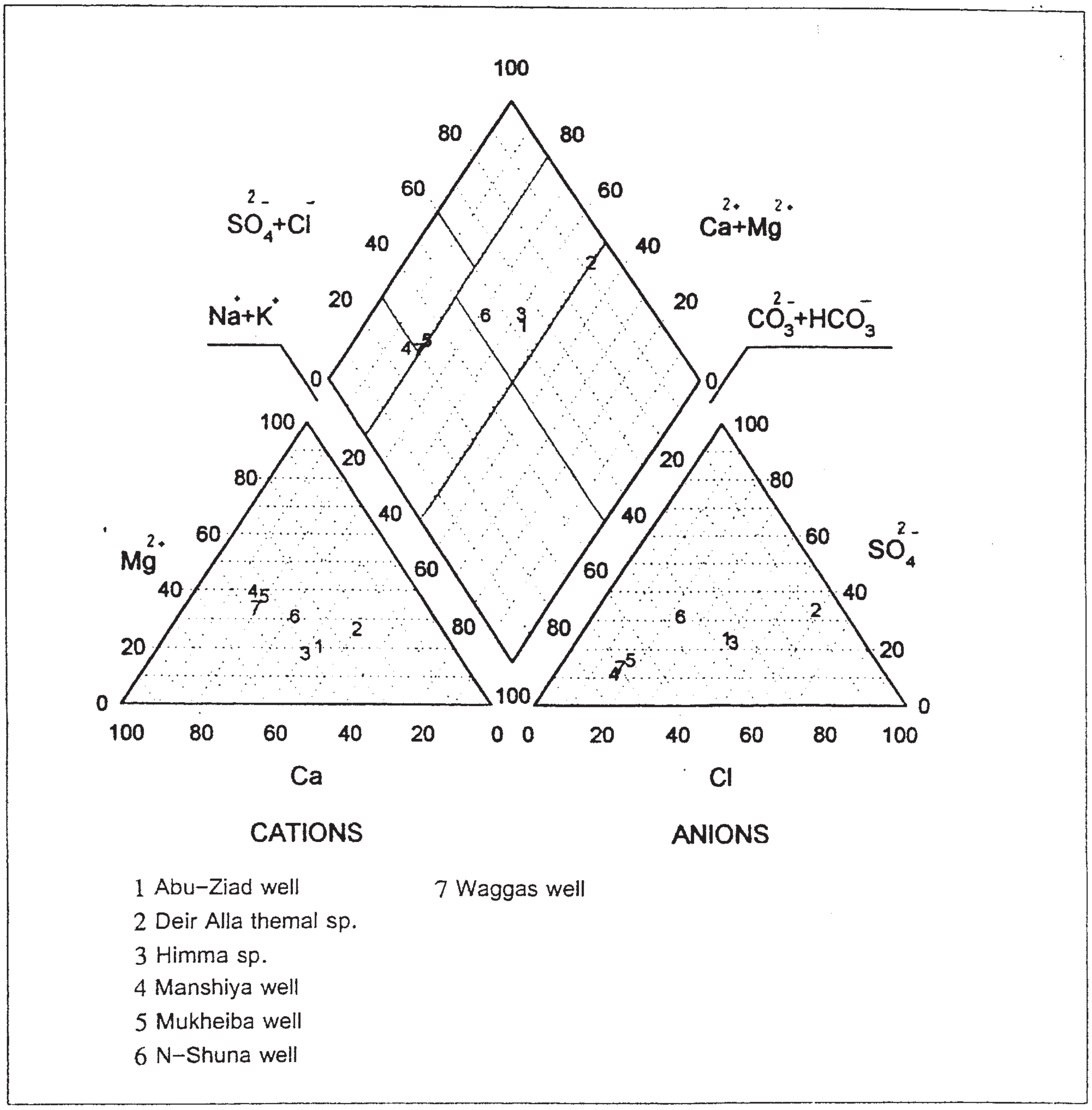

Fig. 11: Piper diagram for profile 5.

Piperdiagramm für Profil 5.

moves along faults and joints upwards into the overlying aquifers, especially the B2/A7 [18]. In the southern most part of the area in Deir Alla, the water is found in the Kurnub and Zerka groups.

The salinity along this northern profile increases from north to south, most probably as a result of increasing contributions from the deep aquifer; the Kurnub (Table 20). In Mukheiba wells the salinity of the water expressed in EC units is 889 µS/cm increasing to 2250 µS/cm in Abu Ziad wells. In Deir Alla spring which emerges from the K and Z group the EC reaches 8860 µS/cm. The salinity parameters of Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-} in addition to bromide and sulfate increase simultaneously from north to south. The water is gen-

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erally nitrate-free and H_2S is released from it at the ground surface indicating the reduction processes of sulfates.

The Na^+/Cl^- ratio is around unity indicating halite dissolution processes. The Ca^{2+}/SO_4^{2-} ratio decreases in accordance with increasing salinity; from 3 to 4 in the low salinity wells and to 0.73 to 1.56 in the higher salinity wells which is also a result of gypsum dissolution or plagioclase weathering and dissolution within the Kurnub group (Table 21). The Na^+/Ca^{2+} ratio increases with increasing salinity as a result of faster dissolution of halite than gypsum and plagioclase.

The water is undersaturated in respect to halite, gypsum, and anhydrite. But with increasing salinity the SI decrease from around –7.5 to 4.5 for halite, from –1.8 to –0.43 for gypsum and from –2.06 to –0.609 for anhydrite (Table 22). The water is generally saturated or very slightly undersaturated with respect to calcite and dolomite. For calcite the SI ranges from –0.617 to + 1.25 and –1049 to + 1.94, increasing with decreasing salinity.

The less salinity water is of normal earth alkaline type with prevailing bicarbonates, changing with increasing salinity to earth alkaline type with increased portions of alkalies and prevailing sulfates and bicarbonates, and finally in Deir Alla thermal spring to alkaline water with prevailing sulfates and chlorides (Fig. 11). The increases in the different constituents of the water result from the increasing confining pressures and reduction of nitrates and sulfates which allow H_2S and CO_2 to attack the rock matrix and dissolve its constituents of carbonates, sulfates, and evaporites.

4.2.3.2 The southern area Deir Alla to Sweima (profile 6)

All the wells drilled along this profile produced water from the Kurnub and Zerka groups. The salinity of the water is high, ranging from 7970 to 14700 µS/cm (Table 23). The main salinity parameters are according to their contributions to salinity Cl^-, Na^+, Ca^{2+}, SO_4^{2-}, Mg^{2+}, and HCO_3^-. The nitrate content is low to very low. The Na^+/Cl^- ratio is around unity indicating halite dissolution.

A general decrease in the SO_4^{2-}/Cl^- ratio is observed from north to south, seemingly as a result of sulfate reduction in that direction as can be indicated by the H_2S content of the produced water (Table 24). The HCO_3^-/Cl^- ratio is almost constant along this north south profile, but it decreases by a certain percentage with increasing salinity.

All samples are undersaturated with respect to halite, gypsum and anhydrite, but they are less undersaturated than the mountain aquifer water, SI halite around –4 compared to –7, SI gypsum around –0.7 compared to –2.0, and SI anhydrite –0.3 to –0.9 compared with –2 to –2.6 (Table 25). All waters here are slightly oversaturated with respect to calcite and except well 5 also with respect to dolomite.

All the waters along this profile are of alkaline type with prevailing chlorides. Earth alkalies, sulfates, and bicarbonates are less relevant and contribute moderately to the salinity of this water type (Fig. 12). The salinity is mainly caused by the dissolution of halite and to a lesser extent of gypsum and carbonates.

4.2.4 Groundwater in the Jordan Valley

Groundwater in the Jordan Valley area is found in different formations (Paragraph 3.2) such as rock debris along eastern mountain slopes, alluvial fans, Lisan Formation (JV3), Ubeidiya and Samra Formation (JV2), Kattar Formation (JV1) and the alluvial fans interfingering with them (JV1–JV3), and recent alluvial fans and alluvial deposits overlying the older formations (JV1–JV3). As previously mentioned the chemistry of the groundwater here is a function of different parameter listed below:

- chemistry of waters flowing along wadis feeding the Jordan Valley area,
- chemistry of the groundwater flowing laterally into the Jordan Valley aquifers,
- precipitation/evaporation processes,
- type of aquifer in the Jordan Valley,
- landuse and irrigation return flows,
- flow mechanisms in between the different JV aquifers.

Therefore, the groundwater shows a wide spectrum of types, characteristics, and salinities. For the purpose of clarifying the origin of the different water constituents in the JV area, two hydrochemical profiles extending from the Yarmouk River in the north to the Dead Sea in the south are studied.

4.2.4.1 The eastern profile (profile 7)

Wells along this profile penetrate the alluvials of the Jordan Valley along its eastern parts. Generally they are not affected by irrigation return flows because they lie in the upgradient areas of the irrigation land or in the upper reaches of the groundwater bodies underlying the irrigated lands.

Northern part: The salinity of the groundwater along the profile extending from the Yarmouk to the Zerka River (Adasiya-to Rajib) is low and reflects the salinity of the corresponding eastern escarpment aquifers, diluted by infiltration of precipitation or floodwater. The salinity ranges from 979 to 555 µS/cm. Adasiya well with 2080 µS/cm seems to receive some of its water from deeper salty aquifers where the sodium chloride concentrations prevail (Table 26). This well water

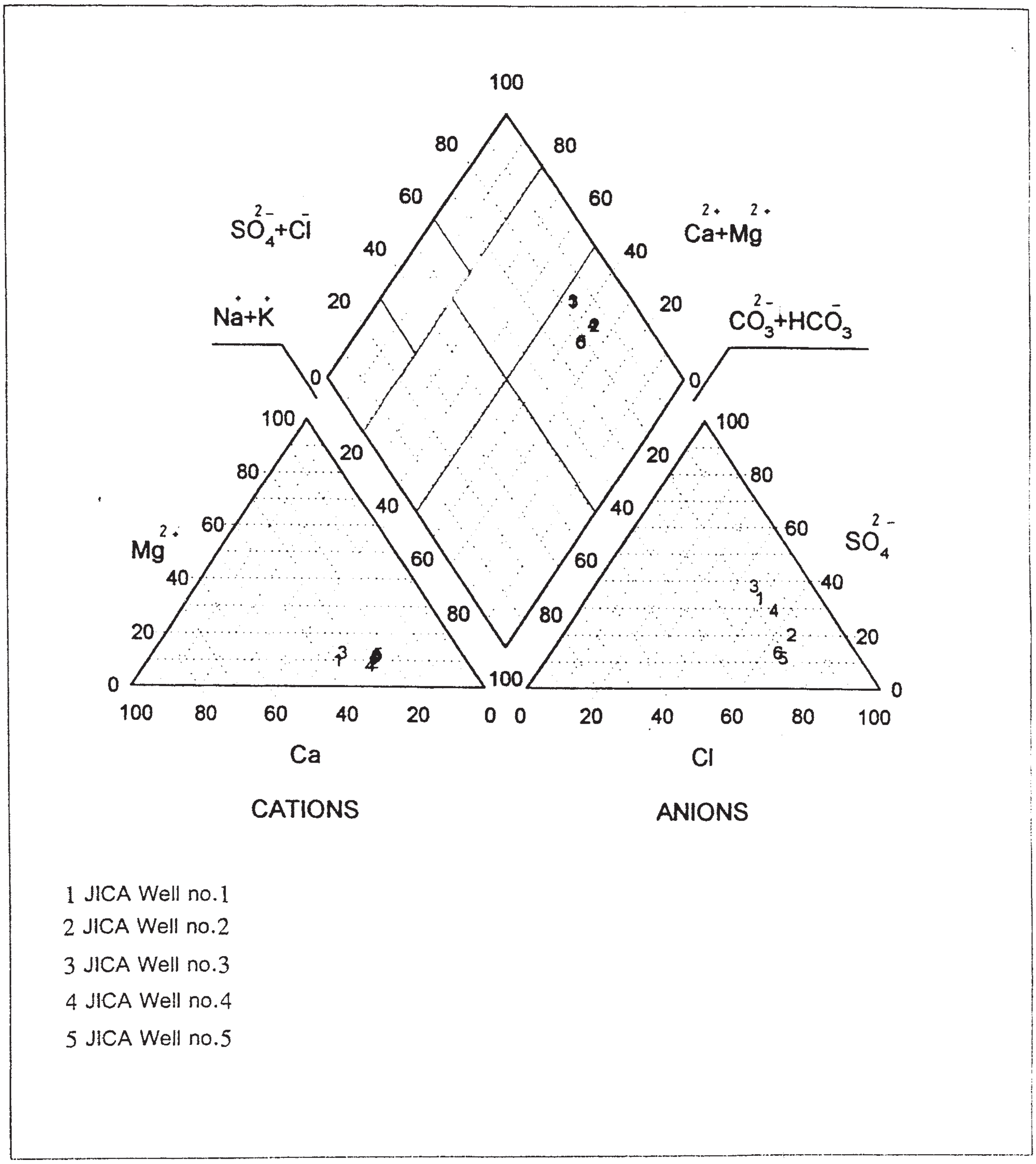

Fig. 12: Piper diagram for profile 6.

Piperdiagramm für Profil 6.

is of alkaline type with prevailing chloride as an indication of a deeper NaCl rich groundwater body. The ionic ratios range widely as a result of mixings of different waters of different chemistries and origins (Table 27).

All other samples are of earth alkaline type with prevailing bicarbonates and their salinities resemble those of the upper aquifers of the eastern escarpment (Fig. 13). All the waters of this group are undersaturated with respect to halite, gypsum,

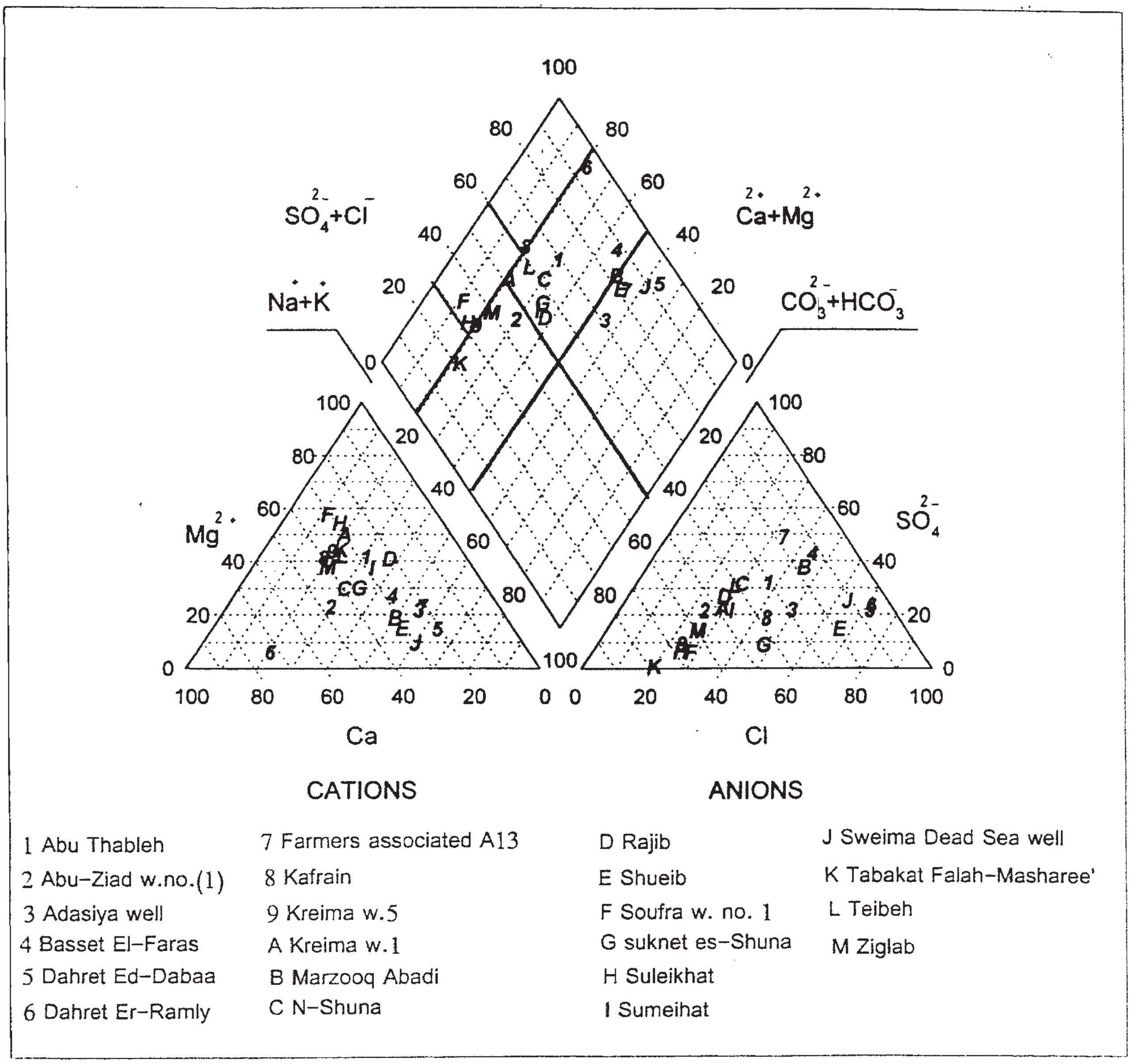

Fig. 13: Piper diagram for profile 7.

Piperdiagramm für Profil 7.

and anhydrite. Most samples are oversaturated with respect to calcite and only few of them are slightly undersaturated on it. Most samples are undersaturated with respect to dolomite (Table 28).

The groundwater in this area is generally a mixture of recent recharge water (direct and indirect) and lateral flows coming from eastern aquifers. Their nitrate contents are relatively low, 2...28 mg/L. The higher values among them such as Adasiya, Ziglab, and Suleikhat of ± 26 mg/L lie within urbanized areas, or along wadis draining urbanized areas. Generally, the groundwater chemistry is not affected by any major source of salinisation or pollution.

Southern part: From Deir Alla (Farmers Association well) to the Dead Sea (Sweima-Dead Sea well), the groundwater has higher salinities except along the area extending from Suknet es-Shuna to Kafrain (Table 26). Water in the Jordan Valley

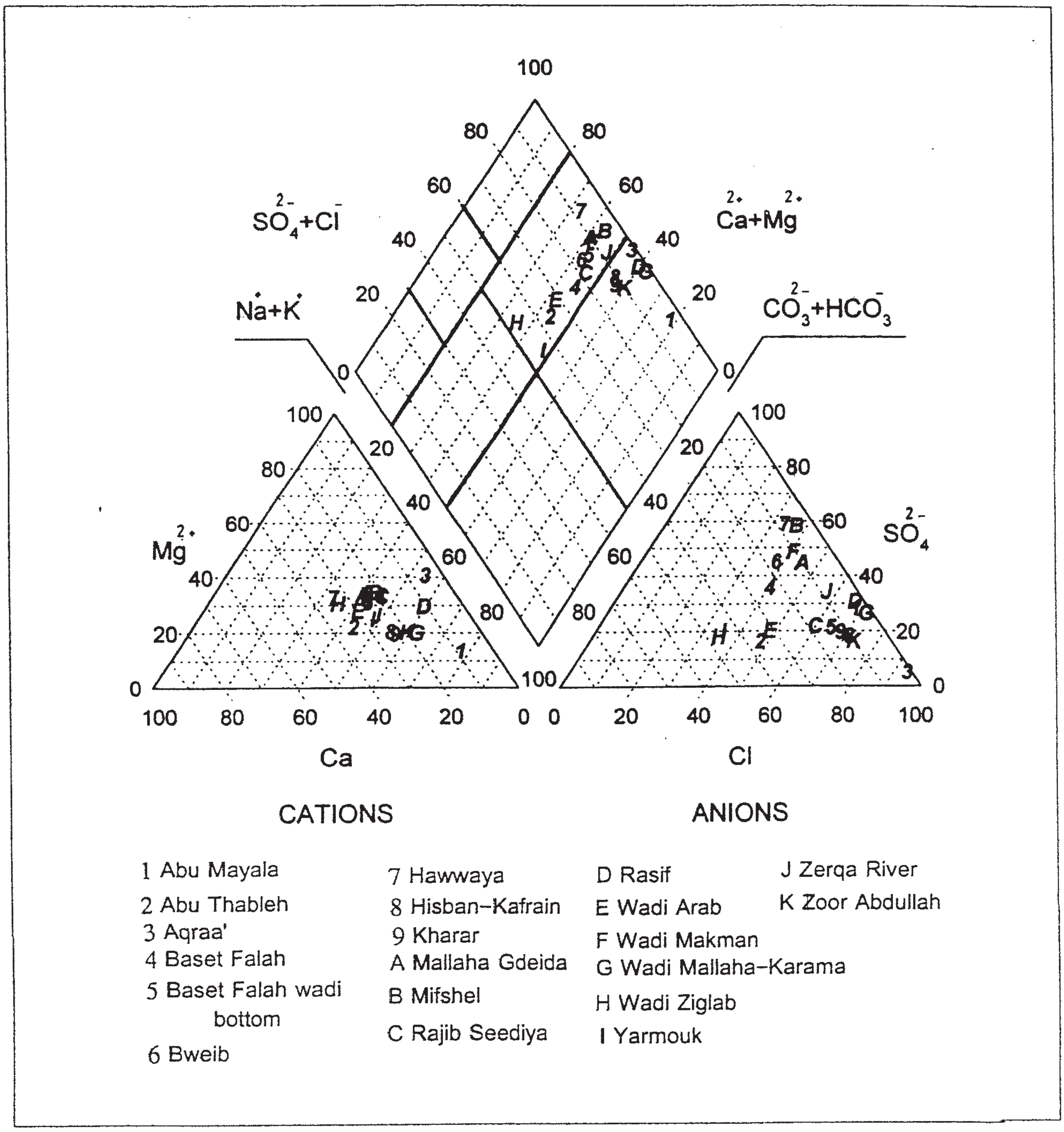

Fig. 14: Piper diagram for profile 8.

Piperdiagramm für Profil 8.

aquifer here has two main sources of lateral flows along the eastern escarpment; one is the Kurnub-Zerka groups groundwater with high salinity (Farmers Association, Dahreter Ramel, Dahret ed Dabaa, Bassal el Fares and Sweima) and the other is the Upper Cretaceous Limestones with the low salinity (Suknet es Shuna, Shueib and Kafrain).

Direct and indirect recharge plays in this area of the JV a minor role since the amount of precipitation is low, 100 to 200 mm/a. Along wadis flowing through alluvial fans; Shueib and Kafrain some indirect recharge takes place and that is reflected in the low salinity and relatively elevated nitrate contents.

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The Na^+/Cl^- ratio ranges from 0.42 in the Kafrain well water up to 1.46 in the farmers association water. Zerka and Kurnub waters have along the escarpment Na^+/Cl^- ratios of around unity, most probably as a result of halite dissolution (Table 27). The Na^+/Ca^{2+} ratio is high in the groundwaters affected by the Kurnub and Zerqa group aquifers, 1.5 to 2.4 as a result of higher dissolution amounts of halite than gypsum. In the groundwater bodies affected by the lateral flows from the Upper Cretaceous aquifers the ratio is low and lies around unity.

The groundwaters affected by Z + K groups are undersaturated with respect to halite, gypsum, and anhydrite with values of around –4 to –5, –0.4 to –0.64, and –0.275 to –0.82, but they are less undersaturated than those groundwater affected by the Upper Cretaceous limestones of about –6 to –7, –1.06 to –1.96, and –1.27 to –2.18 respectively (Table 28).

The K + Z aquifers affected waters are of alkaline type with prevailing chlorides and partly sulfates (Fig. 13). The Upper Cretaceous aquifers affected waters are of earth alkaline type with prevailing chlorides and sulfates. The sources of salinity in this area are:

– In the K + Z affected aquifer from gypsum and evaporites dissolution, maybe from within the Zerqa group aquifer containing these salts.

– In the Upper Cretaceous affected aquifers, the upward leakages of Zerka and Kurnub group aquifer waters contribute to the salinity of the water. Pollution sources are restricted to urbanized and irrigated areas around Shueib, Kafrain, and Suknet es Shuna.

4.2.4.2 The western profile (No. 8)

This profile extends in a north south direction from the Yarmouk River to the Dead Sea at only tens or few hundreds of meters to the east of the Jordan River course. Not many wells are drilled in the area, but some springs and wadi discharges are found discharging baseflows, irrigation return flows, and diverted saline water seepages.

In the northern most area extending from the Yarmouk River in the north to Wadi Abu Thableh in the south, the water discharging into the Jordan River is fresh with a salinity of 880 to 1091 µS/cm. There seems to be no source of salinity in this area at least not at shallow depths of up to 30...40 m (Table 29). The ionic ratios resemble those of the neighbouring escarpment Upper Cretaceous waters (Table 30). The water in this area is of earth alkaline and alkaline types with prevailing chlorides (Fig. 14).

To the south of this area the water shows increasing salinities as a result of mixing processes of different waters in different mixing ratios, irrigation return flows, and dissolution of salts from the Lisan Formation. The salinities range from 2520 µS/cm in Basset Faleh to 17 810 µS/cm in wadi Mallaha. Their concentration show the following relations $Na^+ > Mg^{2+} > Ca^{2+}$ and $Cl^- > SO_4^{2-} > HCO_3^-$, only in few samples $SO_4^{2-} > Cl^- > HCO_3^-$. The nitrate concentration is high, up to 230 mg/L but generally around 100 mg/L. The water classifies as earth alkaline water with prevailing sulfates or alkaline water with prevailing chlorides.

The waters show highly variable saturation indicies, e.g. the SI of halite ranges from –2.28 to –6.71 and of calcite + 1.15 to –0.79. This is a result of mixing of different end members at different ratios (Table 31). The main source of salinity in these waters seems to originate from the Lisan Marls which build up the western area of the Jordanian part of the Jordan Valley lying to the east of the river. The ionic ratio of Na^+/Cl^- is in most samples around unity indicating halite dissolution. The Mg^{2+}/Ca^{2+} ratio is generally higher than 1 and that of Ca^{2+}/SO_4^{2-} less than 1 indicating dissoluting of magnesium salts (evaporites) from the rock matrix or remnants of Dead Sea precursors.

Wadi Mallaha discharges water from the Lisan Marls with the highest salinity among all samples of 17 810 µS/cm. Other samples collected along the lower reaches of the same wadi have salinities of up to 50 000 µS/cm. But the ionic ratios remain the same Na^+/Cl^- of 0.8 to 0.9, Mg^{2+}/Ca^{2+} of 1.10...1.20, Ca^{2+}/SO_4^{2-} of 0.6...0.7, $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$ of 0.6...0.7. These ratios indicate dissolution of evaporites halite, gypsum and magnesium chlorides.

5 Conclusions

Due to its history, development of its hydrologic regime, recharge/discharge mechanisms, geologic formations, and development of its hydrodynamic pattern the groundwater resources of the Jordan Valley show a wide range of chemistries. A variety of end members can be identified which mix in different ratios to yield the groundwater encountered in the different Jordan Valley areas. These are:

First: Recent precipitation water infiltrating into carbonate rocks and issuing from springs as wells. They are characterized by salinities of less than 1000 µS/cm and average ionic ratios of Na^+/Cl^-, Mg^{2+}/Ca^{2+}, K^+/Cl^-. $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$, Ca^{2+}/Cl^-, and Mg^{2+}/Cl^- of around 0.7, 0.3, 0.07, 0.8, 5.2, and 1.6. The water is of normal earth alkaline type with prevailing bicarbonates and in the lower parts of the Upper Cretaceous with slightly elevated chloride contents.

Second: Water percolating in the Lower Cretaceous, Jurassic and Triassic Formations. Generally the water in these formations show rapidly increasing salinities, especially with depth and to a lesser extent along groundwater gradients. The salinity increases rapidly in this type of water to reach a few thousand µS/cm as a result of evaporite dissolution. The Na^+/Cl^- ratio of around 0.9 is slightly higher than those of the first end member as a result of additional dissolution of halite relative to the other evaporites. The Ca^{2+}/Cl^- decreases rapidly from around 5 to 0.5 for the same reason. Ca^{2+}/SO_4^{2-} is higher than 1 and $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$ is around 0.57. The undersaturation state of the water is less pronounced than that of the Upper Cretaceous aquifers.

Third: This end member resembles the water resulting from the interactions of the Lisan formation with different waters entering it. It shows very high salinities of up to 50 000 µS/cm. The Na^+/Cl^- is around 0.54 and the Ca^{2+}/Cl^- ca.0.145 to 0.21. Relative to Cl^- all ratios show decreases. Na^+/Ca^{2+} shows high increases and HCO_3^-/Cl^- show very high decreases as a result of halite dissolution. Very interesting is the ratio of $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$ which here has values ranging from 2.18 to 3.67 indicating calcium chloride brines, which are not known until now in Jordan but in Israel [14].

In general the groundwater in all aquifers shows increases in its salinity with depth and along the profiles extending from the highlands in the east to the Jordan Valley in the west and within the Jordan Valley itself along profiles extending from east to west. The water types change along this same directions gradually from earth alkaline water with prevailing bicarbonates to alkali water with prevailing chlorides and sulfates.

The Ca^{2+}/SO_4^{2-} and $Ca^{2+}/(SO_4^{2-} + HCO_3^-)$ ratio in the western parts of the eastern side of the Jordan River is far higher than unity which shows that other calcium salts are being dissolved into the water than sulfates and bicarbonates. In addition Mg^{2+}/Ca^{2+} ratios are higher than 1; both indicate that magnesium and calcium chloride (halides) are being dissolved from the Lisan Formation.

The nitrate equivalent contents of some Lisan Formation waters is remarkably high, 2...3 mmol/L, which may indicate soda niter crystals within the Lisan deposits.

The final result is that the evaporites within the Jurassic and Triassic rocks as well as those of the deposits of the ancestors of the Dead Sea which used to extend along the whole length of the Jordan Valley are the main contributors to the water chemistries encountered in the eastern side of the Jordan Valley area. Isotope analyses and specific site studies may be necessary to exactly elaborate on the mixing ratios of these end members which result in the present hydrochemical composition of each site within the Jordan Valley area.

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Appendix: Experimental results for the hydrochemical profiles

Table 8: Chemical analyses of samples along profile 1.

Chemische Analysen der Proben entlang Profil 1.

Sample	EC µS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^{+} mmol/L	K^{+} mmol/L	Cl^{-} mmol/L	SO_4^{2-} mmol/L	HCO_3^{-} mmol/L	NO_3^{-} mmol/L
Um-Qeis B4/A5	650	22	7.5	9.24	2.32	0.7	0.06	0.9	0.42	5.16	0.12
Wadi Arab B4/A5	870	21.5	7.6	9.56	4.36	1.86	0.13	1.98	2.5	5.38	0.5
Wadi Arab B2/A7	820	23	7	10.24	5.2	0.88	0.06	1.09	2.3	6.64	0.02
Wadi Ziglab B2/A7	780	24.3	7.07	11.12	4.4	0.73	0.06	1.05	1.14	6.73	0.22
Wadi Yabis B2/A7	680	22.5	7.52	8.48	3.6	0.9	0.12	0.95	0.6	5.75	0.2
Kufranja B2/A7	532	20.3	7.88	6.4	3	0.64	0.02	0.85	1.3	3.84	0.44
Subeihi B2/A7	770	18.8	6.86	10.76	2.94	1.39	0.06	1.21	0.66	6.92	0.13
Salt-Hizzir B2/A7	850	20.1	7.07	8.72	5.02	1.6	0.41	2.37	1.68	4.47	1.06
Salt-Hisban B2/A7	930	20.1	6.5	9.02	5.74	1.82	0.46	2.17	3.06	3.92	1.92
Azraq B2/A7	540	22.6	6.78	4.92	4.1	0.66	0.026	1.58	1.56	2.51	0.21
Nàur Hisban B2/A7	999	21.5	7.65	8.36	6.8	3.78	0.02	4.2	7	3.82	0.44

Table 9: Ionic ratios of samples along profile 1.

Ionenverhältnisse der Proben entlang Profil 1.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-}+HCO_3^-)$	HCO_3^-/Cl^-
Um-Qeis B4/A5	0.78	5.13	1.29	0.25	22.00	0.23	0.15	0.07	0.86	5.73
Wadi Arab B4/A5	0.94	2.41	1.10	0.46	3.82	0.63	0.39	0.07	0.72	2.72
Wadi Arab B2/A7	0.81	4.70	2.39	0.51	4.45	1.06	0.17	0.06	0.66	6.09
Wadi Ziglab B2/A7	0.70	5.30	2.10	0.40	9.75	0.54	0.13	0.06	0.76	6.41
Wadi Yabis B2/A7	0.95	4.46	1.89	0.42	14.13	0.32	0.21	0.13	0.70	6.05
Kufranja B2/A7	0.75	3.76	1.76	0.47	4.92	0.76	0.20	0.02	0.71	4.52
Subeihi B2/A7	1.15	4.45	1.21	0.27	16.30	0.27	0.26	0.05	0.74	5.72
Salt-Hizzir B2/A7	0.68	1.83	1.90	0.59	5.19	0.35	0.37	0.17	0.82	1.89
Salt-Hisban B2/A7	0.84	2.08	1.32	0.64	2.95	0.71	0.40	0.21	0.83	1.81
Azraq B2/A7	0.42	1.56	1.30	0.83	3.15	0.49	0.27	0.02	0.75	1.59
Nàur Hisban B2/A7	0.90	1.00	0.81	0.81	1.19	0.83	0.90	0.00	0.57	0.91

Table 10: Saturation indices for relevant minerals along profile 1.

Sättigungsindizes relevanter Minerale entlang Profil 1.

Phase	Um-Qeis B4/A5	Wadi el-Arab B4/A5	Wadi el-Arab B2/A7	Wadi Ziglab B2/A7	Wadi Yabis B2/A7	Kufranja B2/A7	Subeihi B2/A7	Hizzir B2/A7	Hisban B2/A7	Azraq B2/A7	Nàur-Hisban B2/A7
Anhydrite	−2.721	−1.997	−2.011	−2.271	−2.62	−2.363	−2.508	−2.469	−1.947	−2.381	−1.664
Calcite	0.439	0.521	0.066	0.204	0.465	0.513	−0.076	−0.399	−0.758	−0.0835	0.322
Dolomite	−0.188	0.227	−0.612	−0.423	0.101	0.2	−1.24	−1.017	−2.215	−2.207	0.076
Gypsum	−2.49	−1.765	−1.784	−2.048	−2.391	−2.126	−2.268	−2.232	−1.711	−2.153	−1.432
Halite	−7.862	−7.107	−7.695	−7.794	−7.734	7.916	−7.438	−7.089	−7.076	−7.637	−6.483

Table 11: Chemical analyses of samples along profile 2.

Chemische Analysen der Proben entlang Profil 2.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^+ mmol/L	K^+ mmol/L	Cl^- mmol/L	SO_4^{2-} mmol/L	HCO_3^- mmol/L	NO_3^- mmol/L
Nuayma	590	20	7.34	6.5	4.3	0.44	0.036	0.72	1.32	4.28	0.32
Rason	642	16.1	7.05	8.84	3.28	0.35	0.088	0.93	1.42	5.28	0.34
Wadi Arab	855	28	7.61	11.04	5.5	1.26	0.05	1.2	3.72	6.45	0.106
Mukheiba	889	44.3	7.88	8.6	7.6	1.85	0.135	1.75	3.24	6.55	0.01
N-Shuna	1036	56	8.07	8.8	7.2	3.55	0.13	3.05	8.22	5.92	0
Himma sp.	1387	40.3	8.12	12.4	5.4	5.73	0.4	5.75	6.06	4.82	0.23
Aliwahid	2320	24.7	7.89	10.8	12.2	11.6	0.29	12.15	6.94	6.39	0.63
Shawahin well	1078	28	7.02	6	6.4	4.52	0.06	4.11	2.3	3.56	0.27

Table 12: Ionic ratios of samples along profile 2.

Ionenverhältnisse der Proben entlang Profil 2.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-}+HCO_3^-)$	HCO_3^-/Cl^-
Nuayma	0.61	4.56	2.99	0.66	4.92	0.92	0.13	0.05	0.66	5.94
Rason	0.38	4.75	1.76	0.37	6.23	0.76	0.08	0.09	0.74	5.68
Wadi Arab	1.05	4.60	2.29	0.50	2.97	1.55	0.23	0.04	0.66	5.38
Mukheiba	1.06	2.46	2.17	0.88	2.65	0.93	0.43	0.08	0.53	3.74
N-Shuna	1.16	1.44	1.18	0.82	1.07	1.35	0.81	0.04	0.44	1.94
Himma sp.	1.00	1.08	0.47	0.44	2.05	0.53	0.92	0.07	0.79	0.84
Aliwahid	0.95	0.44	0.50	1.13	1.56	0.29	2.15	0.02	0.55	0.53
Shawahin well	1.10	0.73	0.78	1.07	2.61	0.28	1.51	0.01	0.64	0.87

Table 13: Saturation indices for relevant minerals along profile 2.

Sättigungsindizes relevanter Minerale entlang Profil 2.

Phase	Nuayma	Rason	Wadi el-Arab	Mukheiba	N-Shuna	Himma sp.	Aliwahid	Shawahin well
Anhydrite	−2.365	−2.229	−1.784	−1.885	−1.419	−1.531	−1.687	−2.218
Calcite	0.026	−0.112	0.739	1.093	1.314	1.253	0.861	−0.342
Dolomite	−0.634	−1.234	0.804	1.942	2.391	1.915	1.354	−1.029
Gypsum	−2.128	−1.982	−1.577	−1.774	−1.402	−1.392	−1.467	−2.011
Halite	−8.154	−8.137	−7.513	−7.22	−6.729	−6.218	−5.573	−6.422

Table 14: Chemical analyses of samples along profile 3.

Chemische Analysen der Proben entlang Profil 3.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^+ mmol/L	K^+ mmol/L	Cl^- mmol/L	SO_4^{2-} mmol/L	HCO_3^- mmol/L	NO_3^- mmol/L
Jarash thermal	3420	28.6	6.24	31.76	9.22	15.59	1.21	13.96	29.82	8.61	0.02
Gypsum mine sp.	4490	22.7	7.6	45.2	25.56	10.1	0.3	13.5	45.8	2.49	32.2
Deir Alla thermal sp.	8860	33.8	6.55	41.2	47.2	42.8	2	49.3	56.4	6.09	0
Jica1 well	8550	36.3	6.38	74.3	20.8	51.4	4.2	50	68.6	17.16	0.11
Muallaha spring	24500	23.3	7.61	240.8	54.6	200	9.28	306.4	144.96	6.5	0.21
Farmers,Shallow W.	4650	23	7.23	22.26	23.86	26.55	1.81	18.14	54.24	9.75	1.09

Table 15: Ionic ratios of samples along profile 3.

Ionenverhältnisse der Proben entlang Profil 3.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-}+HCO_3^-)$	HCO_3^-/Cl^-
Jarash thermal	1.12	1.14	0.33	0.29	1.07	1.07	0.98	0.09	0.68	0.62
Gypsum mine sp.	0.75	1.67	0.95	0.57	0.99	1.70	0.45	0.02	0.89	0.18
Deir Alla thermal sp.	0.87	0.42	0.48	1.15	0.73	0.57	1.08	0.04	0.60	0.12
Jica1 well	1.03	0.74	0.21	0.28	1.08	0.69	1.38	0.08	0.72	0.34
Muallaha spring	0.65	0.39	0.09	0.23	1.66	0.24	1.66	0.03	1.52	0.02
Farmers, Shallow W.	1.46	0.61	0.66	1.07	0.41	1.50	1.39	0.10	0.30	0.54

Table 16: Saturation indices for relevant minerals along profile 3.

Sättigungsindizes relevanter Minerale entlang Profil 3.

Phase	Jarash thermal	Gypsium mine sp.	Deir Alla thermal sp.	JICA 1 well	Mallaha sp.	Farmers Shallow W.
Anhydrite	−0.758	−0.567	−0.609	−0.306	0.118	−0.777
Calcite	−0.254	0.563	−0.044	0.468	1.414	0.47
Dolomite	−1.421	0.421	−0.34	0.096	1.763	0.513
Gypsum	−0.555	−0.34	−0.432	−0.145	0.335	−0.551
Halite	−5.426	−5.644	−4.507	−4.441	−3.111	−5.093

Table 17: Chemical analyses of samples along profile 4.

Chemische Analysen der Proben entlang Profil 4.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^+ mmol/L	K^+ mmol/L	Cl^- mmol/L	SO_4^{2-} mmol/L	HCO_3^- mmol/L	NO_3^- mmol/L
Al-Shami	735	20	7.65	7.72	3.9	1.42	0.13	1.5	0.88	4.44	0.95
Kafrain 10	630	30.1	7.03	7.74	3.6	1.41	0.08	1.27	2.52	4.45	0.04
Kafrain 1	827	31.9	6.96	8.2	4.2	1.3	0.13	1.85	3.84	4.55	0.01
Kafrain 11f	4490	31.9	6.22	23	9.8	32.18	2.22	26.55	17.62	17.52	0.02
Hisban deep well	4350	32	6.26	26.56	13.6	29.97	2.41	28.6	14.56	14.31	0
JICA 6 deep well	7917	31.5	6.16	43.44	20.5	52.1	4.5	56.4	23.74	19.16	0.12
Sweima Spring	5500	28	6.38	26.66	35.6	29.5	1.8	49.2	11.78	6.2	0.09
Dead Sea research well	6540	32.5	6.78	32.8	30.62	30.7	1.82	33.6	30.12	13.5	0.01

Table 18: Ionic ratios of samples along profile 4.

Ionenverhältnisse der Proben entlang Profil 4.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-} + HCO_3^-)$	HCO_3^-/Cl^-
Al-Shami	0.95	2.57	1.30	0.51	8.77	0.29	0.37	0.09	0.79	2.96
Kafrain 10	1.11	3.05	1.42	0.47	3.07	0.99	0.36	0.06	0.68	3.50
Kafrain 1	0.70	2.22	1.14	0.51	2.14	1.04	0.32	0.07	0.63	2.46
Kafrain 11f	1.21	0.43	0.18	0.43	1.31	0.33	2.80	0.08	0.44	0.66
Hisban deep well	1.05	0.46	0.24	0.51	1.82	0.25	2.26	0.08	0.62	0.50
JICA 6 deep well	0.92	0.39	0.18	0.47	1.83	0.21	2.40	0.08	0.70	0.34
Sweima Spring	0.60	0.27	0.36	1.34	2.26	0.12	2.21	0.04	1.10	0.13
Dead Sea research well	0.91	0.49	0.46	0.93	1.09	0.45	1.87	0.05	0.57	0.40

Table 19: Saturation indices for relevant minerals along profile 4.

Sättigungsindizes relevanter Minerale entlang Profil 4.

Phase	Al-Shami	Kafrain 10	Kafrain 1	Kafrain 11F	Hisban deep well	JICA 6 deep well	Sweima Hajjar sp.	Dead Sea well
Anhydrite	−2.494	−2.017	−1.83	−1.136	−1.166	−0.908	−1.347	−0.871
Calcite	0.407	−0.077	−0.107	−0.076	−0.048	0.09	−0.353	0.482
Dolomite	0.015	−0.83	−0.829	−0.842	−0.703	−0.466	−0.946	0.617
Gypsum	−2.257	−1.82	−1.642	−0.949	−0.979	−0.72	−1.141	−0.687
Halite	−7.332	−7.431	−7.312	−4.855	−4.854	−4.355	−4.63	−4.791

Table 20: Chemical analyses of samples along profile 5.

Chemische Analyse der Proben entlang Profil 5.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^+ mmol/L	K^+ mmol/L	Cl^- mmol/L	SO_4^{2-} mmol/L	HCO_3^- mmol/L	NO_3^- mmol/L
Mukheiba well	889	44.3	7.88	8.6	7.6	1.85	0.135	1.75	3.24	6.55	0
Himma sp.	1357	40.3	8.12	12.4	5.4	5.73	0.4	5.75	6.06	4.82	0
N-Shuna well	1036	56	6.07	8.8	7.2	3.55	0.13	3.05	8.22	5.92	0
Manshiya well	760	52	6.26	7.62	6.8	1.32	0.04	1.33	1.9	6.09	0.01
Waggas well	1040	52	6.97	8.8	6.34	1.76	0.08	1.54	2.5	6.49	0
Abu-Ziad well	2250	50.2	6.38	17.86	10	9.85	0.71	9.63	11.44	8.95	0.02
Deir Alla thermal sp.	8860	33.8	6.55	41.2	47.2	42.8	2	49.3	56.4	6.09	0

Table 21: Ionic ratios of samples along profile 5.

Ionenverhältnisse der Proben entlang Profil 5.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-} + HCO_3^-)$	HCO_3^-/Cl^-
Mukheiba well	1.06	2.46	2.17	0.88	2.65	0.93	0.43	0.08	0.53	3.74
Himma sp.	1.00	1.08	0.47	0.44	2.05	0.53	0.92	0.07	0.79	0.84
N-Shuna well	1.16	1.44	1.18	0.82	1.07	1.35	0.81	0.04	0.44	1.94
Manshiya well	0.99	2.86	2.56	0.89	4.01	0.71	0.35	0.03	0.54	4.58
Waggas well	1.14	2.86	2.06	0.72	3.52	0.81	0.40	0.05	0.57	4.21
Abu-Ziad well	1.02	0.93	0.52	0.56	1.56	0.59	1.10	0.07	0.61	0.93
Deir Alla thermal sp.	0.87	0.42	0.48	1.15	0.73	0.57	2.08	0.04	0.60	0.12

Table 22: Saturation indices for relevant minerals along profile 5.

Sättigungsindizes relevanter Minerale entlang Profil 5.

Phase	Mukheiba well	Himma sp.	N-Shuna well	Manshiya well	Waggas well	Abu-Ziad well	Deir Alla thermal sp.
Anhydrite	−1.885	−1.53	−1.398	−2.062	−1.897	−1.163	−0.609
Calcite	1.093	1.253	−0.617	−0.458	0.324	0.021	−0.044
Dolomite	1.942	1.916	−1.488	−1.115	0.354	−0.389	−0.34
Gypsum	−1.774	−1.392	−1.381	−2.01	−1.845	−1.097	−0.432
Halite	−7.22	−6.218	−6.729	−7.495	−7.31	−5.809	−4.507

Table 23: Chemical analyses of samples along profile 6.

Chemische Analysen der Proben entlang Profil 6.

Sample	EC µS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^+ mmol/L	K^+ mmol/L	Cl^- mmol/L	SO_4^{2-} mmol/L	HCO_3^- mmol/L	NO_3^- mmol/L
JICA Well no.1	8550	36.3	6.38	74.3	20.8	51.4	4.2	50	68.6	17.16	0.14
JICA Well no.2	14760	31.9	6.47	93.38	33.2	108	6.5	116.7	72.68	26.62	0.065
JICA Well no.3	8080	27.5	6.61	67	26	51.6	3	45.3	75.92	16.44	0.073
JICA Well no.4	12760	31.7	6.62	89.72	25.6	96.5	5.5	88.7	93.38	24.38	0.073
JICA Well no.5	8680	35.3	6.12	45.88	23.96	57.75	4.5	64	22.34	20.72	0.001
JICA Well no.6	7970	31.5	6.16	43.44	20.5	52.1	4.5	56.4	23.74	19.16	0.12

Table 24: Ionic ratios of samples along profile 6.

Ionenverhältnisse der Proben entlang Profil 6.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-} + HCO_3^-)$	HCO_3^-/Cl^-
JICA Well no.1	1.03	0.74	0.21	0.28	1.08	0.69	1.38	0.08	0.72	0.34
JICA Well no.2	0.93	0.40	0.14	0.36	1.28	0.31	2.31	0.06	0.74	0.23
JICA Well no.3	1.14	0.74	0.29	0.39	0.88	0.84	1.54	0.07	0.62	0.36
JICA Well no.4	1.09	0.51	0.14	0.29	0.96	0.53	2.15	0.06	0.63	0.27
JICA Well no.5	0.90	0.36	0.19	0.52	2.05	0.17	2.52	0.07	0.72	0.32
JICA Well no.6	0.92	0.39	0.18	0.47	1.83	0.21	2.40	0.08	0.70	0.34

Table 25: Saturation indices for relevant minerals along profile 6.

Sättigungsindizes relevanter Minerale entlang Profil 6.

Phase	JICA Well no.1	JICA Well no.2	JICA Well no.3	JICA Well no.4	JICA Well no.5	JICA Well no.6
Anhydrite	−0.306	−0.342	−0.338	−0.233	−0.927	−0.908
Calcite	0.468	0.721	0.519	0.807	0.141	0.09
Dolomite	0.096	0.677	0.24	0.741	−0.272	−0.466
Gypsum	−0.145	−0.158	−0.13	−0.047	−0.759	−0.72
Halite	−4.441	−3.776	−4.46	−3.938	−4.271	−4.355

Table 26: Chemical analyses of samples along profile 7.

Chemische Analysen der Proben entlang Profil 7.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^{+} mmol/L	K^{+} mmol/L	Cl^{-} mmol/L	SO_4^{2-} mmol/L	HCO_3^{-} mmol/L	NO_3^{-} mmol/L
Adasiya well	2080	28	7.02	10.2	9.6	11.79	0.242	10.7	9.56	6.33	0.47
N-Shuna	1672	23.8	7.92	15.2	11.4	5.52	0.187	5.1	10.74	6.55	0.45
Teibeh	814		8.2	5.6	6.8	1.79	0.1	2.2	4.8	3.15	0.28
Ziglab	979	24.3	7.36	8.8	8.2	2.23	0.1	2.8	3.1	6.44	0.45
Abu-Ziad w. no. (1)	870		7.23	6.08	2.98	1.65	0.25	2.18	3.94	4.92	0.202
Abu Thableh	1757		6.8	7.8	11.6	3.83	0.39	6.97	11.96	5.73	0.3
Tabakat Falah-Mashareè	868		68	5.88	7.68	1.82	0.1	1.64	0.152	6.3	0.28
Suleikhat w. no. 5	669		7.48	4.66	8.8	1.2	0.14	1.65	0.86	4.5	0.43
Soufra w. no.1	555		7.4	3.5	6.5	0.58	0.05	1.75	0.8	4.15	0.08
Kreima w.5	584	31.8	7.93	4.2	5	1.05	0.064	1.45	1.16	4.06	0.022
Kreima w.1	1095		7.2	6.9	11.62	1.87	0.47	3.19	5	5.35	0.02
Sumeihat	1001		6.7	5.78	7.64	3.28	0.17	3.09	4.2	4.5	0.32
Rajib	1191		7.3	5.38	10.18	4.43	0.23	3.04	5.94	5.06	0.01
Farmers associated A13	4650		7.23	22.26	23.86	26.55	1.81	18.14	54.24	9.75	1.09
Dahret Er-Ramly	4639		6.76	348	30.32	48.9		51.94	34.76	3.9	
Dahret Ed-Dabaà	7754		6.7	55.2	38.66	81.5		93.4	57.8	8.82	
Marzooq Abadi	7000		6.8	49.8	30.4	39.75		36.2	758.75	14	
Basset El-Faras	3500	28.7	6.73	20.8	20.2	15.8	0.85	16.59	32	4.65	0.03
Suknet es-Shuna	1112		7.55	7.88	6.66	3.59	0.186	5.32	2.08	4.9	0.27
Shueib	2776	25.7	6.82	30.86	15.08	25.78	0.71	20.65	9.4	5.87	2.45
Kafrain	1262		7.04	10.12	10.42	2.2	0.13	5.21	4.6	4.54	0.27
Sweima Dead Sea well	6540	32.5	6.78	32.8	10.62	30.7	1.82	33.6	27	6.06	0.02

Table 27: Ionic ratios of samples along profile 7.

Ionenverhältnisse der Proben entlang Profil 7.

Sample	Na^+/Cl^-	Ca^{2+}/Cl^-	Mg^{2+}/Cl^-	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^-	Na^+/Ca^{2+}	K^+/Cl^-	$Ca^{2+}/(SO_4^{2-} + HCO_3^-)$	HCO_3^-/Cl^-
Adasiya well	1.10	0.48	0.45	0.94	1.07	0.45	2.31	0.02	0.46	0.59
N-Shuna	1.08	1.49	1.12	0.75	1.42	1.05	0.73	0.04	0.64	1.28
Teibeh	0.81	1.27	1.55	1.21	1.17	1.09	0.64	0.05	0.50	1.43
Ziglab	0.80	1.57	1.46	0.93	2.84	0.55	0.51	0.04	0.55	2.30
Abu-Ziad w. no. (1)	0.76	1.39	0.68	0.49	1.54	0.90	0.54	0.11	0.44	2.26
Abu Thableh	0.55	0.56	0.83	1.49	0.65	0.86	0.98	0.06	0.33	0.82
Tabakat Falah-Mashareè	1.11	1.79	2.34	1.31	38.68	0.05	0.62	0.06	0.46	3.84
Suleikhat w. no. 5	0.73	1.41	2.67	1.89	5.42	0.26	0.52	0.08	0.47	2.73
Soufra w. no.1	0.33	1.00	1.86	1.86	4.38	0.23	0.33	0.03	0.38	2.37
Kreima w.5	0.72	1.45	1.72	1.19	3.62	0.40	0.50	0.04	0.45	2.80
Kreima w.1	0.59	1.08	1.82	1.68	1.38	0.78	0.54	0.15	0.44	1.68
Sumeihat	1.06	0.94	1.24	1.32	1.38	0.68	1.13	0.06	0.44	1.46
Rajib	1.46	0.88	1.67	1.89	0.91	0.98	1.65	0.08	0.33	1.66
Farmers associated A13	1.46	0.61	0.66	1.07	0.41	1.50	2.39	0.10	0.30	0.54
Dahret Er-Ramly	0.94	3.35	0.29	0.09	10.01	0.33	0.28	0.00	8.18	0.08
Dahret Ed-Dabaà	0.87	0.30	0.21	0.70	0.96	0.31	2.95	0.00	0.73	0.09
Marzooq Abadi	1.10	0.69	0.42	0.61	0.07	0.84	1.60	0.00	0.56	0.39
Basset El-Faras	0.95	0.63	0.61	0.97	0.65	0.96	1.52	0.05	0.50	0.28
Suknet es-Shuna	0.67	0.74	0.63	0.85	3.79	0.20	0.91	0.03	0.66	0.92
Shueib	1.25	0.75	0.37	0.49	3.28	0.23	1.67	0.03	1.46	0.28
Kafrain	0.42	0.97	1.00	1.03	2.20	0.44	0.43	0.02	0.74	0.87
Sweima Dead Sea well	0.91	0.49	0.16	0.32	1.21	0.40	1.87	0.05	0.84	0.18

Table 28: Saturation indices for relevant minerals along profile 7.

Sättigungsindizes relevanter Minerale entlang Profil 7.

Phase	Adasiya well	N-Shuna	Teibeh	Ziglab	Abu-Ziad well	Tabaket Falah-Mashareè	Suleikhate well no. 5
Anhydrite	−1.549	−1.3346	−4.509	−1.986	−1.942	−3.402	−2.742
Calcite	0.018	0.727	−2.175	0.339	−0.022	−0.348	0.089
Dolomite	−0.367	0.89	−4.469	0.22	−0.774	−0.995	0.038
Gypsum	−1.343	−1.122	−4.289	−1.763	−1.723	−3.183	−2.522
Halite	−5.627	−6.262	−9.921	−6.893	−7.119	−7.204	−7.378

Phase	Kreima well 1	Sumeihat	Rajib	Farmers asso.	Dahret Er-Ramly	Dahret Ed-Dabaà	Marzooq El-Abadi	Basset El-Faras
Anhydrite	−1.904	−2.001	−1.926	−0.775	−0.257	−0.568	−0.499	−0.914
Calcite	−0.007	−0.634	−0.043	0.496	0.635	0.231	0.524	−0.211
Dolomite	−0.206	−1.566	−0.229	0.594	−0.184	−0.105	0.411	−0.81
Gypsum	−1.684	−1.782	−1.706	−0.556	−0.04	−0.351	−0.281	−0.711
Halite	−6.917	−6.679	−6.563	−5.098	−4.462	−3.954	−4.648	−5.345

Phase	Shueib	Kafrain	Sweima Dead Sea well	Abu Thableh	Suknet es-Shuna	Kreima well no.5	Sourfa well no.1
Anhydrite	−1.272	−1.791	−0.828	−1.543	−2.182	−2.575	−2.84
Calcite	0.154	−0.076	0.174	−0.0386	0.383	0.552	−0.125
Dolomite	−0.405	−0.559	−0.464	−1.023	0.277	0.863	−0.397
Gypsum	−1.056	−1.571	−0.644	−1.323	−1.963	−2.386	−2.62
Halite	−5.034	−6.637	−4.78	−6.282	−6.408	−7.498	−7.659

Table 29: Chemical analyses of samples along profile 8.

Chemische Analysen der Proben entlang Profil 8.

Sample	EC μS/cm	Temp. °C	pH	Ca^{2+} mmol/L	Mg^{2+} mmol/L	Na^{+} mmol/L	K^{+} mmol/L	Cl^{-} mmol/L	SO_4^{2-} mmol/L	HCO_3^{-} mmol/L	NO_3^{-} mmol/L
Yarmouk	888	28.5	7	6.16	5.7	5.18	0.2	3.88	4.5	4.88	0.07
Wadi Arab	1091	40.4	6.97	6.2	5.8	4.2	0.15	4.92	4.2	3.2	0.11
Wadi Ziglab	904	26.7	6.87	6.18	5.6	3.07	0.15	3.05	3.22	4.06	0.68
Abu Thablah	1920	36.2	5.9	14.4	9.4	8.72	0.46	9.34	6.62	7.13	0.5
Zoor Abdulla	5540	30.2	7.95	24	24.2	34.27	0.46	42.67	19.48	5.91	0.65
Rajib Seediya	3090	24.7	6.69	12.72	20.2	13.3	0.61	16.8	12.42	5.06	1.16
Baset Falah	2520	27.9	6.84	12.3	19.7	12.6	0.59	10.4	18.48	6.06	2.28
Baset Falah wadi bottom	4370	26.6	7.22	25	30.22	19.9	1.02	30.6	20.64	6.65	0.7
Bweib	2690	26.4	6.79	16.2	20.4	12.6	0.69	10.4	25	4.65	1.64
Wadi Makman	5640	26.2	6.79	28.8	41.8	23.8	1.53	23.2	56	6.14	2.44
Hawwaya	6750	24.8	6.78	61.6	59.4	25.5	4.09	29.7	107.4	7.06	1.79
Mifshel	7020	23.4	6.79	34.8	55.4	30.3	4.35	28.1	89.2	3.66	2
Mallah Gdeida	5830	25.8	6.82	30.8	41	22.02	2.6	27.2	54	6.09	0.09
Zerka River	6250	28.2	7.18	35.2	36	30.8	1.66	38.3	46.6	5.76	1.01
Rasif	20800	19.7	6.6	45.2	123	118.7	3.43	136.4	126.6	5.12	1.81
Abu Mayala	16300	18.9	6.32	32.6	50.6	137	3.89	122.9	104	6.4	2.04
Aüraà	65500	21.3	6.69	93.8	757.6	480	20.5	861	97	12.13	3.75
Wadi Mallaha-Karama	17810	32.4	7.22	81.8	93.4	139.6	3.25	163.2	122.2	3.09	2.33
Kharar	8050	24.8	7.08	45.2	36.8	48.6	3.38	62.2	37	11.3	0.22
Hisban-Kafrain	8330	26.1	6.47	47	39	47.4	3.97	65.9	34.6	10	8.99

Table 30: Ionic ratios of samples along profile 8.

Ionenverhältnisse der Proben entlang Profil 8.

Sample	Na^{+}/Cl^{-}	Ca^{2+}/Cl^{-}	Mg^{2+}/Cl^{-}	Mg^{2+}/Ca^{2+}	Ca^{2+}/SO_4^{2-}	SO_4^{2-}/Cl^{-}	Na^{+}/Ca^{2+}	K^{+}/Cl^{-}	$Ca^{2+}/(SO_4^{2-}+HCO_3^{-})$	HCO_3^{-}/Cl^{-}
Yarmouk	1.34	0.79	0.73	0.93	1.37	0.58	1.68	0.05	0.43	1.26
Wadi Arab	0.85	0.63	0.59	0.94	1.48	0.43	1.35	0.03	0.58	0.65
Wadi Ziglab	1.01	1.01	0.92	0.91	1.92	0.53	0.99	0.05	0.54	1.33
Abu Thablah	0.93	0.77	0.50	0.65	2.18	0.35	1.21	0.05	0.69	0.76
Zoor Abdulla	0.80	0.28	0.28	1.01	1.23	0.23	2.86	0.01	0.77	0.14
Rajib Seediya	0.79	0.38	0.60	1.59	1.02	0.37	2.09	0.04	0.56	0.30
Baset Falah	1.21	0.59	0.95	1.60	0.67	0.89	2.05	0.06	0.40	0.58
Baset Falah wadi bottom	0.65	0.41	0.49	1.21	1.21	0.34	1.59	0.03	0.74	0.22
Bweib	1.21	0.78	0.98	1.26	0.65	1.20	1.56	0.07	0.47	0.45
Wadi Makman	1.03	0.62	0.90	1.45	0.51	1.21	1.65	0.07	0.42	0.26
Hawwaya	0.86	1.04	1.00	0.96	0.57	1.81	0.83	0.14	0.51	0.24
Mifshel	1.08	0.62	0.99	1.59	0.39	1.59	1.74	0.15	0.36	0.13
Mallah Gdeida	0.81	0.57	0.75	1.33	0.57	0.99	1.43	0.10	0.47	0.22
Zerka River	0.80	0.46	0.47	1.02	0.76	0.61	1.75	0.04	0.61	0.15
Rasif	0.87	0.17	0.45	2.72	0.36	0.46	5.25	0.03	0.33	0.04
Abu Mayala	1.11	0.13	0.21	1.55	0.31	0.42	8.40	0.03	0.28	0.05
Aüraà	0.56	0.05	0.44	8.08	0.97	0.06	10.23	0.02	0.77	0.01
Wadi Mallaha-Karama	0.86	0.25	0.29	1.14	0.67	0.37	3.41	0.02	0.64	0.02
Kharar	0.78	0.36	0.30	0.81	1.22	0.30	2.15	0.05	0.76	0.18
Hisban-Kafrain	0.72	0.36	0.30	0.83	1.36	0.26	2.02	0.06	0.86	0.15

Table 31: Saturation indices for relevant minerals along profile 8.

Sättigungsindizes relevanter Minerale entlang Profil 8.

Phase	Yarmouk	Wadi Arab	Wadi Ziglab	Abu Thableh	Zoor Abdulla	Rajib Seediya	Baset Falah	Baset Falah wadi bottom
Anhydrite	−1.936	−1.893	−2.054	−1.54	−1.136	−1.451	−1.295	−1.088
Calcite	−0.233	−0.277	−0.441	−0.791	1.146	−0.4	−0.161	0.479
Dolomite	−0.868	0.818	−1.317	−22.028	1.956	−1.022	−0.499	0.647
Gypsum	−1.731	−1.755	−1.841	−1.376	−0.941	−1.23	−1.087	−0.876
Halite	−6.393	−6.405	−6.714	−5.82	−4.627	−5.389	−5.627	−4.989

Phase	Wadi Makman	Hawwaya	Mifshel	Mallah Gdeida	Zerqa River	Rasif	Abu Mayala	Aqraà	Wadi Mallaha-Karama
Anhydrite	−0.703	−0.26	−0.522	−0.689	−0.704	−0.505	−0.638	−0.762	−0.27
Calcite	−0.018	0.234	−0.269	0.035	0.46	−0.372	−0.672	0.245	0.437
Dolomite	−0.284	0.02	−0.788	−0.22	0.552	−0.804	−1.664	0.994	0.615
Gypsum	−0.489	−0.041	−0.297	−0.474	−0.499	−0.272	−0.403	−0.554	−0.09
Halite	−5.048	−4.938	−4.873	−5.012	−4.729	−3.647	−3.618	−2.28	−3.538

Phase	Kharar	Hisban-Kafrain	Bweib
Anhydrite	−0.758	−0.774	−1.082
Calcite	0.6689	0.066	−0.251
Dolomite	0.873	−0.344	0.808
Gypsum	−0.54	−0.56	−0.868
Halite	−4.331	−4.321	−5.629