



THE AQUIFER SYSTEMS IN THE STUDY AREA

**Brackish Water Resources and their Physico-Chemical
Characteristics**

SMART

**Sustainable Management of Available Water Resources
with Innovative Technologies**

Work Package 3-3

**Deliverable 3.2.1 – inventory and characterization of available brackish
water resources in the study area**

Part 1: The western side

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FIRST DRAFT

Explanations and Acknowledgement

The first draft of the report focuses on the Israeli and Palestinian western part of the study area of the Lower Jordan Rift Valley.

The Report includes overview as well as detailed study of the major aquifers in the study area:

- The Judea Group deep aquifer of Cenomanian Turonian age – western side
- The Avdat Group aquifer of Eocene age – western side
- The shallow aquifer (Dead Sea & Jordan Valley Groups) of Pleistocene Age.

The report was written by Akiva Flexer, Annat Yellin-Dror, and Nimrod Inbar from Tel Aviv University with the contribution of additional detailed report on the Dead Sea Group in the area of Jericho and Uja written by Amer Marei from Al-Quds University and Florencia Saravia of Karlsruhe University. As well as contribution of additional detailed report on the Jordan Valley Group in the eastern side of the study area (Jordanian) written by Abdallah Al-Zoubi, Emad Akawwi and Abdelrhman Abueladas from Al-Balqa' Applied University.

Jawad Hassan from Al-Quds University contributed to the study of the Fashkha area and Marwan Ghanem from The Palestinian Hydrological Group (PHG) contributed to the study of the Jeftlik area.

The report on the Eastern (Jordanian) side of the study area was carried out under the responsibility of Abdalla Alzoubi from Al-Balqa' Applied University in Salt.

Since the report of Al-Balqa' Applied University was submitted lately the integration of the reports will be finalized in the nearest future into one complete report as requested by WP3.3 Deliverable 321.

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1. INTRODUCTION

1.1. SCOPE AND OUTLINE OF INVESTIGATIONS

The purpose of the present phase of investigations was set to establish the hydrochemical typology of the main groundwater bodies, their area distribution and concentrating of brackish ground water occurrences.

1.2. HYDROGEOLOGICAL BACKGROUND

The study area extends between the crest of the Hebron-Ramallah (Judea) and Fariah anticlines in the east and the western margins of the Rift Valley, which are partly defined by faults. It covers parts of eastern Judea and Samaria and makes part of the eastern drainage basin.

Four aquifer units are discerned in the study area. Two of them make part of the Judea Group and are known as:

- The Albian-Lower Cenomanian **Lower Judea Group aquifer**.
- The Cenomanian-Turonian **Upper Judea Group aquifer**.

The two other aquifers are:

- The Lower – Middle Eocene **Avedat (Jenin) Group aquifer**
- Permeable beds within the Quaternary **Dead Sea Group** occurring mainly within the Rift Valley.

The main aquicludes in the study area are:

- Argillaceous beds of the **Qatana Formation** underlying the Judea Group Sequence.
- Cenomanian beds of low permeabilities separating between the lower to the upper aquifers. These beds are related to the **Bet Meir, Motza, or yatta, and Kfar Shaul Formations**.
- Most formations of the Senonian - Paleocene **Mt.Scopus Group (Abu-Dis)**.
- Irregularly occurring clay beds within the alluvial fill of the Rift (**Dead Sea Group**).

1.2.1. JUDEA GROUP

The Lower aquifer of the Judea Group comprises highly permeable karstic beds (320 m thick) related to the Kefira, Giveat Yearim, Soreq and Kesalon formations (lower and upper Beit-Kahil formations). **The Upper aquifer of the Judea Group** is also built of highly

permeable and karstic beds of the Aminadav, Weradim, Shivta and Nezer Formation or Hebron, Beit-Lehem and Jerusalem Formations, which attain a total thickness of 250-280 m.

Beds related to both aquifers of the Judea Group are exposed along the core and eastern flanks of the Hebron-Judea, Ramallah Anticlinarium acting there as areas of natural replenishment. These aquifer beds occur also in the subsurface of the eastern accompanied chain of synclines and are exploited by numerous deep wells distributed from the eastern outskirts of Jerusalem and Ramallah, down to the margins of the Rift. **Figure 1.1** and **Figure 1.2** are location maps showing the distribution of water wells in both aquifers.

Groundwater levels in the **Lower Judea Group aquifer** are between 450 m MSL in the west and below – 350 m MSL near the borders of the Rift. Groundwater flow is generally eastwards (**Figure 1.3**). Water levels in the **Upper Judea Group aquifer** vary between +450 m MSL to – 320 m MSL and the flow is generally eastwards.

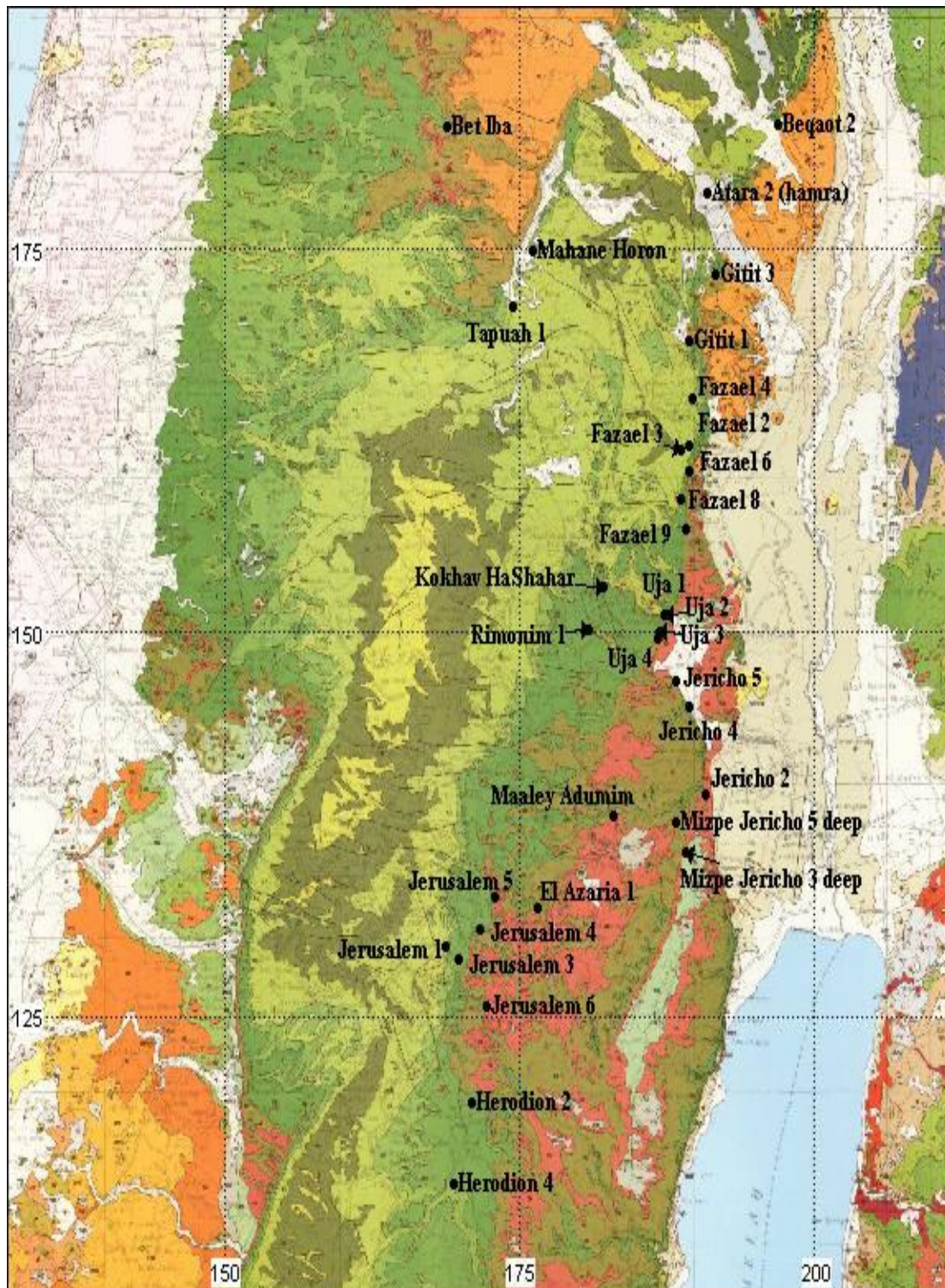


Figure 1.1: Boreholes pumping the lower part of the Judea aquifer

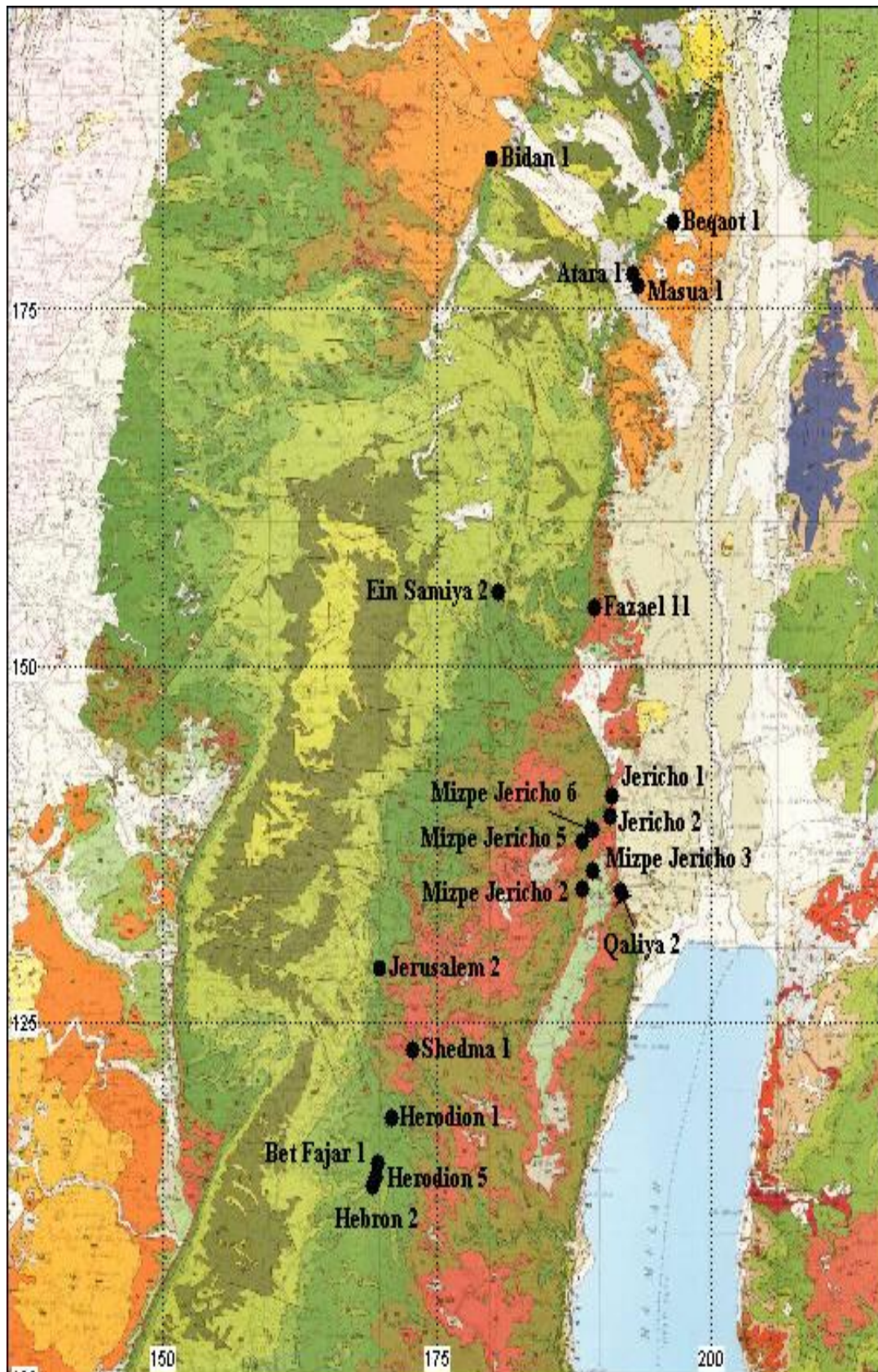


Figure 1.2: Boreholes pumping the upper part of the Judea aquifer

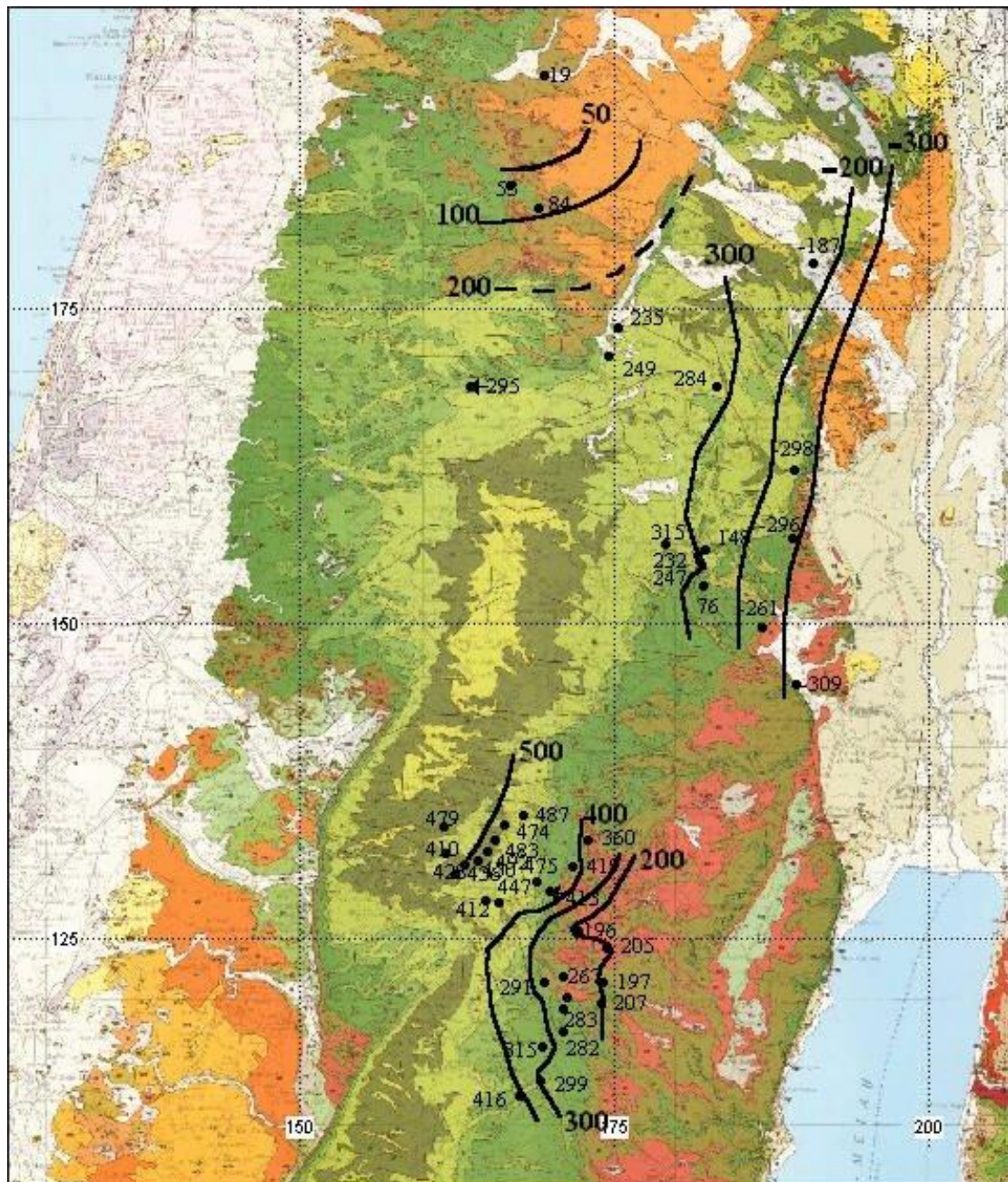


Figure 1.3: water table at the lower part of the Judea aquifer (year 2003)

Table 1-1: Chemical composition of the Judea lower aquifer water

<u>Name</u>	<u>Coord X</u>	<u>Coord Y</u>	<u>Cl, mg/L</u>	<u>SO4,mg/l</u>	<u>Na/Cl</u>	<u>Mg/Ca</u>	<u>Mg/Cl</u>	<u>Q</u>	<u>Cl/Br</u>	<u>18O</u>	<u>D</u>	<u>13C</u>
<i>Herodion 4</i>	169.46	114.08	26	11	0.39	0.95	3.48	0.54	433			
<i>Jerusalem 4</i>	171.7	130.7	27	6.8	0.77	0.88	2.76	0.59	305	-5.79	-21.3	-12.6
<i>Bet Iba</i>	168.9	183	27	3	0.8	0.6	2.38	0.73	270			
<i>El Azaria 1</i>	176.6	132	27	8	0.97	0.6	2.1	0.64	270	-5.69	-21.3	-12.6
<i>Jerusalem 6</i>	172.17	125.59	28	10	0.88	0.66	2.24	0.66		-5.71	-22.6	-12
<i>Tapuah 1</i>	174.48	171.22	28	6	0.94	0.38	2.92	0.61	280			
<i>Kokhav HaShahar</i>	182.1	153	29	11	0.96	0.78	2.42	0.59	262	-5.8		-11.2
<i>Rimonim 1</i>	180.91	150.24	30	24	0.87	0.98	3.22	0.53	300			
<i>Uja 3</i>	186.8	150.05	33	14	1.07	0.81	2.38	0.58	330			
<i>Uja1</i>	187.3	151.2	33	11	0.77	0.65	2.02	0.62	330			
<i>Herodion 2</i>	170.92	119.33	34	27	0.77	0.69	1.97	0.62	340	-5.8		-9.7
<i>Uja 4</i>	186.73	149.59	34	10	0.91	0.78	2.15	0.63	340	-5.6		-11.5
<i>Uja 2</i>	187.35	151.15	34	8	0.91	0.78	2.32	0.63	340			
<i>Mahane Horon</i>	176.1	174.9	34	10	0.86	0.65	2	0.65	340			
<i>Jerusalem 3</i>	169.8	128.77	35	9	0.66	0.73	2.05	0.63				
<i>Jerusalem 5</i>	172.91	132.71	36	9	0.63	0.55	1.66	0.73		-5.7		
<i>Jerusalem 1</i>	168.79	129.49	37	11	0.91	0.73	2.15	0.63	340			
<i>Fazael 3</i>	188.61	161.91	44	23	0.91	0.82	1.88	0.58	440			
<i>Fazael 4</i>	189.7	165.2	49	15	0.82	0.74	1.47	0.63	245	-5.4		-11.3
<i>Fazael 2</i>	189.34	162.15	50	16	0.86	0.74	1.24	0.64	250	-5.4	-24	
<i>Maalely Adumim</i>	183	138	54									
<i>Gitit 1</i>	189.4	168.95	59	16	0.73	0.82	1.26	0.65	295			
<i>Atara 2 (Hamra)</i>	190.84	178.55	65	23	0.78	0.69	1.36	0.66	325			
<i>Maalely Adumim</i>	183	138	80									
<i>Fazael 9</i>	189.06	156.73	123	22	0.73	0.96	0.84	0.59	72			
<i>Fazael 6</i>	189.33	160.45	139	17	0.61	0.91	0.76	0.73	81			
<i>Beqaot 2</i>	196.95	183.05	151	43	0.92	1.75	0.7	0.4	166			
<i>Gitit 3</i>	191.56	173.37	187	24	0.58	1.09	0.72	0.7	89	-5.2		-10.8
<i>Jericho 5</i>	188.25	146.85	190	21	0.56	0.96	0.7	0.76		-5.62	-18	-11.5
<i>Jericho 4</i>	189.4	145.15	231	23	0.53	0.97	0.63	0.83	72.9	-5.9	-23	-11.3
<i>Fazael 8</i>	188.63	158.75	240	24	0.53	1.08	0.59	0.81	73	-5.58	-26.3	
<i>Mizpe Jericho 5 deep</i>	188.21	137.62	1095	41	0.68	1.71	0.32	0.93	61.5			
<i>Mizpe Jericho 3 deep</i>	189.11	135.67	4950	105	0.53	1.95	0.34	6.28	59.6			
<i>Jericho 2</i>	190.72	139.48	12199	868	0.69	0.95	0.15	2.84	55.45	-5.82	-19.6	-12
<i>Average Group A</i>			38.88	12.83	0.83	0.73	2.16	0.63	317.63	-5.65	-22.3	-11.56
<i>St.Deviation Group A</i>			13.91	6.41	0.14	0.13	0.59	0.05	53.24	0.16	1.29	1
<i>Average Group B</i>			180.14	24.86	0.64	1.1	0.71	0.69	92.32	-5.58	-22.43	-11.2
<i>St.Deviation Group B</i>			44.95	8.36	0.14	0.29	0.08	0.15	36.69	0.29	4.18	0.36
<i>Average Group C</i>			6081.33	338	0.63	1.54	0.27	3.35	58.85	-5.82	-19.6	-12
<i>St.Deviation Group C</i>			5637.79	460.11	0.09	0.52	0.1	2.71	3.09			
<i>Average Groups A+B</i>			70.77	15.72	0.78	0.82	1.81	0.64	263.56	-5.63	-22.36	-11.45
<i>St Deviations Gp. A+B</i>			64.48	8.54	0.16	0.24	0.81	0.09	109.78	0.2	2.58	0.85

Table 1-2: Chemical composition of the Judea lower aquifer water

Name	Coord X	Coord Y	Cl, mg/l	SO4,mg/l	Na/Cl	Mg/Ca	Mg/Cl	Q	Cl/Br
<i>Jerusalem 2</i>	169.8	128.78	25						
<i>Ein Samiya 2</i>	180.55	155.2	27	15.5	0.91	0.61	2.38	0.59	245
<i>Herodion 1</i>	170.9	118.3	28	3	0.88	0.78	2.5	0.64	188
<i>Bet Fajar 1</i>	169.6	115.1	30	3	0.87	0.74	2.63	0.62	333
<i>Herodion 5</i>	169.46	114.08	34	9	0.82	0.89	2.4	0.58	425
<i>Hebron 2</i>	169.08	113.58	36	21	0.96	0.74	2.02	0.57	457
<i>Bidan 1</i>	180.01	185.58	45	13	0.89	0.37	0.91	0.82	466
<i>Mizpe Jericho 5</i>	188.21	137.62	65	25	0.95	0.85	1.22	0.56	167
<i>Mizpe Jericho 6</i>	189.12	138.45	75						
<i>Mizpe Jericho 2</i>	188.28	134.27	76	33	0.77	0.7	1.17	0.67	380
<i>Shedma 1</i>	172.74	123.06	86	25	0.86	0.62	1.03	0.81	860
<i>Atara 1</i>	192.8	177.5	95	30	0.77	0.74	1.11	0.66	
<i>Beqaot 1</i>	196.51	181.04	101	32	0.9	0.91	0.94	0.57	202
<i>Masua 1</i>	193.38	176.66	153	27	0.63	0.84	0.79	0.69	109
<i>Mizpe Jericho 3</i>	189.11	135.67	430	258	0.57	1.04	0.42	1.04	
<i>Jericho 2</i>	190.72	139.48	472	41	0.54	1.14	0.44	0.94	71.6
<i>Jericho 1</i>	190.9	140.8	491	42	0.54	1.1	0.45	0.9	73.1
<i>Fazael 11</i>	189.3	154.05	1788	52.7	0.52	1.45	0.35	2.07	69.15
<i>Qaliya 2</i>	191.7	134.13	2091	151.4	0.53	1.68	0.35	1.58	
<i>Average Group A</i>			55.62	19.05	0.87	0.72	1.66	0.64	372.3
<i>St.Deviation Group A</i>			28.22	11.06	0.06	0.15	0.71	0.09	205.35
<i>Rep.Group B</i>			153	27	0.63	0.84	0.79	0.69	109
<i>Average Group C</i>			1054.4	109.02	0.54	1.28	0.4	1.31	71.28
<i>St.Deviation Group C</i>			815.35	95.24	0.02	0.27	0.05	0.51	1.99
<i>Aver. Groups A+B</i>			62.57	19.71	0.85	0.73	1.59	0.65	348.36
<i>St.Dev. Groups A+B</i>			37.58	10.79	0.09	0.15	0.72	0.09	210.36

1.2.2. AVEDAT GROUP

The Eocene **Avedat Group** is exposed in the northeastern part of the study area, in the vicinity of Fariya and of Argaman-Beqaot (Marj-Naja) in the core of the regional syncline of Sartaba, which is diagonally incised by the Fariya Graben. It overlies unconformably the impervious sequence of the Senonian-Paleocene **Mt.Scopus Group** the thickness of which varies in the range of 0 to 380 m.

The Avedat Group is subdivided (from base to top) into the Meroz, Izreel and Bar Kokhba Formations - all built of limestone, attaining a total thickness of 400 m. Field – and borehole evidence indicate that due to mature karst, the Bar Kokhba Formation is characterized by high hydraulic permeabilities. This is not the case for the two other (underlying) formations, which consist of tight limestones often interbedded with chalk and argillaceous horizons.

The aquifer beds of the Avedat Group are directly recharged by local rainfall, which attains 250-300 mm/yr in the western parts of the study area and ± 100 mm/yr in the Rift and its vicinity. In the Beqaot-Argaman area (Marj-Naja), the thickness of the Mt.Scopus aquiclude is strongly reduced or is even entirely absent due to non-deposition. This local geological feature facilitates interflow between the Judea- and Avedat aquifers. It is further enhanced by the intensive faulting along the western margins of the Rift (mostly obscured by the alluvial fill).

Groundwater levels in the Avedat aquifer are between 100 m MSL to – 300 m MSL and the flow is generally to east and south-east (**Figure 1.4**). Table 3 summarizes the groundwater chemical composition.

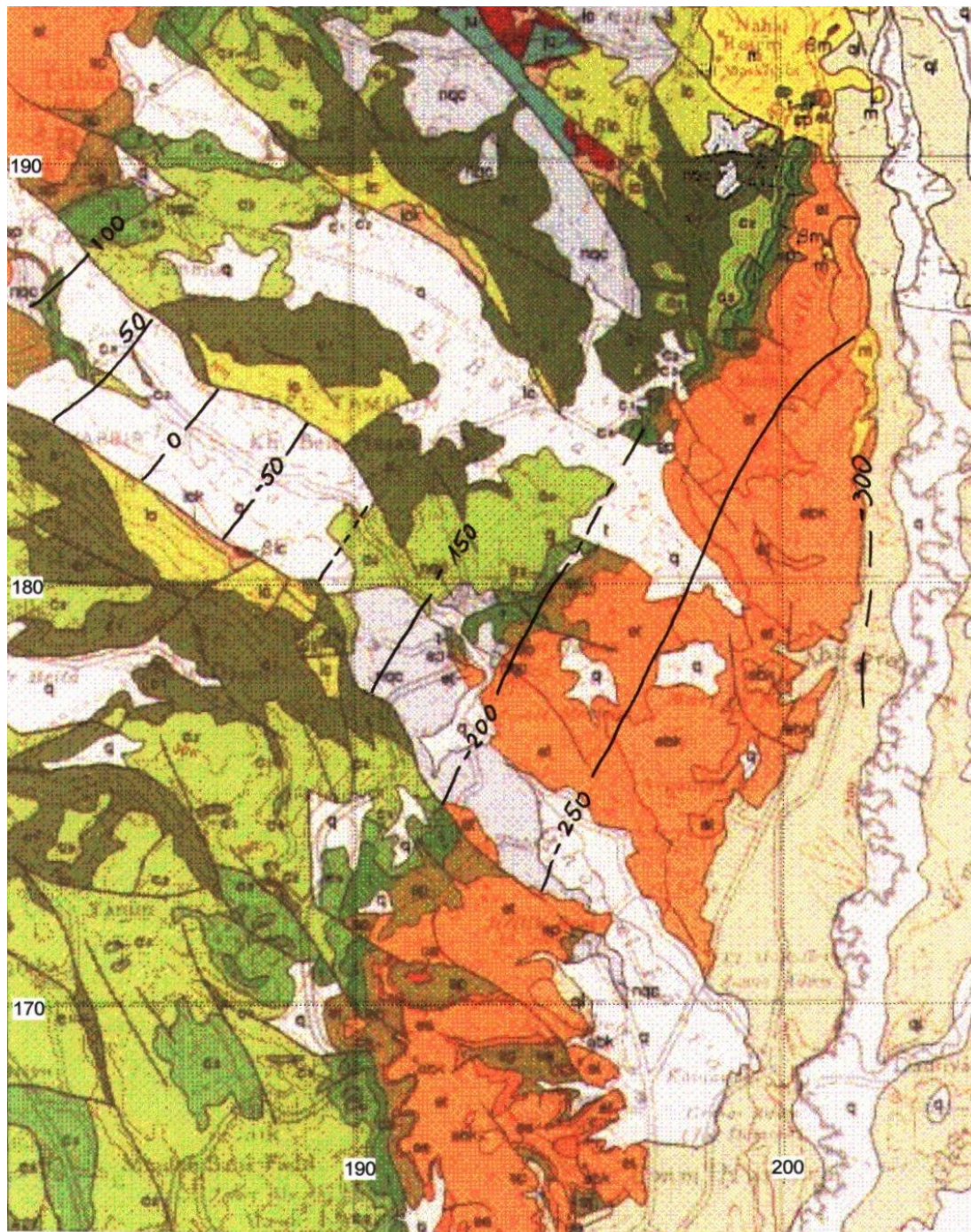


Figure 1.4: water table at Avedat aquifer (years 1995-1997)

1.2.3. DEAD SEA GROUP

The Quaternary **Dead Sea Group** sediments outcrop mainly in the flantlands east of the western fault escarpment of the Rift. This Group is divided into several formations, which contain permeable horizons:

The Samra Formation (Plio-Pleistocene) crops out along the western part of the Jordan Valley floor. It consists mainly of detrital material such as conglomerates, sandstone and silt and is subdivided into two members: the **Silt Member** and the **Coarse Clastic member**. The Silt Mbr. (up to 20 m thick) interfingers with the Lisan Formation.

The Lisan Formation (Plio-Pleistocene) occurs over wide parts of the Jordan Valley and often penetrates the mouths of wadis. The highest outcrops are found at –180 m The 35m thick formation consists essentially of chemical and detrital deposits such as laminated aragonite-chalk, gypsum and sulphur, clay with some sandstone and pebble beds. Algal tufa occurs at a constant elevation of –240 m MSL.

Alluvial deposits contain debris from all formations bordering the Rift. The total thickness of these beds is unknown and could certainly reach, in the central parts of the Rift, to very high figures, thinning out towards the margins.

The present study revealed that in the Valley, all permeable horizons are interconnected and that hydrological and hydrochemical continuity prevails.

Groundwater levels in the aquiferous horizons of the Dead Sea Group are between -280 m MSL to –340 m MSL and the flow is generally to the east (**Figure 1.5**).

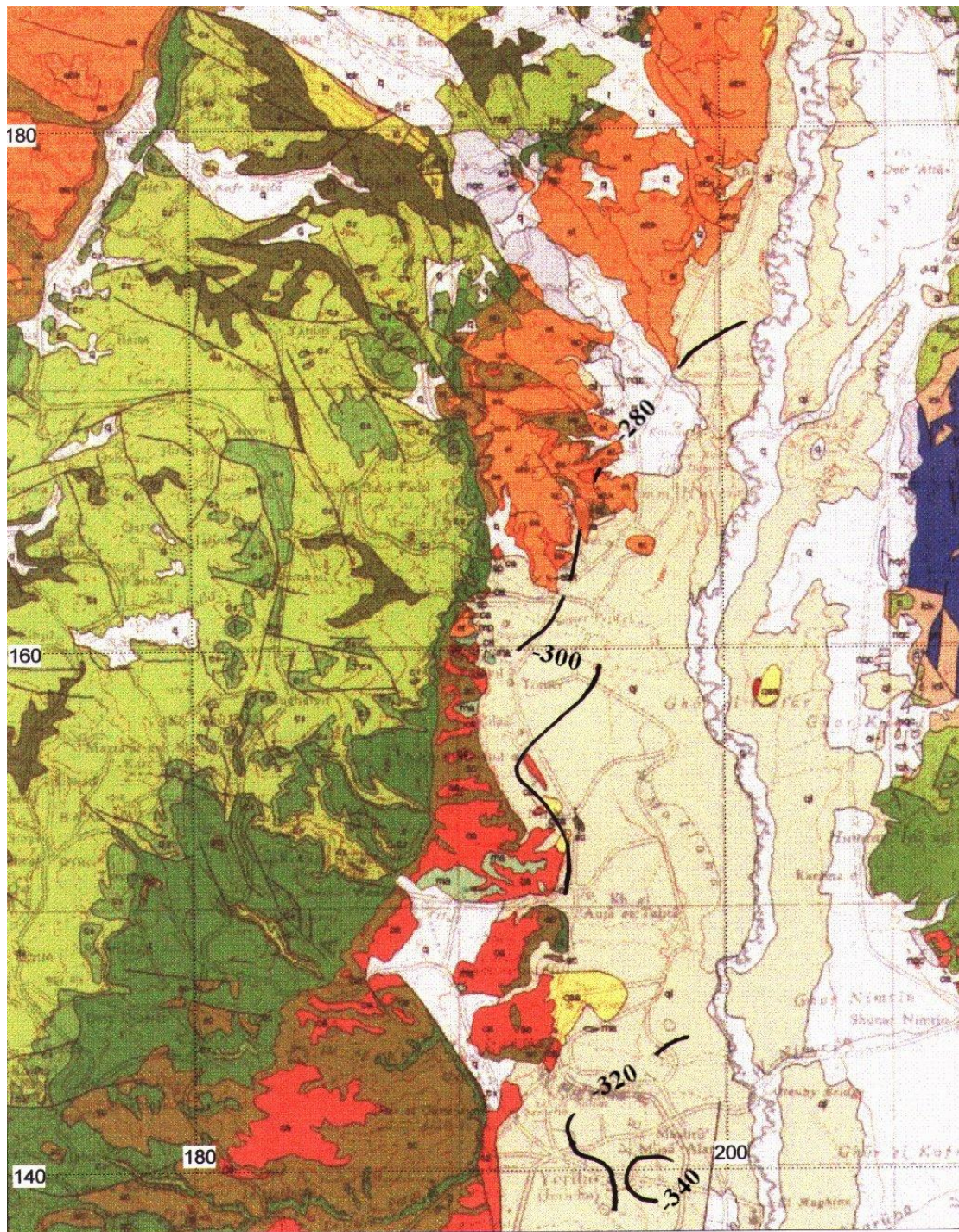


Figure 1.5: water table at the conductive strata of the Dead-Sea aquifer (years 1995-1997)

2. GROUNDWATER CHEMISTRY

2.1. JUDEA GROUP

2.1.1. CL-CONCENTRATIONS

In the **Judea Group** aquifers the longitudinal and parallel isochlore lines indicate that the increase in salinity follows in both aquifers closely groundwater flow direction. The Cl-concentrations are in the 26-12200mg/l range (Figure 2.1 and Figure 2.2).

In the lower aquifer (Albian – Lower Cenomanian) the average Cl-content is 39 ± 14 mg/l whereas in the overlying aquifer (Mid-Cenomanian - Turonian) it is slightly higher, 56 ± 28 mg/l. Such concentrations are characteristic for most parts of the two aquifers. The fresh waters reach in the lower aquifer as far as 10 km west of the Rift boundary. Northward in the Auja area, these fresh waters reach the rim of the Rift. Judging by the shapes of isochlore lines of the upper aquifer, it occurs as if there were two preferential flow paths, one heading from the boreholes in the outskirts of Jerusalem eastward to the Rift and another which is prominent in the northeastern part of the aquifer and directed towards the Atara-Masua-Beqaot wells.

In the lower aquifer, brackish water with the average Cl concentrations of 6000 mg/l was encountered exclusively in the Mitzpe Jericho (# 3 and 5 deep) and Jericho 2 wells. In the upper aquifer, such brackish groundwater attains salinities in the range of 430-2100 mgCl/l and was also encountered in wells Mitzpe Jericho and Jericho as well as in two additional foci, in wells Qaliya 2 and Fazaal 11.

2.1.2. SO₄-CONCENTRATIONS

The waters of both aquifers of the **Judea Group** are generally characterized by low SO₄-concentrations (av. 17 ± 8.5 and 19 ± 11 mg/l respectively). Higher concentration (but not exceeding 45 mg/l) is encountered in the lower aquifer in the northeastern part of the study area, in the Fazaal-Beqaot area.

The brackish water found close to the margins of the Rift in the wells of Mitzpe Jericho, Jericho and Fazaal, have high concentrations of sulfate. In the lower aquifer they reach up to 870 mg/l and stand out as a separate group. In the upper aquifer the concentrations are in the 40-260 mg/l range (Figure 2.3 and Figure 2.4).

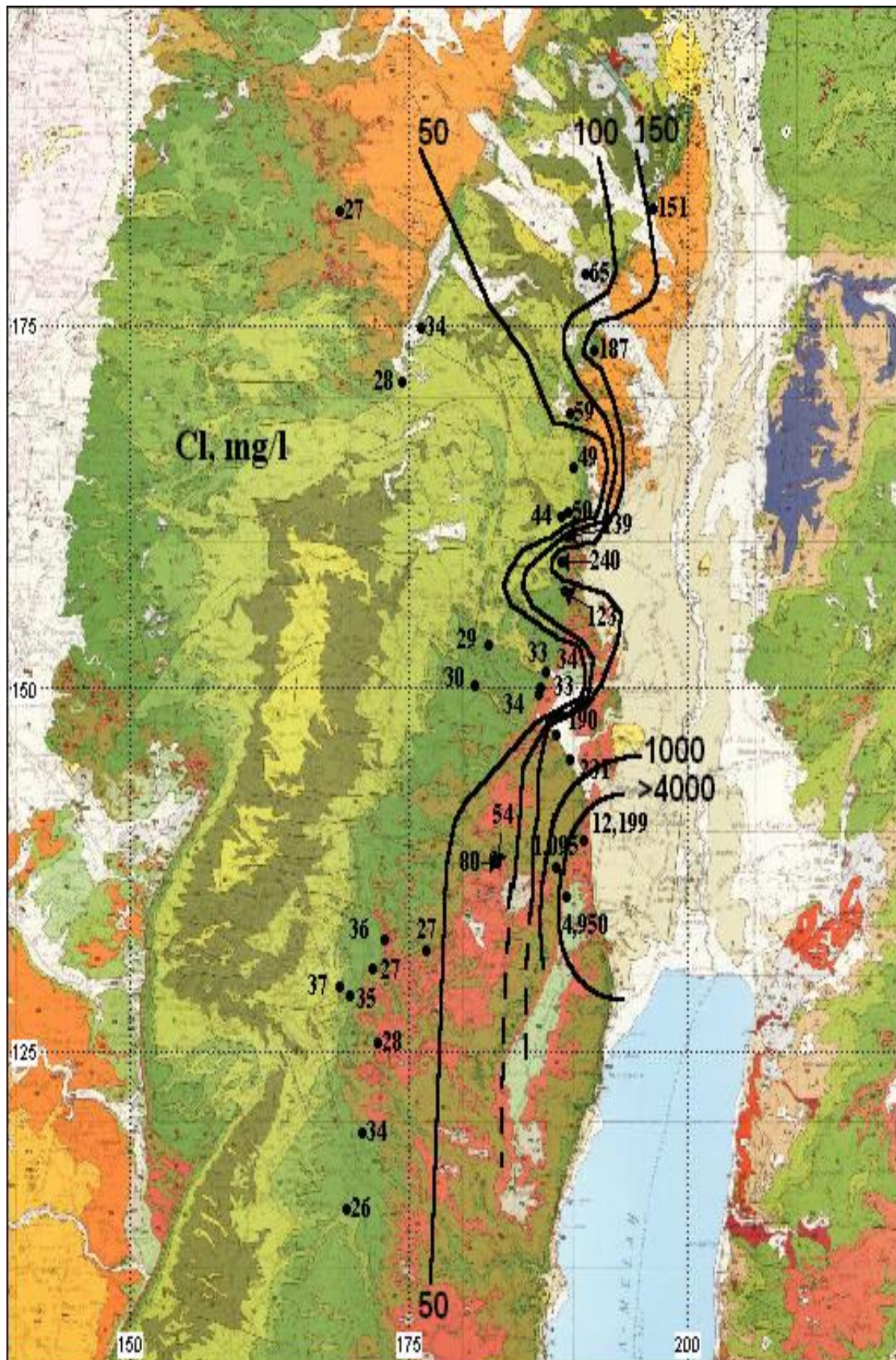


Figure 2.1: Chloride concentration at the lower Judea aquifer

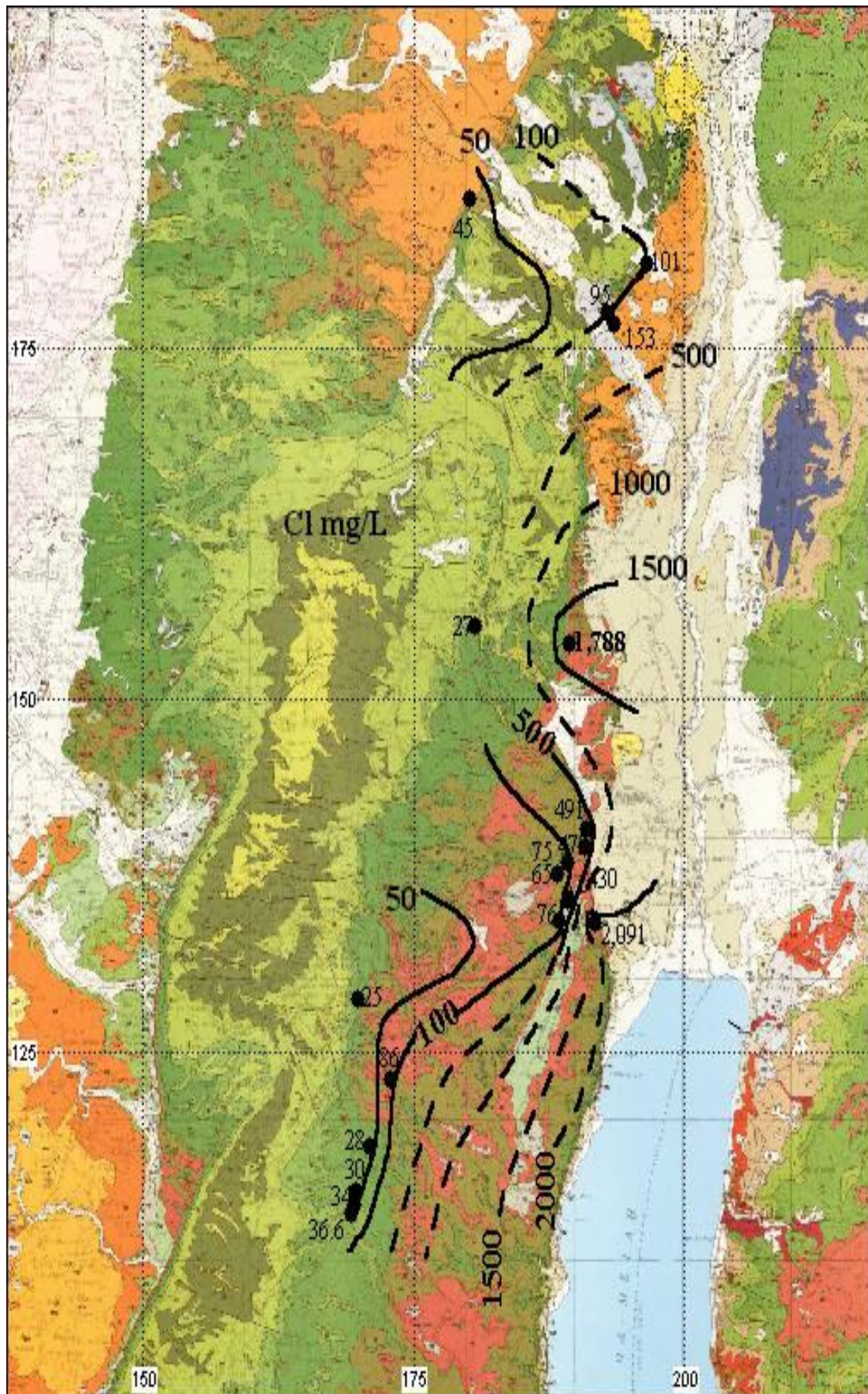


Figure 2.2: Chloride concentration at the upper Judea aquifer

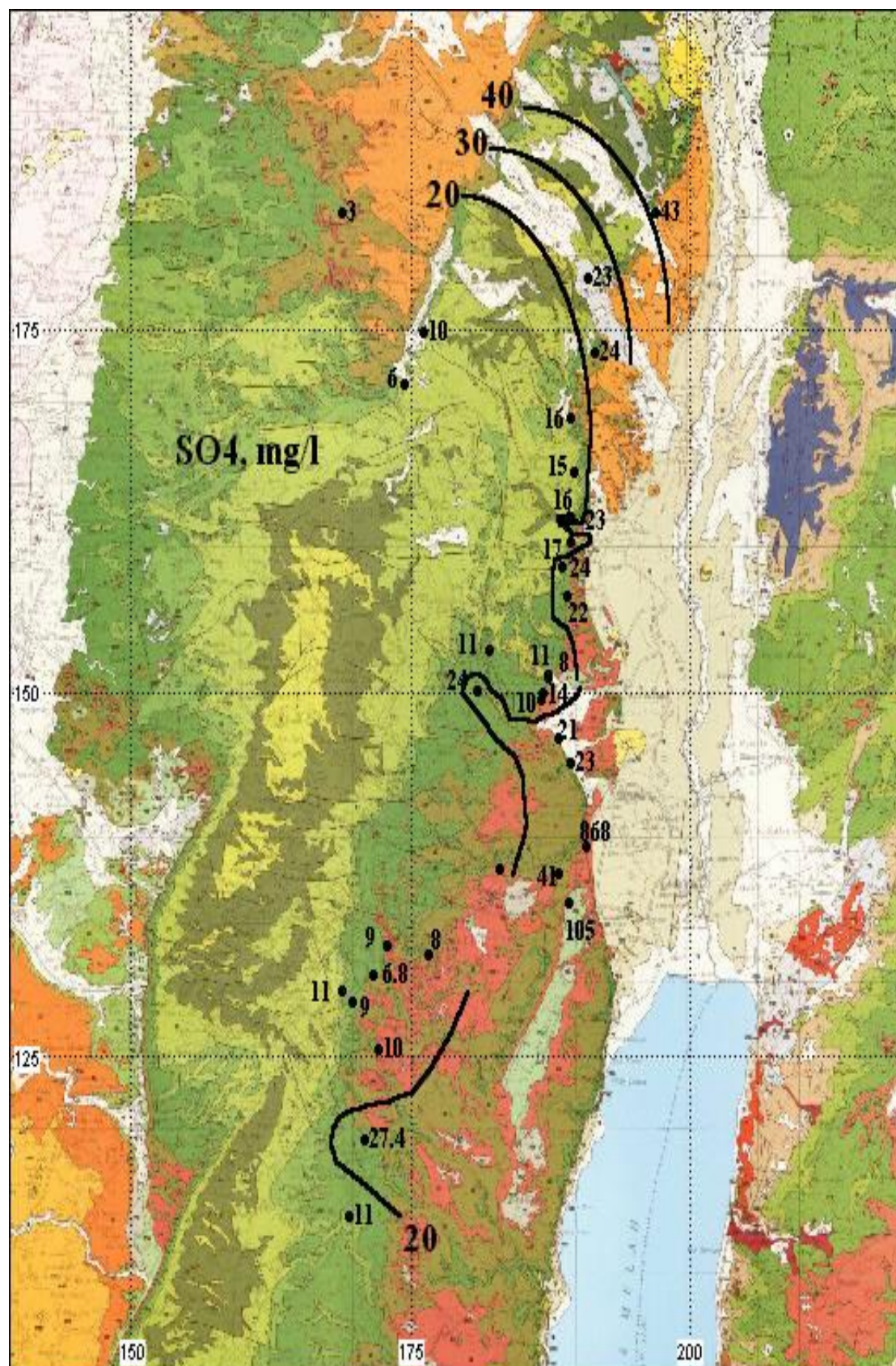


Figure 2.3: Sulfate concentration at the lower Judea aquifer

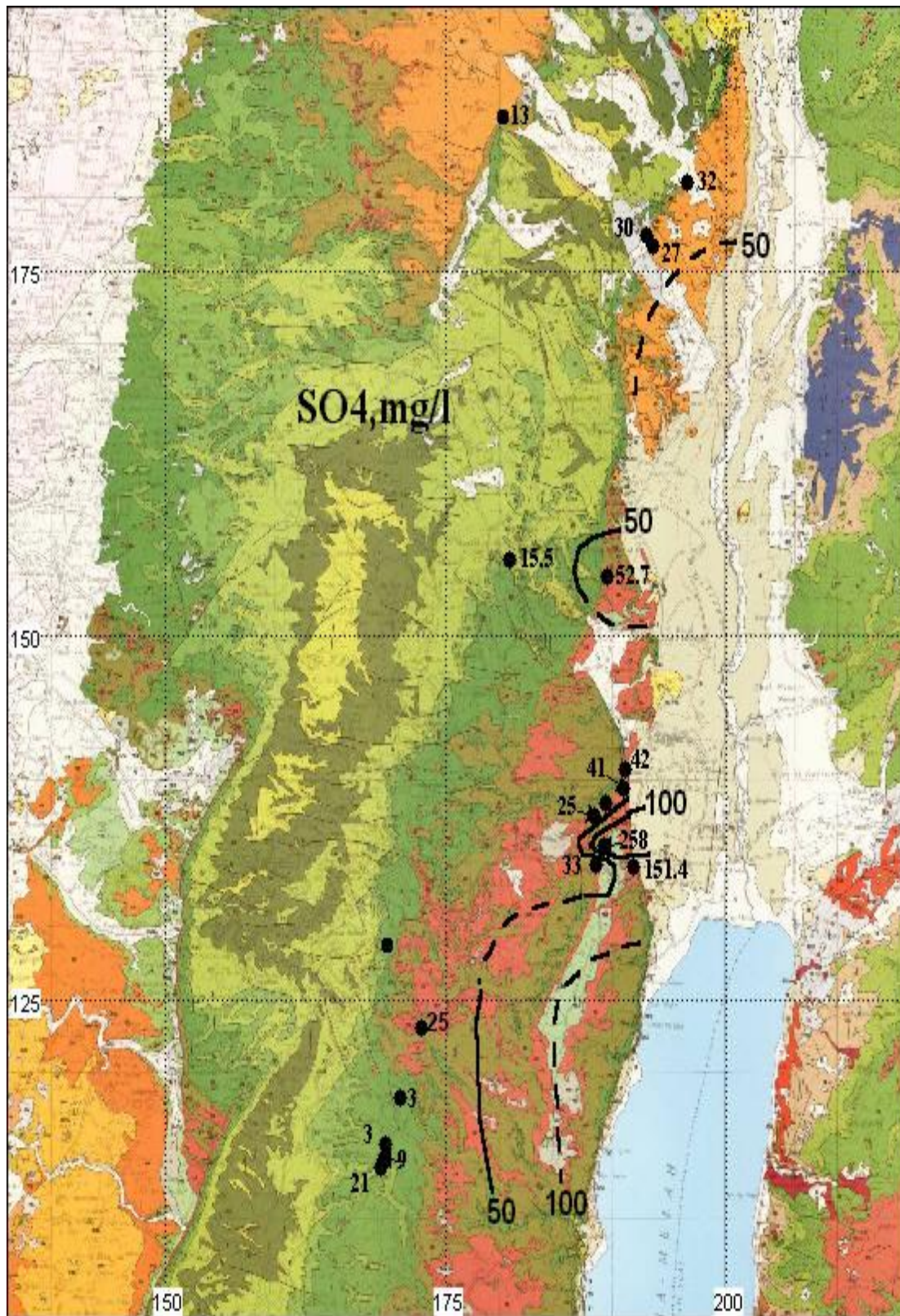


Figure 2.4: Sulfate concentration at the upper Judea aquifer

2.1.3. EVOLUTION OF ION CONCENTRATIONS VS. SALINITY

In the three main aquifers, the evolution in the concentration of the main cations vs. salinity is quite similar. The concentrations of Ca, Mg and Na evolve generally in direct linear dependence of Cl-concentrations. In all cases, SO_4 increases in the vicinity with the western rim of the Rift. Scattering of Ca and of Na around the function line are due to exchange reactions on argillaceous rock components.

2.1.4. ION RATIOS

2.1.4.1. Mg/Ca

Groundwaters in the western and central parts of the two aquifers of the Judea Group are characterized by average Mg/Ca ratio values of 0.73 (± 0.13). Such values are characteristic of water flowing through limestone and dolomite. Eastwards, towards the margins of the Rift, a clear increase of ratio values was observed, particularly in wells located in the Qaliya, Fazaal-Beqaot areas. The waters in the two aquifers differ by the fact that ratio values >1 occur in the upper aquifer at a greater distance westward from the margins of the Rift than in the lower aquifer. The saline waters encountered in the Mitzpe Jericho and Jericho wells are characterized by ratio values in the 0.95-1.95 range.

In the waters of the two aquifers no dependence were discerned between changes in salinities and fluctuation of Mg/Ca ratios (Figure 2.5 and Figure 2.6).

2.1.4.2. Mg/Cl

In both aquifers of the **Judea Group**, the distribution patterns of this ratio follow closely that of Cl and three data clusters were discerned. In the lower aquifer, the average ratio values are 2.16 ± 0.59 with two prominent maxima of 3.48 and 3.12 in wells Herodion 4 and Rimoni 1, which are both in-, or close to the replenishment area. In the overlying upper aquifer, the average ratios are lower (1.59 ± 0.72). In both aquifers the ratio values decrease eastwards towards the borders of the Rift there low ratio values ($\text{av. } 0.27 \pm 0.1$) characterize the saline waters of Mitzpe Jericho and Jericho well (lower aquifer) whereas slightly higher average values (0.4) characterize the upper aquifer. In both aquifers, there is a clear inverse dependence between increasing Cl-concentrations and the ratio values, which level off at 0.4-0.5 (Figure 2.7 and Figure 2.8).

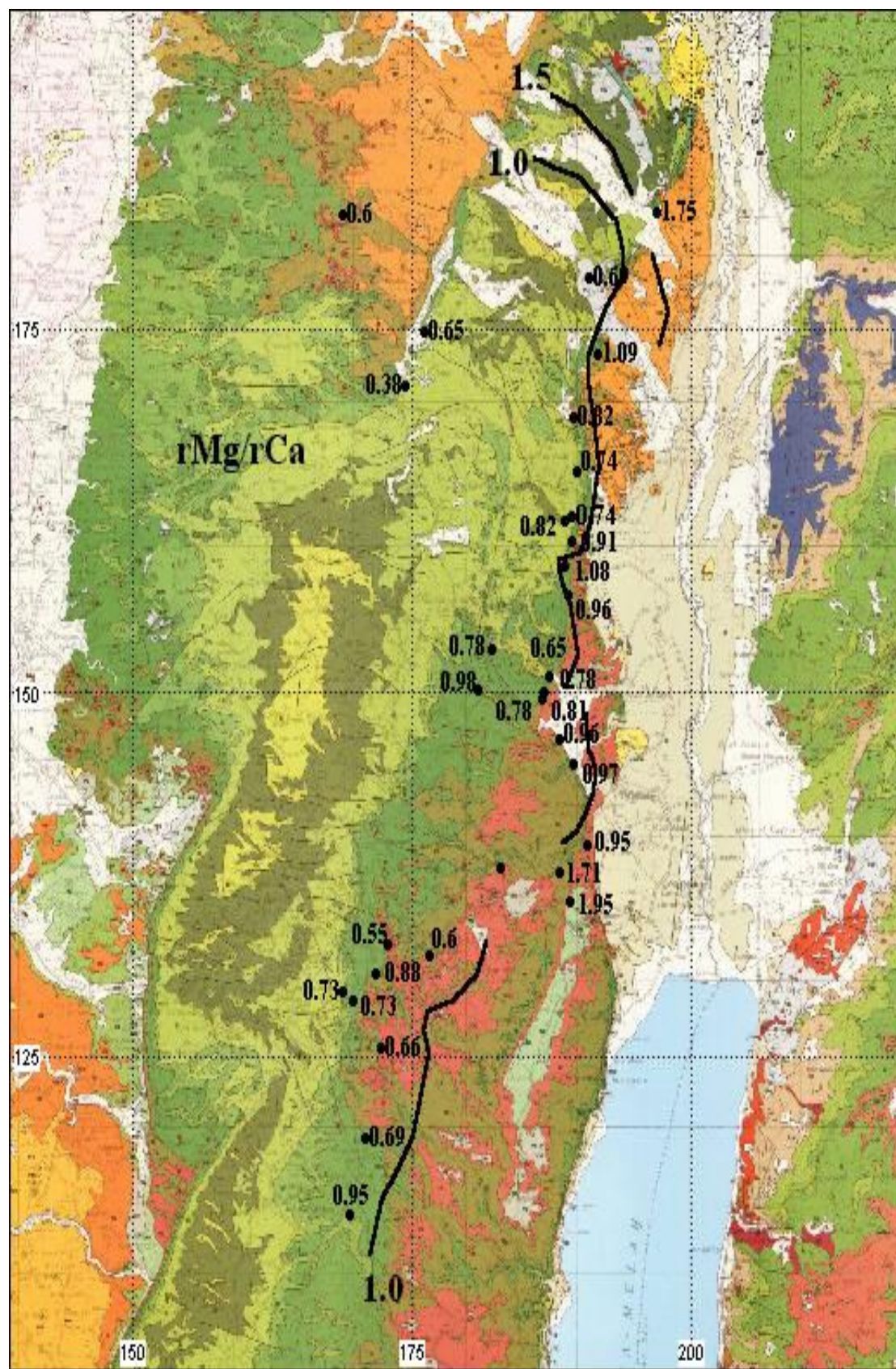


Figure 2.5: rMg/rCa ratio at the lower Judea aquifer

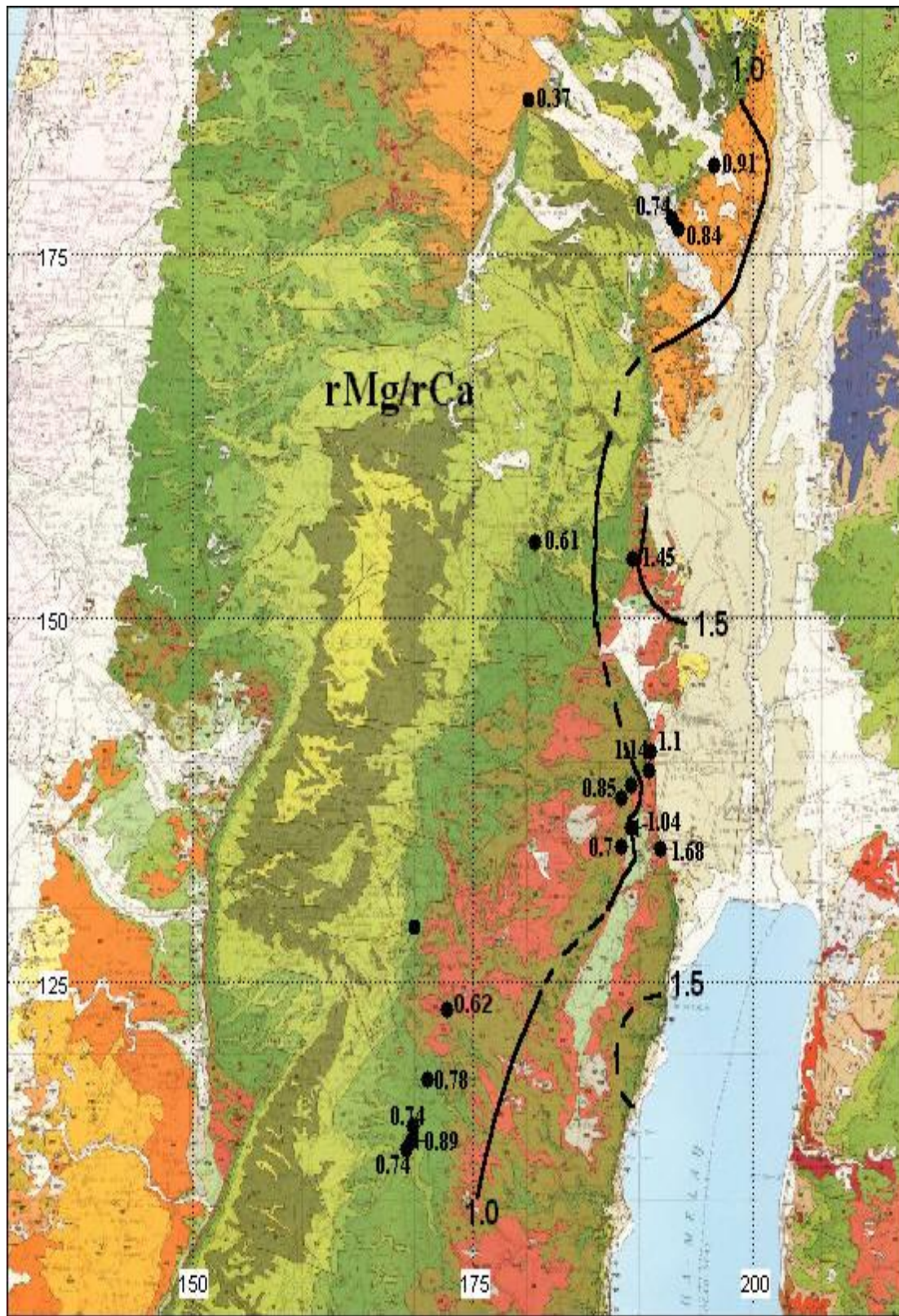


Figure 2.6: rMg/rCa ratio at the upper Judea aquifer

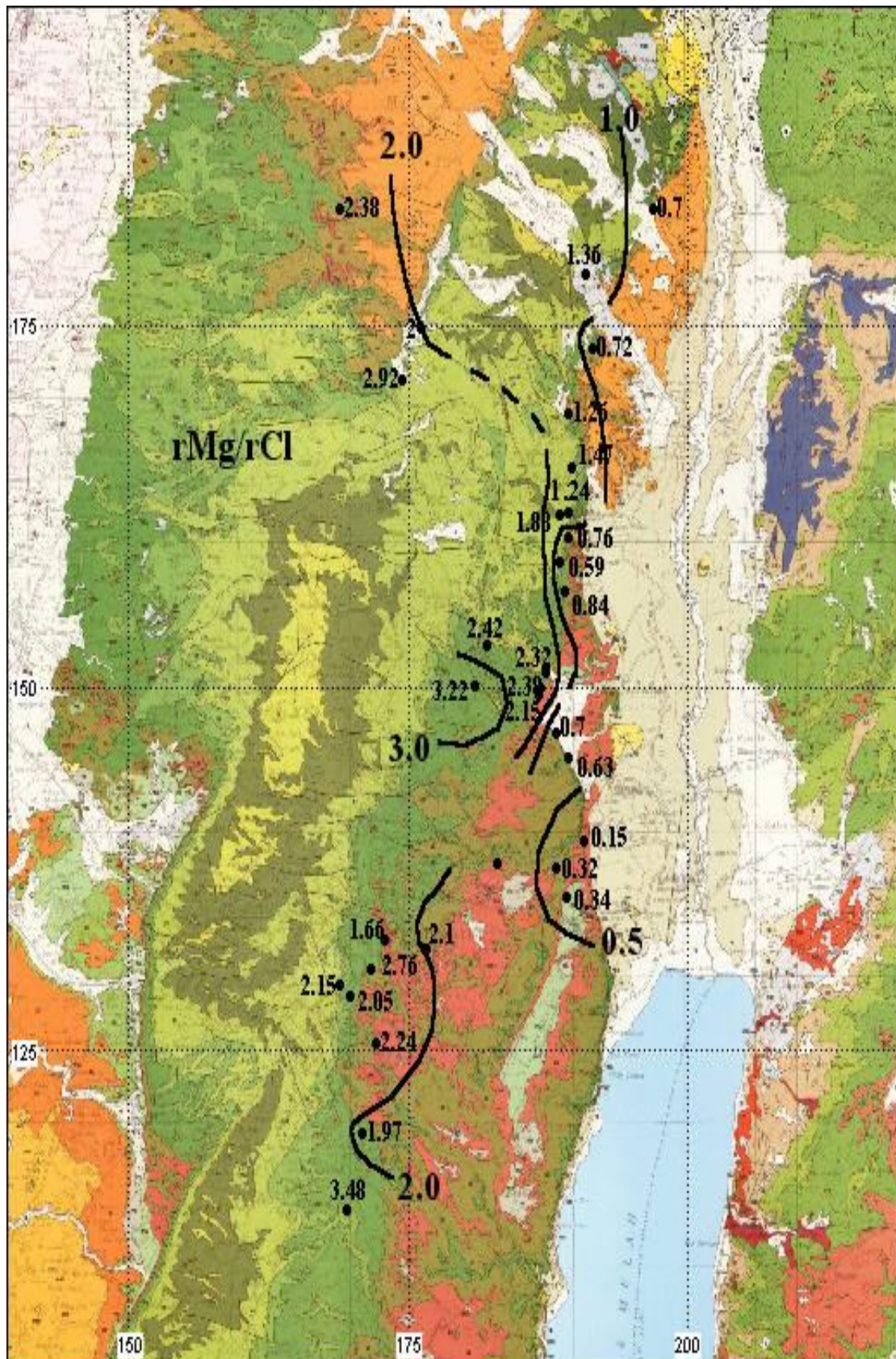


Figure 2.7: rMg/rCl ratio at the lower Judea aquifer

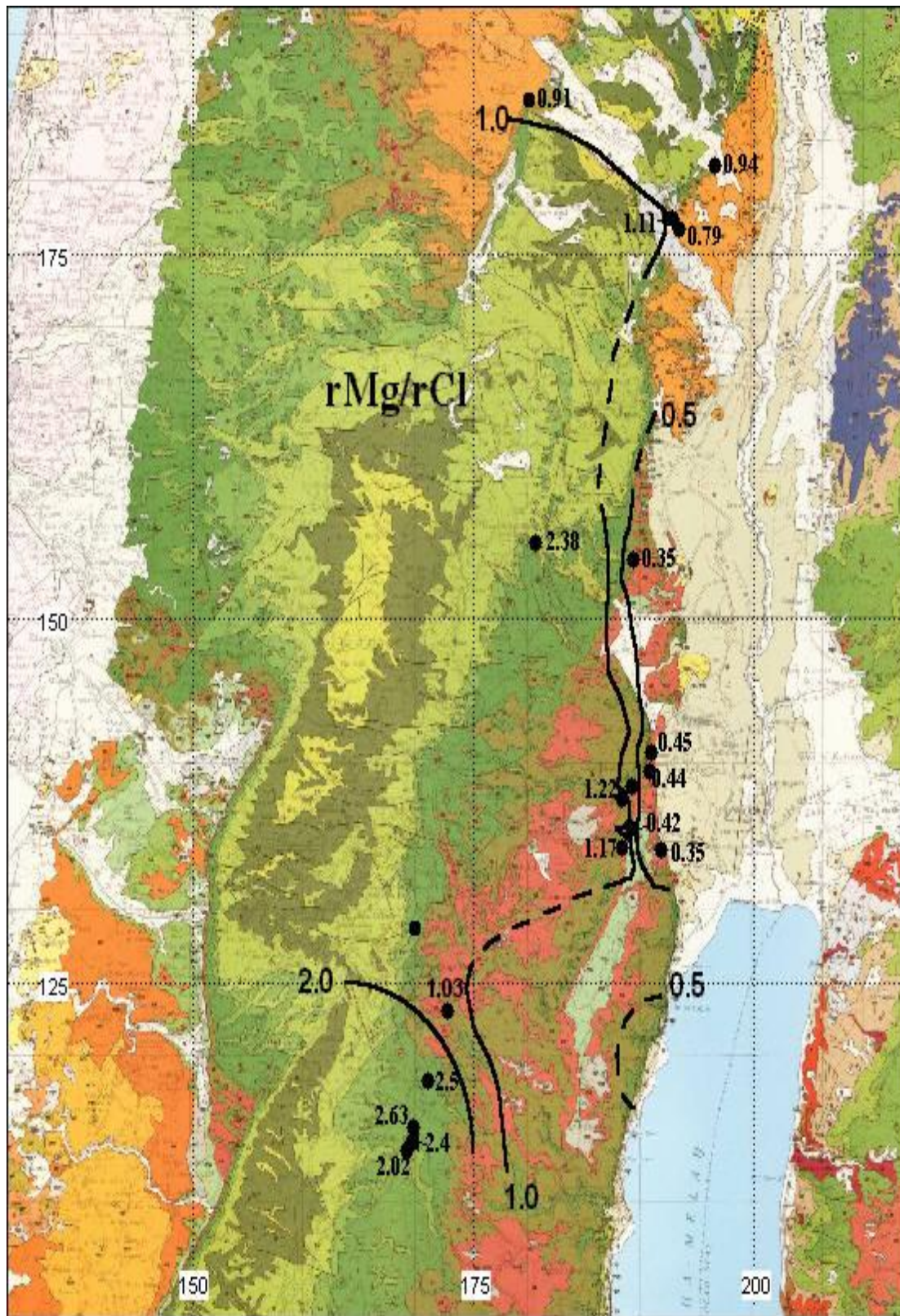


Figure 2.8: rMg/rCl ratio at the upper Judea aquifer

2.1.4.3. $Q=[Ca/(SO_4+HCO_3)]$

Throughout the **Judea Group aquifers**, between the zones of natural replenishment in the west and close to the margins of the Rift, ratio values are within the 0.53-0.83 range (av 0.66 ± 0.1). In wells located close to the margins of the Rift, ratio values increase reaching values (>1.0). In both aquifers, extreme values occur in the saline groundwater of the Mitzpe Jericho, Jericho, Qaliya and Fazael well fields located at the margins of the Rift. In waters of higher concentrations ($>150-200$ mgCl/l) there is a clear linear dependence between the Q-ratio and Cl-concentrations. Waters with $Q > 1$ are always characterized by Na/Cl ratio values in the 0.5 – 0.6 range (Figure 2.9 and Figure 2.10).

2.1.4.4. Na/Cl

In the western parts of the **Judea Group aquifers**, close to replenishment areas, ratio values are low (<0.7) evolving gradually to an average of 0.83 ± 0.14 (Figure 2.11 and Figure 2.12). Further eastwards close to the margins of the Rift and in the saline groundwater of Jericho, ratio values drop to 0.6. The relationship of $Na/Cl=f(Cl)$ reveals that in both aquifers, increase in salinity correlates with decrease of ratio values to 0.5 – 0.6.

2.1.4.5. Cl/Br weight ratio

There are two distinct clusters of ratio values: throughout most of the two **Judea Group aquifers** (fig 69,70). One cluster includes ratio values in the 245-433 range (av. 317 ± 53), which are typical for an actively recharged calcareous aquifer. Close to the Rift and concomitantly with the increase of water salinity, the ratio values in the lower aquifer drop to average values of 92 ± 37 . The saline waters of Jericho and Mitzpe Jericho are characterized by ratio values as low as 59 ± 31 . In upper horizons of the same wells i.e. in beds related to the upper aquifer, salinities are lower and these ratio values are slightly higher (71). In the lower **aquifer**, low (<100) Cl/Br ratios coincide with high (>1) Q-ratio values. The brackish and saline waters characterized by $Cl/Br < 100$, are unequivocally characterized by Mg/Cl ratios of 0.5-0.6.

2.1.5. PARAMETERS INDICATING PROCESSES OF ION EXCHANGE

2.1.5.1. $(Ca+Mg)-(SO_4+HCO_3) = f(Na+K)-Cl$

In the **Judea Group** aquifers there are clear indications for ion exchange processes resulting in the enrichment of Ca in water and their concomitant impoverishment in Na. In the lower aquifer there are clear indications of two different dependences. Whereas one function shows a "background" process similar for the two aquifers, there occur also additional processes of considerable Ca enrichment probably due to inflow of Ca-rich brines.

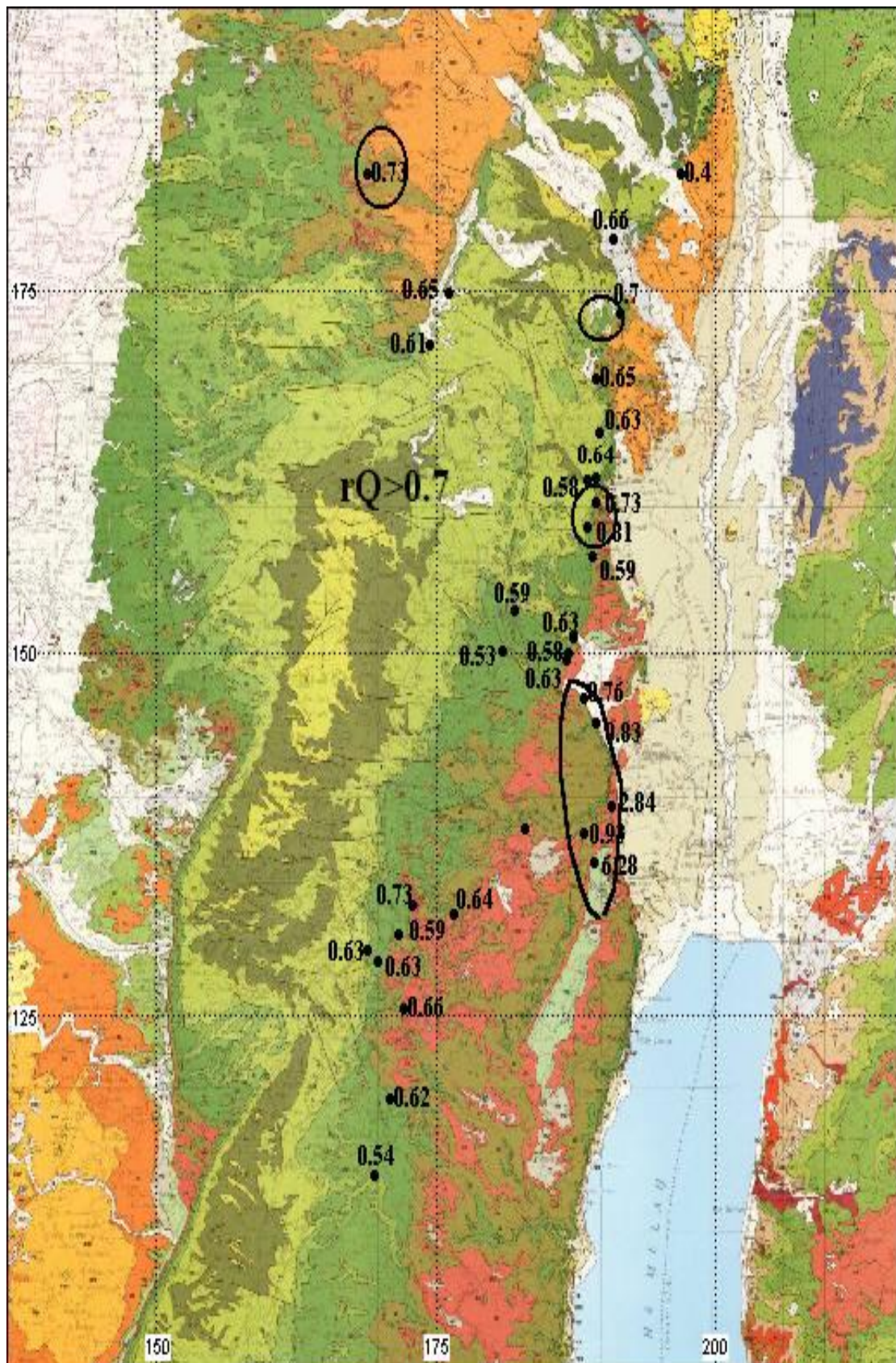


Figure 2.9: rQ ratio at the lower Judea aquifer

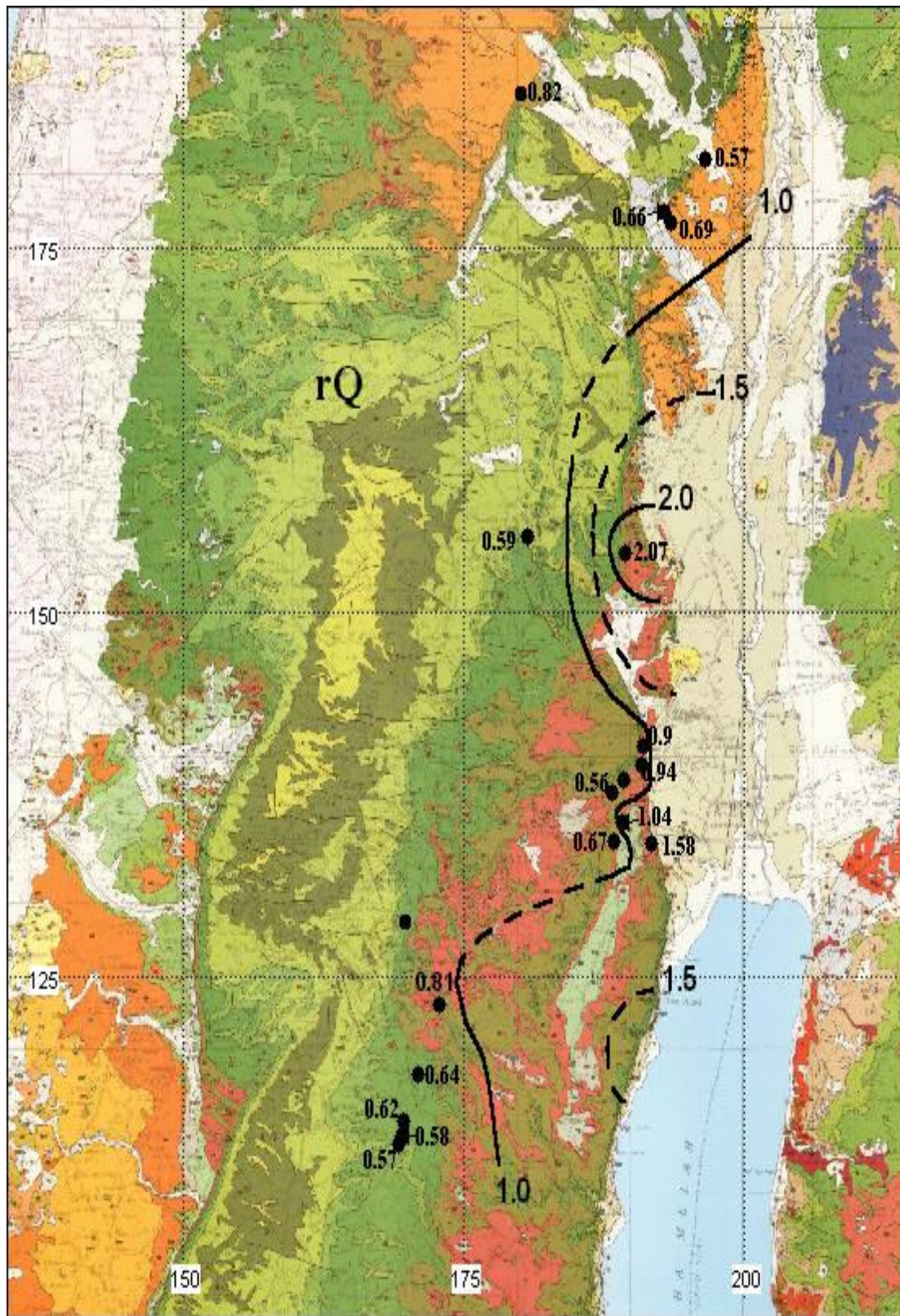


Figure 2.10: rQ ratio at the upper Judea aquifer

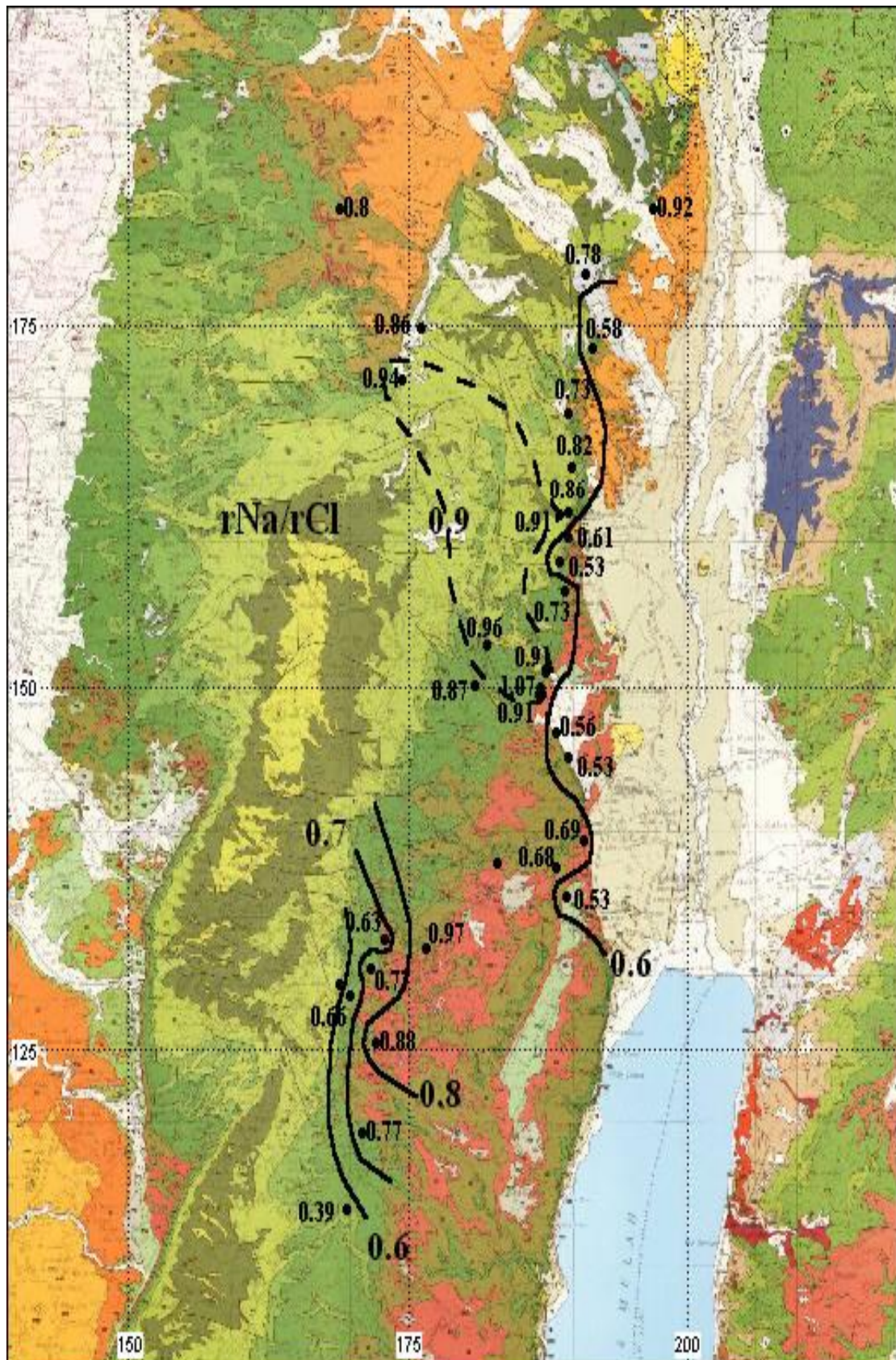


Figure 2.11: rNa/rCl ratio at the lower Judea aquifer

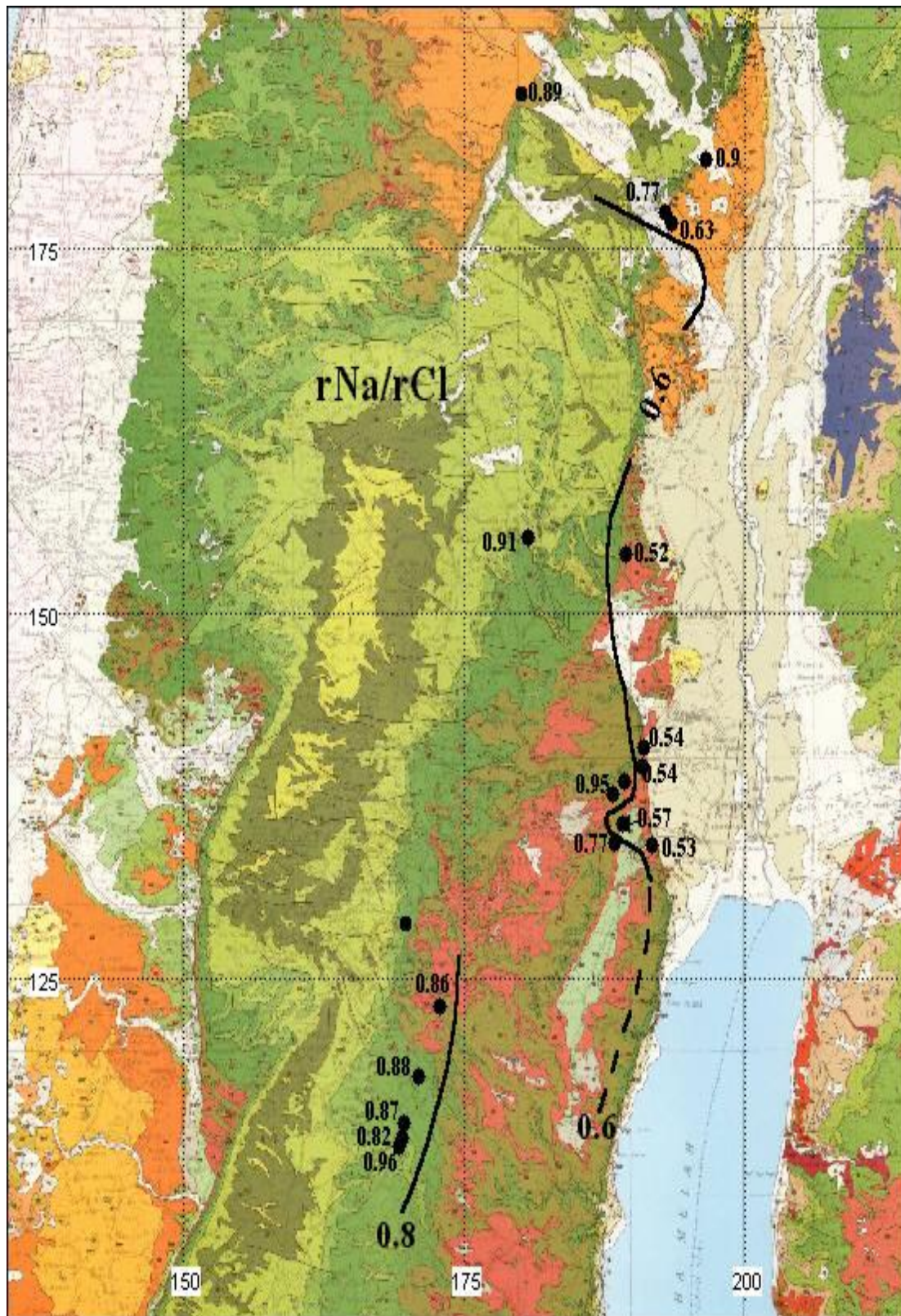


Figure 2.12: rNa/rCl ratio at the upper Judea aquifer

2.1.6. CHEMICAL COMPOSITION OF GROUNDWATER EMERGING FROM SPRINGS

The waters emerging from the springs are characterized by the lowest concentrations in the area and their hydrochemistry resembles closely that of groundwater from the Upper Aquifer of the Judea Group. On the other hand, the water of the Auja and Duyuk springs are characterized by relatively low Cl/Br ratios (206-217).

2.1.7. SALT NORM VALUES

The Salt Norms represent the calculated theoretical assemblage of salts the dissolution of which would produce the chemical composition of the investigated water sample.

The fresh groundwater (<100 mgCl/l) in both aquifers of the **Judea Group** are characterized by similar salt norms. The prevalent salts are CaCO_3 (22-45 wt%) and MgCO_3 (19-35 wt%) followed by NaCl (10-20 wt%). Closer to the margins of the Rift the percentage of NaCl increases to 35wt%. The norm for CaSO_4 is low, in the 3-7wt% range. Waters with higher salinities (in the 100-250 mg/l range) differ from the previous group by higher norms for NaCl (30-36 wt%), by the occurrence of the Ca-MgCl₂ norms attaining together up to 35wt% and by the lowering of the norms for Ca- and Mg-carbonates. The brackish and saline groundwater stand out by their high NaCl norms (40-67 wt%) and by Ca- and MgCl₂ norms which attain 35-40wt%. These waters are characterized by low norms for CaSO_4 .

2.2. AVEDAT GROUP

2.2.1. CL-CONCENTRATIONS

In the Avedat Group aquifer, the isochlore lines indicate that salinity increases east-southeastwards (fig 31). Cl-concentrations are in the 37-1300mg/l range. The lowermost concentrations (37-82 mg/l) were encountered close to the western margins of the study area and represent groundwater replenished in the southern part of the Shekhem-Nablus syncline. In the central part of the study area, the groundwater have an average Cl-content of 520 mg/l (SD 152) whereas close to the western margins of the Rift, the concentrations are in the 800-1300 mg/l range (av 1000 mg/l, SD 176). By considering the shapes of isochlore lines paths of preferential groundwater flow could be outlined. This is particularly prominent in the vicinity of wells Yunis and Saleh 22 and Suleiman Saleh (North). It may also indicate that the Bugeia valley could be a major karstic feature.

2.2.2. SO₄-CONCENTRATIONS

In the Avedat Group aquifer the fresh groundwater in the western parts of the study area are characterized by low sulfate concentrations (av.20 mg/l), which are quite similar to the

concentrations encountered in the Judea Group aquifer. Throughout the central part of the study area, the average concentrations are 60 mg/l, i.e. slightly higher than in the underlying Judea Group aquifers. Groundwater in wells located along the eastern margins of the Rift has concentrations reaching as high as 300 mg/l. The distribution of concentrations is not equal; concentration maxima and minima are unevenly distributed along the borders of the Rift and are probably controlled by structural features. The increase of SO_4 -concentrations along the margins of the Rift is almost identical to that observed for groundwater flowing in the upper aquifer of the Judea Group (Figure 2.13).

2.2.3. EVOLUTION OF ION CONCENTRATIONS VS. SALINITY

In the three main aquifers, the evolution in the concentration of the main cations vs. salinity is quite similar. The concentrations of Ca, Mg and Na evolve generally in direct linear dependence of Cl-concentrations. In all cases, SO_4 increases in the vicinity with the western rim of the Rift. Scattering of Ca and of Na around the function line are due to exchange reactions on argillaceous rock components.

2.2.4. ION RATIOS

2.2.4.1. Mg/Ca

In the **Avedat Group aquifer** Mg/Ca ratio values characteristic for calcareous aquifers (generally < 1 but particularly 0.4-0.6 for aquifers built of pure, non-dolomitic limestones) were encountered only in few sources located in the western parts of the study area. Elsewhere were found ratio-values of >1 (av.1.11 sd 0.77) which increase considerably at the margins of the Rift (av 1.42 sd 0.22). In view of the considerable scatter of data (fig.34) it appears that there is no clear linear relationship between Cl-concentrations and Mg/Ca ratio values.

2.2.4.2. Mg/Cl

In the **Avedat Group** and throughout the central parts of the Sartaba syncline, the ratio values are in the 0.42-0.77 range, probably due to the absence of dolomites or of other Mg-containing minerals in aquifer rocks. Along the margins of the Rift, average ratio values drop to 0.36, which are quite similar to values encountered in aquifer # 400. There seems to be no clear dependence between salinity and ratio values, which are constant in the range of 0.3-0.4 (Figure 2.14).

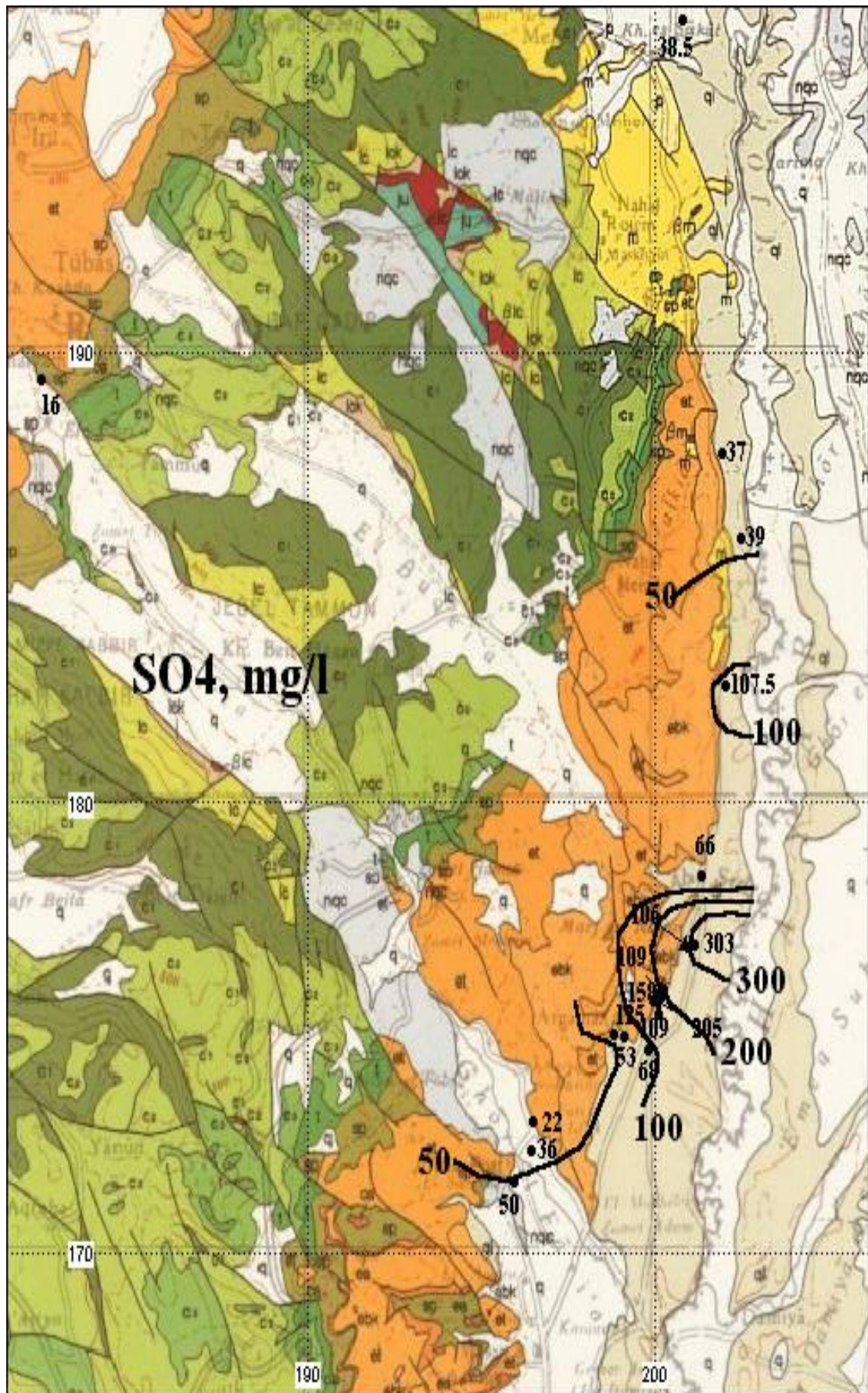


Figure 2.13: SO4 concentrations at the Avedat aquifer

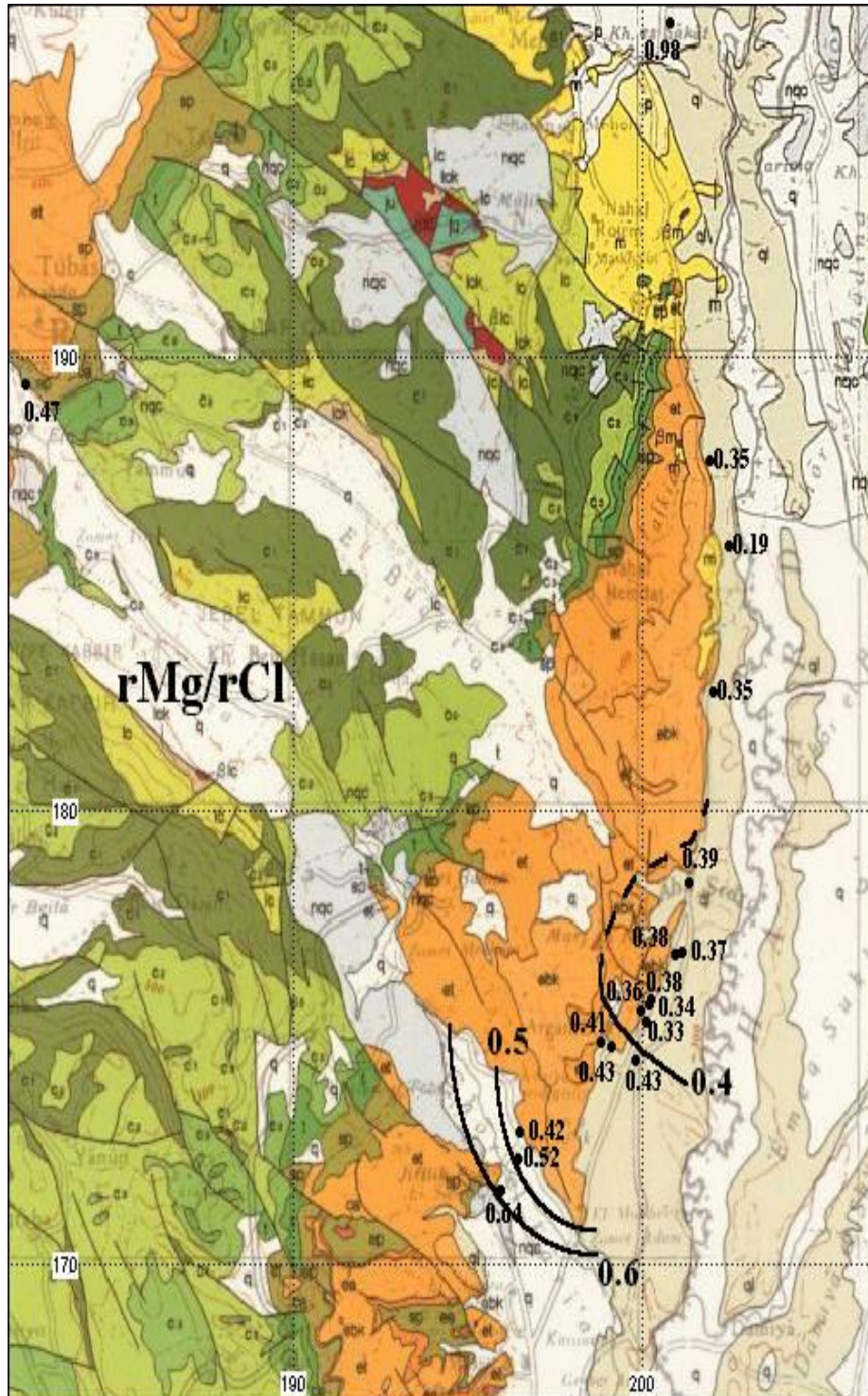


Figure 2.14: rMg/rCl ratio at the Avedat aquifer

2.2.4.3. $Q = [Ca/(SO_4+HCO_3)]$

In the western part of the **Avedat Group aquifer**, the ratio values are <1 (av 0.68). In the central and eastern parts of the study area, ratio values are >1 (av.1.2) and in certain cases (Argaman 14 and Marj Naja 13A), exceed 2. The mapped distribution of ratio values supports the existence of preferential flow paths of fresh waters, particularly between the Beqaot - Bugeia valley and Marj Naja.

In waters with $Q > 1$, there is an inverse relationship with Na/Cl ratio values. Waters with $Q > 1$ are characterized by low (80-130) Cl/Br ratios (Figure 2.15).

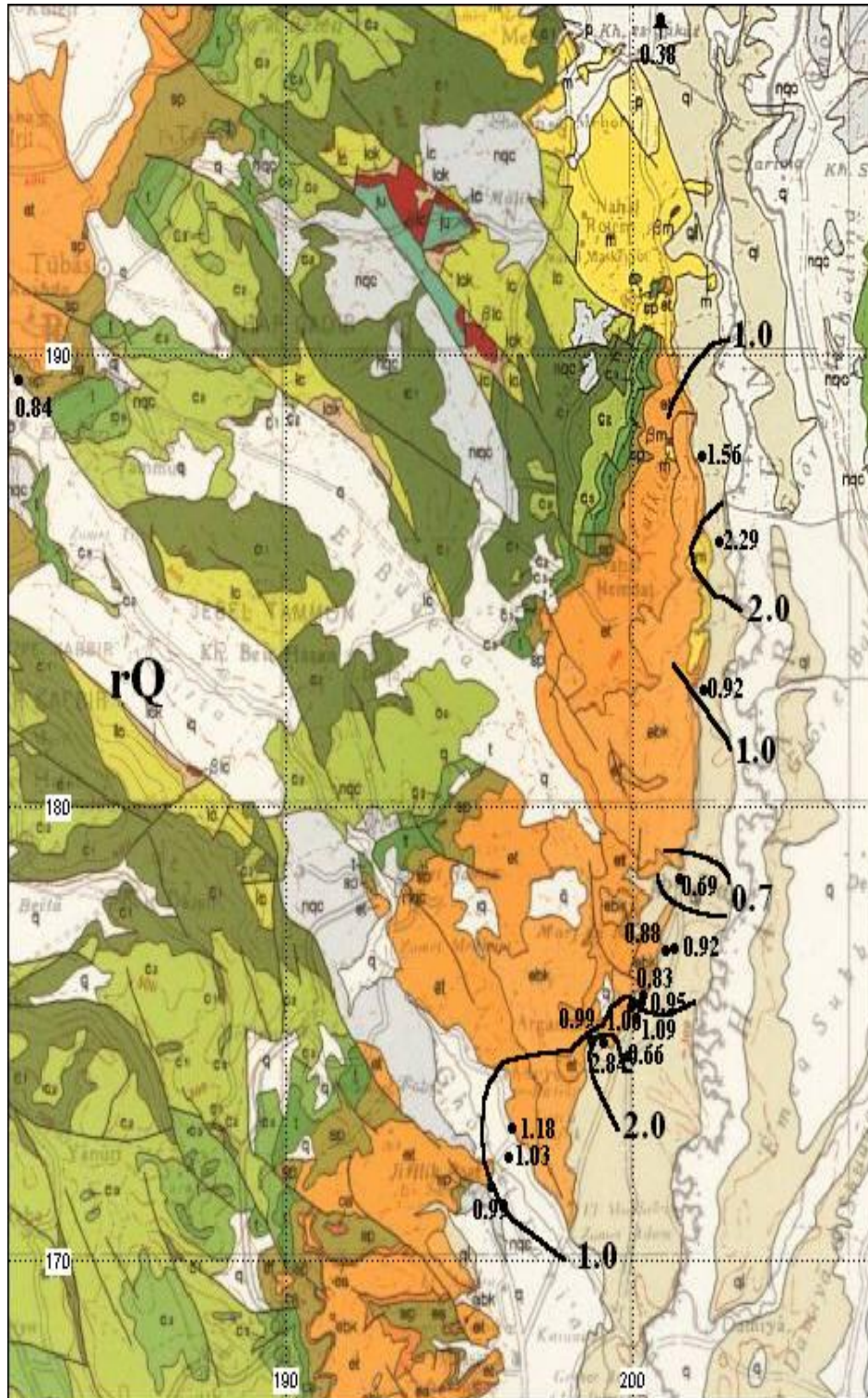


Figure 2.15: rQ ratio at the Avedat aquifer

2.2.4.4. Na/Cl

In the western and central parts of the **Avedat Group aquifer**, the ratio values are of the order of 0.7-0.8. Eastwards, the ratio values gradually decrease to av.0.62. Particularly low ratio values occur at the intersection of W. Fariya and the Rift faults (< 0.5) (Figure 2.16).

2.2.4.5. Cl/Br weight ratio

There are two distinct clusters of ratio values throughout **the Avedat Group** aquifer. One cluster includes ratio values in the 261-370 range ($\text{av.}329 \pm 59$), which are typical for an actively recharged calcareous aquifer (Figure 2.17). Close to the Rift and concomitantly with the increase of water salinity, the ratio values drop to average values of 88 ± 14 . The saline waters of Argaman. Marj Naja and Fariya are characterized by ratio values of 80. Waters with low Cl/Br ratios (80-130) are in all cases characterized by low (0.6) Na/Cl ratios (Figure 2.18).

2.2.5. PARAMETERS INDICATING PROCESSES OF ION EXCHANGE

2.2.5.1. $(\text{Ca}+\text{Mg})-(\text{SO}_4+\text{HCO}_3) = f(\text{Na}+\text{K})-\text{Cl}$

The **Avedat Group** groundwater manifests clear indication for ion exchange processes resulting in the enrichment of Ca in water and their concomitant impoverishment in Na. In the Avedat aquifer there are clear indications of two different dependences. Whereas one function shows a "background" process similar for the two aquifers, there occur also additional processes of considerable Ca enrichment possibly due to inflow of Ca-rich brines.

2.2.6. SALT NORM VALUES

Brackish to saline waters of the **Avedat Group** stand out by a high norm for NaCl (50 wt%), by the occurrence of the Ca-MgCl₂ norms attaining together up to 27 wt%, CaSO₄ reaching up to 15 wt% and by the total norms for Ca- and Mg-carbonates reaching up to 10 wt%.

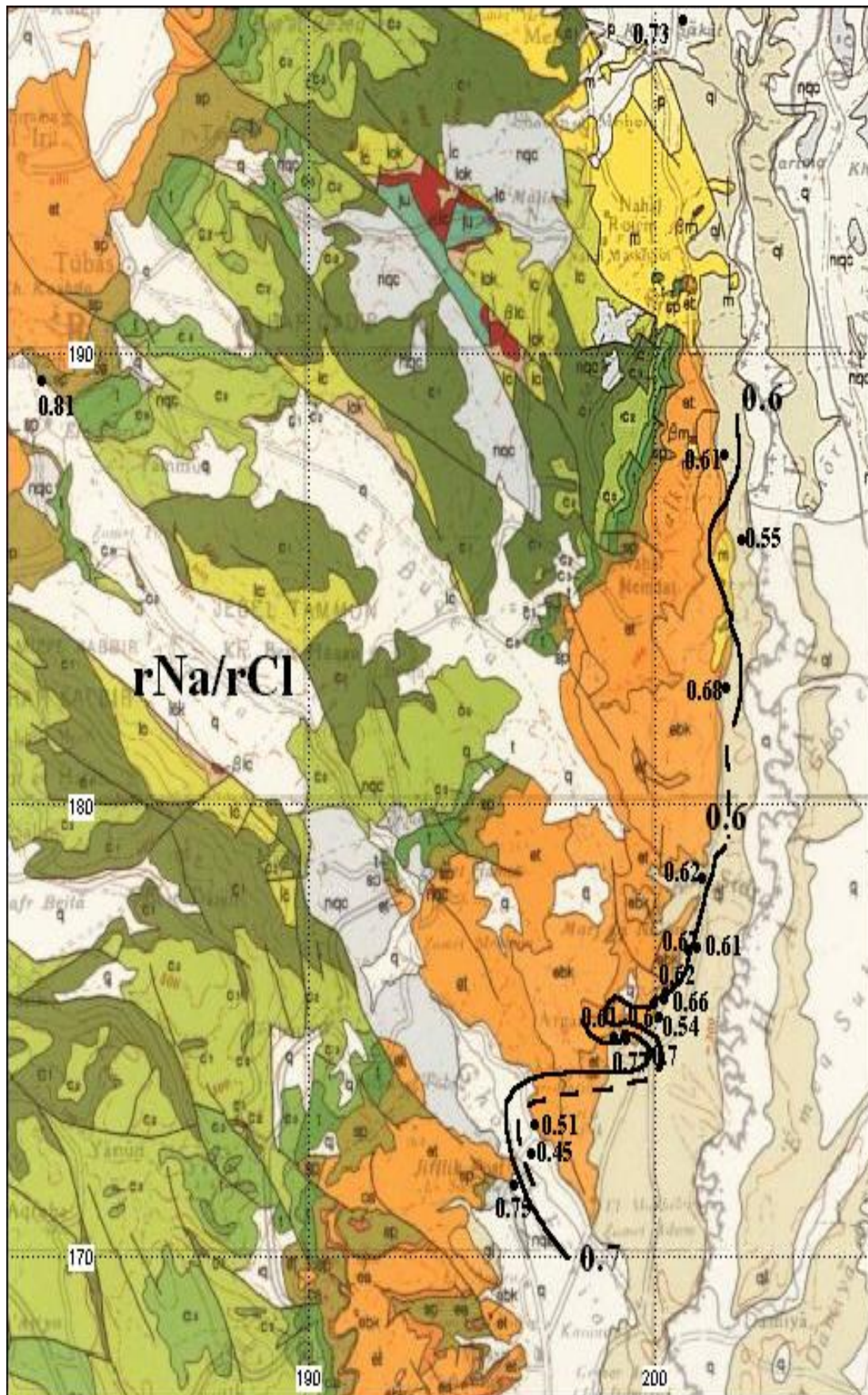


Figure 2.16: rNa/rCl ratio at the Avedat aquifer

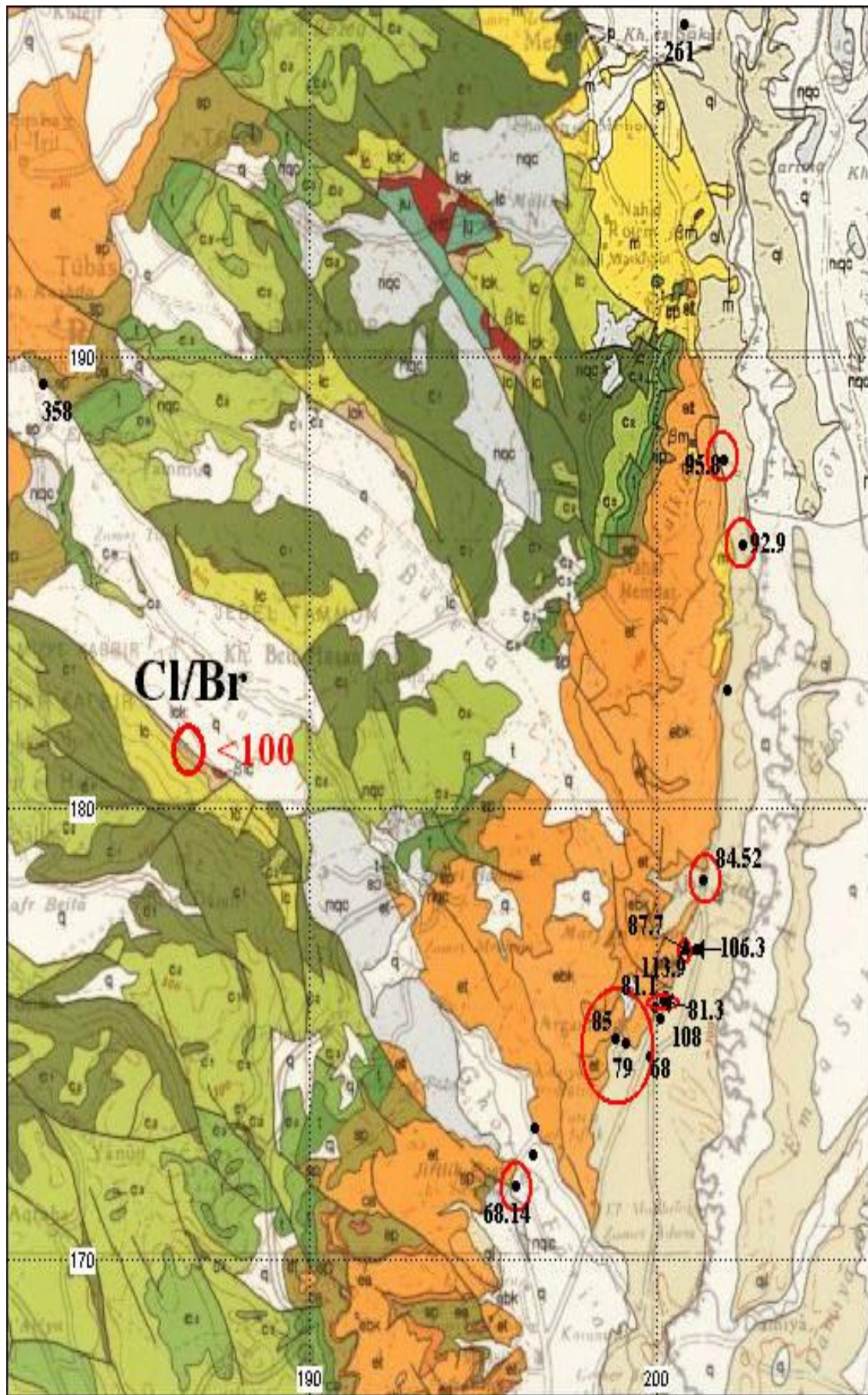


Figure 2.17: rCl/rBr ratio at the Avedat aquifer

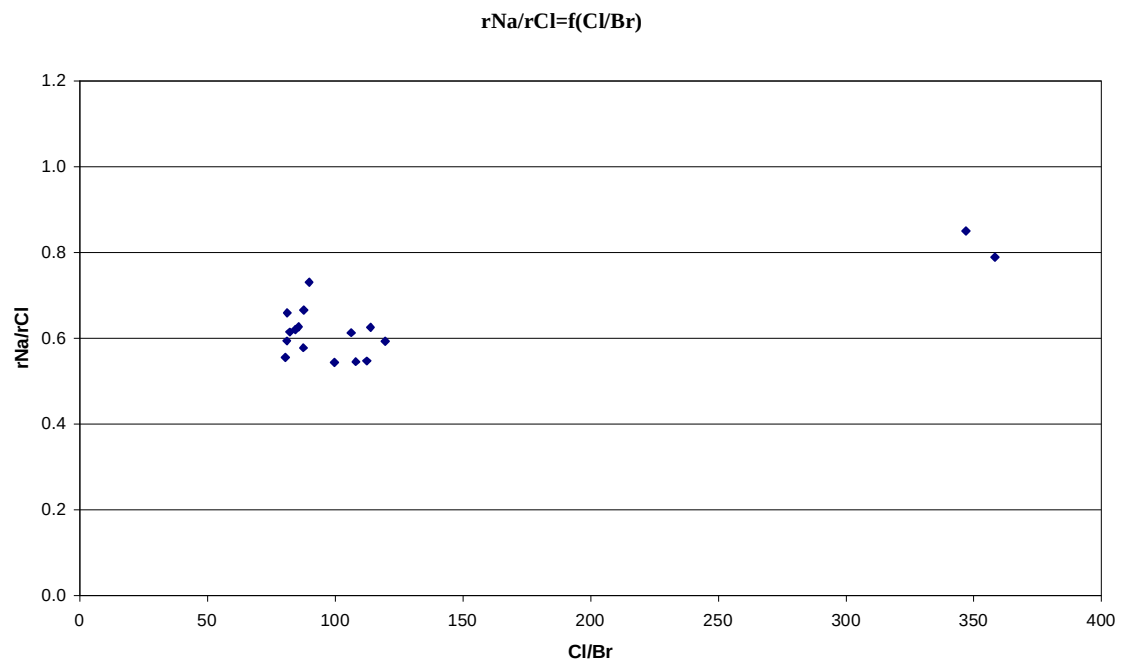


Figure 2.18: r_{Na}/r_{Cl} ratio as a function of Cl/Br ratio at the Avedat aquifer

2.3. DEAD SEA GROUP

2.3.1. CL-CONCENTRATIONS

In permeable horizons of the Dead Sea Group Cl-concentrations are in the 50-2200 mg/l range (Figure 2.19). The pattern of isochlores clearly emphasizes recharge of the Dead Sea Group aquifers by inflow of fresh groundwater from the major wadis draining the East Judea Mountain range. The lowest Cl-concentrations occur close to the outlet of the wadis Qelt, Auja and Fari'a to the Central Jordan Valley. Salinities evolve with the further flow of groundwater eastwards. Salinization rate in the Dead Sea Group aquifers is quite high. Groundwater of < 200 mgCl/l at the outlet of W. Qelt, reaches concentrations of > 1200 mg/l after subsurface flow of about 5 km. The same phenomenon occurs in W. Fariya, though at a slightly lower rate. A prominent salinity high (>1200 mgCl/l) occurs east of Jericho, in the vicinity of the Alami wells.

2.3.2. SO₄-CONCENTRATIONS

In the permeable horizons within the Dead Sea Group subsurface inflow of waters originating from the mountain wadis, is characterized by sulfate concentrations of up to 100 mg/l. These concentrations evolve to much higher values (>200 and up to 900 mg/l) particularly near and east of Jericho (Figure 2.20).

2.3.3. EVOLUTION OF ION CONCENTRATIONS VS. SALINITY

In the three main aquifers, the evolution in the concentration of the main cations vs. salinity is quite similar. The concentrations of Ca, Mg and Na evolve generally in direct linear dependence of Cl-concentrations. In all cases, SO₄ increases in the vicinity with the western rim of the Rift. Scattering of Ca and of Na around the function line are due to exchange reactions on argillaceous rock components.

2.3.4. ION RATIOS

2.3.4.1. Mg/Ca

The fresh waters recharging aquifer beds of the **Dead Sea Group** and originating from the wadis draining the mountains in the west are characterized by ratio values of < 1.0 which is typical of calcareous surroundings. With the exception of wells located in the immediate vicinity of wadi outlets, all groundwater of the Valley are characterized by ratio values > 1 reaching as high as 4.7. The highest ratio values were encountered in the Alami wells and east of Auja. It was not possible to establish a gradual evolution between the ratio values and Cl-concentrations (Figure 2.21).

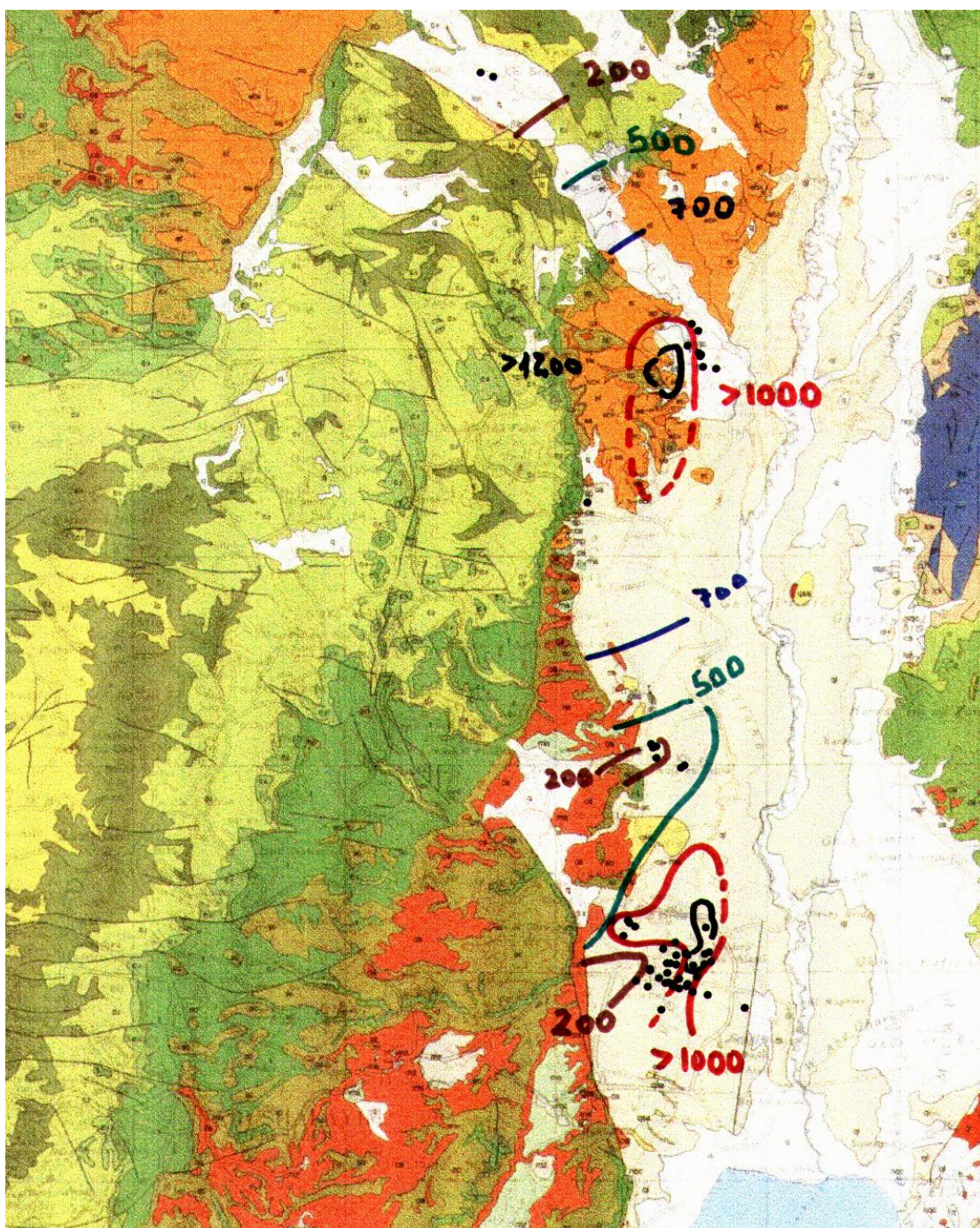


Figure 2.19: Chloride concentration at the conductive strata of the Dead-Sea Group

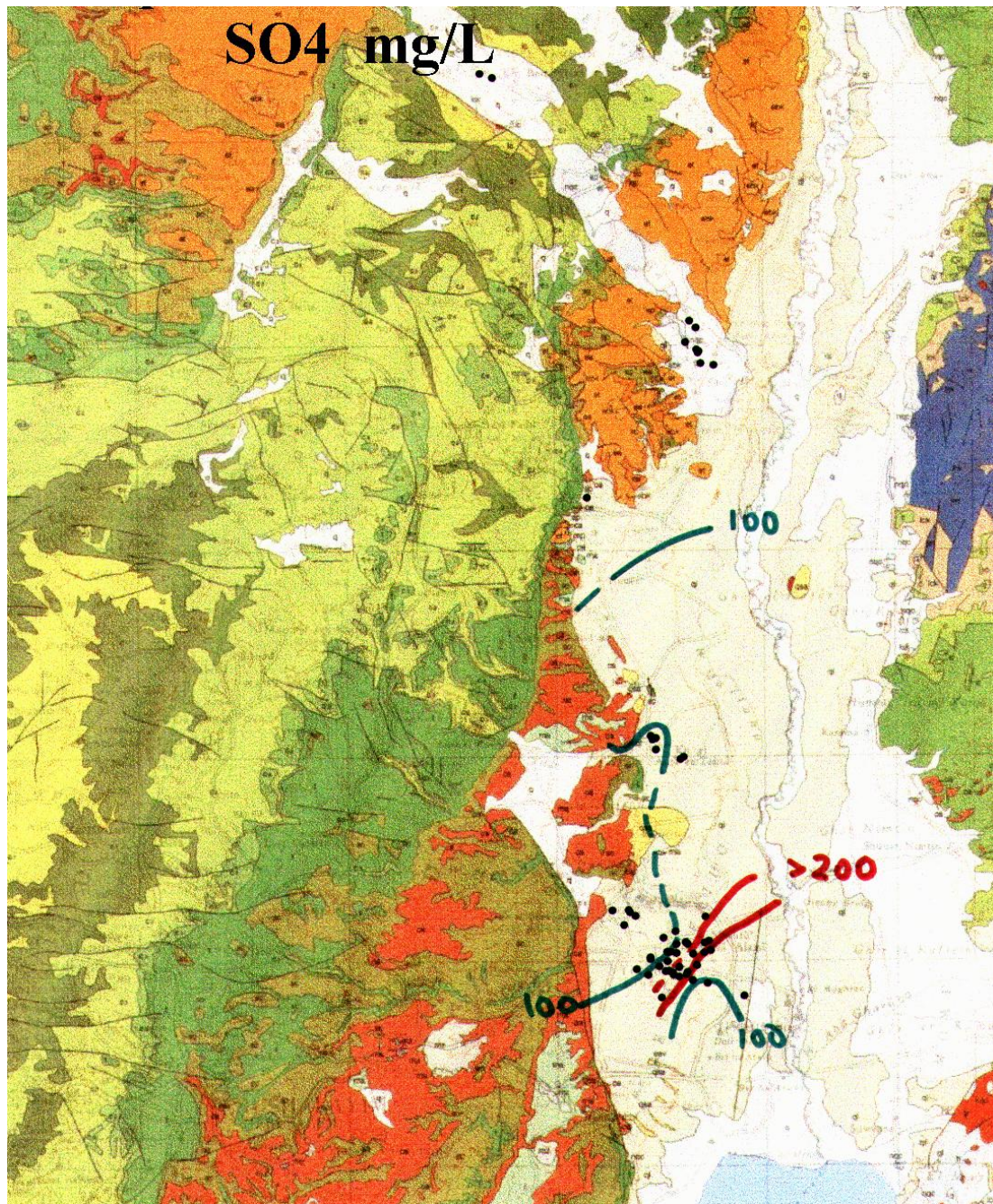


Figure 2.20: SO₄ concentration at the conductive strata of the Dead-Sea Group

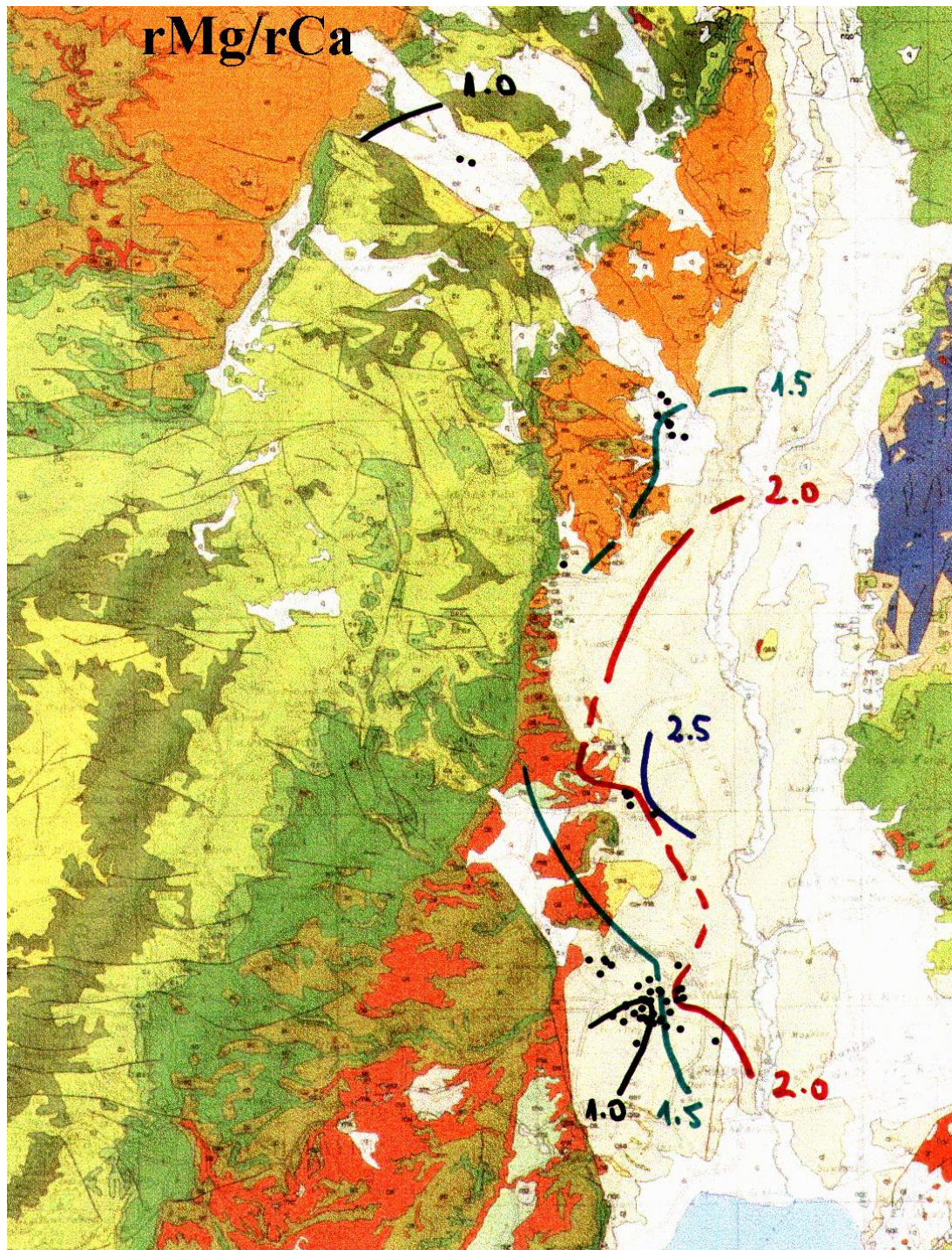


Figure 2.21: rMg/rCa ratio at the conductive strata of the Dead-Sea Group

2.3.4.2. Mg/Cl

In the **Dead Sea Group** groundwater deriving from the wadis draining the mountain range in the west is characterized by ratio values of up to 1.96, which are typical of calcareous and dolomite-containing rocks. Such waters were encountered close to the outlets of the wadis Qilt, Auja and Fariya. Further eastward flow through these aquifer horizons, lowers the ratio

values leveling out at 0.5 – 0.6 (av.0.59; st.dev 0.3). This is a clear inverse dependence between evolution of Cl-salinity and decrease in the ratio values (Figure 2.22).

2.3.4.3. $Q=[Ca/(SO_4+HCO_3)]$

East of the western fault escarpment, the groundwater within the Dead Sea Group is characterized by a wide range of values varying from 0.25 to 1.62. Sources with high Q values (> 1) are clustered close to the fault escarpment west of Jericho and at the outlet of w. Fariya (Figure 2.23).

For higher Q values, the corresponding Na/Cl and Cl/Br values are low, 0.4-0.5 and 80-90 respectively.

2.3.4.4. Na/Cl

In the **Dead Sea Group**, the distribution of Na/Cl ratio values reveals that waters of low Cl-concentrations are characterized by ratio values in the 0.7-0.8 range. Increasing salinity lowers this ratio to values in the 0.3-0.6 range. Hence it is possible to outline the inflow paths of fresh waters from the mountains in the west towards the Valley, i.e. through wadi Qelt, Auja and Fariya (Figure 2.24).

2.3.4.5. Cl/Br weight ratio

The waters in the **Dead Sea Group** are characterized by ratio values in the 50-170 range. Usually high values (>200) characterize fresh water recharged from the mountains in the east whereas the low values are typical of the Rift brines. Such values were encountered in sources located near the western margins of the Rift (west of Jericho, Auja and in the Alami wells and their vicinity). Waters with low Cl/Br ratios are characterized by high Q and low Na/Cl ratio values (Figure 2.25).

2.3.5. PARAMETERS INDICATING PROCESSES OF ION EXCHANGE

2.3.5.1. $(Ca+Mg)-(SO_4+HCO_3) = f(Na+K)-Cl$

The groundwaters in the **Dead Sea Group** aquifers manifest clear indications for ion exchange processes resulting in the enrichment of Ca in water and their concomitant impoverishment in Na. The scatter of the points is usually characteristic of the irregular mixing with Ca-rich, brine derived waters.

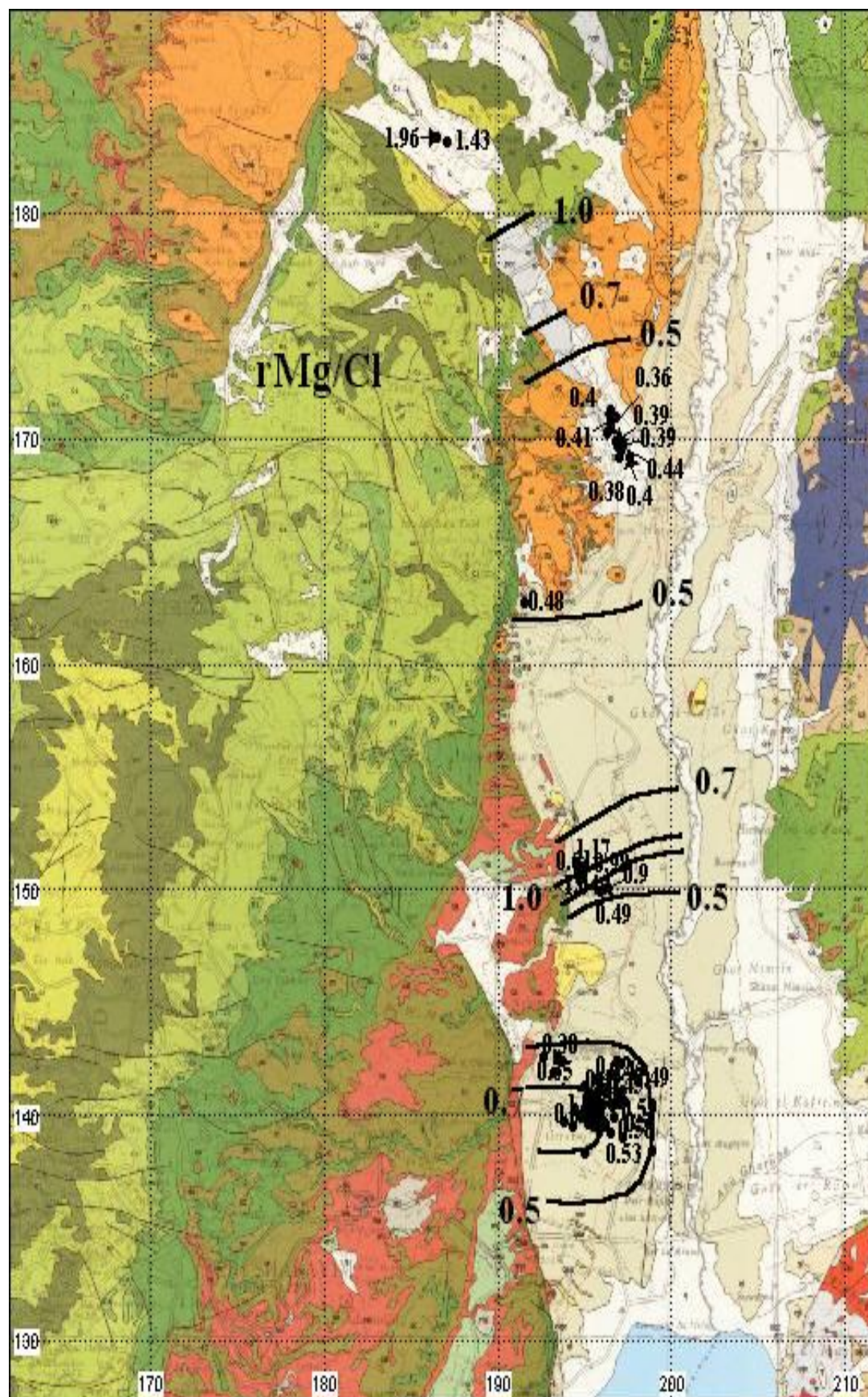


Figure 2.22: rMg/Cl ratio at the conductive strata of the Dead-Sea Group

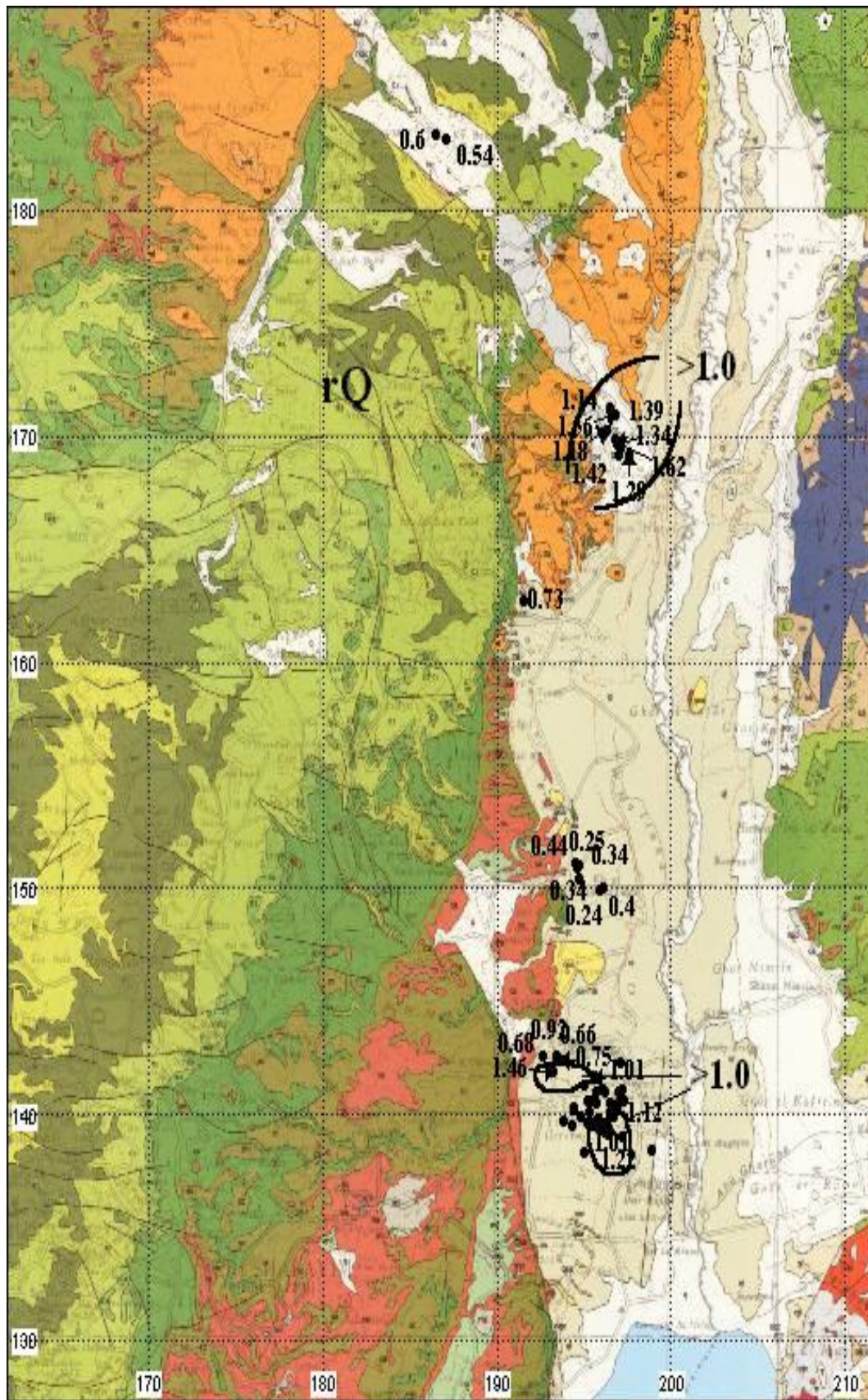


Figure 2.23: rQ ratio at the conductive strata of the Dead-Sea Group

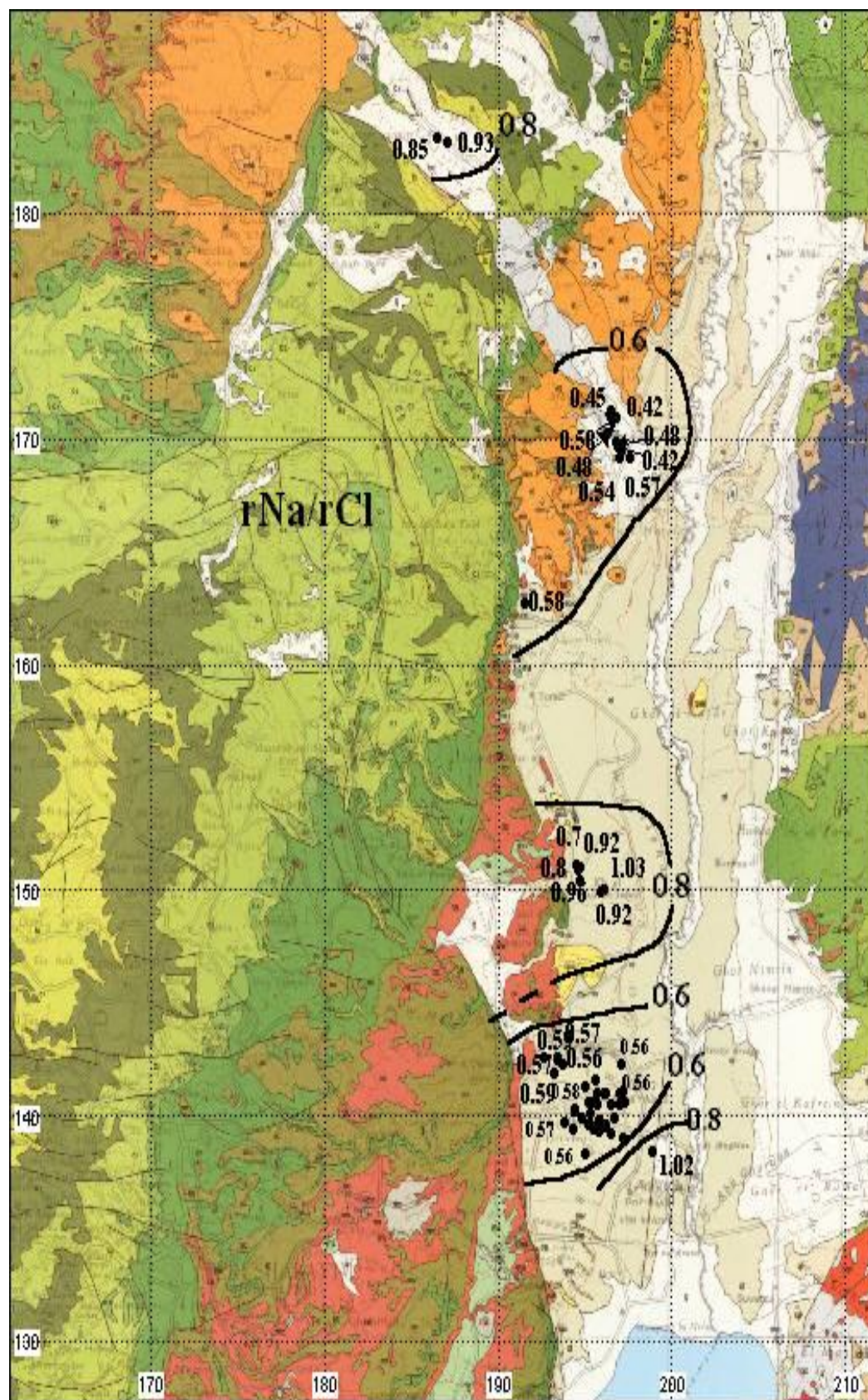
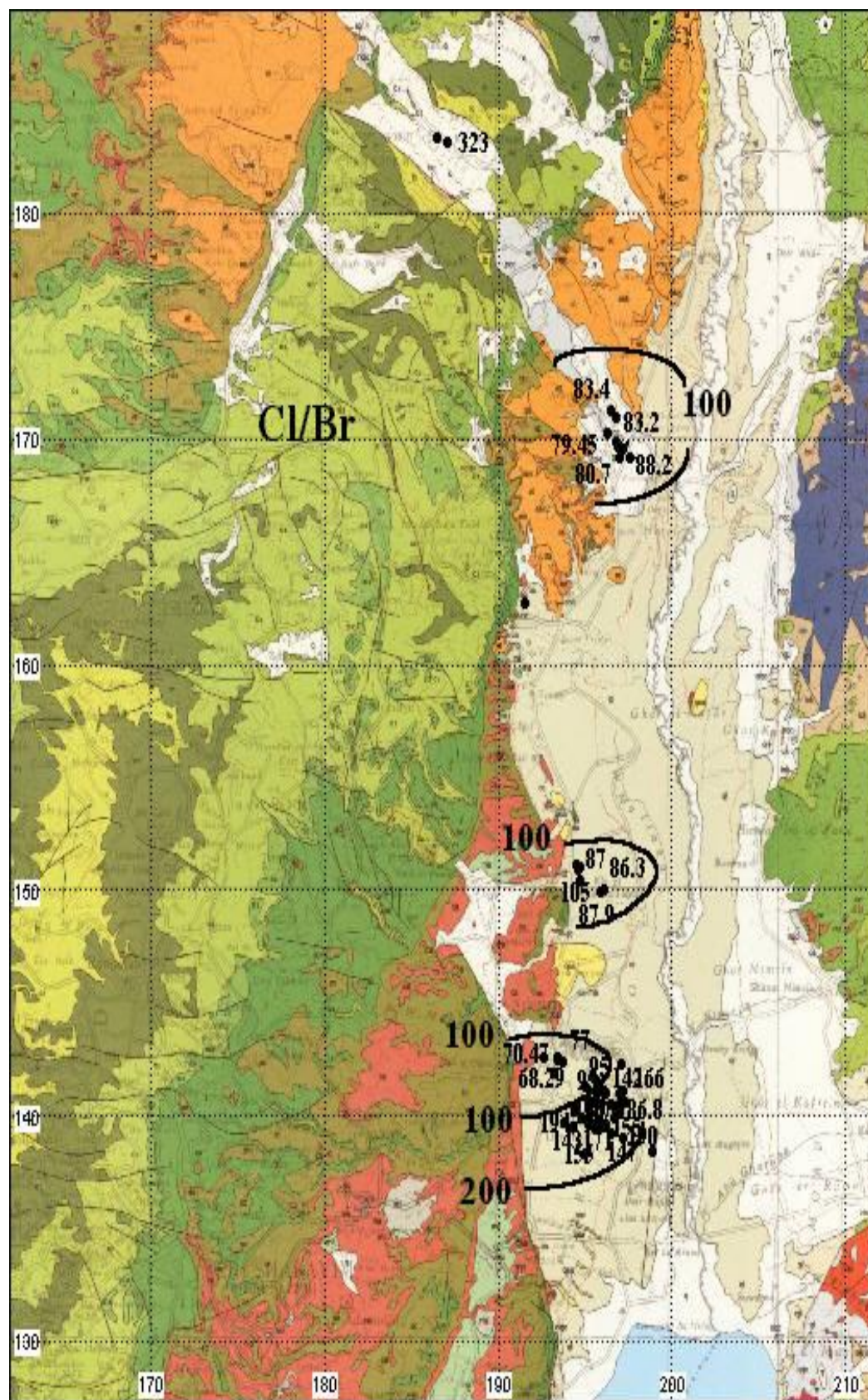


Figure 2.24: rNa/rCl ratio at the conductive strata of the Dead-Sea Group



2.3.6. SALT NORM VALUES

There are no great differences between the salt norm assemblages of waters flowing in the permeable beds of the **Dead Sea Group**. They are characterized by approx. 45% NaCl, a high percentage (up to 35%) of Ca and Mg chlorides, 9-13% carbonates and 6-8% sulfates. Of special interest are the groundwaters found in the Alami wells, east and northeast of Jericho. These waters stand out by the exceptionally high sulfate norm (22%). This is in excellent agreement with the occurrence of massive gypsum depositions in Wadi Massidat, at about 1 km further NE from the Alami farms. This is caused by precipitation from sulfate rich waters which originate from seepages which are outlets of the permeable beds in which circulate the Alami waters. This particular chemistry probably reflects local subsurface accumulation of gypsum beds.

3. DETAILED STUDY OF THE DEAD SEA GROUP (PLEISTOCENE AQUIFER SYSTEM) IN THE JERICHO AND UJA AREAS

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3.1. INTRODUCTION

The current study is focused on two main areas in the western part of the Jordan valley. These areas are Jericho, and Uja areas (Fig. 3.1 and 3.2). These two areas are related to the research site of AQU, where Jeftlik area related to the task of Dr. Mrwan Ghanem, and Fashcha area is under the responsibility of Dr. Jawad Hassan. Groundwater wells are available, where many agricultural wells were drilled during the last century, and many new wells were installed recently. The study areas locate in the lower Jordan valley, in the western part of the West Bank. The investigated areas include urban and rural area like Jericho and Uja respectively. Both depend on their development on the availability of groundwater. Politically, the two areas are related to three categories according to Oslo agreement between Israel and Palestine Authority. These areas are A–area like Jericho (under the Palestinian control), B-area under the Israeli and Palestinian controls like Uja, and C areas under the Israeli control. These conditions make the management and development of water resources a serious challenge facing decision maker in all levels.

Currently, about 40 000 people are living in this area. The majority of them are working in the agricultural sector. Historically, spring water was used from the inhabitant of the Jordan Valley, where the oldest agricultural settlements was established since 7000 years ago.

Since 1948, the population of this area was dramatically changed, due to the ware about 80 000 people found a place to stay around Jericho city in Aqbat Jaber Refugee Camp. This unnatural growth of the population caused high water demand for drinking and agricultural purposes, so spring water became scare to cover this demand. Groundwater boreholes started in the fifties of the last century.

The majority of the new comer were originated from the coastal plan, where agricultural was daily practice. Before the 1948, the Shallow aquifer system was not in used, after 1948 many fund agencies started to drill new groundwater wells in order to cover the human water needs. The depth of these wells was not more than 40 meter, and water from the upper stock aquifer was taped, citrus and orange trees were planted, in addition to Banana trees, this layer was used for 20 years, at the end of the sixties, when about 80 thousand people immigrated to Jordan, the pressure on the shallow aquifer system decreased, and Israel introduced the water quote to each well and a register in the licence. This action protects the degradation of water quality. During the eighties, many farmers increased the

depth of most of the wells to a depth of 80 meter, with increasing depth salinity increased, which means that the second stock aquifer was in used. During this period, many wells, which are close to the mountain foot dry out, and groundwater table drop down.

During the nineties until today, where many wells were drilled without licences, or any hydrogeological investigation, and the well quote was excluded from most of the wells, farmer have to increase well depth continuously, well discharge decrease, and the groundwater salinity of the majority of the wells rise rapidly to about 5 mS/cm. The produces aquifer becomes the lower part of the second layer, and the third layer. Currently, farmer, privet sector are investing in the agricultural sector are facing a real challenge in developing their water resources in term of quality and quantity. The main objective of this study is to evaluate groundwater quality in the four study sites in order to identify what type of technology can be adapted for desalination. The second goal is to evaluate salinity source/sources of groundwater.

3.2. WATER RESOURCES

Water resources in the study area divided into three categories; 1- spring water, that naturally discharge through three major spring groups; which are Jericho Group, (includes Sultan, Dyuk, Nuwemah) , Quilt group (includes Fara, Fawar, Quilt), Uja spring. The discharge of these spring group ranges between 18 and 28 MCM/a. The second source of water is groundwater boreholes that taped water from the shallow alluvial aquifer system of Plio-Pleistocene age, these are 70 groundwater wells taped annually 22,5 MCM distributed between 8.5 MCM for Jericho wells, 4 MCM for Uja wells, 5 MCM for Jeftlik wells, and 5 MCM for Marj Najeh/Zbedat wells. The qualities of groundwater taped through these wells are varied from site to another, depending on the location, history of the well (discharge volume, depth). The third sources which is still not used in the area is the wastewater, our current estimation show that about 30 MCM of waste water drain into the related natural drainage system (wadies), this volume need to be development.

In order to understand the hydro-chemical constituents of the groundwater in the Jordan valley, it is important to present the hydro-geological frame work of the aquifer system.

3.3. HYDROGEOLOGY OF THE SHALLOW AQUIFER SYSTEM

This aquifer consists of alluvial deposits from Pliocene to recent deposits. This aquifer extend over the area of the Jordan Valley, it consists of Alluvial, Lisan, and Samra Formations. Gravels, Marl, aragonite, gypsum and halite are the major minerals that build these layers. Alluvial deposits locate close in different locations over the valley mainly close to the Wadi drainage systems. The average thickness of the Lisan layers dose not exceeds the 15 m in the

western part and reaches 30 m close to the Jordan River. Samra formation underlay the Lisan layers, and consists of gravel, sand, silt, inter-bedded with clay layers, that make this formation a good aquifer. In few sites, this aquifer can be considered as confined.

Currently, the groundwater table locates in lenses, which are mostly separated from each other's. In general, groundwater table locates by 50 meter under the ground in the eastern part of the aquifer system (by the eastern part of Jericho, and Uja locations), and increase to 90 m under the ground surface in western part close to the mountain feet. The vertical and horizontal heterogeneity of this aquifer, from site to another, causes different groundwater quality across the aquifer, and in the well. The regional groundwater flow direction is from west to east. In the same direction, sediments become saltier, which act as a barrier for groundwater flow east wards.

Recharge to this aquifer in Jericho area is limited to the flooding days, annually 3-10 days/year, where three wadies drain 1.5 MCM of fresh water during winter months. These wadies are Quilt, Nuwemah and Murar (Subeih, 2006). Other source which is still under investigation is a connection between the mountain aquifer and the shallow aquifer in places like in Nuwemah, where the Mountain aquifer drains water into the Shallow aquifer.

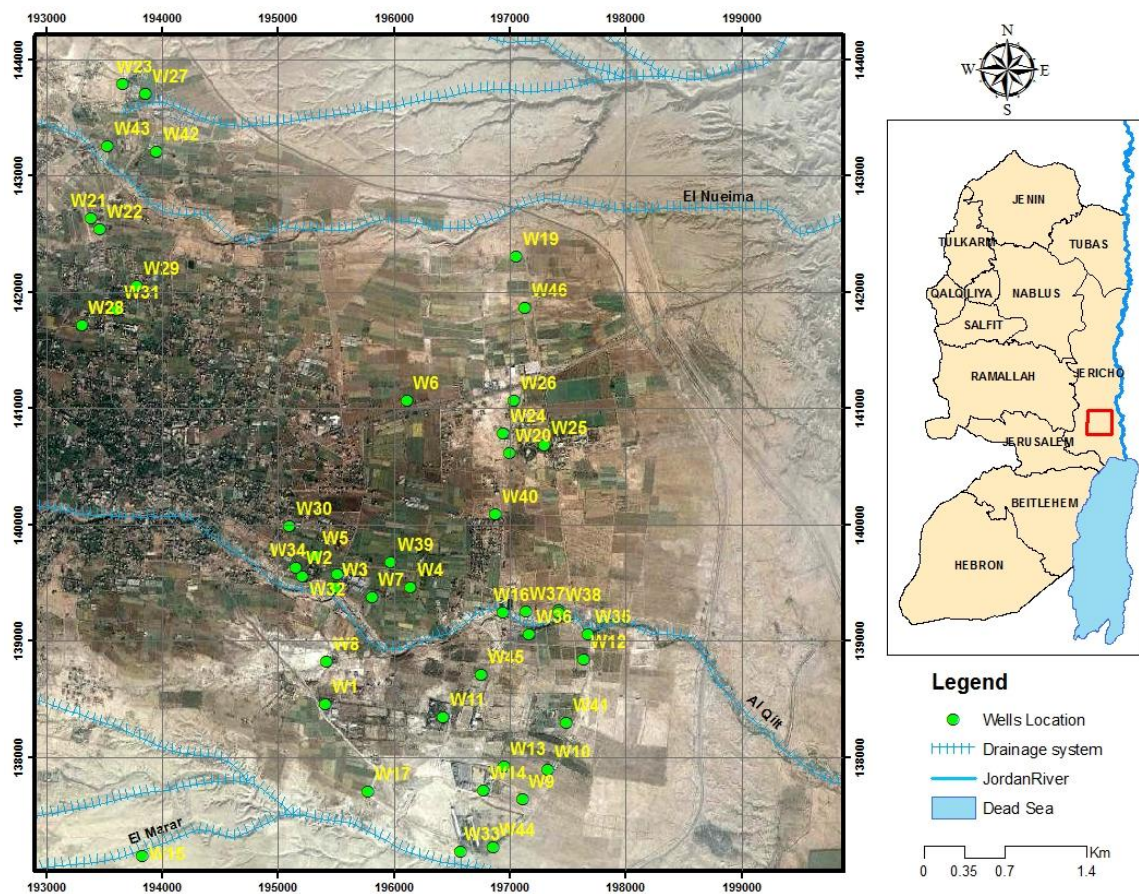


Figure 3.1: study area, and locations of groundwater sampling sites in Jericho area

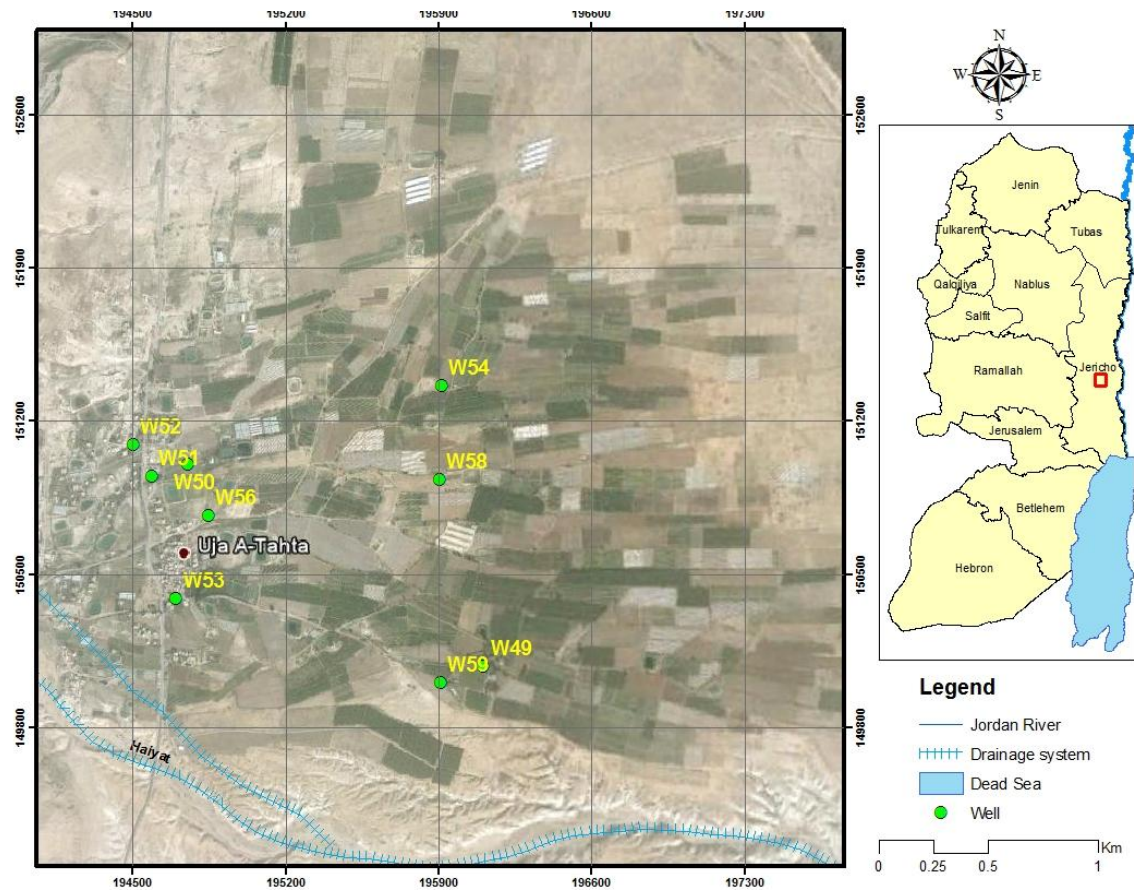


Figure 3.2: locations of groundwater sampling sites in Uja area

The hydrogeological condition in Uja area is mostly similar to that in Jericho area , where the shallow aquifer system of Plio-Pleistocene age is major source of irrigation water, where about 9 groundwater wells are tapping 4.5 MCM/a. The Groundwater table locates by 90 m, and 45 m under the ground in the western and eastern parts of the aquifer system respectively. (See Fig. 3.2). Groundwater recharge take places along the only drainage system which is Wadi Uja, the recharge volume is still under investigation.

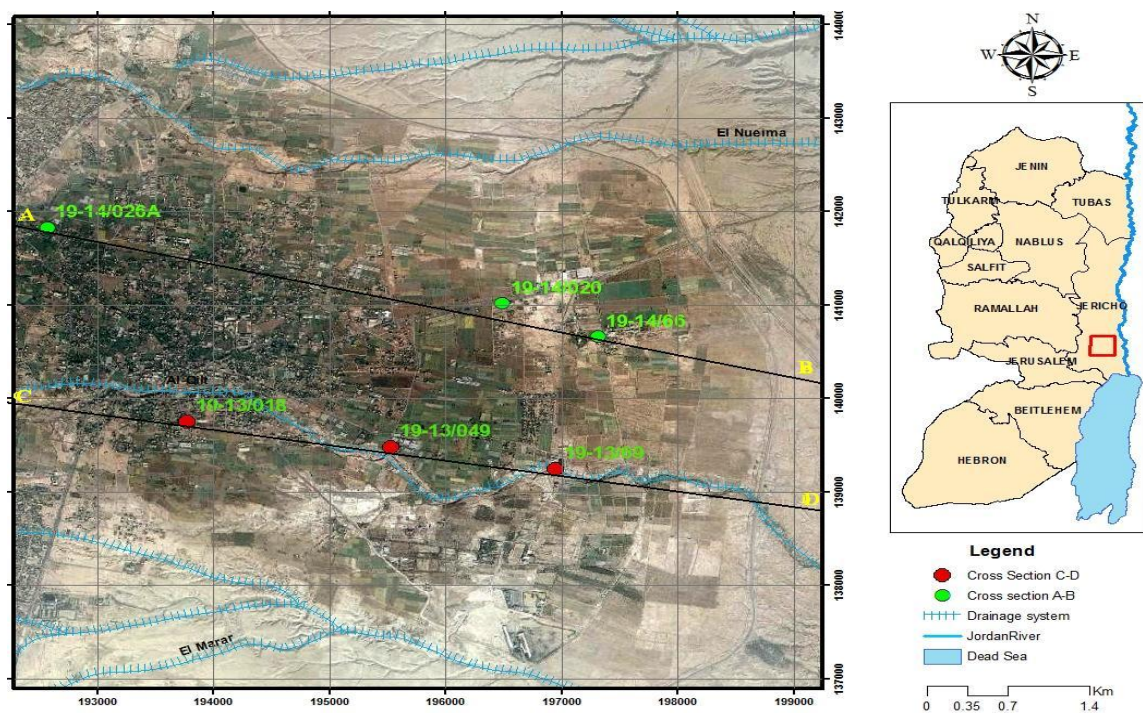


Figure 3.3: locations of the two W-E cross sections in Jericho study area

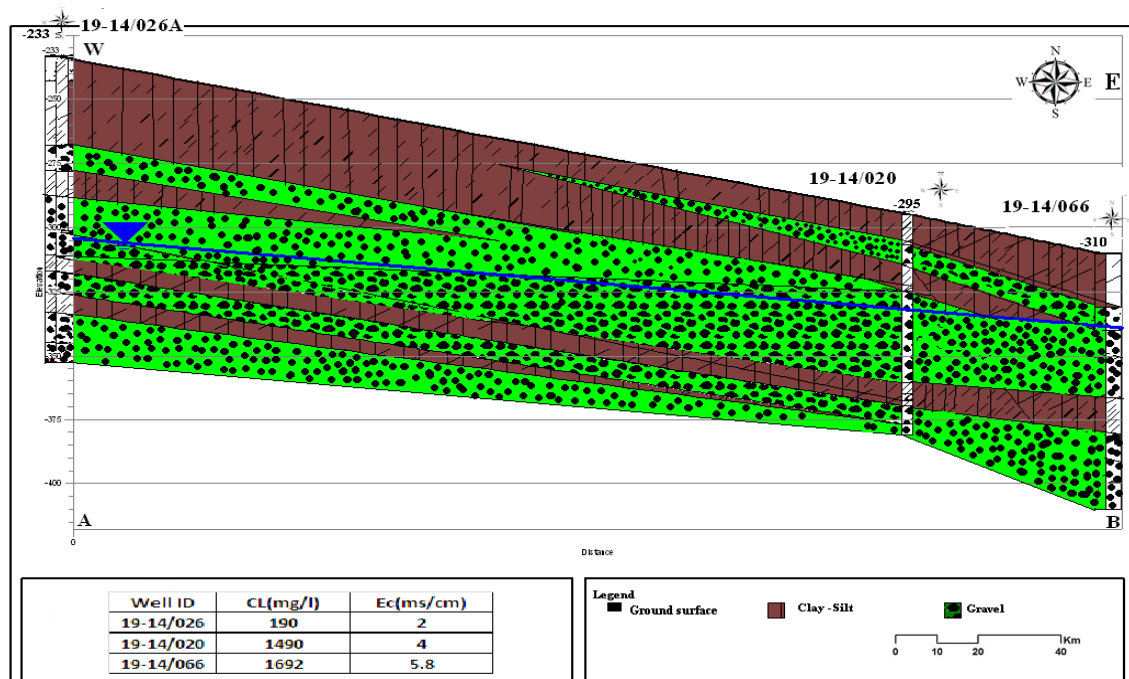


Figure 3.4: Lithological cross section of the shallow aquifer in Jericho study site

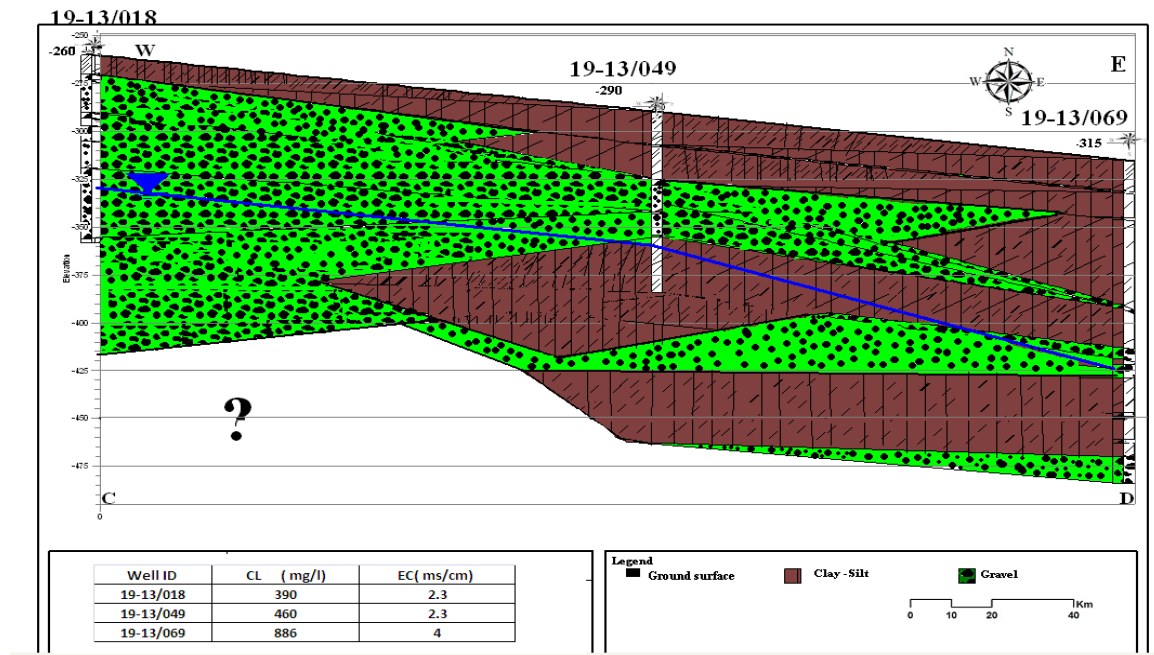


Figure 3.5: W-E lithological cross section of the shallow aquifer in Jericho study site

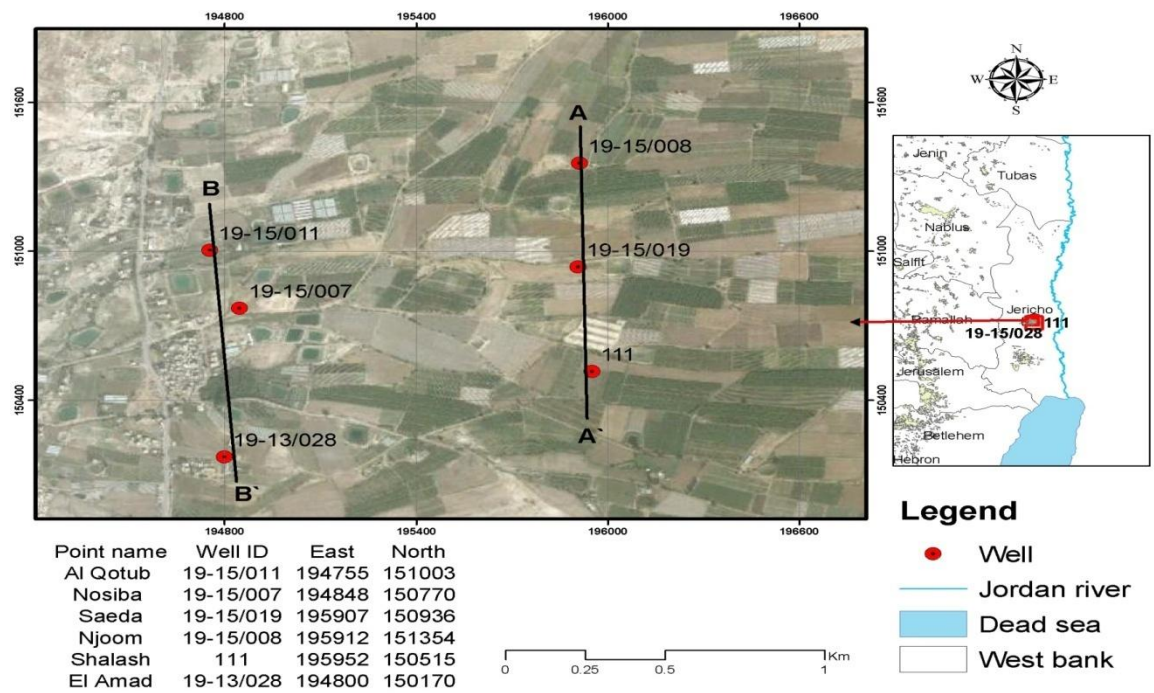


Figure 3.6: Uja area with groundwater sampling sites, and two N-S cross sections

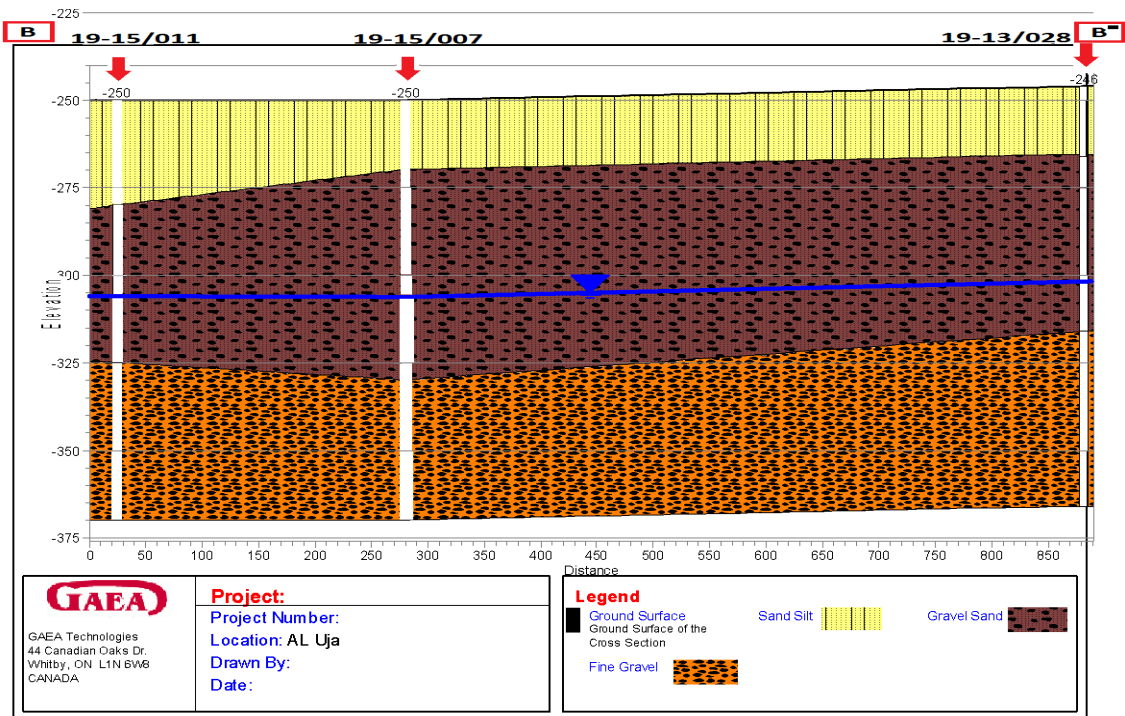


Figure 3.7: Lithological cross section (B-B') in Uja area, and groundwater table

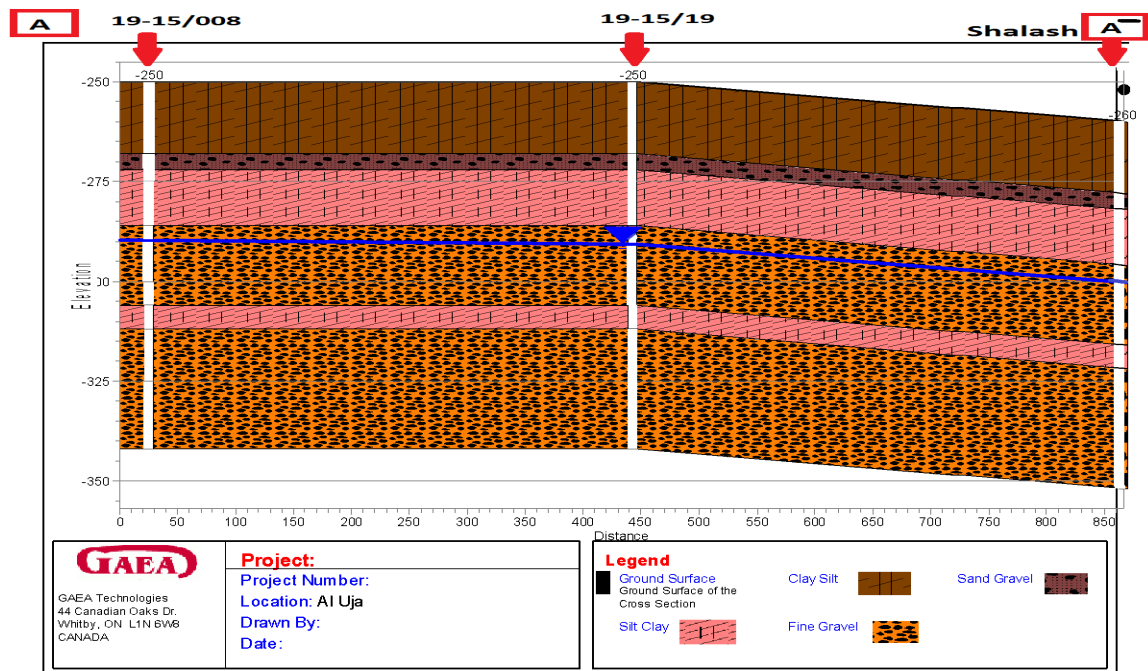


Figure 3.8: Lithological cross section (A-A') in Uja area, and groundwater table

3.4. METHODOLOGY

In order to understand the hydro-chemical characteristics of the groundwater it is important to present the lithological profiles that carried out through AQU working group. Water samples were collected through AQU team, and analysed in the AQU lab, and in Karlsruhe Technical Institute (KTI) lab. The team of AQU carried the field work in cooperation with Ministry of Agriculture, who are very interested about the results of SMART-project. Physical properties of the water were measured in the field, and major and minor ions (Ca, Mg, Na, K, Cl, NO₃, SO₄, HCO₃), (Si, DOC, F, Br, Si, B, Sr) were carried out in both labs. During the last research period, seventy groundwater samples were collected from the area of the Jordan Valley. All water samples are collected from boreholes related to the shallow aquifer system, and represent groundwater in Jericho and Uja area, where Fashcha and Jeftlik study sites are under the responsibility of other partners. Water sample were collected after 15 minute of well running, and collected in PVC bottles, and remained at 4 °C temperature until analysis. Fig. 3.1 and 3.2 present the distribution of groundwater samples in the two study sites.

3.5. RESULTS AND DISCUSSION

Table 1 present the maximum and the minimum of all concentration elements of the groundwater samples collected during 2010/2011 for the Jordan Valley area (Jericho/ Uja study sites)

3.5.1. ELECTRICAL CONDUCTIVITY (EC IN $\mu\text{S}/\text{CM}$)

Ec-value is an easy, and field measurable factor, that present the salinity of groundwater. Two Ec-maps of Jericho and Uja sites are present in Fig. 3.9, the map shows high values above 4 mS/cm in a zone locates in the eastern part of the study area. This area locates out of the influence of the two major drainage systems of Wadi Quilt and Wadi Nuwemah. To the south of Wadi Quilt, relatively, low salinity water with EC-values between 2 and 3 mS/cm were found, this zone shows the influence of Wadi Quilt flooding water. Fig. 3.10 (A-B) and Fig. 3.11 (C-D) present a west–east direction for the Ec-values. Both figures show different trend, where A-B profile show a continues increase in the salinity which is related to the long contact time between water and evaporates minerals as well as to the decrease in permeability east wards, on the other hand the C-D profile show different behaviour – an increase followed by a decrease in the salinity – which is due to the influence of Wadi Quilt recharge as well as to the alluvial deposits in that area.

Table 3-1: Maximum, minimum of major and minor ions concentration 2010/20012

	Max	Min	Average	SD	No. of samples
pH	8.35	7.48	7.95	0.2	57
EC (ms/cm)	19.2	0.92	3.8	2.5	57
Na ⁺ (mg/L)	3018	74.3	434.8	425.3	57
Ca ²⁺ (mg/L)	568.1	19	107.1	83.9	57
K ⁺ (mg/L)	249.2	9.8	65.2	42.6	57
Mg ²⁺ (mg/L)	218	45.9	94.5	32.7	57
Al (mg/L)	<25	<25	-	-	57
B (mg/L)	2485	295	972.8	613.8	57
Ba (mg/L)	238	<25	97	57	57
Fe (mg/L)	<25	<25	-	-	57
Si (mg/L)	13.3	4.7	8.6	2.14	57
Sr (mg/L)	14.7	0.31	2.9	2.7	57
Cl ⁻ (mg/L)	5650.1	113.6	912.6	769.4	57
Br ⁻ (mg/L)	26.5	0.77	11.2	9.6	57
NO ₃ ⁻ (mg/L)	69.3	<0.5	24.6	18.9	57
SO ₄ ²⁻ (mg/L)	1224.6	40.1	207.5	220.8	57
HCO ₃ ⁻ (mg/L)	501.6	131.02	273.3	78.9	57

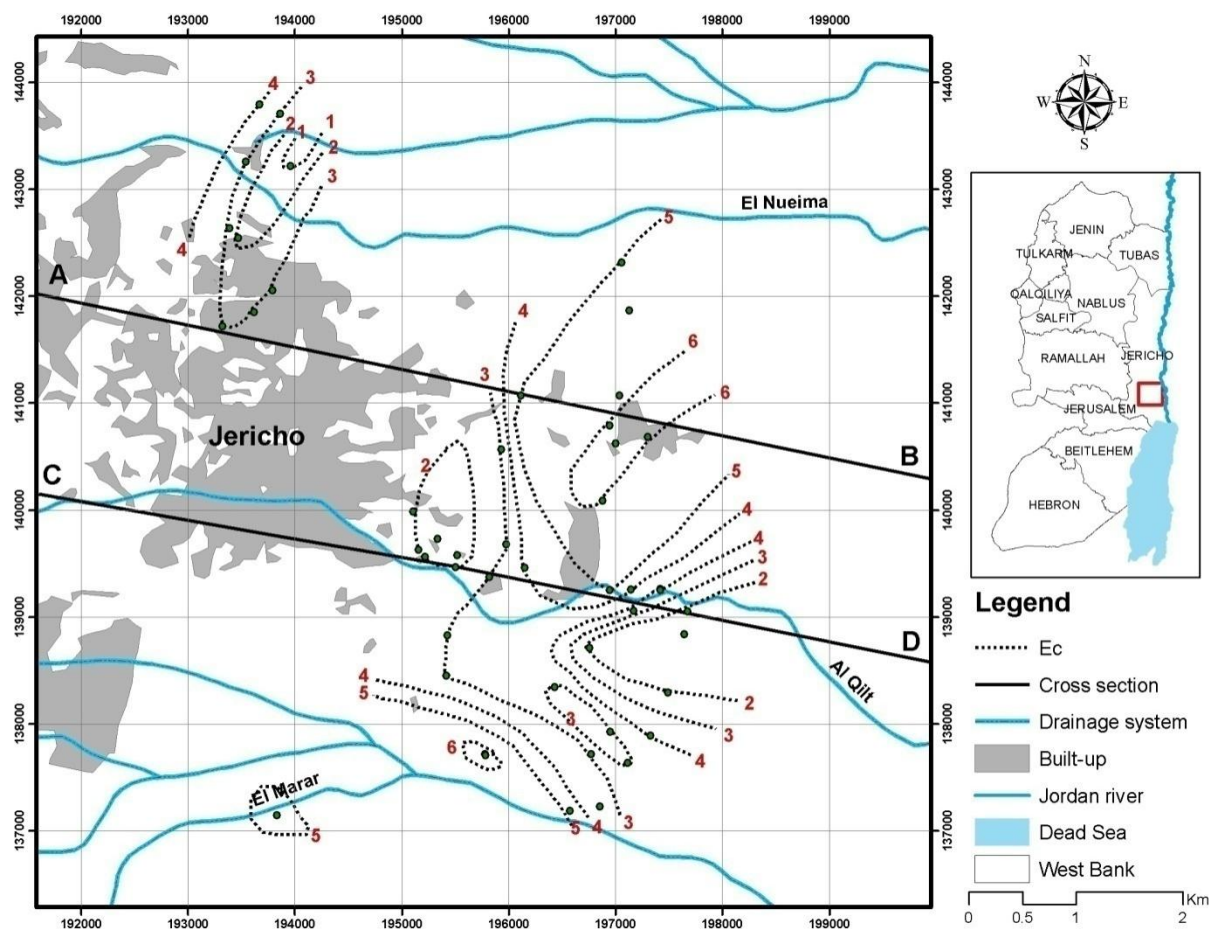


Figure 3.9: Electrical conductivity in Ec in mS/cm, for groundwater 200/2012

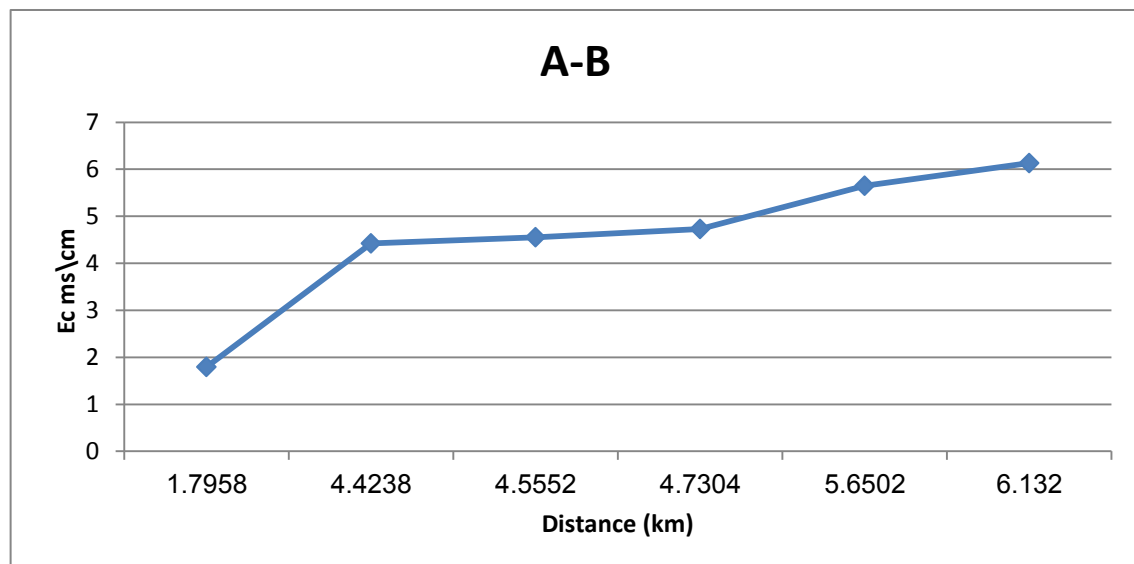


Figure 3.10: W-E electrical conductivity profile in Jericho 2011/2012

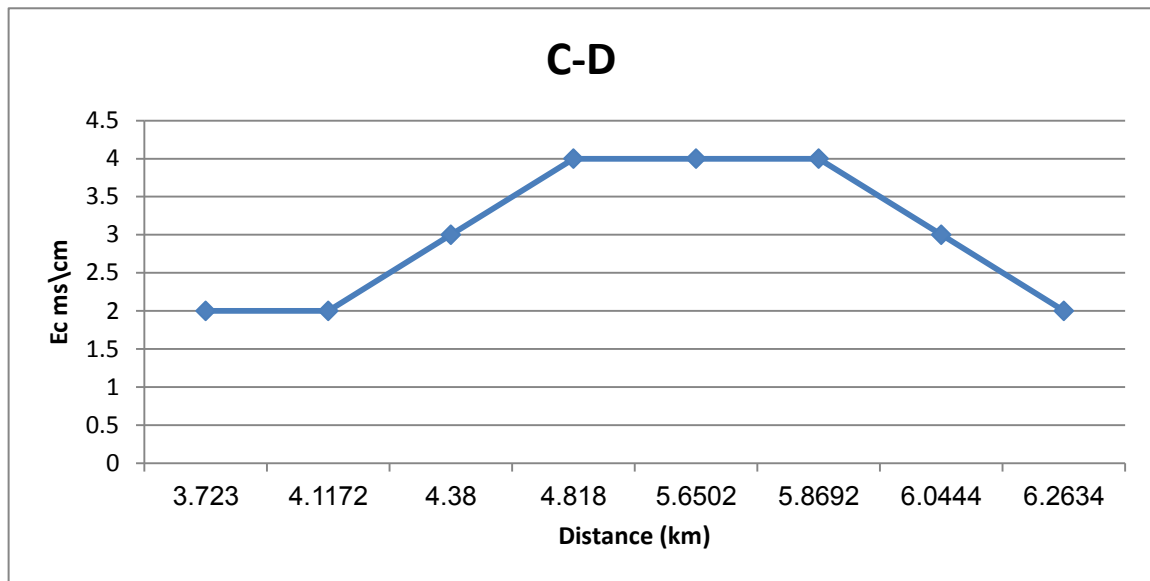


Figure 3.11: W-E electrical conductivity profile in Jericho 2010/2011

3.5.2. CHLORIDE CONCENTRATION

Fig. 3.12 presents the distribution of chloride concentration in Jericho area, which shows a general increase east wards. High chloride concentration values are found in a zone located between Wadi Quilt and Wadi Nuwemah, these values range between 1200 and 1400 mg/L. Fig. 3.18 and 3.19 present a west-east cross section along the aquifer system, A-B profile shows a continuous increase in the concentration east wards, which is related to the dissolution of evaporates, but the CD- profile shows a different trend which strengthens the hypothesis that gravel deposits are located in this area, with low influence of evaporate dissolution on the groundwater quality. It is also predicted that old wadi teases are located in this zone, so this advances the recharge from the wadi in this area.

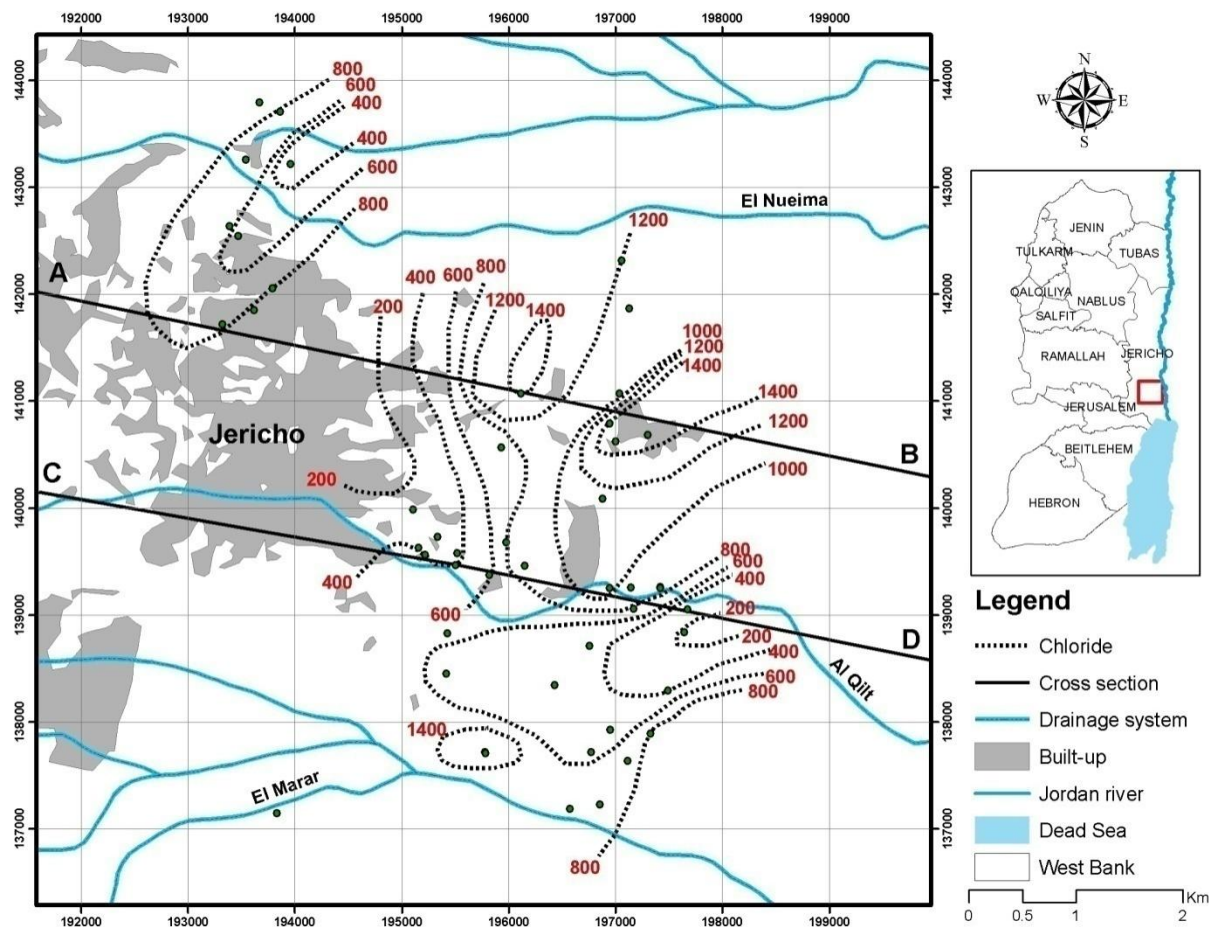


Figure 3.12: chloride concentration in mg/L for groundwater in Jericho area, 2011/2012

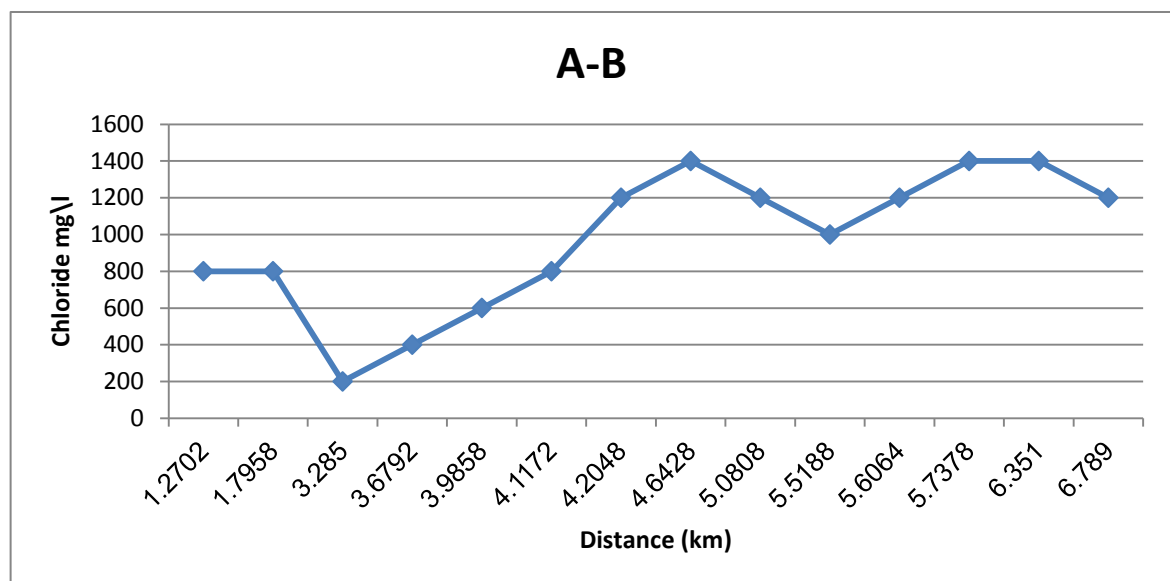


Figure 3.13: W-E chloride concentration profile in Jericho site 2010/2011

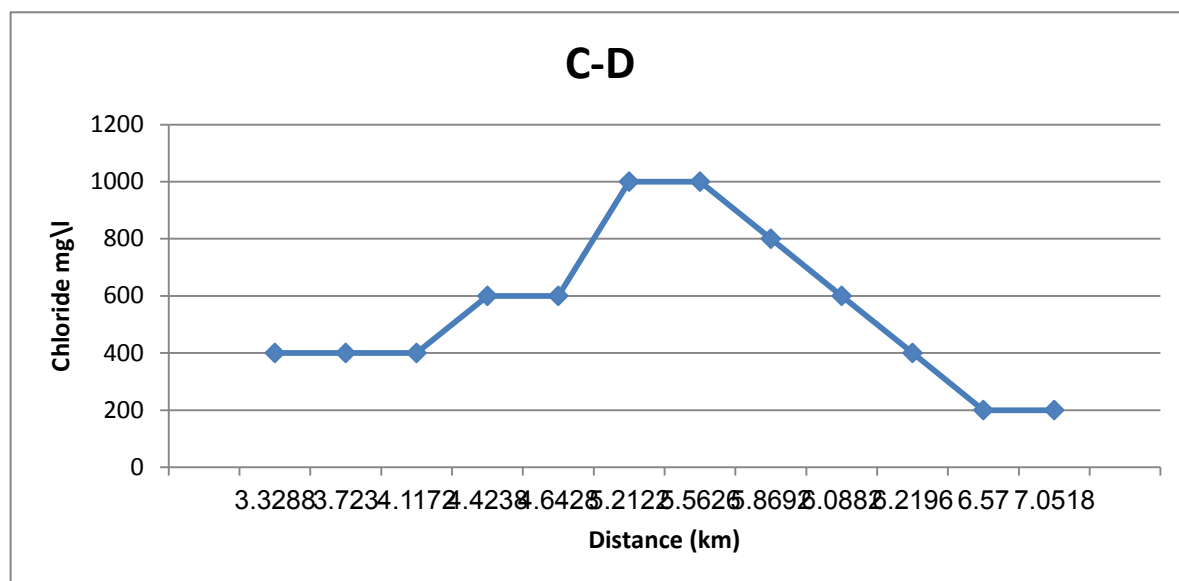


Figure 3.14: W-E chloride concentration in Jericho site 2010/2011

The annually abstraction of the high salinity zone is about 6 MCM, with Ec-value range between 4 and 6 mS/cm. This zone locates between Wadi Quilt, and Wadi Nuwemah.

3.5.3. BROMIDE CONCENTRATION

The bromide concentration in most of groundwater samples range between 1 and 26 mg/L, only one extreme value of 64 mg/L was measured. Fig. 3.15 below shows the distribution of Bromide concentration in Jericho area.

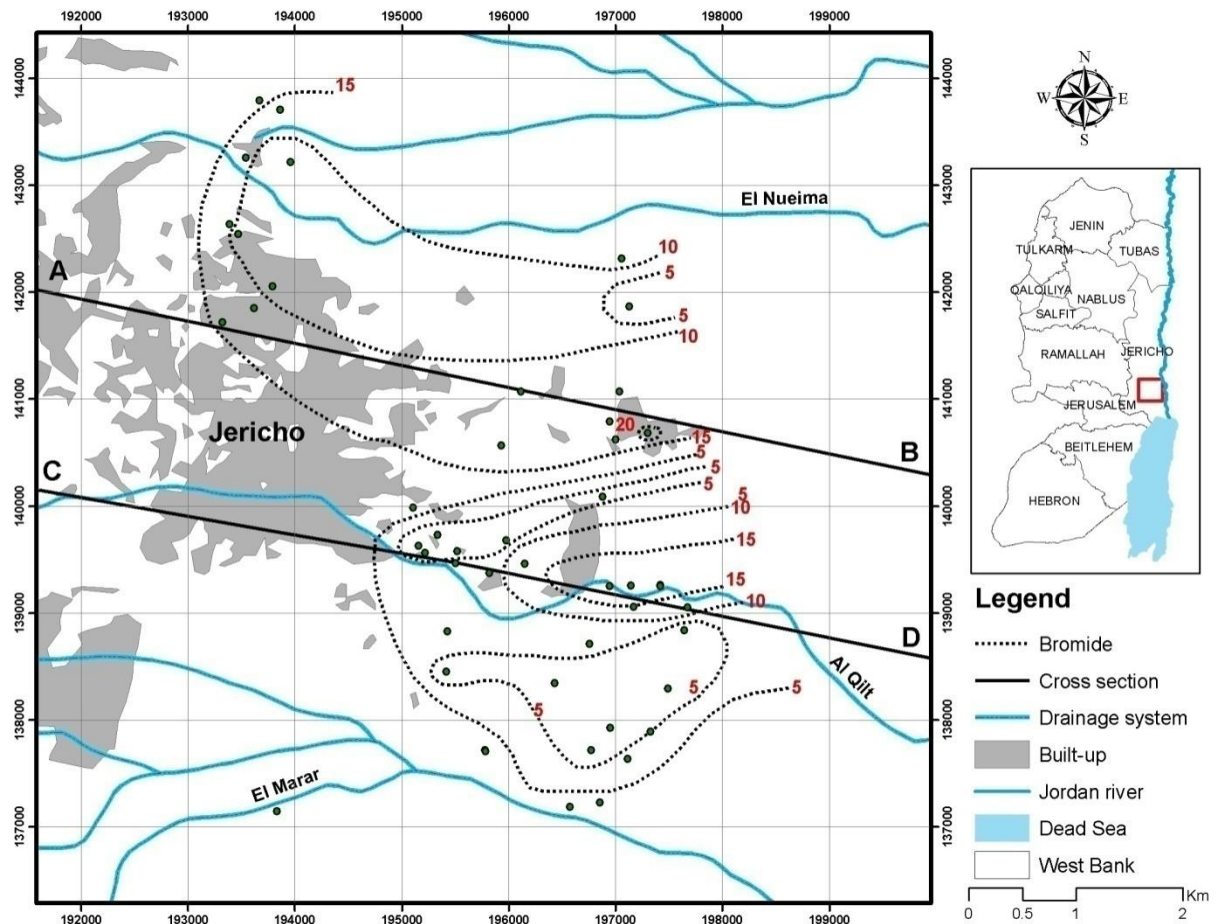


Figure 3.15: Bromide concentration in Jericho area 2011/2012

High Br-values were identified in the area between Wadi Quilt and Wadi Nuwemah, where the concentration range between 5 and 20 mg/L, to the south of Wadi Quilt and to the north of Wadi Marar bromide concentration is less than 5 mg/L, which could be related to the washing out of bromide from the aquifer sediments through fresh water recharge from both wadies. Fig. 3.16 show an increase in bromide concentration east wards, but at the end of the profile the concentration decrease due to the changes in the aquifer sediments which become more gravel, which related to the wadi old terraces

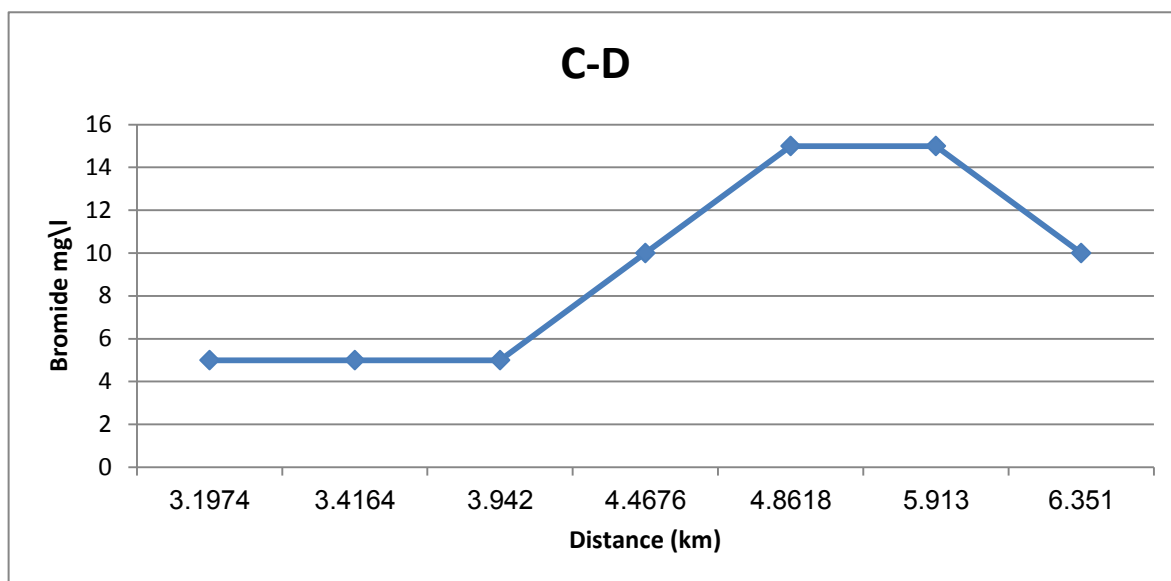


Figure 3.16: Bromide concentration along the C-D-cross section in Jericho area5.5

3.5.4. SILICON CONCENTRATION

Si-concentration of groundwater samples of Jericho study area is shown in Fig. 3.17. The concentration range between 5 and 11 mg/L. Sand, silt layers of Samra formation could be the sources of silicon in groundwater. Fig. 18 and 19 present the silicon concentration from west to east. The two profiles do not show clear trend in this direction, which means that, the sources of silicon is available along the geological profile. The highest values are found in sites with high electrical conductivity.

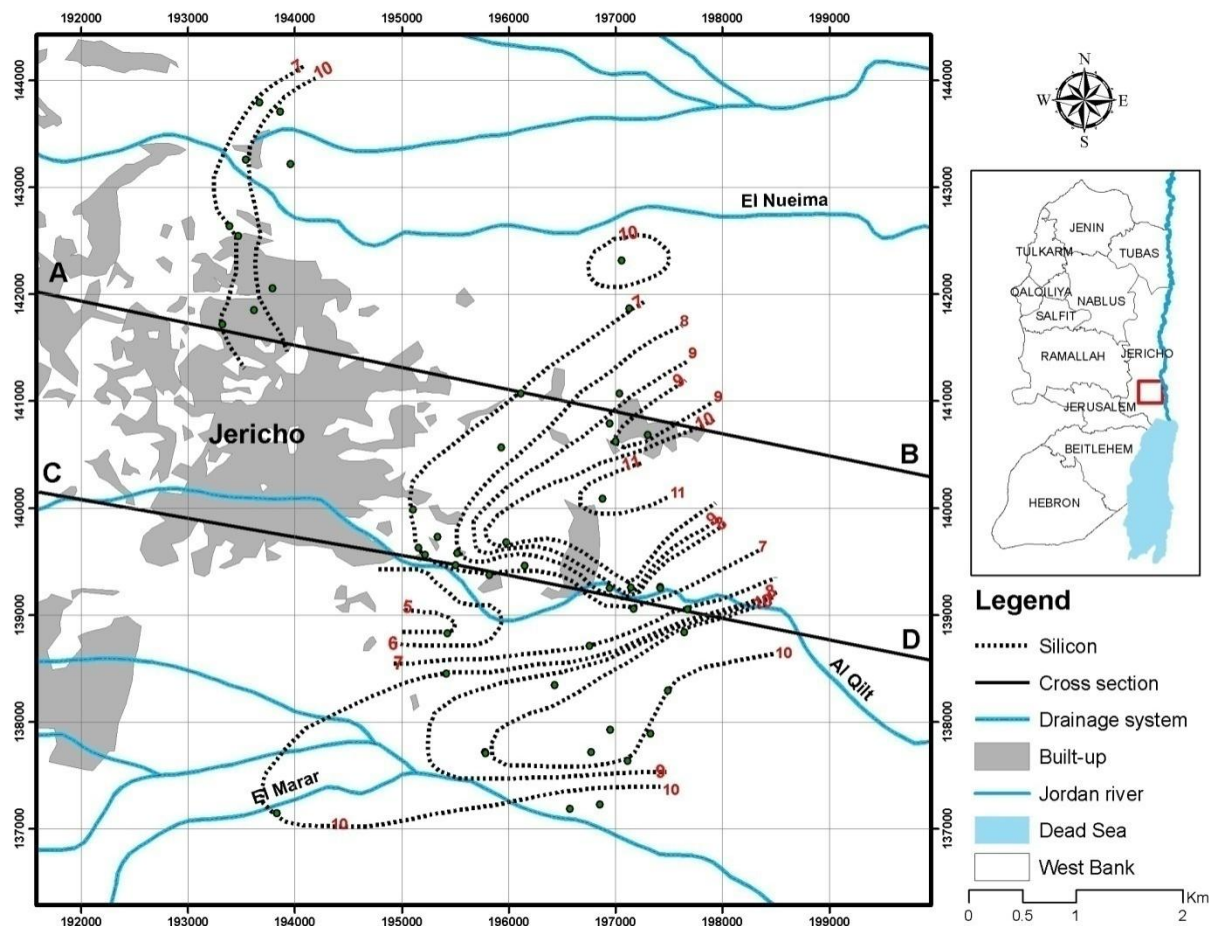


Figure 3.17: Si-concentration in groundwater of Jericho area

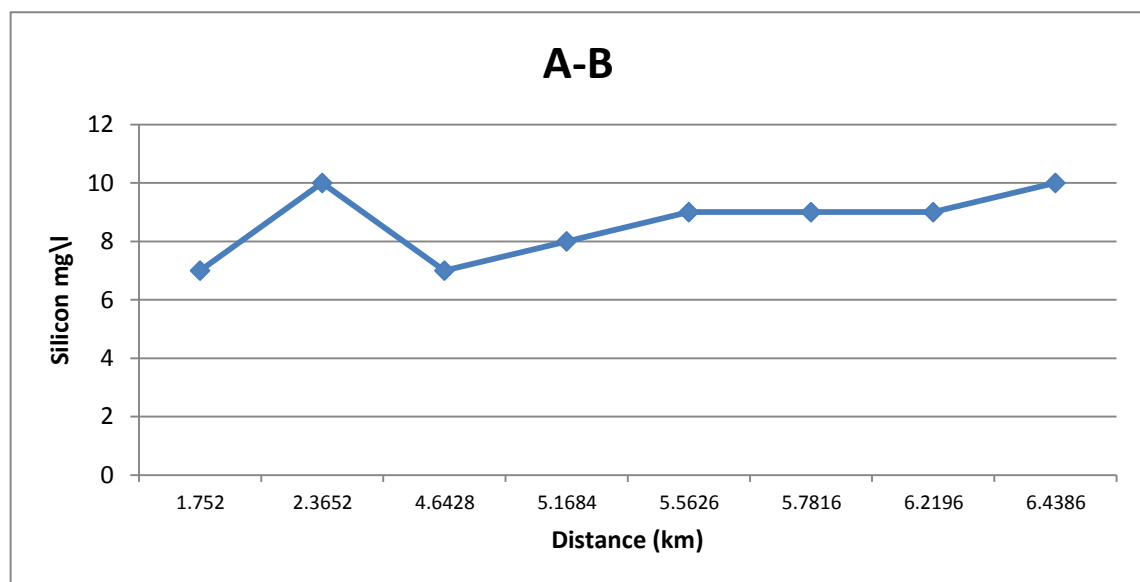


Figure 3.18: W-E profile of Si-concentration in Jericho study area 2011/2012

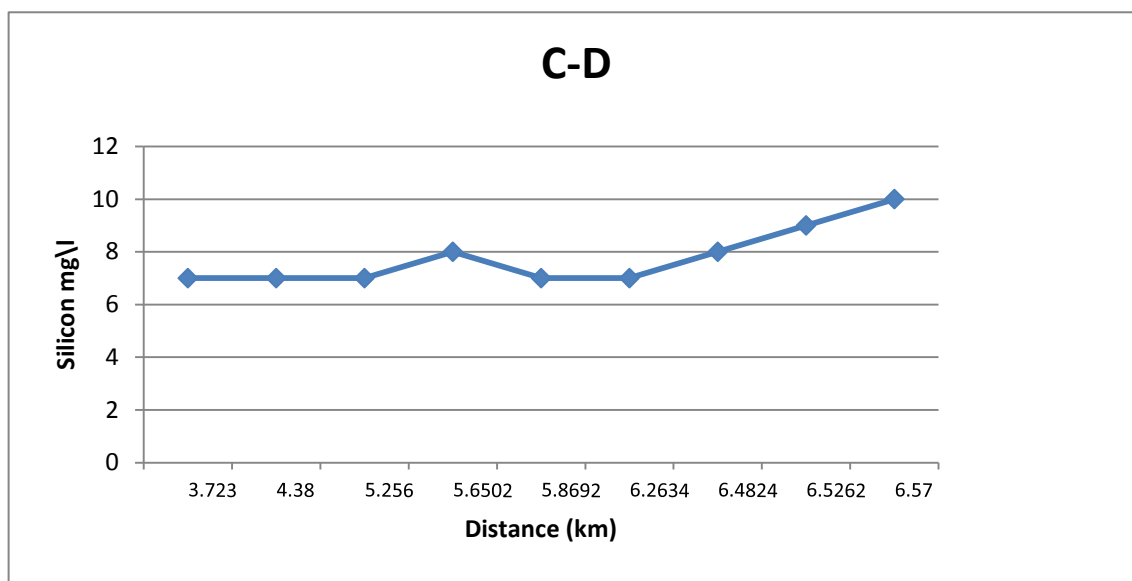


Figure 3.19: W-E profile of Si-concentration i Jericho study area 2011/2012

3.5.5. WATER TYPE

Water samples were introduces into AQU-CHEM software, and water types were identified. Fig. 3.22 presents different water types. Eleven water types are identified, these could be classified into four major groups, which are (Mg-Na dominant group, Na-Ca group, Na-Cl group, Na-Mg group) in more specific these are the water types : Mg-Na-Cl-HCO₃, Mg-Na-HCO₃-Cl, Na-Ca-Mg-Cl-SO₄, Na-Cl, Na-Mg-Ca-Cl, Na-Mg-Ca-Cl-HCO₃, Na-Mg-Ca-CL-SO₄, Na-Mg-Cl, Na-Mg-Cl-HCO₃, Na-Mg-Cl-SO₄, and Na-Mg-HCO₃.

Water type changes from west to east along the groundwater flow path way, along the profile A-B water type change from Na-Mg-Cl-HCO₃ in the west to Na-Cl type in the east. Along the C-D-profile, water types modified also from Na-Mg-Ca-Cl-HCO₃ type in the west to Na-Mg-Cl type in the middle of the profile and change to Na-Mg-Cl-SO₄ type in the east.

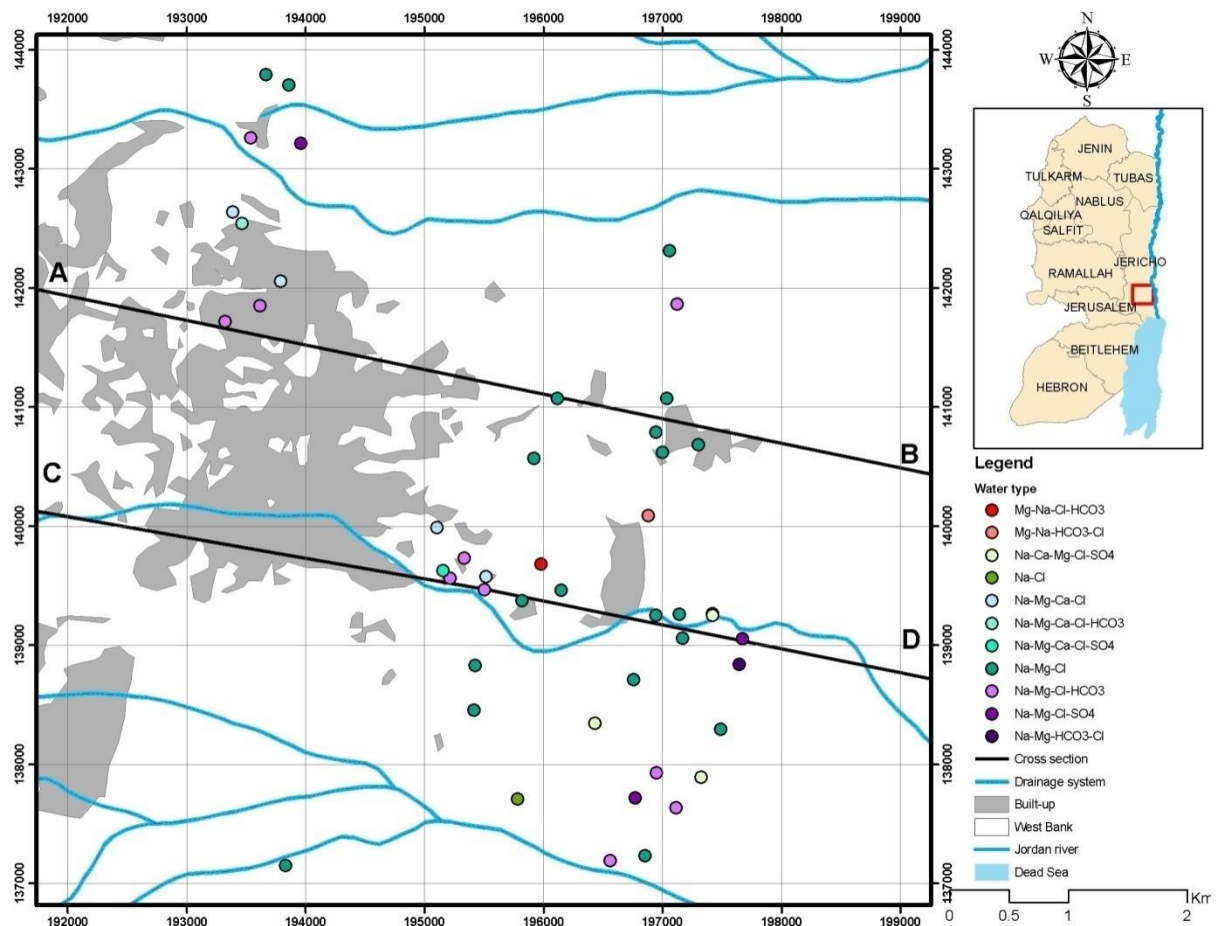


Figure 3.20: Water types in Jericho study area, 2010/2011

In Uja area five water types are found (Fig. 3.20), the dominant group are Na-Mg-Cl, and Na-Mg-Cl-SO₄ groups.

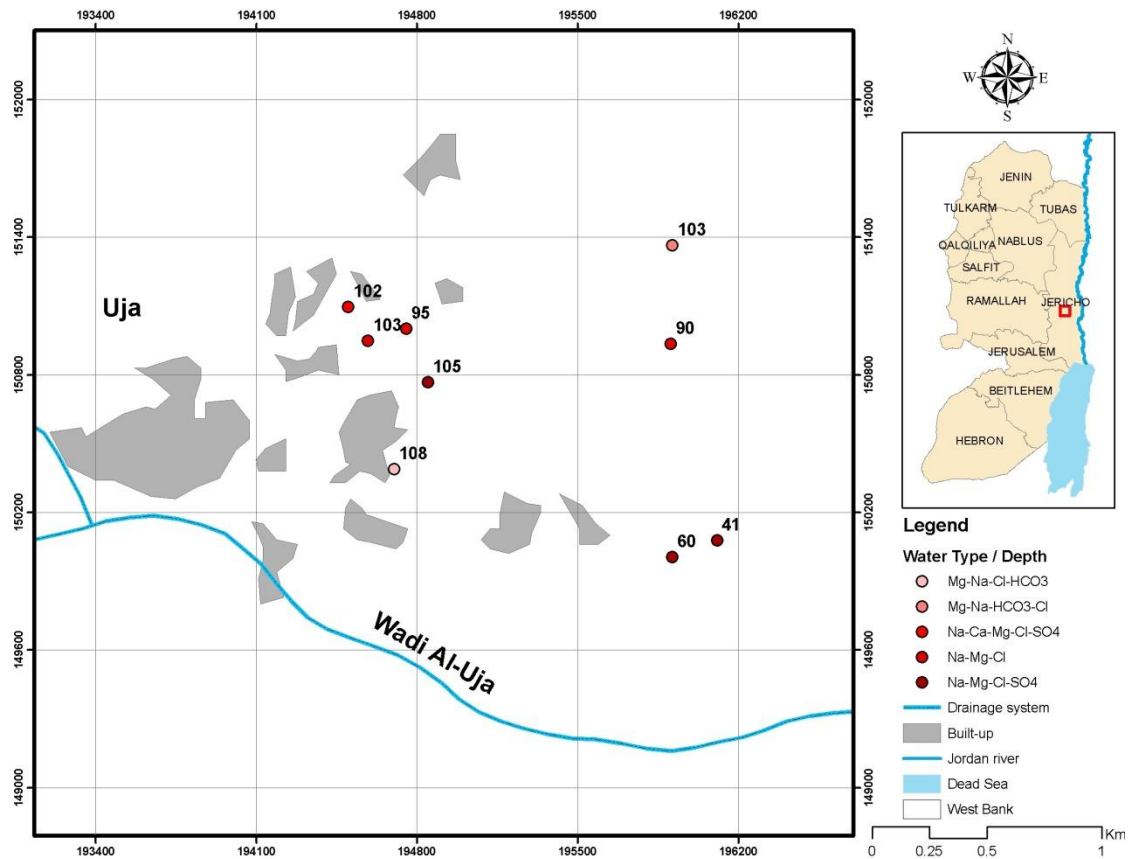


Figure3.21: water type, and well depth to groundwater table in Uja area

3.5.6. 5 VOLUME OF BRACKISH WATER

Table 3-3 summarized volume of taped groundwater with chloride contents above 1500 mg/L in Jericho study area. This volume is about 3 MCM/a, in the other hand a volume of about 6 MCM taped annually with EC-value above 4 mS/cm. Table 3-2 and Fig. 3.22 summarized the well production along the west-east profile, which indicate that by G3-wells the abstraction is higher than by G1 and G2

Table 3-3: groundwater wells with chloride concentration above 1500 mg/L

Well	Code
Arab project.Deaq3	Deaq3
Arab project.Badeco 2	A. project.Badeco 2
A.Project2	19-14/067
A.Project4	19-14/066
Iron-Factroy	*
Badeco 2	*

Table 3-2: well production along the west-east profile

Cross section A-B				
Well code	Productivity (m3/h)	Productivity (m3y)	Ec(m/s/cm)	CL - (mg)
G1	W29	45	194400	800
	w32	7	30240	800
G2	w6	60	259200	1400
	w27	30	129600	1000
G3	w25	40	172800	1400
	w21	30	129600	1400
	w26	35	151200	1400

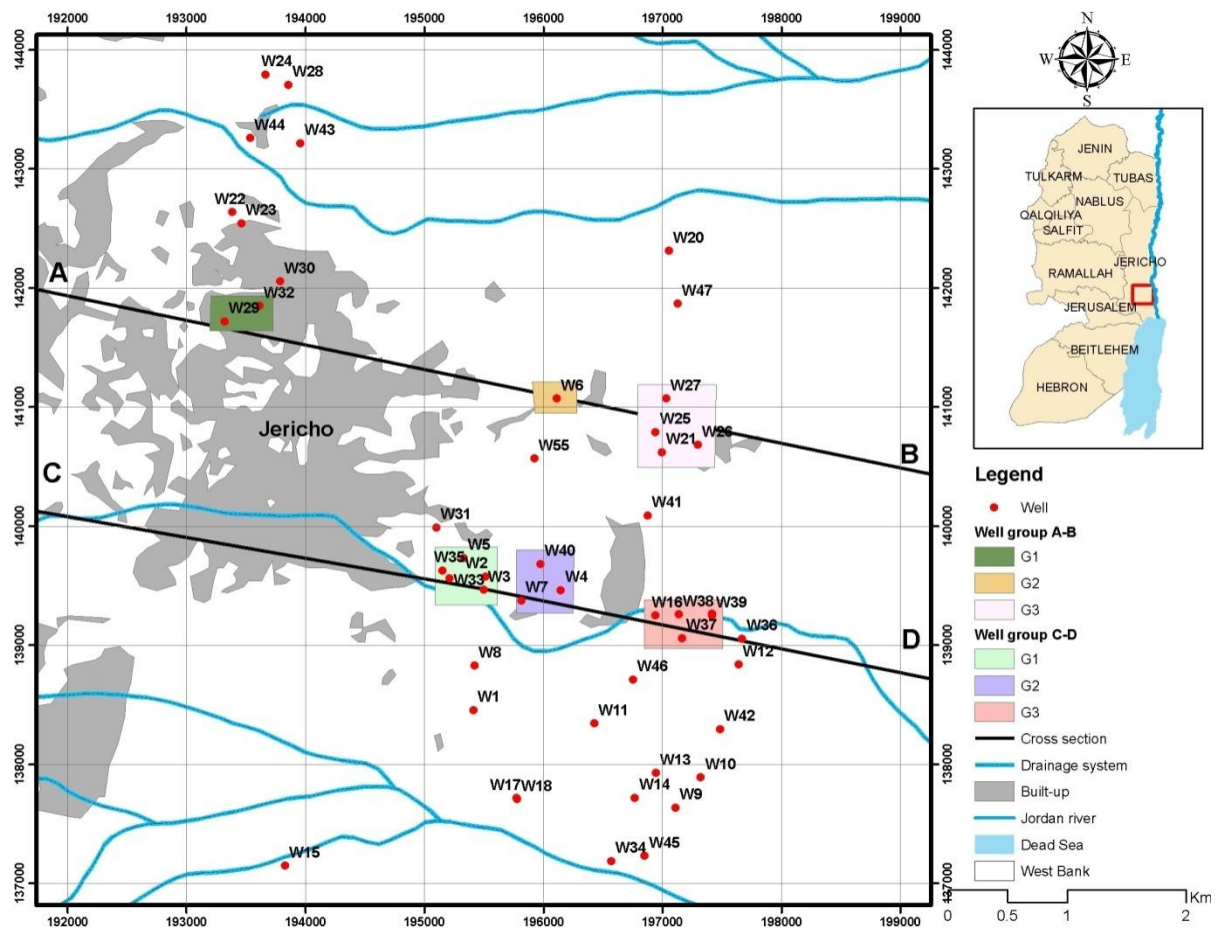


Figure 3.22: well group along the west-east profile