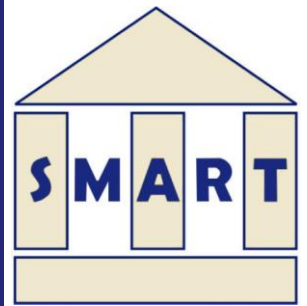




BMBF IWRM R&D Programme

Funding No.: FKZ 02WM1079

SMART – IWRM

Deliverable No. 407

**Assessment of temporal evolution of water
quality in selected wadis**

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10.02.2014

Funded by



Federal Ministry
of Education
and Research

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The quality and composition of water resources is the most important background information, even before it is quantified. However, mixing of groundwater either geogenically driven or anthropogenically induced may change the composition of known reservoirs.

As base for the reliable development of IWRM scenarios in the Lower Jordan Valley and its side-wadis, selected wadis have been investigated concerning their groundwater resources quality. Along the Westbank, focused studies were carried out in the Wadis Qilt, Nueima and Auja, while general investigations covered also the areas situated further northwards until the Bet She'an area. The focus area in the Eastbank was the northern most Wadi Al Arab and Zarqa, including their tributaries, whereas further southwards situated wadis were investigated on a more general level (Fig. 407-1).

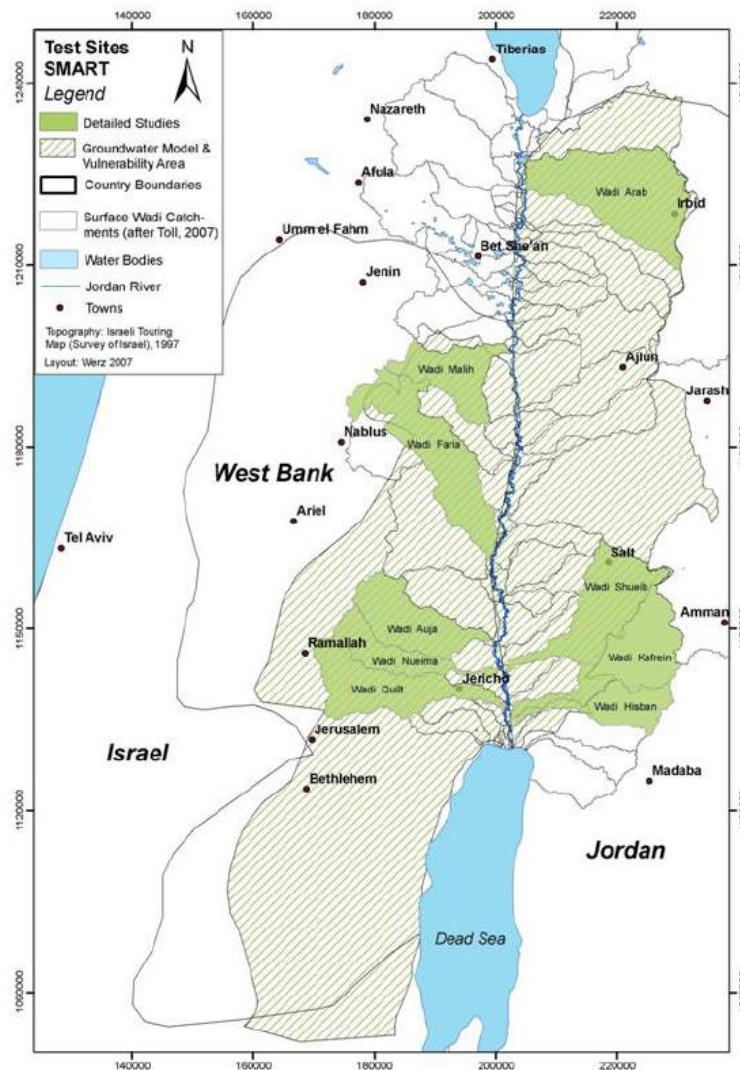


Fig. 407-1: SMART project area (hatched) and focus catchments are high lightened in green.

DEVELOPMENT OF SURFACE WATER QUALITY ALONG THE EASTERN LOWER JORDAN VALLEY
(ELIAS SALAMEH, JORDAN UNIVERSITY)

The urban, industrial and agricultural developments during the last decades have resulted in increasing waste production of all types; industrial, urban wastewater and irrigation return flows in addition to solid wastes of all types deposited within the catchment areas off all, major side wadis along the eastern side of the Jordan Valley.

Although wastewater treatment plants, solid waste disposal sites and industrial wastewater treatment and reuse projects have been implemented, the treated effluents and solid waste leachates are still reaching the major wadi courses. This development has been badly reflected in the quality of the waters of the side wadis, which changed significantly within the last two decades (Table 407-1). In general, the salinity of the water in all the wadis increased, and in the special case of Zerqa River even dramatically.

Table 407-1: comparison of water composition in major side wadis 1990ies until recent.

parameter	Yarmouk		W.Arab		Ziglab		Zerqa		Shueib		Kafraïn		Hisban	
	90s	recent	90s	recent	90s	recent	90s	recent	90s	recent	90s	recent	90s	recent
EC ($\mu\text{S}/\text{cm}$)	830	1019	780	1874	666	1068	1216	8210	635	930	705	950	921	1854
pH	8.87	8.11	7.38	8.09	7.97	7.43	8.42	8.13	8.34	8.32	8.34	7.3	8.26	8.72
T ($^{\circ}\text{C}$)	28	22.5	22	24.5	18.2	23.1	20.6	26.2	13.0	25.2	14.0	26.2	13.0	27.3
Ca (meq/l)	2.66	2.33	3.06	8.3	3.80	4.27	3.45	20.4	3.5	5.2	3.4	4.2	3.89	7.09
Mg (meq/l)	1.67	2.72	2.65	3.3	3.28	3.21	3.54	28.9	1.6	4.23	1.9	1.2	2.36	5.11
Na (meq/l)	3.43	4.78	2.98	6.96	0.79	2.23	5.18	46.2	1.24	2.87	1.88	7.57	4.34	6.22
K (meq/l)	0.14	0.15	0.02	0.72	0.08	0.12	0.36	1.53	0.16	0.26	0.16	0.205	0.30	1.18
Cl (meq/l)	2.86	3.42	2.97	9.92	1.37	2.86	5.1	52.5	1.45	2.43	2.0	4.02	4.7	9.42
SO ₄ (meq/l)	1.79	1.50	1.70	3.36	0.677	1.08	3.0	36.3	1.51	1.09	1.50	2.43	1.67	6.16
CO ₃ (meq/l)	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.24
HCO ₃ (meq/l)	3.33	3.95	4.10	6.0	5.64	6.05	4.01	7.25	3.34	7.57	3.09	4.11	3.28	3.79
NO ₃ (meq/l)	0.19	0.50	0.17	0.08	0.03	0.17	0.22	1.0	0.527	0.60	0.419	0.226	0.26	0.38
PO ₄ (mg/l)	0.11	0.29	1.18	32.6	1.74	1.25	0.768	6.60	0.6	29.7	0.676	2.2	-	1.08

In addition, the health parameter, NO₃ registered increased concentrations in the majority of the side wadis, but the concentrations remained below the Jordanian drinking water guidelines JS 893-2006 of 70 mg/l or 1.13 meq/l.

Wadis receiving effluents of wastewater treatment plants or leachates of solid waste disposal sites show high increases in the PO_4 concentrations, which are: Wadi Al Arab, Zerqa River, Wadi Shueib, and Wadi Kafraïn.

Both, the NO_3 and PO_4 concentrations are far above the concentrations required for eutrophication processes. Therefore, storage of such water in surface reservoirs in the Jordan Valley or along its side wadis will certainly result in eutrophication processes with accompanied clogging problems in drip irrigation systems and to irrigation water depleted in oxygen.

In all the wadis, the salinity increased to roughly 140% of the original salinities. The Zerqa River is an exception with an increase of around 600%. This is due to the inflows of treated and untreated wastewaters into the river, leachates of solid wastes reaching the river water indirectly, irrigation return flows of lands along the River course and in the Jordan Valley itself and discharges of desalination brines of Abu Zighan plant in Deir Alla area.

In general, the change in water quality was accompanied by changes in water types. The Yarmouk River water changed from Earth alkaline water with increased portions of alkalis and prevailing sulfates to strongly prevailing sulfates, which means that more sulfate salts were added to the river water compared to other salts. This also applies to Wadi Arab water.

Zerqa River which water witnessed a six fold increase in salinity and which was of an earth alkaline type with slightly increased sulfate changed to prevailing sulfates which incorporates stronger increases of gypsum dissolution or addition.

Wadi Shueib water changed from earth alkaline type with increased portions of sulfates to normal earth alkaline type with prevailing bicarbonates.

Wadi Kafraïn water changed from earth alkaline with increased portions of sulfates to lower portions of sulfates and increases in bicarbonates.

Both Shueib and Kafraïn water reflect additional of carbonate water as a result of the inflows of the good functioning wastewater treatment plants effluents and removal of sulfates in an anaerobic environment.

Wadi Hisban water remained of earth alkaline type but changed from containing increased portions of sulfates to prevailing sulfates. This is the result of tapping the reduced artesian groundwater along Wadi Hisban course by wells and the uncontrolled flow of the deep water containing higher concentrations of sulfides, which oxidize when in contact with the atmosphere to produce sulfates.

On the eastern side of the Lower Jordan Valley area a variety of groundwater chemistries is found reflecting different sources of chemical constituents. In the study the end members which undergo mixing processes to produce the existing water chemistries in the different areas of the eastern Jordan Valley are identified as waters of: Precipitation, floods, upper aquifer, deep aquifer, Lisan Formation, salt bodies, irrigation return flows and local recharge.

The chemical characteristics of the water end members and their specific content on chemical species are defined and the sources of the chemical species leading to the groundwater genesis are identified.

Analyses of common water constituents, $d^{18}O$ and dD isotopes, bromide concentration, ionic ratios and chemical clustering were used to characterize the groundwater types and to understand their genesis.

The findings show distinctive composition of the end members and their evolution as they pass from precipitation to infiltration to down-percolation into the different geologic formations and from one formation into the other.

Saltwater bodies in the underground of the Jordan Valley, Lisan Formation and Triassic-Jurassic rocks are found to be the main sources of salinity and chemical species in the groundwater of the area.

Irrigation return flows contribute also to the salinity of the groundwater, but with only small amounts of salinity parameters and fertilizers causing water salinity to rise to a few thousands of $\mu S/cm$ to become brackish.

GEOLOGICAL CONTEXT

The valley floor consists mainly of nonconsolidated alluvial sediments of gravel, sand, shale marl and clay. In addition, evaporates which precipitated from the precursors of the present Dead Sea are found in the form of extensive deposits and lenses, especially in the western parts of the study area. Basalts and their weathering products are found in the North Shuneh area.

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 of Triassic to Recent ages crop out with their western extensions covered by the more recent valley deposits. Table 407-2 contains the relevant information about the escarpment foothills formations and Table 407-3 contains the relevant information about the recent formations in the Jordan Valley area. More details can be found in Bender (1968) and Burdon (1959).

Table 407-2: Geologic formations along the foothills of the eastern Jordan Valley escarpment of the study area

Tertiary	Mainly chalks and marls of different types
Wadi Shallala Formation (B5)	Chalky and marly limestone. 250m in thickness, medium aquifer.
Umm Rijam Formation (B4)	Chalk, chert and limestone. Thickness: 40 m, only locally an aquifer.
Upper Muwaqqar Formation (B3)	Chalk, marl, chalky limestone with chart nodules. Thickness: 200-240 m, aquiclude.
Upper Cretaceous	Mainly limestone of different types
Lower Muwaqqar Formation (B3) & Amman Formation (B2)	Silicified limestone, chart, phosphate. Thickness: 30-120 m, excellent aquifer.
Wadi Ghudran Formation (B1)	Chalks and marls. Up to 70m in thickness, in same places missing, aquiclude.
Wadi es Sir Formation (A7)	Hard massive karstified limestone. Thickness: 180m, very good aquifer.
Shueib Formation (A5, A6)	Thick marls alternating with thin bedded limestone. Thickness: 50-100 m, aquiclude.
Hummar Formation (A4)	Hard crystalline and dolomitic limestone. Thickness: 60-120 m, excellent aquifer.
Na'ur-Fuheis Formation (A1-A3)	Marl, limestone and marl limestone thickness: 300m, poor aquifer
Kurnub Group (K)	Mainly sandstone. Thickness 200-300 m, good aquifer
Zerqa Group (Z)	Mainly siltstone. Thickness 0-400 m, semi aquifer

Table 407-3: Quaternary formations in the Lower Jordan Valley

Thickness m	Formation Name
0 – 100	Alluvial fans and recent deposits
40 – few hundred	Lisan
35	Ubeidiya and Samra
100	Abu Habil Conglomerates
~ 350 m	Shagur Conglomerates

PRECIPITATION

The Electric Conductivity (henceforth EC) in precipitation water of the Lower Jordan Valley (LJV) area (Deir Alla station) is relatively high (Table 407-4) compared with that of the highland (Salt station as a representative station for the highlands). This is a direct result of precipitation interception by the high thickness of the atmosphere over the LJV, which lies at an average altitude of -200m mean sea level (msl.) compared to 800-1000m msl. of the surrounding highlands. Br concentration in the precipitation of the LJV are far higher than those in the highlands seemingly as a result of use of Br-based biocides by farmers in the LJV irrigated

agriculture. The isotopic composition on $d^{18}O$ and dD is also enriched in the precipitation of the LJV also as a result of interception and re-evaporation before it reaches the JV bottom.

Table 407-4: weighted average of 16 precipitation samples (EC in $\mu S/cm$, NO_3 , PO_4 , Br and Cl/Br in mg/l, all others in meq/l)

Station	EC	pH	Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br
Deir Alla	163	7.45	0.7	0.04	0.31	0.03	0.6	0.3	0.55	3.6	0.32	0.32
Salt	98.7	7.61	0.47	0.04	0.32	0.05	0.42	0.19	0.32	3.5	0.21	0.066

Station	$d^{18}O$	dD	Cl/Br	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca+Mg/SO ₄ +CaCO ₃
Deir Alla	-4.04	-14.05	67.6	0.52	2.33	0.92	0.87
Salt	-6.9	-32.0	225	0.76	2.47	0.76	1.34

FLOOD WATER

Floodwater composition (Table 407-5) depends strongly on the natural set-up of the catchment area, particularly the rock type cover, the catchment size and its land use. The EC values are generally below 300 $\mu S/cm$ reflecting the concentrations of the salinity parameters. NO_3 and PO_4 reflect the land use type and geological setting, with outcropping rocks containing bromide such as phosphates, oil shales or Jurassic and Triassic rocks (Salameh et al. in preparation)

Table 407-5: Flood water from wadis sampled several times during flood flows (EC in $\mu S/cm$, NO_3 , PO_4 , Br and Cl/Br in mg/l all others in meq/l)

EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br
183 - 278	8.2- 9.19	1.5- 1.62	0.1- 1.1	0.08- 0.3	0.29- 0.44	0.3- 1.79	018- 0.83	084- 1.47	3.0- 20	4.22- 23.5	0.04- 0.39

Cl/Br	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca+Mg/SO ₄ +HCO ₃
46.9-390	0.46-1.0	1.43-4.2	1.46-4.9	0.97-1.37

BASE FLOW

The composition of base flows within the wadis (Table 407-6) depends on the aquifers from which the base flow emerges and on the human activities within the respective catchments. In the study area the major base flows originate from springs and seepages in the Upper Cretaceous rocks, hence they reflect the composition of the groundwater in these aquifers. The EC values vary in a range of 600-800 $\mu S/cm$. The Br concentrations of around 1 mg/l are

relatively high compared to meteoric water with yearly recharge and discharge mechanism, but it is normal for the types of aquifers composed of phosphates and oil shale rocks. The isotopic composition resembles slightly enriched highland precipitation water. Ionic ratios reflect slight water rock interactions with carbonate aquifers.

Table 407-6: Base Flow: Many wadis were sampled several times during the dry season base flows (EC in $\mu\text{S/cm}$, NO_3 , PO_4 , Br and Cl/Br in mg/l all others in meq/l)

EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br
642-830	7.7-8.6	2.37-3.35	1.88-3.5	0.1-0.26	0.99-2.19	1.6-3.4	0.5-2.67	1.4-4.64	10-45	7.3-15.3	0.80-1.4

$\delta^{18}\text{O}$	dD	Cl/Br	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca+Mg/SO ₄ +HCO ₃
-4.5 to -5.6	-22 to -27	59-113	0.57-0.88	0.85-7.0	1.52-2.8	1.06-1.35

UPPER AQUIFER

The composition of the water from the Upper Aquifer (Table 407-7) depends on the lithology of the subaquifers and on the human activities within the recharge areas of the unconfined aquifers. In the study area the groundwater is mainly found in the Upper Cretaceous rocks, hence the composition of the water reflect the composition of these carbonatic formations. The EC values vary in a range of 500-800 $\mu\text{S/cm}$ and reflect the concentrations of the salinity parameters. The Br concentrations in the unconfined parts of the aquifers are relative to other water sources low, less than 0.5 mg/l while they increase in the confined parts. There, water is in contact with rocks composed of phosphate and oil shale (Siebert et al., subm.). The isotopic composition resembles slightly enriched highland precipitation water. Ionic ratios reflect slight water rock interactions with carbonate aquifers and calcium chloride dissolution in the lower parts of the Upper Cretaceous Formations, which are a badly developed semi aquifer (Springs of Baggurieh, Azraq and Jarban).

Table 407-7: Upper aquifer lateral flows into the Jordan Valley aquifers: Average of several samples for each of the 7 sources (EC in $\mu\text{S/cm}$, NO_3 , PO_4 , Br and Cl/Br in mg/l all others in meq/l)

EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br
500-950	6.8-8.1	3.1-5.8	1.6-3.2	0.05-0.2	0.6-1.83	1.2-1.7	0.5-2.0	3.3-6.0	0.5-54.0	0.02-10.6	0.02-4.76

d ¹⁸ O	dD	Cl/Br	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca+Mg/SO ₄ +HCO ₃
-5.9 to -6.77	- 21 to -29	11->1000	0.32-1.14	1.02-7.3	1.81-4.57	0.94-1.45

TREATED WASTE WATER

Treated wastewater has salinities in the range of 1,200 to 2,000 $\mu\text{S}/\text{cm}$ reflecting the contents of salinity parameters (Table 407-8). It still contains high concentrations of NO_3 and PO_4 compared to the other water sources with low salinities. The bromide content reflects the concentrations of the supplied drinking water.

Table 407-8: Treated Waste Water (one year average of monthly sampling). EC in $\mu\text{S}/\text{cm}$, NO_3 , PO_4 and Br in mg/l all others in meq/l

EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br
1200-1950	7.22-7.52	2.4-4.5	1.7-4.6	0.76-1.2	5.1-10.0	4.7-8.15	1.24-2.0	4.3-10.0	41-120	12-32	0.36-0.92

LISAN MARL FORMATION

The Lisan Marl water contains high concentration of salts and can be classified as salt water. Its EC of around 20,000 $\mu\text{S}/\text{cm}$ reflects very strong dissolution of NaCl and CaSO₄. The ionic ratios show also some dissolution of CaCl₂ (Table 407-9). The isotopic composition indicates highly evaporated water.

Table 407-9: Lisan Marl water (average of 5 analyses). EC in $\mu\text{S}/\text{cm}$, NO_3 , PO_4 , Br and Cl/Br in mg/l all others in meq/l

Lisan Formation	EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	Br	d ¹⁸ O	dD
Lisan Marl	18290	7.82	33	41.2	6.39	113.1	137.8	53.6	4.57	145	8-15	-4.1	-18.7

Lisan Formation	d ¹⁸ O	dD	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca+Mg/SO ₄ +HCO ₃
Lisan Marl	-3.4 to -4.5	-15.7 to - 21.7	0.82	0.61	0.03	1.22

IRRIGATION RETURN FLOWS

Irrigation return flows contain medium concentrations of salts, which allow their classification as brackish water (Table 407-10). Their salinity reflects the concentration of salinity parameters, mainly Na and Cl. Their bromide content is high because of leakages from the Lisan Formation

partly underlying the irrigated areas, in addition to the use of Br-based biocides by farmers. Their isotopic composition is enriched as a result of evaporation of irrigation water.

Table 407-10: Irrigation returns (average of return flows to Zerqa River (average of 6 samples). EC in $\mu\text{S}/\text{cm}$, NO_3 , PO_4 and Br in mg/l all others in meq/l

Source	EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	PO ₄	Br	d18O	dD
Return Flow	7770	7.99	15.05	12.49	3.07	40.6	50.03	16.17	5.62	55	6.67	8-15	-4.4	-22.2

DEEP AQUIFERS WATER

The deep aquifers bordering and underlying the LJV deposits belong mainly to the Triassic and Jurassic aquifers. Their water discharges in two areas of the LJV namely Deir Alla and Sweima (Table 407-11). The salinity of the water is high allowing its classification as brackish to saline water. It anyhow reflects the high dissolution of NaCl, CaSO₄ and carbonate compounds. The isotopic composition of the water is highly depleted indicating a recharge area on the highlands of Jordan, or recharge during more humid times. The high Br content is the result of Br salts dissolution from the evaporate-containing Jurassic and Triassic aquifer matrix.

Table 407-11: Deep aquifer water (average of 5 analyses). EC in $\mu\text{S}/\text{cm}$, NO_3 , PO_4 and Br in mg/l all others in meq/l

Source	EC	pH	Ca	Mg	K	Na	Cl	SO ₄	HCO ₃	NO ₃	Br
Deir Alla	11650	5.99	30.49	10.66	2.58	76.26	76.52	24.22	19.46	2.5	4.5
Sweima	6480	6.29	15.34	9.13	2.35	38.5	41.2	9.00	13.89	3.6	16

Source	d ¹⁸ O	dD	Cl/Br	Na/Cl	Ca/SO ₄	HCO ₃ /Cl	Ca=Mg/SO ₄ +HCO ₃
Deir Alla	-6.22	-39.6	603	1.0	1.25	0.25	0.94
Sweima	-5.3	-24.7	91	0.93	1.7	0.34	1.07

SALTWATER BODIES IN THE LOWER JORDAN VALLEY AREA

Water emerging from salt bodies underlying the LJV area is characterized by its very high salinities, very high Br contents and strongly enriched isotopic composition (Table 407-12). It seems that such salt bodies were precipitated from the ancestral lakes of the Dead Sea. The isotopic composition is highly enriched especially in Qurein and Karama where it lies close to Dead Sea water.

Table 11: Water in salt bodies underlying the Jordan Valley (average of 2 analyses for each source) EC in $\mu\text{S/cm}$, NO_3 , Br and Cl/Br in mg/l all others in meq/l

Salt bodies	EC	pH	Ca	Mg	K	Na	Cl	SO_4	HCO_3	NO_3	Br
Qurein/ Mallaha	171700	6.55	62.47	3153	340	2203	5230	525	29.84	1845	1119
Wakid (S. of Tiberias)	40600	8.17	73.1	32.2	2.91	381.0	354.7	132.0	19.46	2.4	288
Karama sp.	16040	8.33	7.32	13.6	4.27	146	115	48.3	3.55	220	616

Salt bodies	d^{18}O	dD	Cl/Br	Na/Cl	Ca/ SO_4	HCO_3/Cl	Ca+Mg/ SO_4+HCO_3
Qurein/ Mallaha	+2.8	+2.9	166	0.42	0.12	0.005	5.79
Wakid (S. of Tiberias)	-1.8	-14.9	43.7	1.07	0.55	0.06	0.695
Karama sp.	+4.3	+13.3	6.63	1.27	0.15	0.031	0.40

CONCLUSIONS

The delineation of the groundwater chemistry groups and the origin of their salinity may assist in defining protection zones for the groundwater resources and also in defining areas where fresh water can be extracted before becoming salinized by mixing with salt water sources.

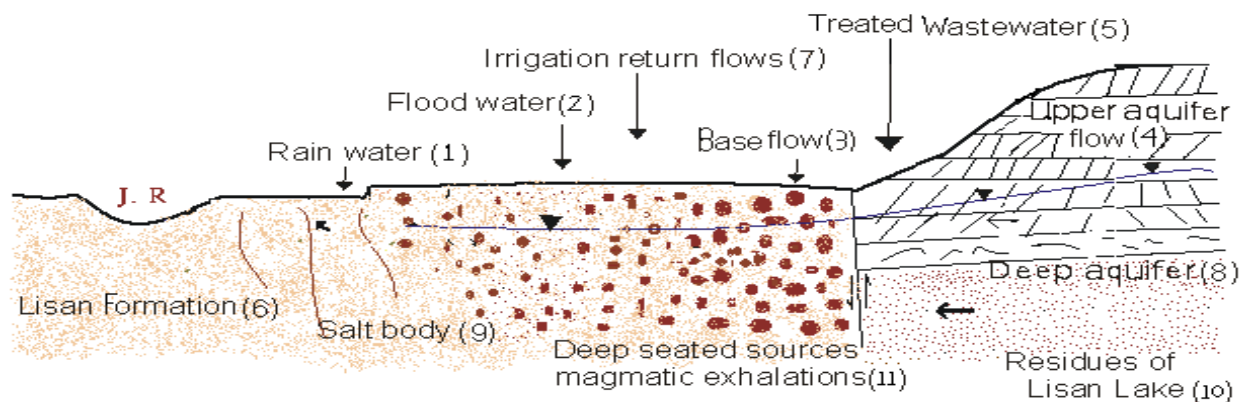


Fig. 407-2: Sources of water salinity in the groundwater of the Jordan Valley

1. Rainfall natural recharge.
2. Flood flows
3. Base flows
4. Shallow aquifer lateral flow
5. Treated waste water
7. Irrigation returns flow.
8. Deep aquifer lateral flow
9. Salt bodies leachates
10. Residues of Lisan Lake
11. Magmatic exhalations

6. Lisan Formation water

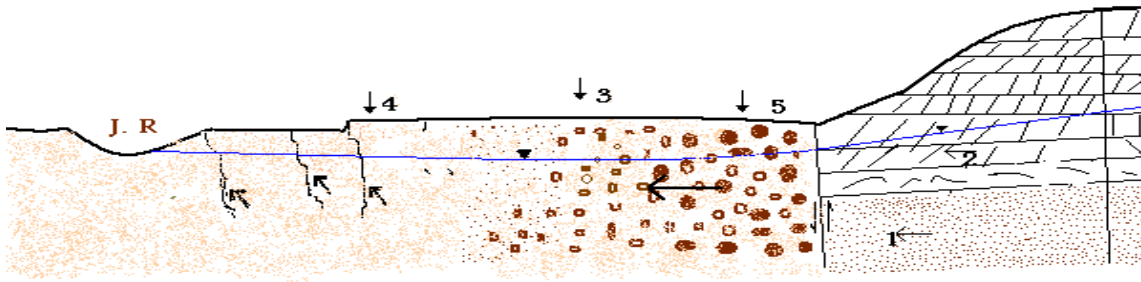


Fig. 407-3: Groundwater sources in the Jordan Valley area:

- | | |
|----------------------------------|----------------------------|
| 1. Lateral Flows deep aquifer | 4. Surface water |
| 2. Lateral Flows shallow aquifer | 5. Irrigation return flows |
| 3. Rain water | |

WADI AL ARAB - ANALYSIS AND QUANTIFICATION OF EROSION PROCESSES AND RESULTING
CONSEQUENCES FOR THE SURFACE WATER IN WADI AL-ARAB (SABINE KRAUSHAAR, T.
SCHULMANN, C. SIEBERT, UFZ)

Wadi al Arab is a semi-arid catchment in NW Jordan (Fig. 407-4) located between the Yarmouk River gorge in the north, the Jordan River Valley in the west (-20 m msl.), the foothills of the Ajloun Dome in the south and the branch of the Azraq plain in the east (+1,100 m msl.). Due to geological setting, its subsurface basin is about 300 km², while the surface catchment covers just 200 km², the latter of which incises south of Irbid and continues to NW with a neotectonically induced abrupt change of its flow-direction to the SW.

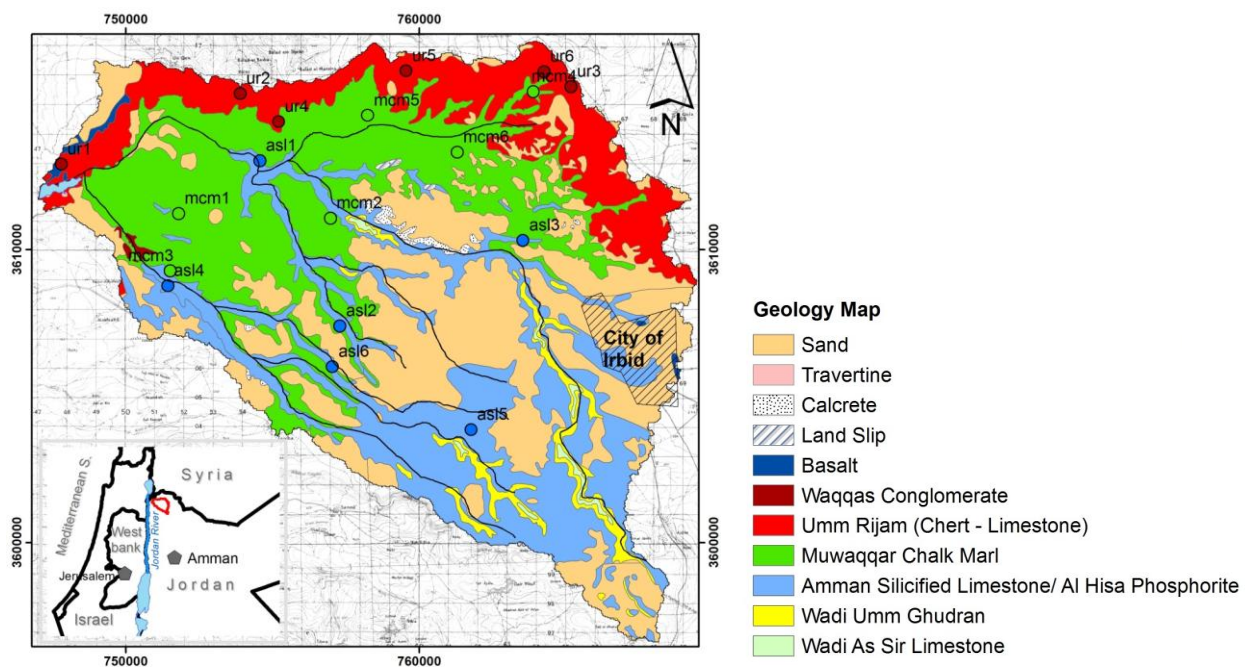


Fig. 407-4: Location of Wadi Al Arab and Geological Map of the catchment

Alternating sedimentary sequences of Cretaceous to Cenozoic age represent the geological setting of the catchment. The fractured and karstified Ajloun (A7) and Lower Belqa (B1, B2) Groups represents the major aquifer. It is covered by an aquiclude on which top the regional productive B4 aquifer feeds the only occurring springs of the catchment. Due to the NW-wards dip of the formations, the A7/B2 and below seated aquifers become confined towards the Jordan Valley. Wadi Al Arabs eastern part is dominated by agriculturally used rolling hills. Westwards, the relief energy increases and agricultural areas are limited to top, saddle and foot slope positions. Terra Rossa, Rendzina, Entisols and Vertisols are the typical soils with greatly varying thicknesses, which are controlled by the vegetation cover. The predominant landscape units are olive orchards (27%), fields (14%), natural shrubs (low Maquis) and bare soil/ rock on steep

slopes (~45%) (Fig. 407-5). Precipitation is restricted to the season from October-April and seldom exceeds 550 mm/a, of which roughly 80% occur in December-February (Rödiger et al., 2014). The dry and immature soils possess only small capabilities to store an adequate amount of precipitated water. Thus, and due to the steep morphology, precipitation excess accumulates quickly inducing flash floods.

INTRODUCTION

The soil layer and its physical integrity is a key player to slow down runoff, safeguard infiltration, buffer and filter pollutants, and a sensible parameter in hydrological models (Blum 1997; Pierzynski 1997). On the other side, soil erosion and sedimentation harm surface water reservoirs due to filling up and subsequent reduction of storage volume, and even worse by contamination of these water bodies. The Wadi Al Arab dam is an important storage reservoir for the northern Ghor area and its degradation has or would have a huge impact on the agricultural economy in the region.

Hence, it is of great importance to understand erosion processes, define sediment/pollutant sources and sinks and analyse interdependencies with land use and climate changes in Wadi Al Arab. Specific objectives include:

- determination of long-term erosion rates and connectivity to the fluvial system,
- geochemical characterisation of sediment sources and calculation of their relative contribution to the sink,
- quantification of the current sedimentation rate in the dam and its effects on the water quality,
- analysis of the spatial distribution of the erosion hot spots, simulation of land use changes and the effects on the sediment delivery.

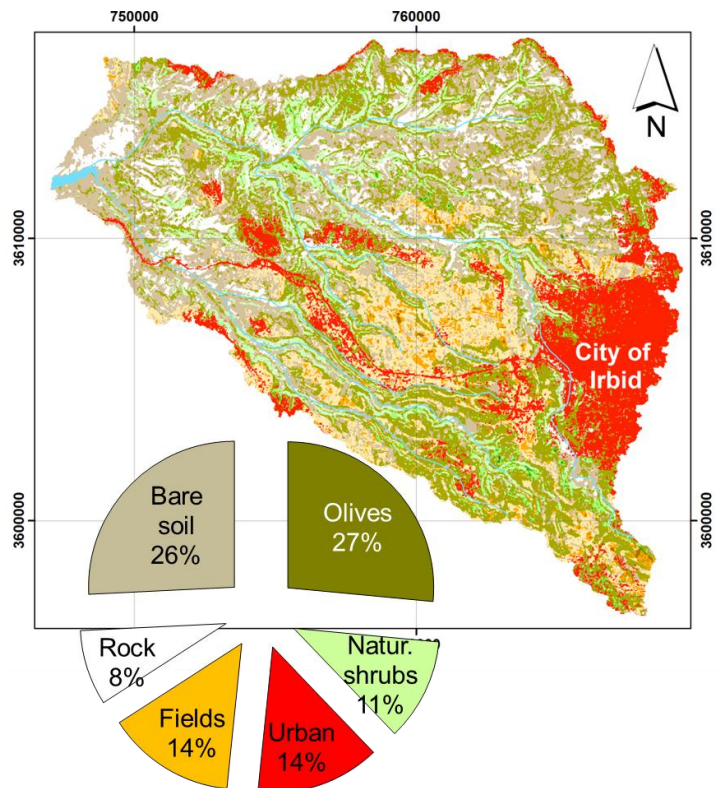


Fig. 407-5: Landuse map of Wadi Al Arab catchment (Kraushaar et al., 2014).

We used a multiple response approach combining a broad spectrum of erosion measurements on the slope and in the sink with a geochemical sediment fingerprint study. Results of these three studies cover different spatial scales and only partly integrate the transport way. Hence, they cannot be directly compared but consider the problem from different perspectives and are used in the final step to calibrate and validate the setup of the SedNet model (Wilkinson et al. 2008) for the catchment. SedNet is a coupled conceptual and physical based process model for erosion and sediment transport. Its implementation helps to cultivate more sophisticated questions to the research focus and allows a conceptual scenario development for mitigation strategies.

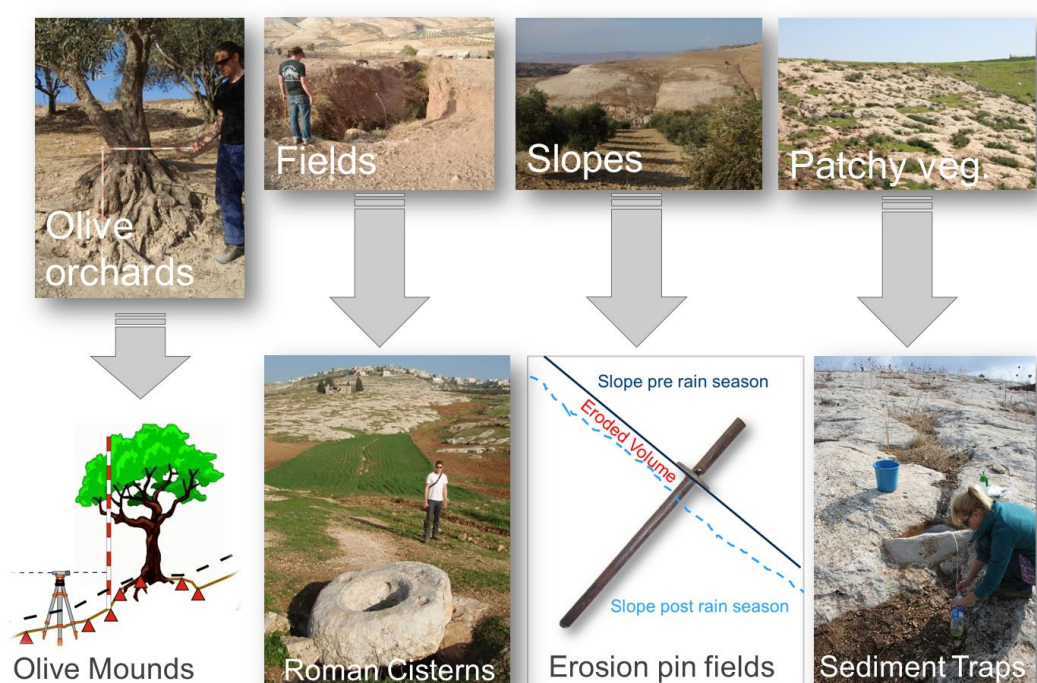


Fig. 407-6: Erosion Measurements in different landscape units.

EROSION MEASUREMENTS ON THE SLOPE

Measurements on the slope were conducted on four defined land units: olive orchards on slopes, agriculturally used nearly levelled positions, slopes under low Maquis and patchy vegetation both used for grazing. The methods included the measurement of topographic olive mounds within 7 orchards (each around 800 m²) in synergy with tree-coring and age estimation of the orchards. Furthermore, the OSL dating of deposited sediments in two roman cisterns adjacent to fields together with catchment measurements and volume estimations. On slopes

under low Maquis 9 erosion pin fields (each 200m²) were installed and finally, in the typical patchy Mediterranean landscape sediment traps build and maintained throughout the rainy seasons (Fig. 407-6).

SEDIMENTATION MEASUREMENTS IN THE SINK

An echo sounding campaign was undertaken on the Wadi Al-Arab dam at the western outlet of the catchment, leading to a recent map of the sediment level in the reservoir. Together with the abstraction of a DEM from former topographic measurements, the sedimentation volume in the reservoir and an average sedimentation rate was calculated. Furthermore, 4 physico-chemical water profiles as well as 6 sediment cores derived from the lake bottom were analysed (Fig. 407-7).

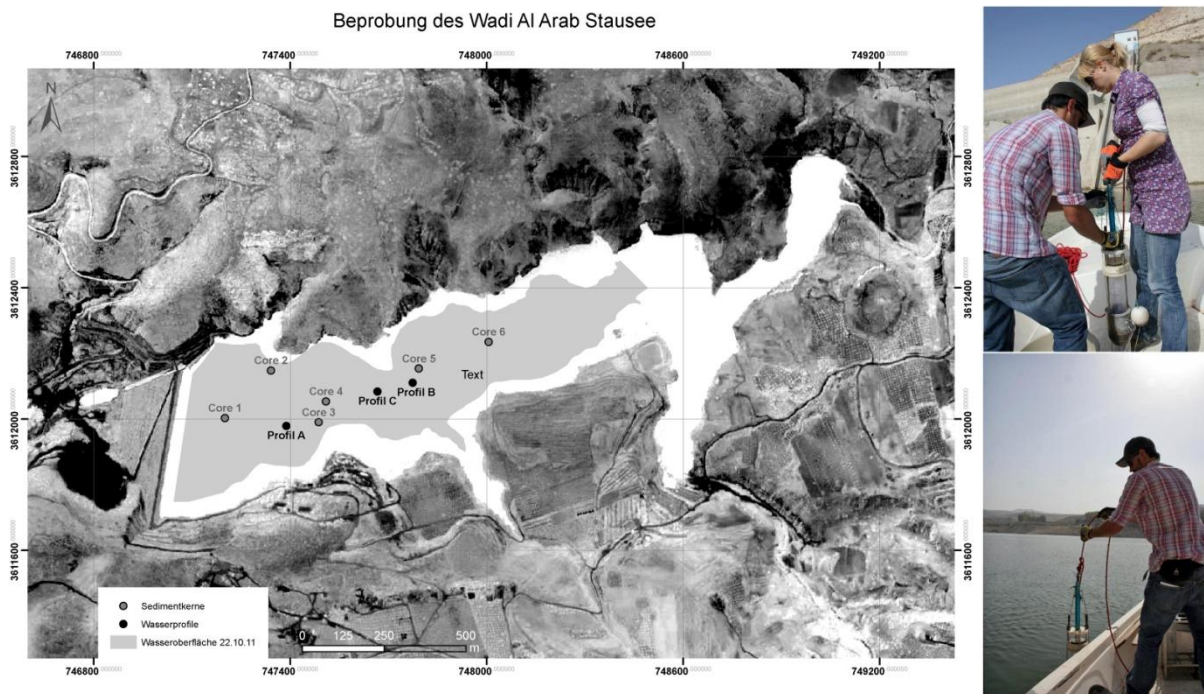


Fig. 407-7: Sampling scheme of the Wadi Al-Arab reservoir (Google 2004; mod. Kraushaar & Schumann 2011, Fotos Aymad 2011).

MULTIPLE SEDIMENT FINGERPRINT

In a sediment fingerprint study in the Wadi Al-Arab catchment reservoir sediments were analyzed for their provenance and percental contribution. This analysis is based on the comparison of concentrations of conservative and source discriminating elements. Regional specifications such as the carbonate background of the sediments and the anaerobic condition of the lower water body in the reservoir led to a revised approach for the determination of correction factors and to additions to the generally chosen conservative elements. We analyzed

36 sediment samples from six source areas and 38 sink samples from five lake sediment cores using X-ray fluorescence analysis (XRF) and gamma ray spectrometry. Additional element analyses of three Wadi deposit samples and physicochemical as well as element analyses of two vertical water profiles of the lake corroborated the new approach. Based on the *stepwise multiple regression analysis model (SMRAM)* influencing parameters and respective interrelations were detected and arithmetical filtered. In a second step a decision tree for the chosen conservative elements was developed and complemented with a concentration comparison between reservoir water and sediments, respectively (Fig. 407-8). Based on Monte Carlo Simulation runs the mixing model revealed the existence of three major source areas dominated by anthropogenic land use and a pedogenetic background, namely (i) olive cultivated slopes with 59 ± 8 %, (ii) agricultural fields on more or less stable positions with 11 ± 9 %, and (iii) slopes with natural vegetation used for grazing with 29 ± 15 %. With a mean residual error of 1.04 % the sum of the source concentrations differ only slightly from sink concentration and prove the model to be reliable.

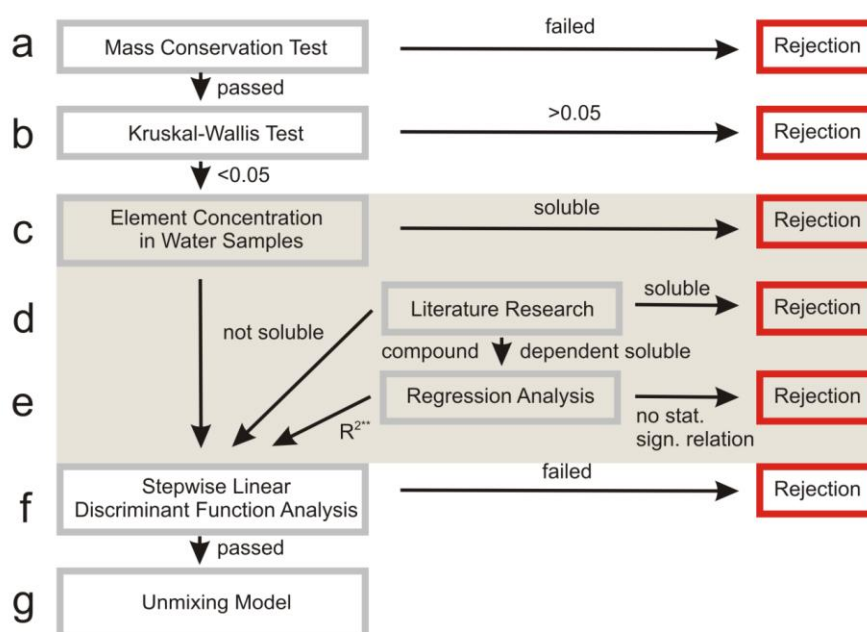


Fig. 407-8: Decision tree to eliminate elements from fingerprinting analysis

The study showed that the conventional approach of deriving correction factors in fingerprinting studies would have overcorrected this dataset. Applying the suggested revised SMRAM would be of advantage especially in catchments with no pre-knowledge on element contents and

geochemical milieu of the sink. The results point out the importance of checking and adapting the basic assumption of the method to the given individual circumstances.

SEDNET MODEL

The SedNet model is “[...] a spatially distributed sediment budgeting model. Sed Net couples erosion, hydrological, and sediment transport modeling to predict sediment loads and deposition throughout river networks...” (De Rose et al. 2005).

As Fig. 407-9 shows the model consists of different possible sediment sources and sediment sinks and allows the sediment to be routed through the catchment. Erosion values are derived using the conceptual model RUSLE (Renard et al. 1997). Depending on the sediment transport capacity sediment is transported until the reservoir, or deposited in the riverbed/ floodplain.

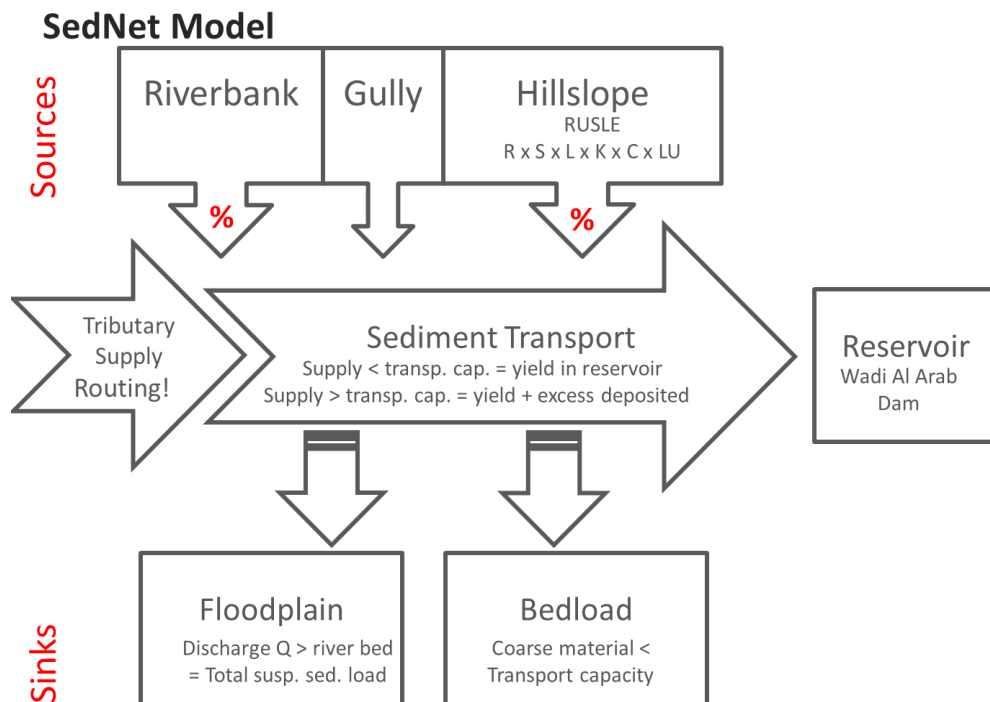


Fig. 407-9: Schematic diagram of the SedNet model.

The model was developed for Mediterranean to semi-arid regions in Australia and for the simulation of current status and future management strategies in big catchments. Due to the data scarcity in Jordan the combination of the conceptual (erosion) and the physical process based transport model is the ideal combination for the Wadi Al-Arab. The model produces averaged annual results, which reflect the precision that is integer concerning the limited datasets and produces still valuable information for mitigation planning.

RESULTS

This chapter only focuses on several results of the study as the full display would have exceeded the report.

The erosion measurement methods on the slope cover different time scales from 560 years for the fields, an average of 32 years for the olive orchards, up to two rainy seasons for the erosion pin fields and single rain events in the recent sediment traps. Results show that olive orchards on steep slopes ($>10\%$) have the highest erosion potential in the region with $95 \pm 8 \text{ t ha}^{-1} \text{ y}^{-1}$ followed by natural vegetated slopes with $37 \pm 4 \text{ t ha}^{-1} \text{ y}^{-1}$ and fields with $4.66 \pm 0.05 \text{ t ha}^{-1} \text{ y}^{-1}$ of eroded material. Recent events on limestone rock with soil patches still show $1.79 \pm 1.3 \text{ t ha}^{-1} \text{ y}^{-1}$ of dislocated material.

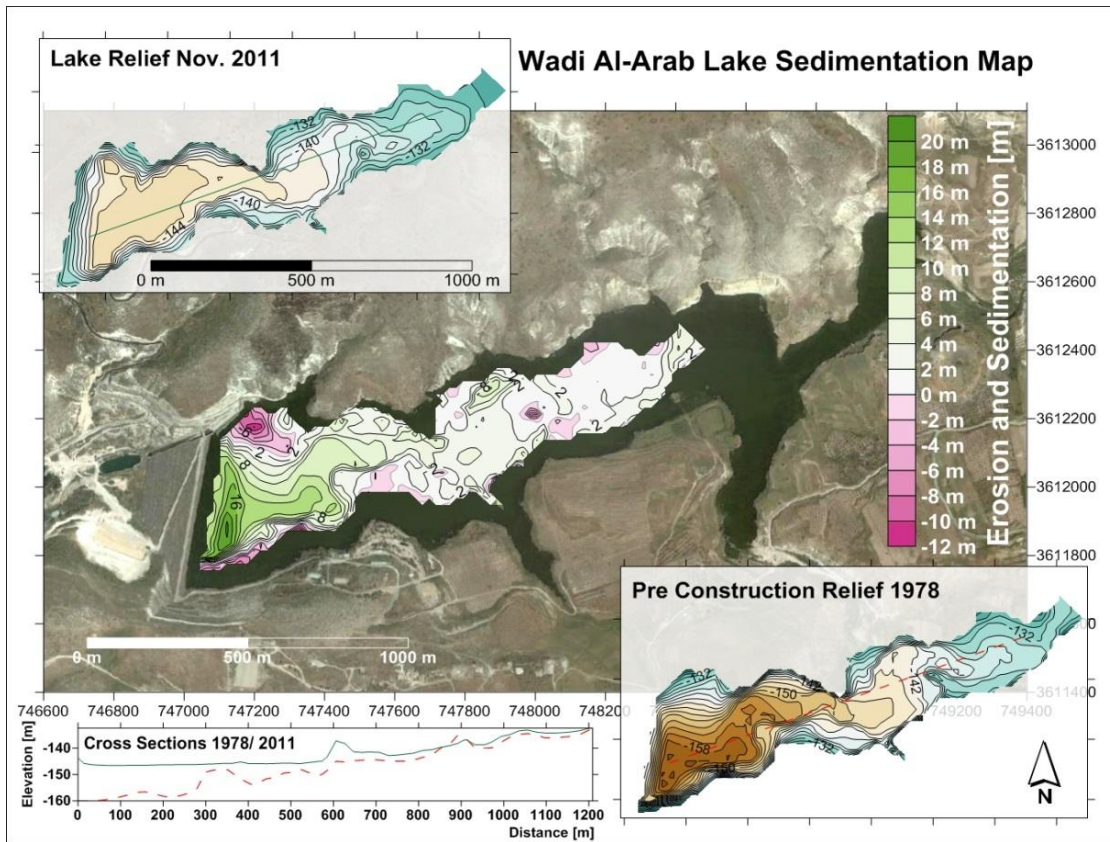


Fig. 407-10: Wadi Al-Arab Dam sedimentation map.

These spatially constrained outcomes are supported by the geochemical sediment fingerprint results of lake sediments from the catchment. Based on Monte Carlo simulations the mixing model revealed the existence of three major source areas, namely (i) olive cultivated slopes with $59 \pm 8 \%$, (ii) agricultural fields on more or less stable positions with $11 \pm 9 \%$, and (iii) slopes with

natural vegetation used for grazing with 29 ± 15 %. With a mean residual error of 1.04 % the sum of the source concentrations differ only slightly from sink concentrations and prove the model to be reliable.

The Wadi Al-Arab reservoir receives annually a sediment input of $67,000 \text{ m}^3 \pm 6$ %, which shortens the life span of the dam dramatically (Fig. 407-10). The lake sediments showed a high contamination on different heavy metal such as Cd, Cr, and Ni. However, the carbonatic environment and thus, the alkali pH prevent the mobility of these pollutants and in the water samples only Mn concentration exceeds the threshold. However, the water quality is affected by herbicides and insecticides (Trifluralin, Hexazinon, t- NP), which probably entered the reservoir bount to sediments.

Finally, the model made the compilation of the findings possible and the spatial distribution of soil erosion is visible in Fig. 407-11. The model validation results show that the measured values correspond well with the modeled ones for the agricultural fields and the slopes under Maquis. The measurements under olives were restricted by the means of the method to orchards that show strong signs of erosion; hence, results only correspond well to the modeled maximum values (Fig. 407-12).

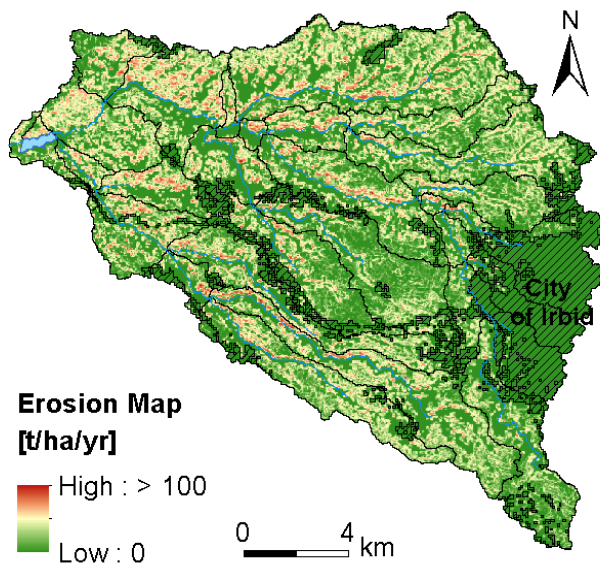


Fig. 407-11: Erosion Likelihood Map W. Al-Arab.

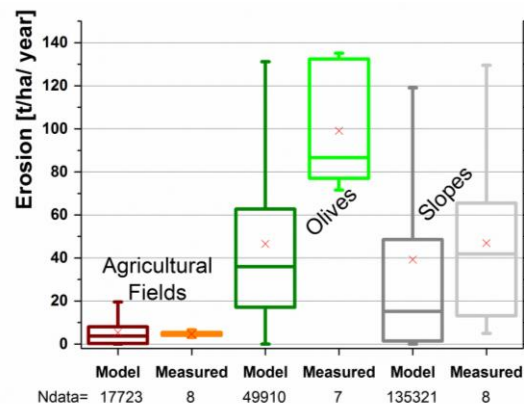


Fig. 407-12: Validation of the SedNet model.

CONCLUSION AND INTEGRATION INTO THE SMART PROJECT

Within the framework of the SMART project, sediment sources and soil erosion values were studied and a sediment budget developed for the exemplary catchment Wadi Al-Arab.

Results underline the necessity to consider sediment studies in the region when addressing integrated water resource management. These are:

- soil erosion reduces the potential of infiltration, accelerates runoff, and pollutes fresh water resources
- young olive orchard fields on marly substrate deliver large amounts of sediments to the catchments outlet. Intensification of this land use is expected with future economic changes.
- the model shows the connectivity in the catchment between slope and Wadi is high. Hence, the system is very susceptible to changes on the slope.
- resulting spatial information on sediment erosion, delivery and sediment loads in the Wadi are a decision tool for the planning of hydrological structures for managed aquifer recharge.
- a sediment budget can be produced solely considering the sediments in the lake and the debris cones.

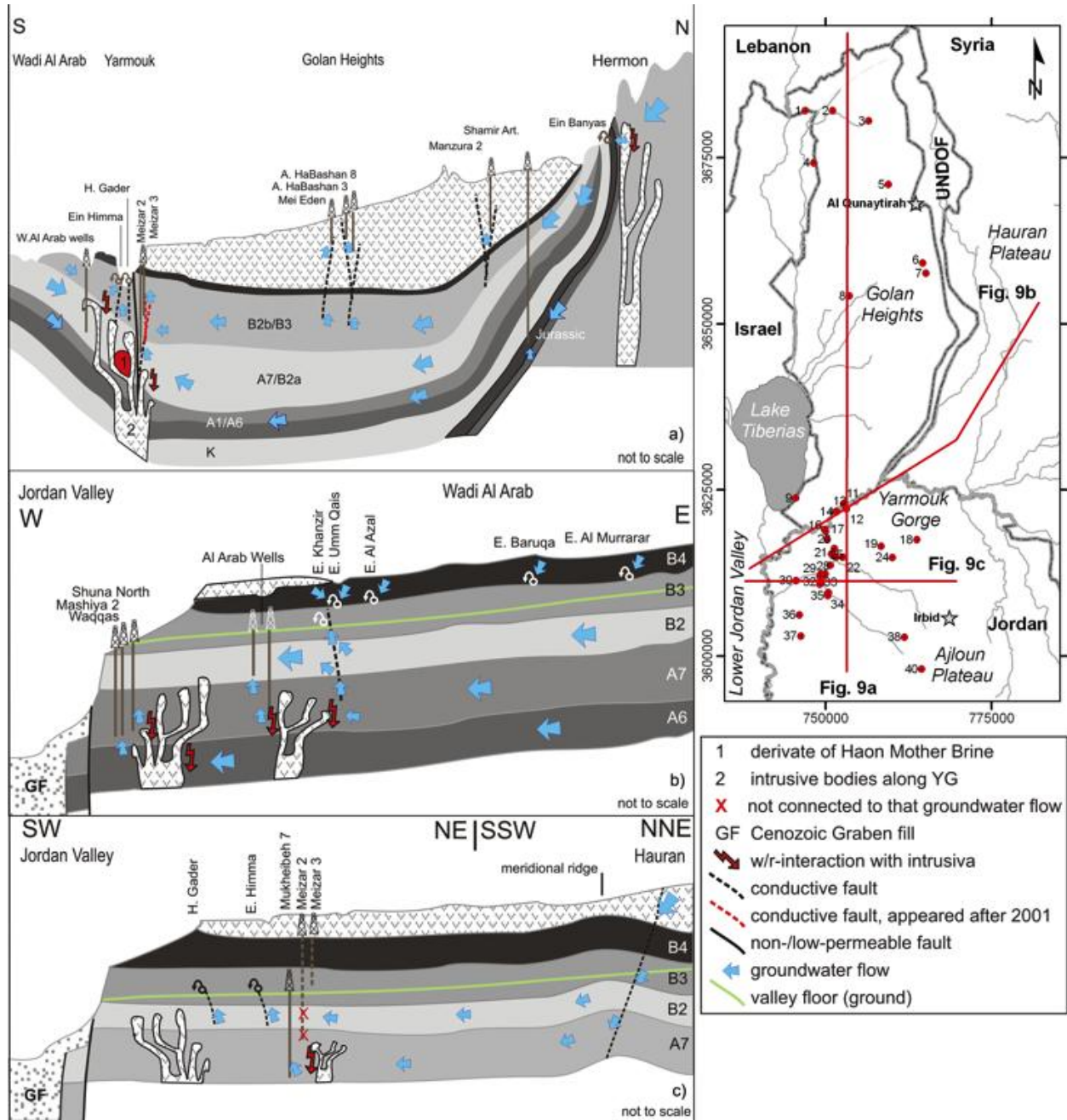
Thermal Waters in the Lower Yarmouk Gorge, Wadi Al Arab and their Relation to Surrounding Aquifers. (Christian Siebert, T. Rödiger, S. Geyer, S. Kraushaar UFZ; Y. Guttman, Mekorot; A. Subah MWI)

Within the Yarmouk Gorge and along the western Escarpment of the Ajloun Plateau, thermo-haline waters emerge artesian from outcropping rocks. However, due to their enhanced temperatures the source of water is assumed to can be found in deeper strata. Simultaneously, groundwaters abstracted from the A7/B2 aquifer in Al Arab well field show indications of influence from these sources. Hydraulic studies of Rödiger et al. (2014; in prep.; ref. to D402 and D409) show, artesian conditions within the confined section of A7/B2 are past due to the enhanced abstraction from the Arab and Kufr Asad well fields, respectively. Consequently, conditions changed which seem to allow high-pressurised thermal waters from A1/A6 aquifer (e.g. Waqqas, Shuneh North, Manshiya) to ascend into the above-situated reservoir. Even fault-bounded springs, emerging from B3 aquiclude and fed from B2 show indications of thermal waters (Siebert et al., subm.).

The water supply in the NW part of Jordan highly rely on different sources, which are:

- groundwater from A7/B2 in W. Al Arab for drinking water supply of urban areas (e.g. Irbid),
- groundwater from B4 in W. Al Arab for soaking stock and local consumers
- groundwater from A7/B2 in Yarmouk G. for supply into King Abdullah/Ghor Canal
- surface water from W. al Arab Reservoir for supply into Ghor Canal

Due to the complexity of anthropogenic water fluxes we decided to not restrict investigations to Wadi Al Arab, but have a broader view on the resources of the Ajloun and adjacent areas and their assumable interactions.



The subsequent studies in SMART proved the decision to be correct. An individual observation of the groundwaters in Ajloun without taking the functioning of Yarmouk Gorge and Golan/Hauran Plateau) into account cannot reveal answers on the dynamic of the hydrogeological system with its complexity of hydrogeochemical interactions in the area surrounding the intersection of the two major fractures of the region (Jordan-Dead Sea Rift and Yarmouk Gorge) (Fig. 407-13).

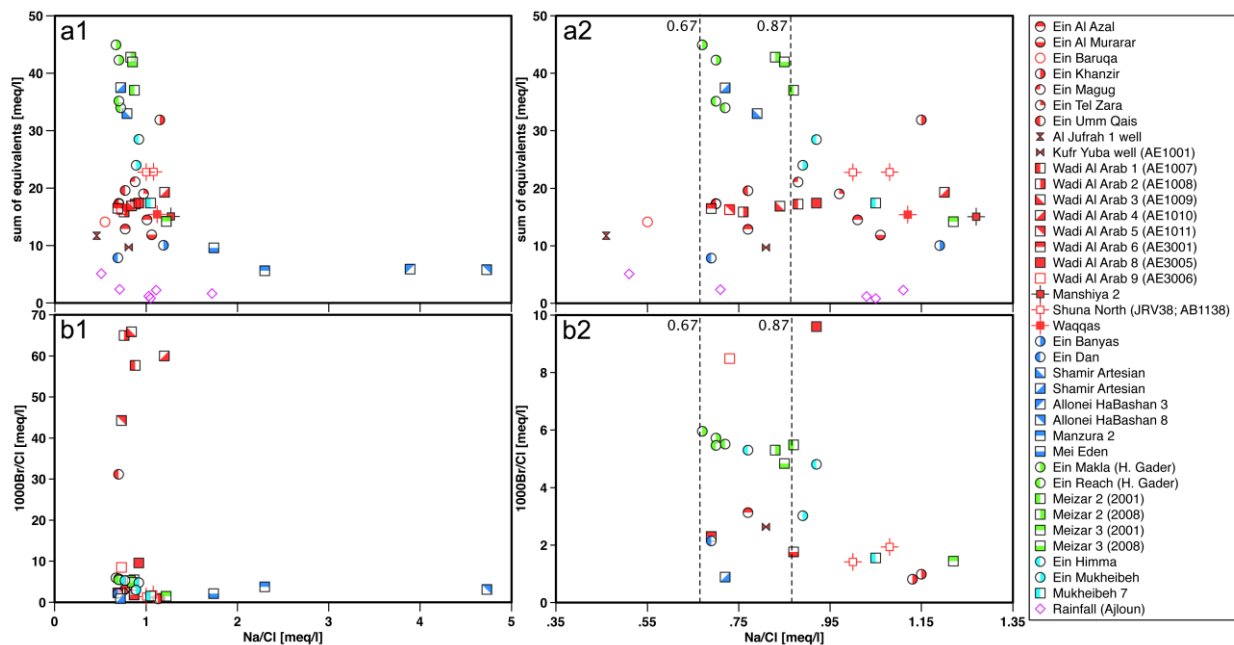


Fig. 407-14: Correlations of (a) total dissolved ion equivalents and (b) 1000Br/Cl ratios versus Na/Cl ratios in groundwater. For clearness, left-hand plots are showing all values and right-hand plots show only a selective range of Na/Cl ratios,

Fig. 407-13 shows several hydrogeological cross-sections cutting the region and revealing subsurface flow paths of groundwater accumulating within the Yarmouk Gorge and in front of the Ajloun. One of the most important features of the area is the Lower Yarmouk Gorge, which is a nearly impermeable boundary for groundwaters approaching from the north. It is indicated by a non-/low permeable fault (black line) separating the groundwater flows in the Ajloun and Golan Heights (Fig. 407-13a). At the same time, the Yarmouk Gorge collects water from south-Syrian Hauran-Plateau and transfers it towards the Jordan Valley, also partly feeding the still artesian Mukheibeh wells along the southern flank of the gorge (Fig. 407-13c).

Applied methods were major element chemistry, stable isotopes of water and sulphate and rare earth elements including yttrium to reveal geogenic influences within the reservoirs and to outline areas of recharge as well as flow paths. These information are crucial for a reliable resources management (Fig. 407-14, 15, 17).

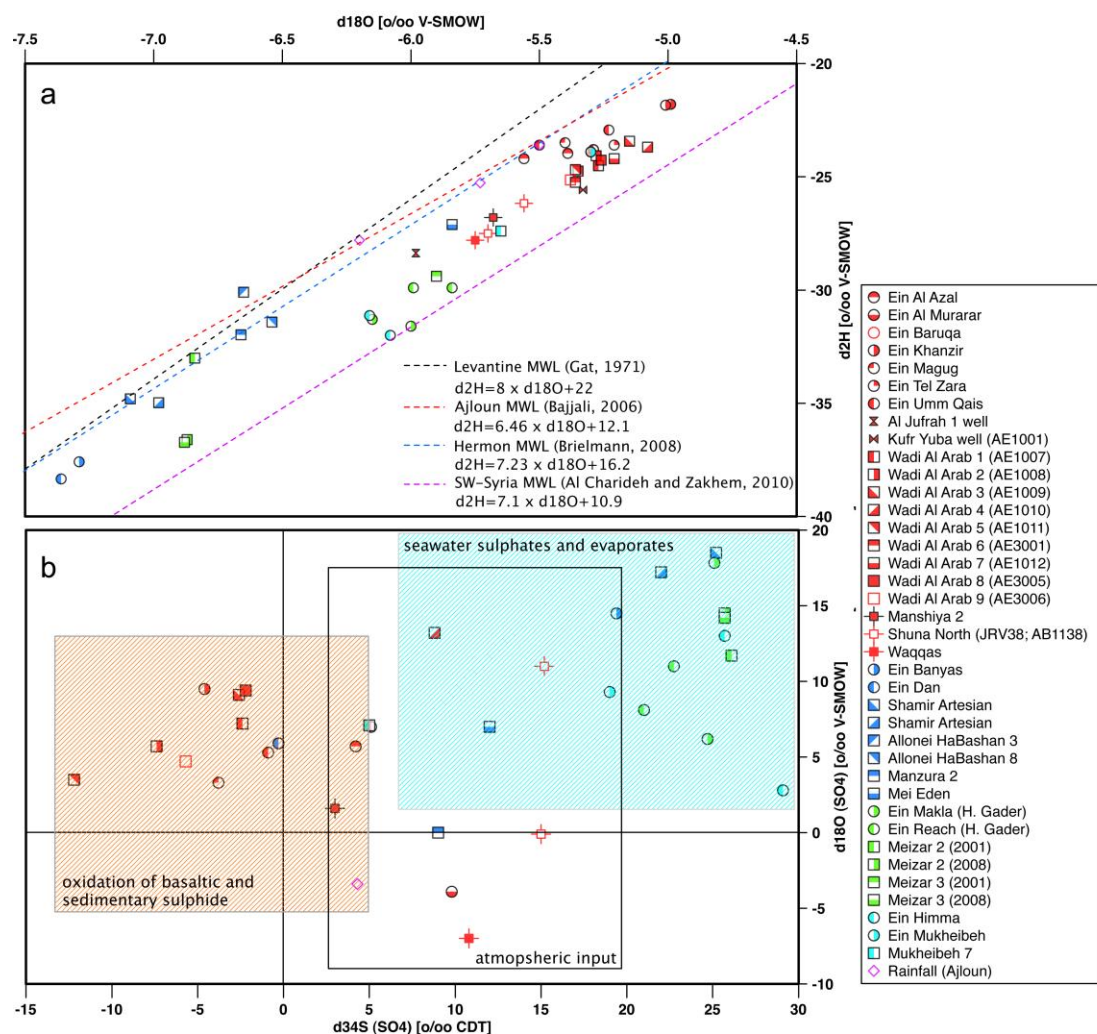


Fig. 407-15: Stable isotopes in groundwater. (a) $\delta^{18}\text{O}$ and $\delta^2\text{H}$ in water samples and (b) $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ in dissolved sulphate.

Chemical signals show further (i) hidden intrusive bodies are much more abundant in depth than assumed so far, adding considerable amounts of Na to the water, (ii) bituminous rocks are source rocks for Br and (iii) residual brines, which are encapsulated in the aquifer matrix and get released by karstification of their host rocks. On top, groundwater that once approaches the Lower Yarmouk Gorge get in contact with a trapped brine, which is a derivate from the Lake Tiberias region (Möller et al., 2011).

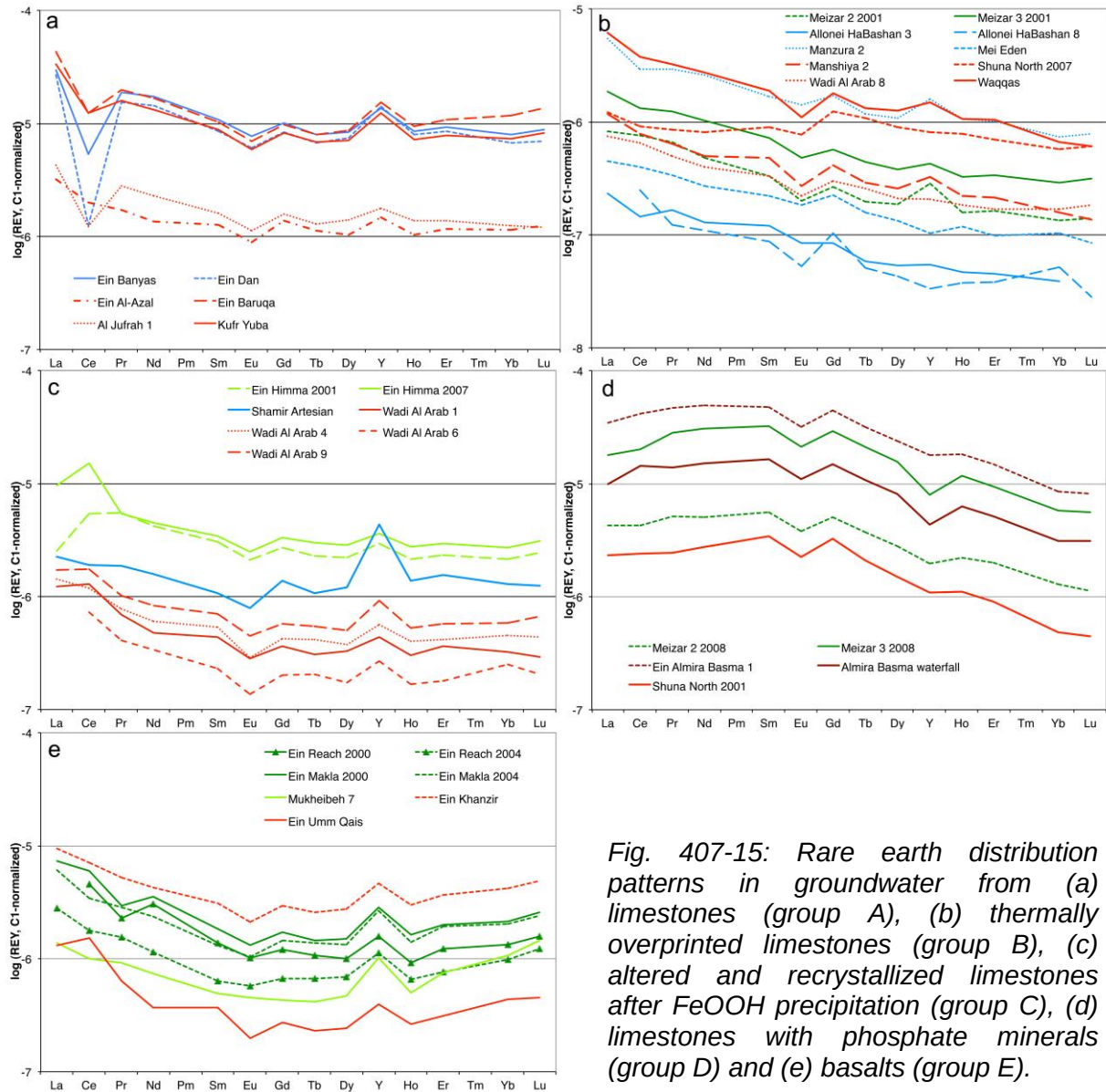


Fig. 407-15: Rare earth distribution patterns in groundwater from (a) limestones (group A), (b) thermally overprinted limestones (group B), (c) altered and recrystallized limestones after FeOOH precipitation (group C), (d) limestones with phosphate minerals (group D) and (e) basalts (group E).

Within the systems, temporal changes were observable, conjecturally due to tectonic activities, which changed pathways along the Yarmouk Gorge. It becomes particularly observable in Meizar wells on the northern flank, but also in Himma, where the famous spa spring disappeared.

Pollution and overexploitation of scarce groundwater resources is a serious problem in the Zarqa River catchment, Jordan (Fig. 407-16). The study was focused on the quantification of recharge within the catchment, which is one of the strongest anthropogenic influenced catchments in Jordan. Hence, vulnerability studies within that basin are of high importance and shall be carried out in the future. To build a base, spatial distributed information where and to which amounts recharge occurs are crucial.

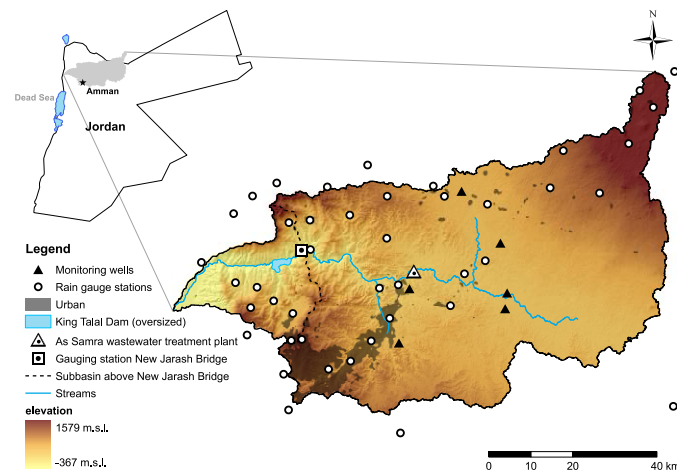


Fig. 407-16: Zarqa catchment and observation locations (Schulz et al., 2013).

Groundwaters from observed springs in the area (Fig. 407-17), which discharge from A1/A6 in the lower parts of the catchment, do show only slightly enhanced inorganic compositions, including indicators for enhanced contribution from agricultural and urban areas, e.g. NO_3 and PO_4 . Although the latter is below limit of detection, NO_3 (up to 68 mg/l) reveals clear signals of anthropogenic pollution and is far above the allowable limit of 30 mg/l (JS 893-2006).

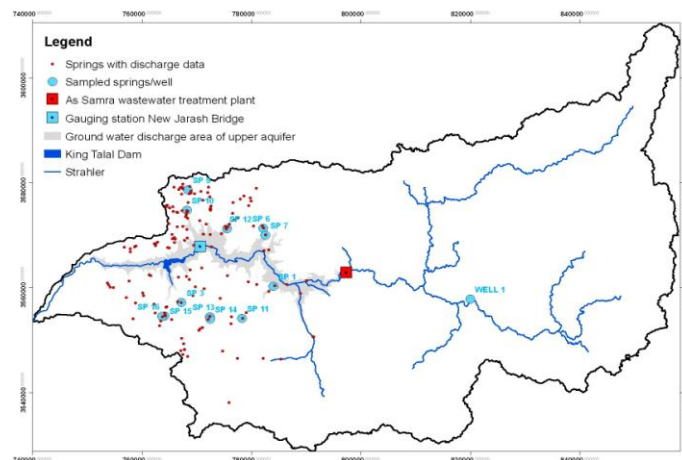


Fig. 407-17: Locations of sampled springs and wells in the catchment of Wadi Zarqa.

The Bet She'an and Harod Valleys (Fig. 407-18) in Israel are regional recipients and mixing zones for groundwater draining from a multiple aquifer system, which includes carbonate and basalt aquifers and deep-seated pressurized brines. The aquifers drain through two types of outlets, distinct and mixed. The latter type is mainly conditioned by the occurrence of fault-blocks

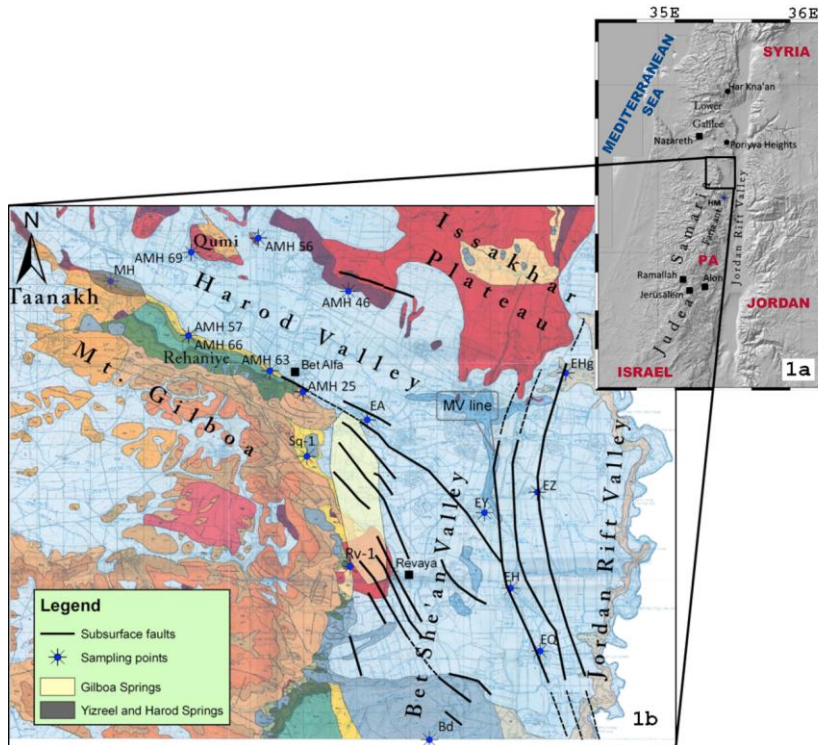


Fig. 407-18: Geological map showing the study locations General setting of the study area, presented over the Digital Terrain Model (DTM). Major geo-tectonic and geomorphological units are specified (DTM after Hall, 1993). A sample point, HM (Hamam-el-Malih), is indicated. Detailed location map of the study area, overlaying geological map. Location of sampling points, geotectonic and geomorphological units as well as the subsurface faults interpreted within Bet She'an and Harod Valleys are indicated.

Sampling points: Bd – Bardala; EA – Ein Amal; EH – Ein Hisha; EHg – Ein Huga; EQ – Ein Qarnaym; EZ – Ein Zemed; EY – Ein Yehuda; MH – Maayan Harod (spring); Rv-1 – Revaya-1 well; Sq1 – Shoqeq-1 well.

related to the Jordan Rift system, which act as connecting media between the aquifers and facilitate inter-aquifer flow.

The study focused on the conjoint application of stable isotopes and REY distribution in groundwater aiming at the detailed elucidation of the replenishment areas of groundwater in wells, well-fields and springs located in areas highly disturbed by faults. In these areas intricate inter-aquifer flow is a common occurrence. This enables detecting the local areas of rainfall infiltration and, in connection with the position of wells or springs, the identification of groundwater flow paths. A detailed knowledge of the replenishment areas and of flow paths

(Fig. 407-19) leading to the areas of exploitation is fundamental for designing concepts for water resources management in complex aquifers with intricate flow conditions. The identification of the different hydrogeo-logical components of such systems is important for the development of

exploitation strategies of well fields in respect to quality (salinity) and quantity in order to build sustainable management of the water resources and land use.

Simultaneously, the knowledge about correct recharge areas allows tracking back to areas of anthropogenic pollution (vulnerability), particularly in highly fractured and karstified aquifers, where the reporting of catchment sizes is usually difficult or even unfeasible.

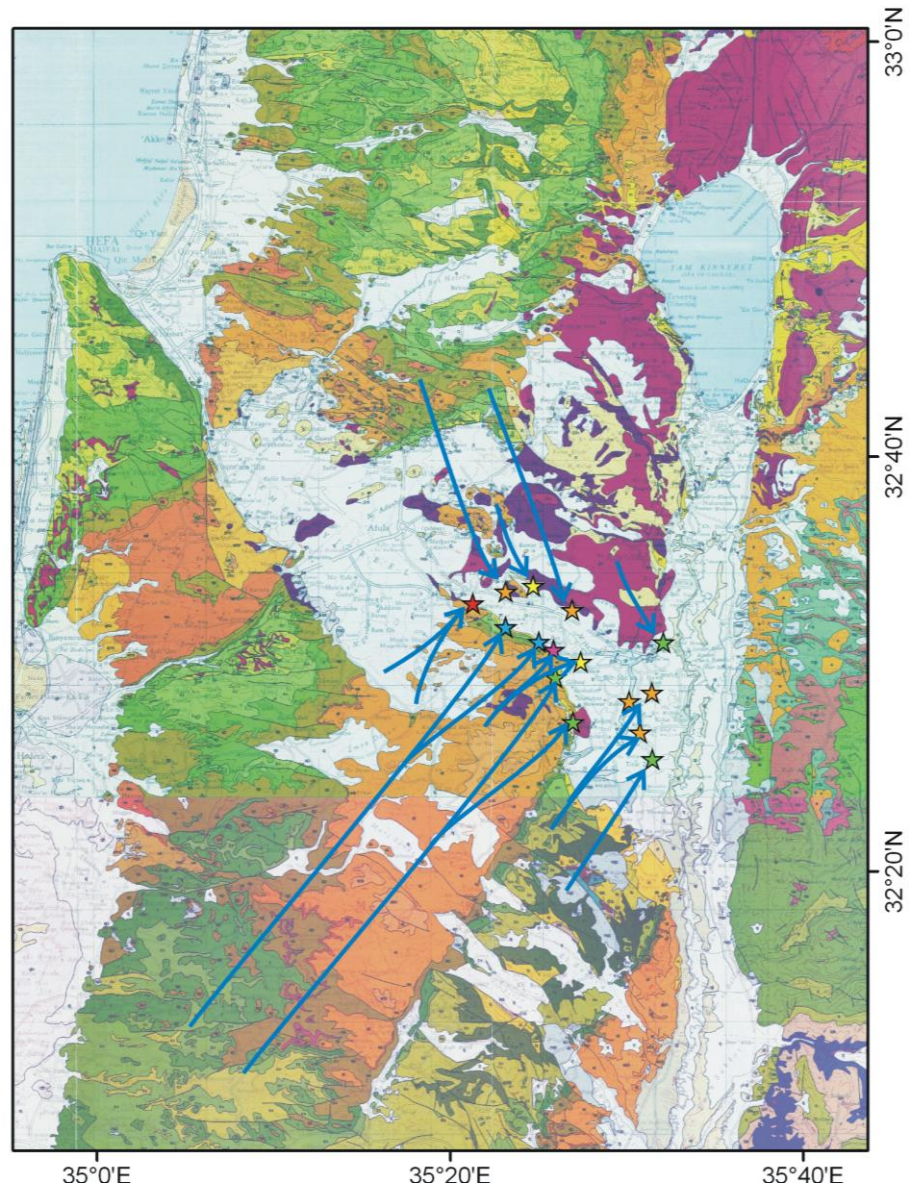


Fig. 407-19 shows the Bet She'an/Harod valleys with indications of flow paths and recharge areas of the respective groundwaters, exploited along the foothills of the Mountain ranges.

The spatial and temporal changes of the composition of the groundwater from the springs along Wadi Qilt stream in the Jerusalem–Ramallah Mountain slope area and in the Jericho Plain (Fig. 407-20), Palestine are both fed by the catchment. The residence time as well as the intensity of recharge plays the important role in controlling the changes in the chemical composition of spring water which is mainly affected by the distance from the main recharge area.

A very important factor is the oxidation of organics derived from sewage and garbage resulting in variable dissolved CO_2 . High CO_2 yields lower pH values and thus under-saturation with respect to calcite (and dolomite). Low CO_2 concentrations result in over-saturation, thus the beginning and at the end of the rainy season calcite saturation is achieved.

The degradation of DOM is a major source to increase water hardness and mineralization. A detailed analysis of dissolved species reveals that besides dissolution of carbonates, nitrate, chloride and sulfate are leached from soil and the aquifer rocks together with small amounts of Mg. Thus, Mg not only originates from carbonates but also from Mg-Cl saline waters included in the rocks. This effect is particularly high at the beginning of the winter season and lowest at its end.

Two zones of recharge are distinguishable. Along the eastern mountain slopes recharge is mainly by direct infiltration of precipitation and runoff of with less groundwater residence time and high flow rate. The second zone is near the western border of Jericho at the foothills, which is mainly fed by the underground water flow from the eastern slopes. This zone shows higher groundwater residence time and slow flow rate than zone 1. Both zones have varied isotopic signatures where the later zone shows more enriched deuterium values in the early season which confirmed the long residence of the groundwater which flushed out later and replaced by the new replenished groundwater that have more depleted values.

The main factors affected the groundwater residence time and flow rate are the geological structure of the aquifer, the amount of active recharge to the aquifer, and the recharge mechanism.

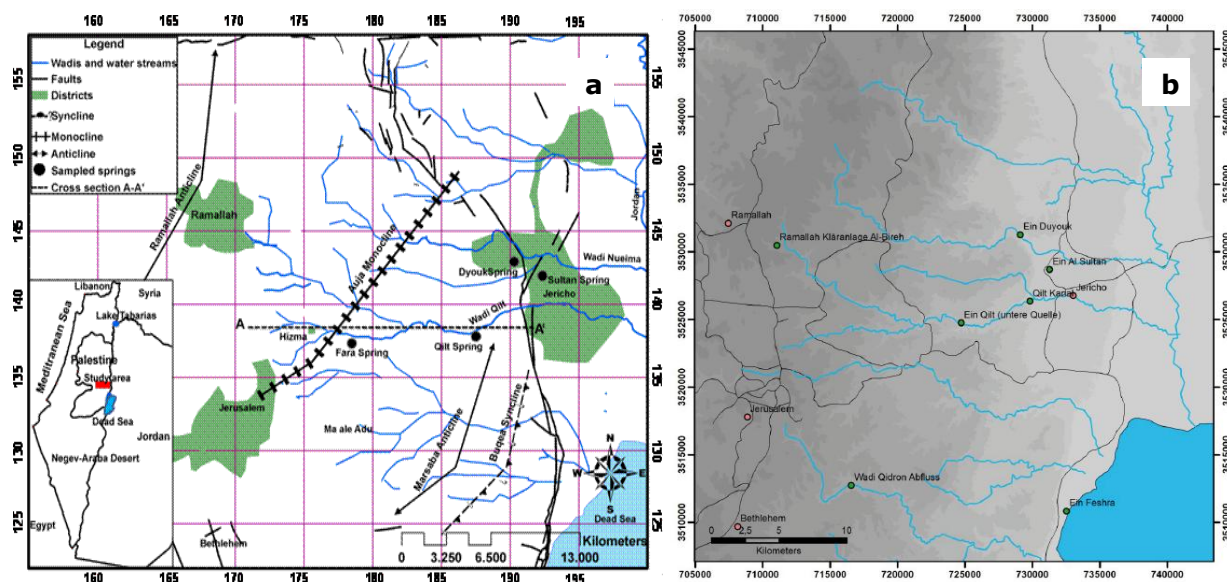
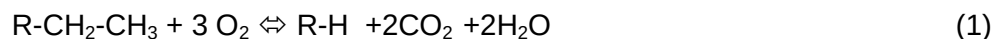


Fig. 407-20: Study area and location of springs in the eastern part of the Jerusalem-Ramallah basin (a) and the subcatchments of the region, indicated by blue lines (b).

The Jerusalem-Ramallah sub-basin is part of the eastern aquifer in the West Bank and extends from the Jerusalem-Ramallah Mts. towards the western border fault of Jericho and Auja. Geologically, it consists of karstified Upper Cretaceous lime- and dolostones. They host the Upper and the Lower sub-aquifer, separated by a marly and chalky aquiclude. Within Wadi Qilt, springs Ein Fara (Ferat), Ein Qilt and Ein Fawwar and in Wadi Auja the Ein Auja discharge perennially from the 170-200 m thick Upper one (Fig. 407-20). According to Toll (2001) and Wolfer (1998), these springs are strongly controlled by the Auja Monocline and Marsaba Anticline. Water resources in the study area are deteriorated by pollution from natural and anthropogenic sources. Runoff water mixes with treated and untreated wastewater and leaches garbage from the Bedouins and urban areas along its pathway.

In front of the outlets of Wadis Qilt and Nueima, several important springs, namely Ein Nueima, Ein Duyuk and Ein Sultan appear from a mix of clastic and evaporitic sediments. The further east, pumped groundwaters start to show enhanced mineralisation due to admixture of saline waters and dissolution of evaporates, both hosted in the Lower Jordan Valley graben fill.

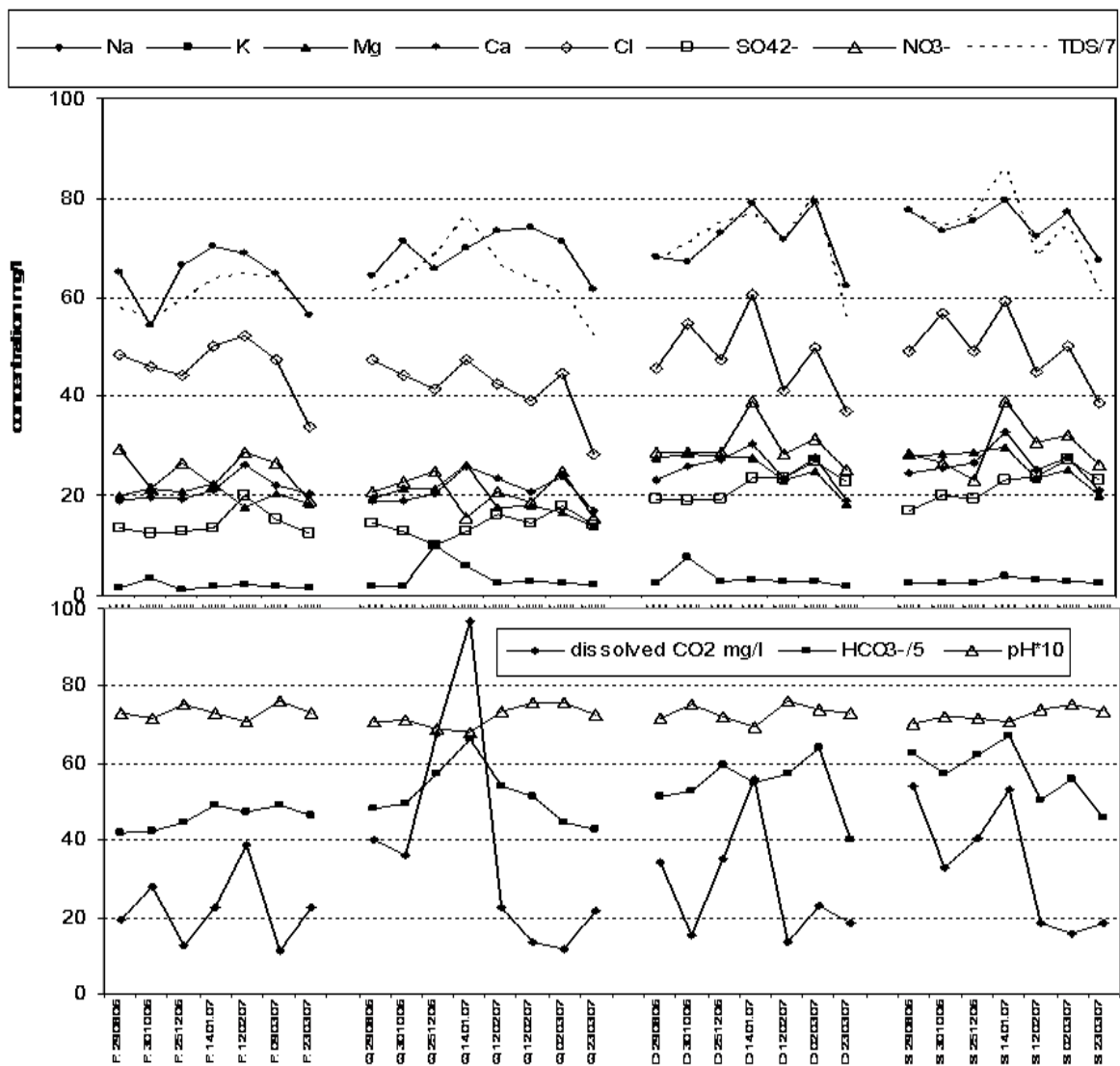
Within all the observed groundwaters, DOC plays a significant role. Organic substances, leached from soil and garbage, are oxidized according to reaction (1).



Because HCO_3^- is always greater than dissolved CO_2 oxidation of organics has a greater impact on dissolved CO_2 in closed systems and thus pH decreases (eq. 2).

$$\text{pH} = \text{pK}_1 + \log[\text{HCO}_3^-] - \log[\text{CO}_2] \quad (2)$$

DOC is the residual of organics dissolved in the early infiltrating water. At the end of the rainy season, enhanced values in groundwaters indicate that oxidation has not been efficiently decomposed the organic freight and might need more time. The initially, at the end of dry season, low values are the product of low water flow and negligible infiltration during the summer. Assuming that the high peak of dissolved CO_2 in Fig. 407-21 represents the water that was enriched in CO_2 during the summer season and is now replaced under the influence of the first significant precipitation event with a time interval of about 2.5 months characterizes the flow time from the recharge in the mountain aquifer to Ein Qilt, Ein Dyouk and Ein Sultan.



Fid. 407-21: Time-dependent concentrations of dissolved species in spring water from Ein Fara (F), Ein Qilt (Q), Ein Dyouk (D) and Ein Sultan (S)

This peak is not repeated as a response to later strong precipitation events, which suggest that the organics present as DOC are immediately washed out by water at the beginning of the rainy season. Towards the end the CO_2 concentration is the same in all springs and similar to that at the beginning of the winter period in Ein Ferat. Due to changes in dissolved CO_2 pH, varies and consists of an early and late branch (Fig. 407-21).

This increase in dissolved CO_2 induced dissolution of carbonates and thus Ca but not Mg increase. The dissolution of calcite dominantly leads to increase in TDS. The increase in the concentrations of Ca^{2+} , HCO_3^- , (and Mg^{2+}), especially during the dry period, resulted from the dissolution of the host matrix, mainly composed of calcite. Dissolution plays a role in the first half of the winter period. Thereafter, concentrations of most dissolved species and hence TDS decrease due to dilution. After the first rainfalls in early winter time the flow of water increases, the residence time decreases and thereby the possibility for decomposing reactions of DOC.

The step like trend of Mg and Na in Ein Dyouk and Ein Sultan reflects the dilution effect. Simultaneous SO_4^{2-} increases probably due to gypsum leaching from pockets in the Cretaceous aquifer and from Quaternary sediments in the Jericho area, and affects the low concentrated SO_4^{2-} much more than the highly abundant Ca from limestone dissolution. In Jericho springs Ein Dyouk and Ein Sultan, sulfate behaves oppositely to Mg.

At high water level in the aquifer, gypsum is leached from the overlying Quaternary Formation, which is abundant in the Jericho area but relatively rare in the recharge area. Hence, gypsum is an additional source for Ca and sulfate in Dyouk and Sultan springs, while it only plays minor role in Qilt and Ferat springs.

Nitrate concentrations in the spring waters, as indicator for (anthropogenic) pollution, correlate relatively well to SO_4 and Cl, which indicates irrigation return flow and/or infiltration of sewage (Fig. 407-22). The rather constant $\text{NO}_3^-/\text{Cl}^-$ ratio may be due to leaching both components from soil or this may be due to sewage.

The correlation of sulfate, chloride and nitrate reflect that these species are most probably introduced into the aquifer by infiltrating sewage along the wadi course. Indeed, Ein Dyouk and Ein Sultan yield significant higher nitrate concentrations than Ein Qilt and Ein Fara. The slope of the indicated trend line in Fig. 407-22 yields NO_3/Cl wt. ratios of 0.54, which is quite high indicating contamination by human activity.

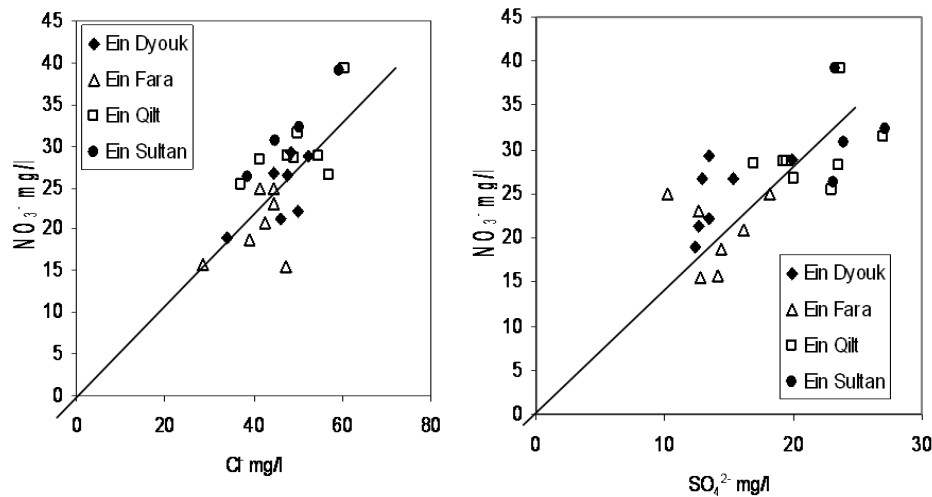


Fig. 407-22: cross plots of NO_3^- versus Cl^- (a) and SO_4^{2-} (b).

In general, the compositional changes in Ca and Mg concentrations mainly depend on the residence of water in the aquifer, which is controlled by the volume and mechanism of recharge as well as the distance from recharge area. The Mg/Ca ratio is commonly used as an indicator of the residence time of the water in aquifers resulting from the incongruent dissolution of calcite (CaCO_3), Mg-calcite and dolomite $(\text{Ca, Mg})\text{CO}_3$. The absolute ratios, however, do not yield a measure of the residence time. For instance, the Mg/Ca wt. ratio of 0.5 indicates long residence time in Fara and Qilt, but short ones in Ein Dyouk and Ein Sultan, although all these springs discharge water originally from the same aquifer. The mineralogical composition of the aquifer of the springs in Wadi Qilt show less soluble Mg bearing minerals than that from which the Jericho springs originate. Enhanced Br-concentrations in the springs of Wadi Qilt also refer to an input of sewage and/or agricultural fertilization and subsequent infiltration.

WADI QILT-FESHKHA-JUDEA : ANALYSIS OF ANTHROPOGENIC ORGANIC COMPONENTS IN THE
AQUIFER SYSTEM IN THE (NORTH-) WESTERN DEAD SEA CATCHMENT (CORNELIA
WILSKÉ, C. SIEBERT, UFZ)

Within this study, chemical components in the groundwaters are used to characterize and separate the groundwaters of the two main Upper Cretaceous aquifer units and to outline possible groundwater flows and their area of origin. Anthropogenic organic substances are considered to be significant for urban and agricultural inputs.

Urban wastewater in Jerusalem and Ramallah is partly collected and subsequently treated before it will be added to the Wadi drainage or collected in basins for agriculture irrigation. However, yet mostly untreated sewage of East Jerusalem get discharged into Wadis like Og and Qidron, being possible infiltration areas for the Upper Judea Group Aquifer. These untreated waters as well as treated waters (dependent on the treatment process and individual resistance of the substance) may (still) contain organic contaminants. Hence, urban areas are deemed to be emitter for substances like caffeine, carbamazepine, naproxene and artificial sweeteners like Aspartame and Acesulfame. Contrastingly, agricultural areas are supposed to be sources of pesticides like simazine, atrazine, DEET and metabolite like desethylatrazine.

METHODOLOGY

Samples for the analysis on organic parameters were taken in October 2012, February 2013 and May/June 2013. Surface water considered as the potential input sources of anthropogenic organic substances like the outflow of the Al-Bireh WWTP, the Wadi Og basin as well as the groundwater of the two main Cretaceous aquifers, the Pleistocene aquifer in the Valley and the spring outlets in Ein Feshkha were sampled (Fig. 407-23). For comparison, analyses of spring waters along the western coast and of well waters in the Lower Cretaceous Kurnub were taken from a parallel study.

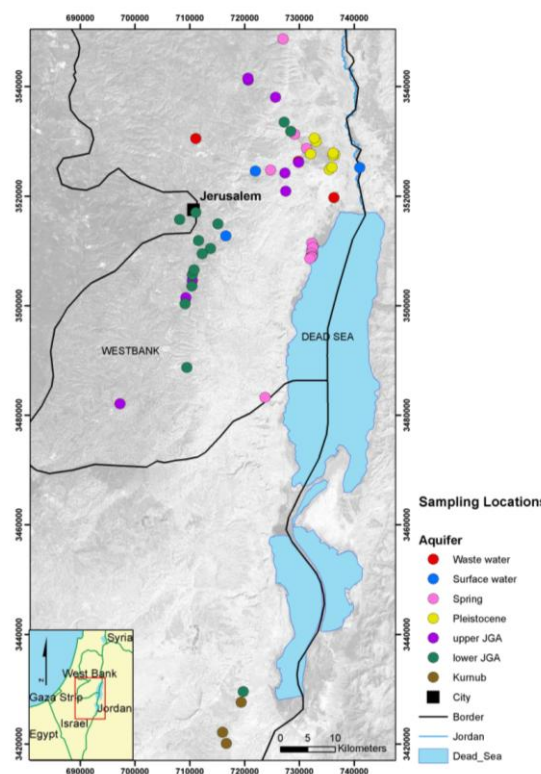


Fig. 407-23. Location of sampling points within the investigation area.

RESULTS

In Ein Feshkha and all wells and springs of the surrounding region, the concentrations of specific parameters e.g. caffeine, sweeteners, pesticides simazine, DEET, atrazine and degradation products like desethylatrazine were investigated. In May 2013 the analytical spectrum was extended to naproxen and aspartame, which are presented as well. Substances, which concentrations were below the limit of detection, are not presented.

During the post-processing of the samples it was found that the sorbent of the cartridges is under the existing conditions only limited suitable to bond acesulfame, leading to analytical results, lower than the real concentrations. Hence, presented acesulfame concentrations are not total concentration but can be used as additional binary indicator for urban input.

GROUNDWATERS OF THE UPPER JUDEA GROUP AQUIFER

The groundwaters from springs of the Upper Judea Group aquifer Ein Dyouk, Ein Samia and Ein Samia Well 2 are contaminated by organic pollutants from agriculture (Fig. 407-24, in reddish colours) and significantly by urban pollutants (in bluish colours). In May 2013, there are the

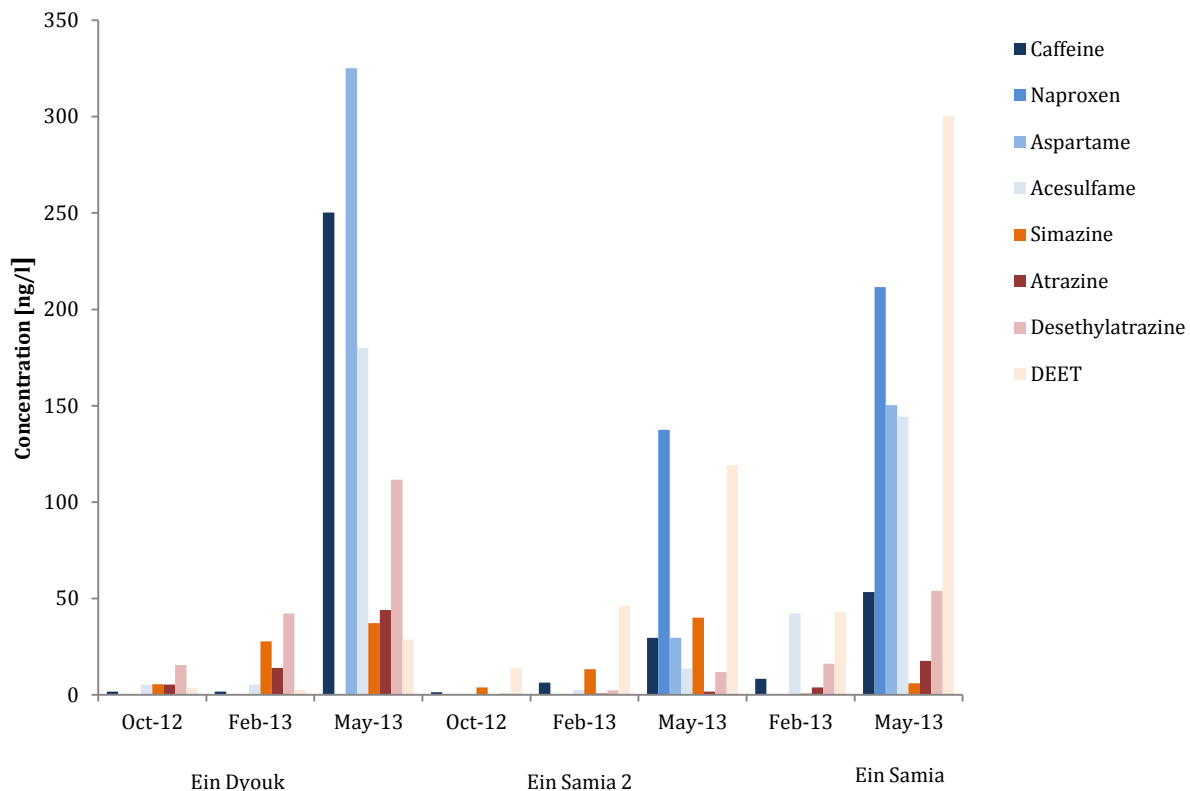


Fig. 407-24: Organic components in groundwaters from the Upper Judea Group. While Ein Dyouk 1 and Ein Samia 2 were sampled in Oct 2012, Feb 2013 and May 2013, Ein Samia is missing in the first campaign.

highest concentration considering all parameters and Ein Samia and Ein Dyouk showed similar pollutant patterns. This may indicate that infiltrating recharge from the previous rainy season mobilised these substances and flushed them through the aquifer. However, Ein Dyouk, situated at the outlet of Wadi Qilt is much higher affected than waters in the Auja catchment. This is also observable in waters from Ein Auja, which shows similar trends but very low concentrations of organics (Fig. 407-25). Surprisingly, only caffeine and acesulfame could be detected in that spring in May 2013, indicating a predominantly urban source of contaminants. Groundwaters in Ein Pazael are very low contaminated, showing individual concentrations of less than 30 ng/l and are in equal parts affected by urban and agricultural substances (Fig. 407-25). That refers to a different landuse and settlement structure for the catchment of Ein Pazael in comparison to the southwards situated basins of Auja and Qilt.

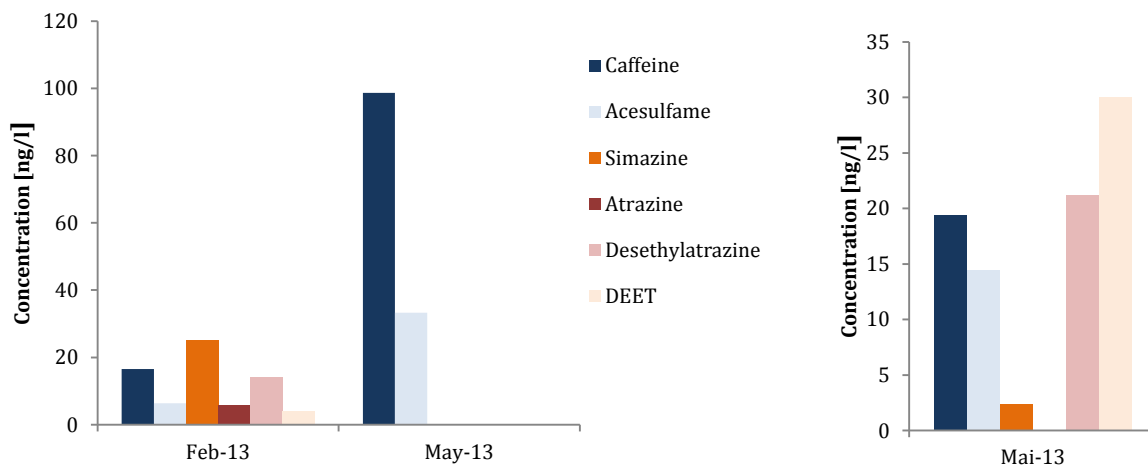


Fig. 407-25: Organic components of water from Ein Auja (left) and Ein Pazael (right).

The seasonal fluctuation, which could already be observed in spring waters of the Upper Judea Group, is repeated in groundwaters from wells drilled in the recharge area and transfer zone of that aquifer (Fig. 407-26). The lowest concentrations occur during the begin of the rainy season and in deep winter, while in May, a few months after the dry season started, pollutants appear in variable concentrations.

Beit Fayyar, located in the recharge area contains significantly less organic pollutants than those wells in the transfer- and discharge areas. Although being in general very low affected, water from Yatta Exploration Well contains in May 2013 very high concentrations of caffeine and aspartame (up to 500 ng/l), referring to a temporary active source of urban sewage. Compared to Ein Dyouk, water from the nearby well Jericho 2 is less contaminated, while water from Mitzpe Jericho 2 and 5, both pumping from Upper and Lower Aquifer, show a comparable trend and contamination pattern.

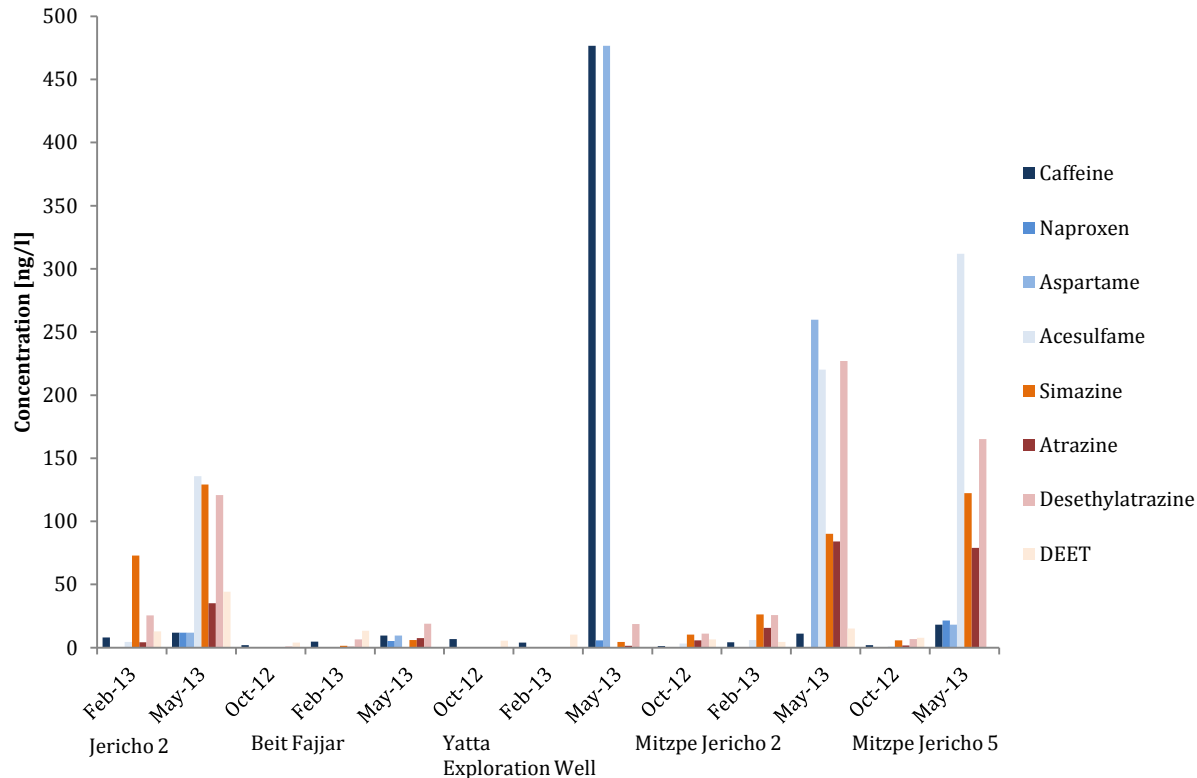


Fig. 407-26: Organic component distribution in groundwater from Upper Judea Group Aquifer. Groundwaters in Jericho 2 and Mitzpe Jericho 5 could not be sampled in Oct 2012 and Feb 2013, respectively.

GROUNDWATERS OF THE LOWER JUDEA GROUP AQUIFER

Groundwaters taken from the Lower Judea Group Aquifer in the Jerusalem area show very variable amounts of pollutants and pollution patterns, respectively (Fig. 407-27). Jerusalem 4, situated nearby the old city is much higher contaminated in respect to agriculturally used substances than the other groundwaters from the area in May. Due to the lack of agriculture in the surrounding of well no. 4 and in the vicinity of Jerusalem at all, the source might be leakage from dump- or storage-sites for pesticides, which get mobilised due to recharge. Interestingly, urban pollutants, such as caffeine, naproxene, etc. seem to be negligible throughout the winter, but become also mobilised from unsaturated zone due to recharge. In a first assumption, these facts indicate no intense source of urban pollutants (sewage, etc.) in the vicinity of Jerusalem, but a continuous pollution of the unsaturated zone, which get flushed into the aquifers during the rainy season. However, these interpretations are still under research and needs to be clarified in

more detail by the combination with inorganic and isotopic information, taken as samples at the same time.

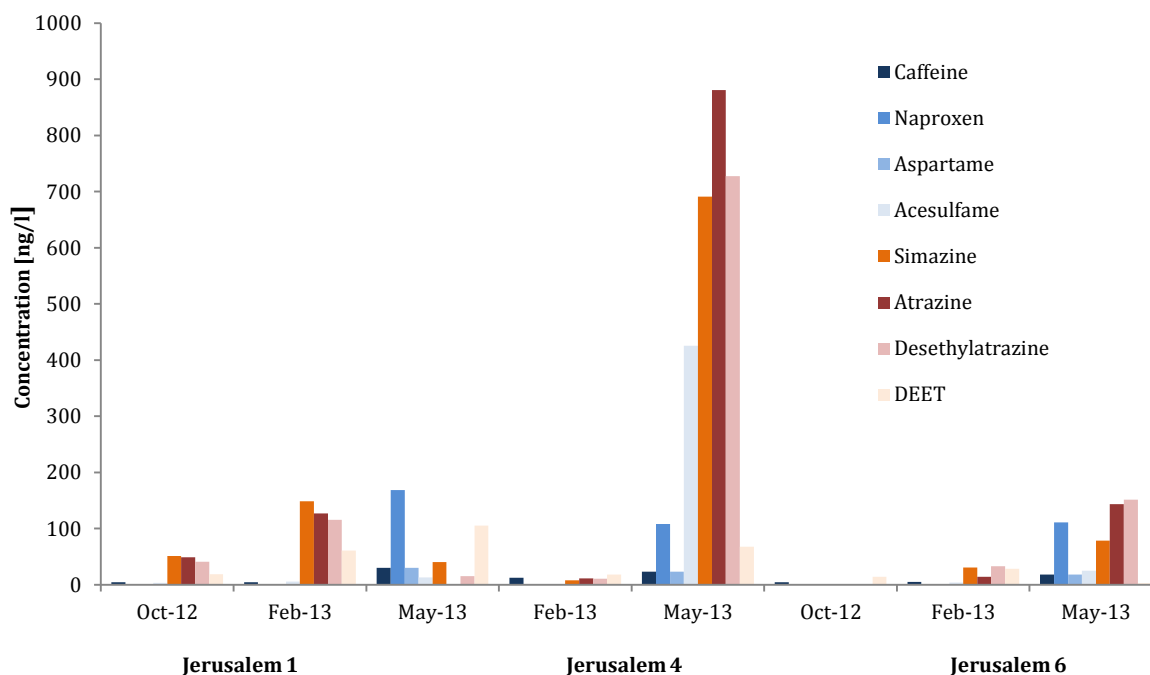


Fig. 407-27: Organic component distribution in groundwater from Lower Judea Group Aquifer. Groundwaters in Jerusalem 4 could not be sampled in Oct 2012.

Samples from other wells in the recharge area of the Lower Judea Group Aquifer, but also from the discharge areas nearby Jericho show relatively low concentrations of organics during the late autumn and deep winter (Fig. 407-28). In May however, concentrations increase as already known from the Upper JGA, but the pollution patterns vary. South of Jerusalem and Betlehem, in Herodion well field and Al Azaria wells, sewage seems to be responsible for the enriched urban tracers (bluish colours in Fig. 407-28). However, the latter wells and particular Azaria 1, show also significant contribution from agricultural areas. The same stands true for Jericho 4 and Shdemona 1 wells, which show high contributions of simazine and desethylatrazine from agriculture. Surprisingly low pollution is observable in PWA 3 and Bani Naim wells.

GROUNDWATER IN THE PLEISTOCENE AQUIFER

The sampled wells, which are located in the Pleistocene aquifer in the Lower Jordan Valley are mainly used for irrigation and are situated within or nearby Jericho. Some are partly surrounded by agriculture fields. In general the concentrations of anthropogenic substances are low

(<50ng/l) (Fig. 407-29). Desethylatrazine and DEET was proved in every sampling campaign. In May 2013, the water in the Arab Project wells contains higher concentrations of caffeine, naproxen, aspartame and acesulfame compared to February 2013, referring to sewage from the City of Jericho, which is located upstream the groundwater flow. Obviously, also in the

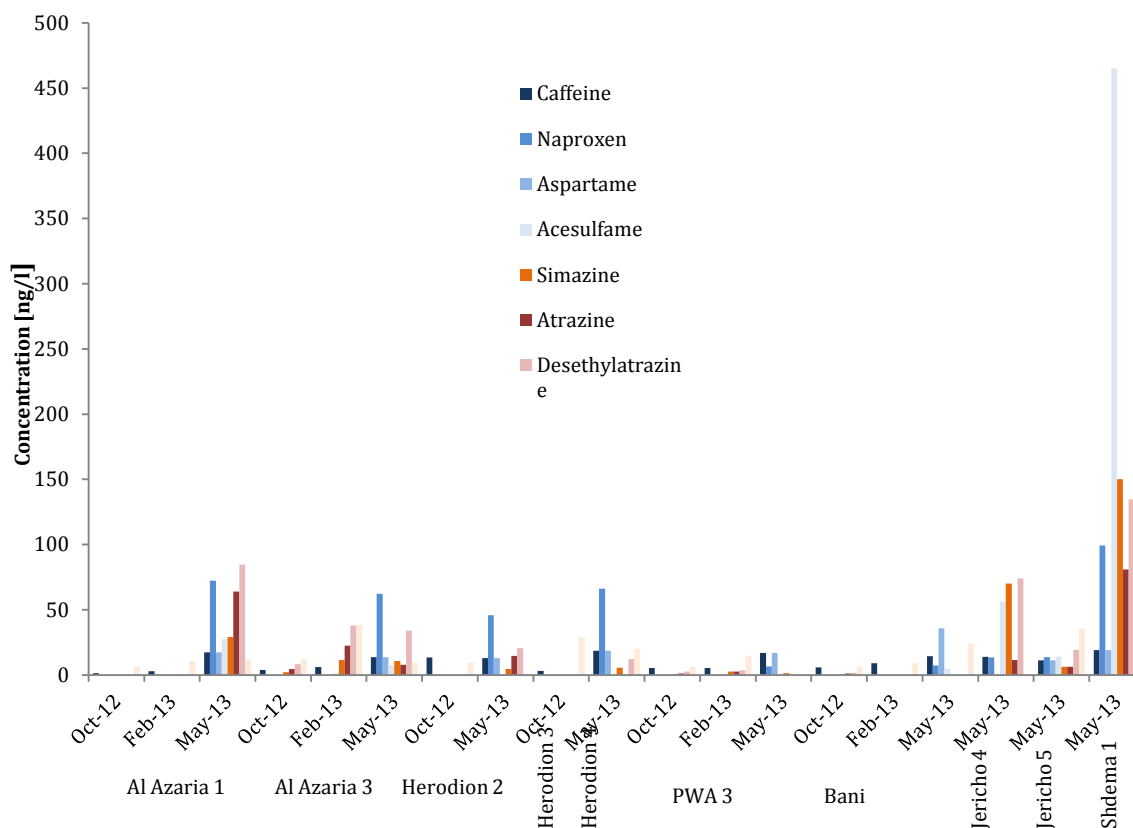


Figure 407-27: Organic component distribution in groundwater from Upper Judea Group

Pleistocene groundwaters, the flushing effect by groundwater recharge from wintertime is visible. Well Khader Hamaidat seem to be not connected to the Pleistocene Aquifer, but receives water from down faulted blocks of Cretaceous rocks. Water from Abu Kahlil is mainly affected by the agricultural activity in the surrounding area and could be improved by use of pesticides in a more sensitive way.

SURFACE WATER

Analyses of the surface water from the Wadi Og Basin, Wadi Qidron and treated water from the outflow of the Al-Bireh treatment plant is shown in Figure 407-29. The treated water of the Al-Bireh Treatment plant contains residues of acesulfame, caffeine and the pesticides. Aspartame is a very stable substance; hence, it is passing WWTPs and persists in the treated water. Of course, aspartame is found in untreated wastewater in the Wadi Qidron and Wadi Og Basin too.

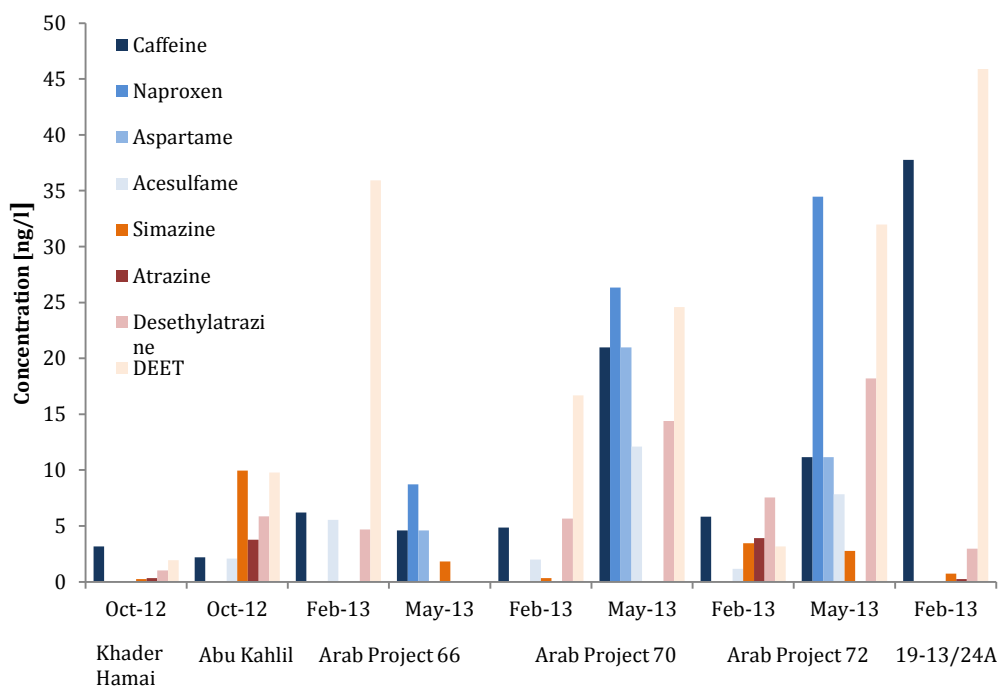


Fig. 407-28: Organic pollutants in wells in the Jericho area (Pleistocene aquifer).

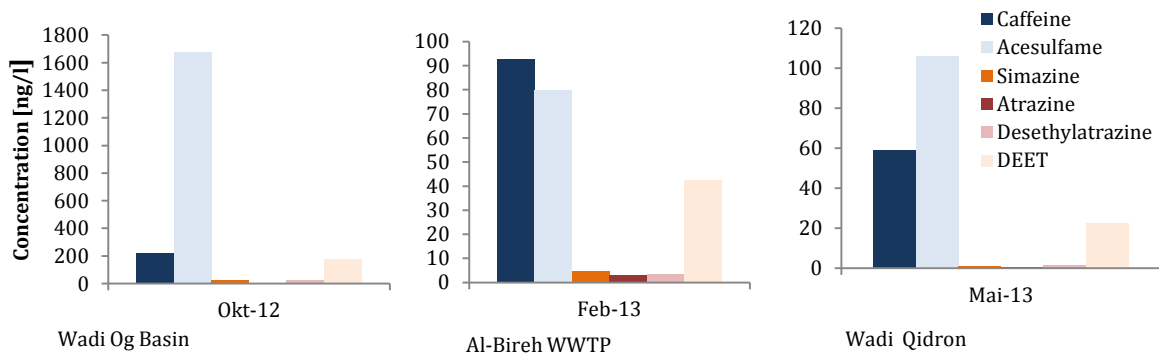


Fig. 407-29: Concentrations of Organic components in selected surface waters of the area.

EIN FESHKHA SPRINGS

In the Nature Reserve of Ein Feshkha a huge amount of springs appear. Those, which are less or marginal affected by contact with the Dead Sea sediments were chosen for analysing the contribution of the hard rock aquifer to the organic contamination in the spring area. Out of these 2 major springs are selected to show the results (Fig. 407-30). The summer spring (Ein Onait) and Enot Zukim, which is kept artificially alive, were sampled and show that all analysed substances are low (Caffeine < 10 ng/l, Atrazine and Simazine < 0,5 ng/l, Desethylatrazine < 2

ng/l) during late autumn and deep winter. However, in May 2013, mainly urban contaminants suddenly appear with immense concentrations of up to 2,400 ng/l caffeine, and 900 ng/l of desethylatrazine.

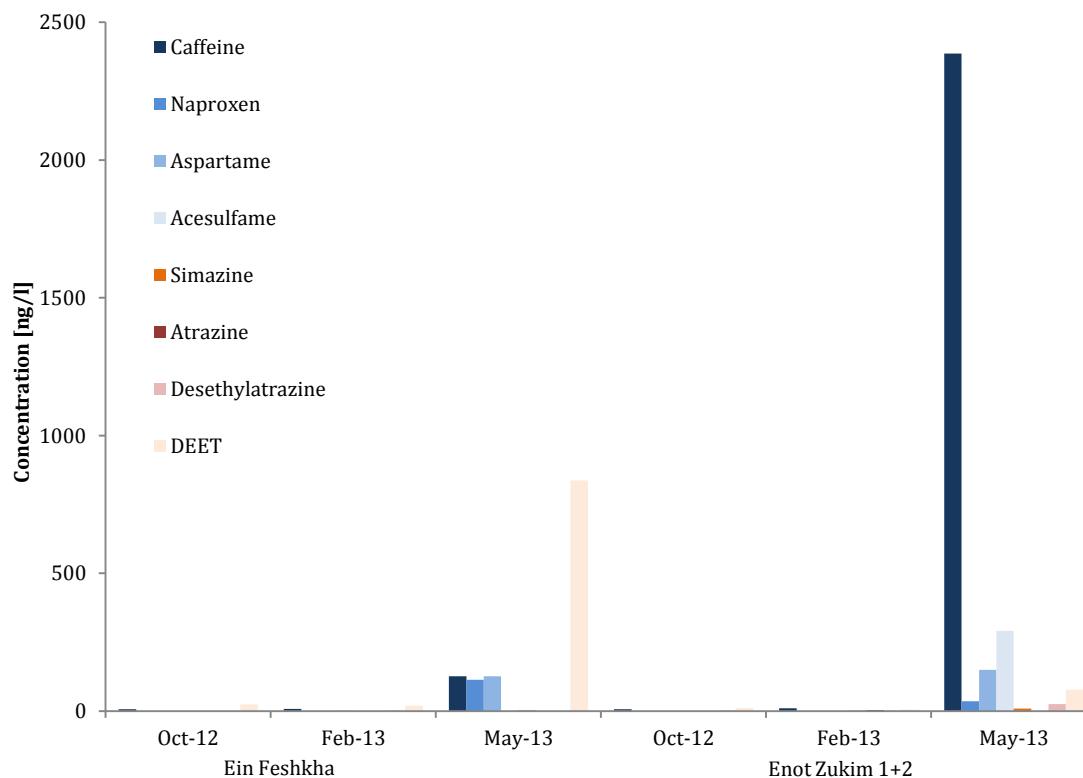


Fig. 407-30: Organic Components in selected spring waters of Ein Feshkha

CONCLUSION

The groundwaters in the tributaries of the Lower Jordan Valley are suffering commonly from infiltration of untreated sewage and leaking solid waste dump sites, both in urban, but also in rural areas with no connection or access to treatment facilities. Additionally, during recharge events flushing of the unsaturated zone leads to enhanced concentrations of organic agriculturally used residuals and metabolites in the investigated groundwaters. There is no trend observable, indicating accumulation of organic compounds in the studied Cretaceous and Pleistocene aquifers, neither in the Graben shoulder nor in the Graben itself. However, the appearance of seasonal enhanced values gives back information on impact of contaminating sites/areas in the particular catchments and the relative development of connectivity of sampling locations to quickly responding flow-systems (macro-pores, karstification).

Possible contamination with anthropogenic organic substances was investigated along the western Graben flank only, showing enhanced concentrations in Jerusalem and Ramallah areas with a diversion towards the Jordan Valley through the Qilt-Feshkha groundwater system, while Auja spring and springs along the Dead Sea shoreline are little or marginally affected, respectively.

Interestingly, in Jerusalem area, groundwaters from Lower Judea Group Aquifer are equally or even higher contaminated by agricultural compared to urban substances. In the Lower Jordan Valley, although agricultural use of the area is intensely, anthropogenic organic components in the groundwaters are rare. Analysed concentration of simazine (2µg/l), atrazine and desethylatrazine (100 µg/l) are below the guideline values of health significance in potable water given by the WHO.

Beyond that, surface water resources and their temporary storage facilities, e.g. Wadi al Arab Dam get endangered by huge sediment loads, carried during flash flood events. These sediments on one hand reduce storage volume but moreover, reduce water quality, particularly in stratified reservoirs with reducing conditions in the lower water masses. Under these constraints, the mobilisation of (heavy) metals becomes possible and in association with enhanced BSR further deteriorates the water quality.

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