Ajloun and Golan – a transboundary groundwater resource?

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Abstract

The conjoined application of major and trace elements and isotopic methods yield a deep insight into the development and flow paths of groundwater in the Golan Heights and Ajoun within the border triangle of Israel, Jordan and Syria. Despite location, salinity or temperature of spring or well waters, stable isotopes showed, that the main areas of recharge are the elevated Hermon-Massif and the plain area of southwestern Syria and northern Jordan, with high to medium annually precipitation amounts. Although not connected to the Golan Heights, Jordan may be involved in a comon system as the same Cretaceous aquifer is exploited. Derived flow paths of infiltrated groundwaters strongly indicates partial occurring lateral flow across boundaries from Syria to Jordan and Israel.
By means of the investigated groundwaters we could show, that the combined hydrochemical and isotopic approaches reveal complex and large-scale groundwater infiltration- and flow-systems much better than a focused view on a specific band of elements and changes somehow coomon knowledge on the observed resources. That may have implications on further use.

Key words: REY, stable isotopes, inter-aquifer flow

INTRODUCTION

Within the Western Levant, the climate gradient from semi-arid to arid is important for the generation of modern groundwater. Large groundwater aquifers occur all over Israel, Palestine and Jordan, although the entire region suffers from over-utilization of that freshwater resources. Because of decreasing precipitation southwards, resources in the north of Israel and Jordan are the most productive. Particularly, the Golan Heights (Israel and Syria) and the Ajloun (Jordan) rank as major extraction areas of groundwater of good quality and quantity. Both are separated by the tectonically forced gorge of the Yarmouk river, which is the international border between Israel and Jordan and further eastwards between Syria and Jordan. The gorge is assumed to be a hydraulic barrier.

Within the BMBF-funded projects GIJP (German-Israeli-Jordanian-Palestinian Joint Research Program for the Sustainable Utilisation of Aquifer Systems), and the multilateral IWRM project SMART (www.iwrm-smart.org; www.ufz.de/smart), hundreds of water samples were taken from all over the Jordan-Dead Sea rift-system to understand groundwater flow-systems and salinisation of resources. The following study was carried out to investigate the highly exploited freshwater resource in a relative humid Wadi Al Arab and assumable connections to the groundwater system in the Golan Heights. For that purpose, each sample was analysed for major and minor ions, rare earth elements including yttrium (REE+Y), stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$) and tritium as radioisotope.

The interaction of recharged precipitation with soils and permeable rocks in the catchment and along the flow path of the resulting groundwater defines its chemical composition. If the passed lithology is predominantly homogeneous, the water parcel receives a unique chemical signal, determined primarily by the particular major and minor mineralogy along the flow path. However, if the lithology varies along that path (e.g. inter-aquifer flow), the solute inventory is altered by the varying water/rock interactions.

Contrasting the major elements, REY behave differently: their saturation in groundwater is achieved immediately and their low concentrations (pmol/l) result from adsorption onto mineral surfaces and coprecipitation. The first water-rock interaction during infiltration establishs REY distribution in groundwater and during passage of pores, dissolved REY undergo ion exchange with and adsorb to mineral surfaces. However, after geological time spans, aquifer surfaces are in static equilibrium with the REY-content of the through-flowing water. Consequently, REY abundance in groundwaters reflects the leachable components of sediments and rocks of the recharge areas even if inter-aquifer flow occurs.

Stable isotopes of water δ^2H and $\delta^{18}O$ are less controlled by water-rock interaction than by climatic and geomorphological factors (temperature, elevation, distance from sea, etc.) at the time of replenishment. Applying the REY signature as a grouping criterion of groundwaters, δ18O vs. δ2H plots yield a new dimension in interpreting isotope data.

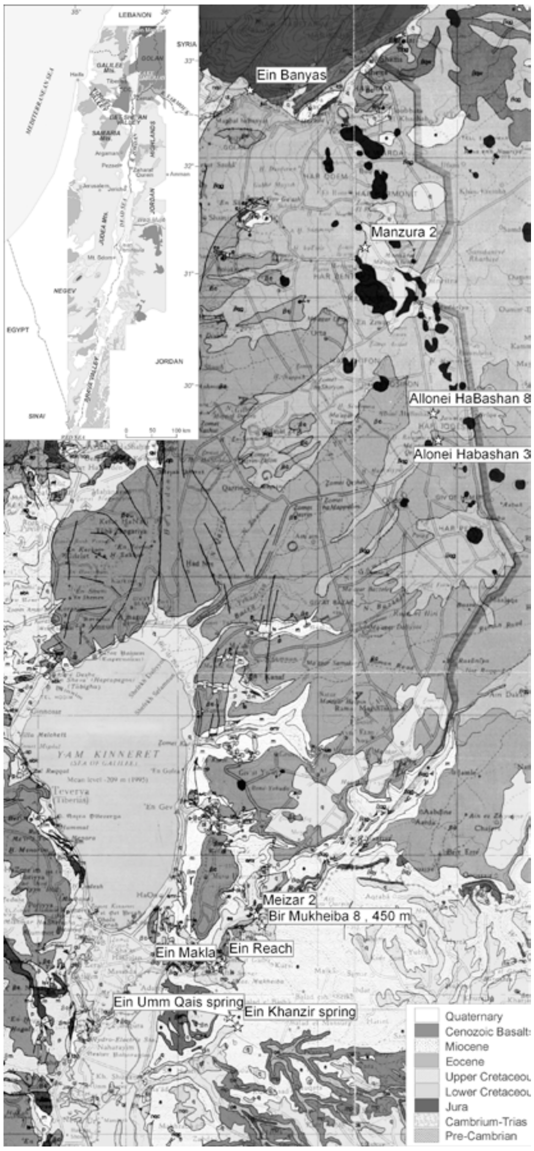

Fig. 1: geological map of the study area, situated in the north of Israel and Jordan, locations are indicated by stars.

STUDY AREA

Jordans northwesternmost corner, Wadi Al Arab and Yarmouk gorge as part of the Ajloun, is dominated by alternating strata of limestone, dolomite, chert, marl and phosphorites which are uplifted and dip towards the Jordan Valley and Yarmouk as a result of tectonical movements accompanying the Dead Sea Rift. The major hydrogeological units are the Coniac-Campanian A7/B2 aquifer (<400 m thick) and the Eocene B4 aquifer (<300 m thick) which are seperated by the marly B3 aquitard.

Along the fault driven lower Yarmouk Gorge (the border to Israel), B3 dives into the subsurface. Above, about 600 m Eocene to Oligocene Avedat Group (chalks, cherts and limestones) are followed by the up to 800 m thick sequence of Miocene to Pliocene sand-, lime- and mudstones and conglomerates (Kefar Gil'adi Group). Northwards, Golan is delimited by faults from the 2800 m (msl) high anticlinal structure of Mt. Hermon Massif. It consists of partly karstified lime- and dolostones of Jurassic and Cenoman-Turonian age and forms a typical transboundary groundwater basin between Israel, Lebanon and Syria.

The Golan Heights are predominantly covered by up to 600 m thick Pliocene-Qaternary alkali-olivine basalts, while only small deposits occur on (a) the northwesternmost nose of Wadi Al Arab, and (b) ne' of Irbid, being not thicker than some tens of meter and covering Eocene limestones (B4). Within the Yarmouk gorge, basalt flows are rarely observable at the rims. The basalt in Golan Heights is continued eastwards, where it covers vast areas of southwest Syria.

The average annual precipitation exceeds 1100 mm in the Hermon Massiv and declines to 300-500 mm in the Yarmouk gorge and in the Ajloun area (Margane *et al.*, 2002), leading to strong springs on the foot of Mt. Hermon. Springs emerge also on the Golan; along the margins of the Yarmouk gorge and within deep incised Wadis such as Al Arab, leading either to surface runoff (e.g. Jordan, Meshushim, Daliyyot) or large pools as in Hammat Gader.

SAMPLING

During field campaigns in 2001, 2004 and 2007/2008, water samples were collected at 44 locations in Wadi Al Arab and its surroundings, in the Golan and in the Yarmouk gorge to cope with the general aim of the project. Out of that, 11 locations show indications concerning the question, whether Yarmouk gorge is permeable for groundwater or not. In addition and in order to determine the easily leachable fraction of REY for various aquifer rocks, predominant rocks were sampled and leached. Sampling and lab prcedure for rocks is described in detail in Möller & Giese (1997), for water samples in Siebert (2006).

RESULTS

REY in rocks and corresponding leachates

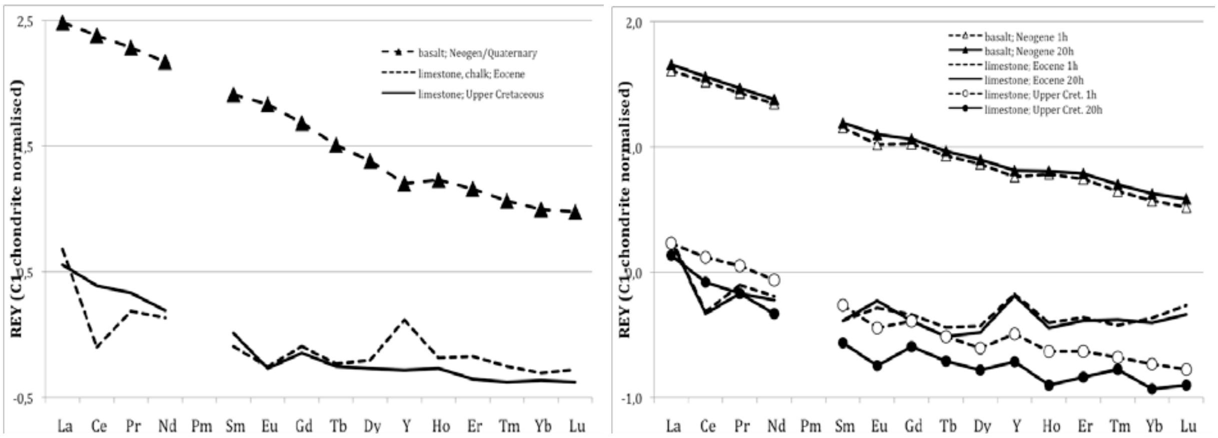

Fig. 2: C1-chondrite normalised REY patterns of (a) selected rocks and (b) their corresponding 1 hour (h) and 20 h leachates.

Eocene limestone and chalk show strong negative Ce-, and positive Y-anomalies, typical for marine and clay poor limestones (Dulski *et al.*, 1977), not observable in Upper Cretaceous rocks, pointing on higher abundance of clay minerals, i.e. marls.

The leachates of Upper Cretaceous and Eocene limestones, as predominant water conducting strata, are similar to their rocks because of dissolution of calcite (Fig. 2). Consequently, abundance of Y and medium to heavy REY (Eu-Lu) in Eocene rock leachates is higher than in the analysed Upper Cretaceous ones (Fig. 2b). Hence, Cretaceous limestone patterns decrease stepwise, while Eocene patterns are relatively horizontal. The normalised basalt pattern and their corresponding leachates show a continuous decrease from La to Lu. In magmatic rocks Y behaves as Ho (Bau and Dulski, 1995), resulting in a small step. According to Irber (1996) the similarity between REY patterns of basalt and its leachates indicates, that the glassy matrix has already reacted with groundwater.

Although REY are expected to be not as leachable under natural conditions (pH=6 to 9) as in lab experiments (pH=3), their leachte patterns give hints for the processes occuring under water/rock interaction and affecting REY fractionation.

REY IN SELECTED GROUNWATERS

Groundwaters in Figure 3a show REY patterns decreasing from La to Lu, with variable Ce-, negative Eu-, positive Y- and Gd-anomalies, resembling those of limestones. The water of Ein Banyas spring, discharging from the karstic Mt. Hermon massiv, is dominated by a remarkable negative Ce-anomaly which is much smaller in waters from Manzura 2 and Alonei HaBashan 3. These anomalies point either on clay poor limestones or oxygen-rich conditions (Bau, 1999) as expected in karstic systems. Actually, the described waters show Eh-values of +228 mV up to +445 mV (standart hydrogen electrode).

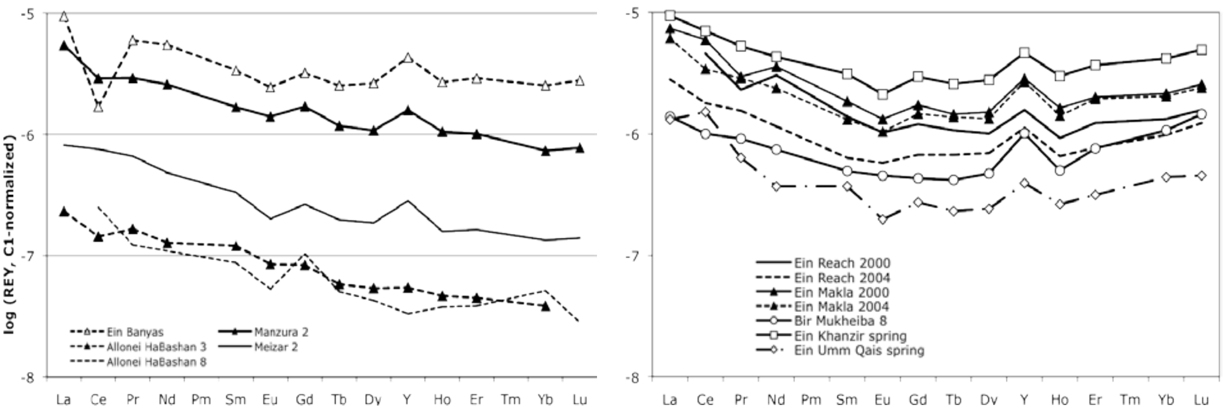

Fig. 2: REY pattern of groundwater from Golan Heights, Yarmouk gorge and Wadi Al Arab (Ajloun), referring to specific aquifers and/or recharge areas of (a) calcareous and (b) basaltic composition.

Similar but with no Ce-anomalies refer waters from Meizar 2 and Alonei HaBashan 8 to either lost of oxygen because of reducing conditions (Eh=-105 mV in Meizar 2) and hence repulping of former precipitated (Fe, Mn)OOH complexes, usually scavenging REY and preferential Ce or marly limestones.

Groundwaters with variable anomalies of Ce and Y but a minimum abundance of C1-normalised medium REY (Fig. 3b) are typical for basaltic aquifers (Paces *et al.,* 2001). These soup-bowl like pattern are dissimilar to the leachates of basalts, because water/rock interaction depends on various factors. Oxidizing sulfides cause free H_2SO_4 which improves weathering of minerals. Albitisation of plagioklas releases Ca which precipitates as calcite on porewalls, observable in basalts of Golan Heights (Siebert, 2006). The easiest weatherable mineral within the basalts is olivine, releasing Fe which precipitates as (Fe,Mn)OOH. Both processes intensely evoke coprecipitation of REY and hence distinct fractionation, developing more or less that soup-bowl shape.

Since REY in groundwaters resemble the lithology of their respective recharge areas, in principle two types of infiltration areas are definable: (a) limy and (b) basaltic.

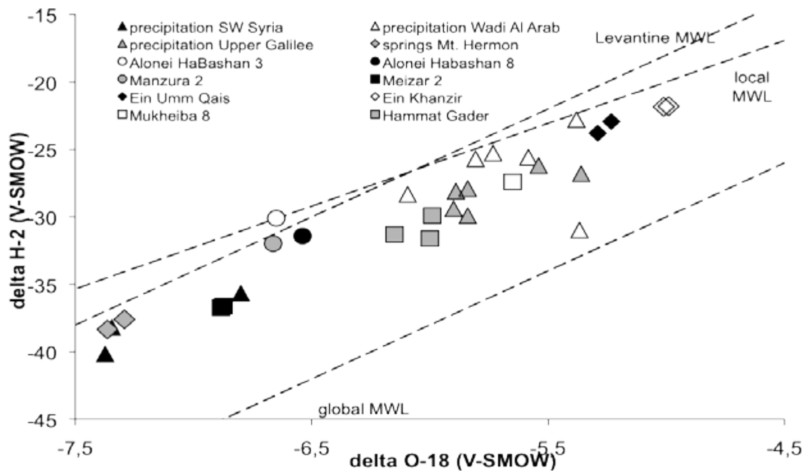

Fig. 4: shows stable isotopes of water (18O and 2H) standardised to Vienna Standart Mean Ocean Water (V-SMOW). Dashed lines indicate Levantine, local and global meteoric water lines (MWL), respectively.

Symbols in Figure 4 indicate the stable isotope composition of the sampled waters and show, all groundwater and precipitation samples are located between the levantine and global MWL. Only Alonei HaBashan 3 catches the local MWL. That common behaviour points to strong evaporation immidiately after rainfall and before precipitation finally leaves the atmospheric affected unsaturated zone and becomes groundwater. Evaporation leads mainly to enriched $\delta^{18}O$ and fewer entriched $\delta^{2}H$ signatures in the water, pictured by a positive shift along the axes.

Springs in Wadi Al Arab (Ein Umm Qais and Ein Khanzir) show heaviest isotopic composition, even heavier than the respective precipitation in the area. On the other side, Ein Banyas, recharged in the high elevated Mt. Hermon Massif, represents the lightes water (Fig. 4), as result of the temperature and elevation effect. Investigated groundwaters from Golan Heights and Yarmouk Gorge are distributed in between. However, they show unusually light signatures compared to precipitation falling in their recharge areas (in Fig. 4: “precipitation Upper Galilee”, representing average precipitation on Golan Heights) (Siebert et al., 2009).

Relatively similar signatures to the Hermon Massif are observable in precipitation over the SW corner of Syria, which is due to the continental effect.

CONCLUSIONS

By combination of information, gathered from stable isotopes and REY analyses, most of the groundwater in the region show distinct inconsistencies concerning common knowledge and hydrochemical results.

Alonei HaBashan 3; 8 and Manzura 2 are drilled into the basaltic cover of the Golan Heights. However, REY signatures refer clearly to a limy and in Alonei HaBashan 3 and Manzura 2 wells to karstified lithology in their recharge area. The isotopic compositions of Alonei and Manzura wells are much lighter than recharge in the Golan Heights pointing to recharge in the elevated Hermon Massif, later percolation into the basalts and flow southwards.

The water in Meizar 2 is obtained from Upper Cretaceous limestones. Because (1) groundwater in that strata flows southwards, (2) REY indicate limestone catchment and (3) the entire Golan Heights are covered by basalts, its water was originally replenished in the Hermon region too. That hypothesis is supported by the very light isotopic signatures of the water.

On the other hand, springs in Hammat Gader (Ein Reach and Ein Makla) and in Wadi Al Arab (Ein Umm Qais; Ein Khanzir) emerge from Eocene B4 aquifer, although their REY signatures clearly show a basaltic area of replenishment. Ein Umm Qais and Ein Khanzir closely emerge on a limestone ridge, of whats west is covered by basalts. Although their assumed catchments would be further eastwards, both springs are mainly recharged by the basaltic area, fitting to outcomes of Rödiger *et.al.* (in prep.).

Groundwater in Hammat Gader, situated on the southern flank of the Golan obviously infiltrate into the basalts above and percolate towards B4 aquifer. At the same time, stable isotopes show that the area of infiltration must be situated in the higher elevated Golan Heights or in the Syrian Golan. The first assumption is not possible, because in that case, flow paths of groundwater within the Israelian Golan Heights would cross each other.

Well Mukheib 8, situated on the southern rim of the Yarmouk Gorge and drilled into A7/B2 aquifer shows REY signatures clearly referring to a basaltic infiltration area and its isotopic compositions is similar to precipitation over Wadi Al Arab. However, the entire Ajloun neither bears volcanic rocks over outcrops of the A7/B2 formation nor in necessary amounts anywhere else. Consequently, Mukheiba 8 must receive water from the areas north of the Yarmouk, where the vast basalt covers exist. Although it would be the nearest possibility, Israeli Golan does not feed the Mukheiba area but the basalt areas in SW Syria do. That assumption is supported by the investigations of Salameh (2004). Groundwater flow from Israeli Golan Heights cannot occur because groundwater flow within the Ajloun part of the A7/B2 is directed northwestwards. The relatively enriched isotopic composition of Mukheiba 8 can be argued as result of strong evaporation during infiltration process into the basalts of Jebel Druse Volcan field.

As a result of that study, the Yarmouk gorge and the international borders of Jordan, Syria and Israel are not a compulsory boundary for groundwater, flowing according to natural conditions.

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