Salinity sources of Kefar Uriya wells in the Judea Group aquifer of Israel. Part 1—conceptual hydrogeological model

D. Avisar\textsuperscript{a,}\textsuperscript{*}, E. Rosenthal\textsuperscript{a}, A. Flexer\textsuperscript{a}, H. Shulman\textsuperscript{a}, Z. Ben-Avraham\textsuperscript{a}, J. Guttman\textsuperscript{b}

\textsuperscript{a}Department of Geophysics and Planetary Sciences, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel
\textsuperscript{b}Mekorot, Water Supply Company, 9 Lincoln St., Tel Aviv 61201, Israel

Received 8 January 2001; revised 17 June 2002; accepted 18 July 2002

Abstract

In the Yarkon–Taninim groundwater basin, the karstic Judea Group aquifer contains groundwater of high quality. However, in the western wells of the Kefar Uriya area located in the foothills of the Judea Mountains, brackish groundwater was locally encountered. The salinity of this water is caused presumably by two end members designated as the ‘Hazerim’ and ‘Lakhish’ water types. The Hazerim type represents surface water percolating through a highly fractured thin chalky limestone formation overlying the Judea Group aquifer. The salinity of the water derives conjointly from several sources such as leachates from rendzina and grumosols, dissolution of caliche crusts which contain evaporites and of rock debris from the surrounding formations. This surface water percolates downwards into the aquifer through a funnel- or chimney-like mechanism. This local salinization mechanism supercedes another regional process caused by the Lakhish waters. These are essentially diluted brines originating from deep formations in the western parts of the Coastal Plain.

The study results show that salinization is not caused by the thick chalky beds of the Senonian Mt Scopus Group overlying the Judea Group aquifer, as traditionally considered but prevalently by aqueous leachates from soils and rock debris. The conceptual qualitative hydrogeological model of the salinization as demonstrated in this study, is supported by a quantitative hydrological model presented in another paper in this volume.

© 2002 Published by Elsevier Science B.V.

Keywords: Sources of groundwater salinity; Aqueous leachates of rocks; Salinization by deep brines; Percolation through chimney-like systems

1. Introduction and scope of investigations

Along the mountainous backbone of Judea and Samaria, the subsurface water divide determined by structure, stratigraphy and karst developments, creates two groundwater basins. The western one is known as the Yarkon–Taninim basin (Weinberger et al., 1994) (Fig. 1) in which groundwater flow in the Judea Group aquifer, of Cretaceous age. This aquifer is a major resource of fresh water for both Israelis and Palestinians. The groundwater of the eastern basin, flow to the Dead Sea-Jordan Valley and is beyond the scope of this study.

In the Yarkon–Taninim basin, the Judea Group aquifer contains groundwater of low salinities (< 100 mg/l Cl, Weinberger et al., 1994). However, in the southwestern foothills of the Judea Mts, brackish groundwater was locally encountered in this aquifer (Rosenthal et al., 1999). In the well field...
of Kefar Uriya located in the northern part of Hashefela Syncline (Fig. 1), characteristic phenomena of groundwater salinization, mainly generated by excessive groundwater exploitation, were observed since the 1950s.

The main scope of the present study was to elucidate the hydrogeological model of the study area. To reach this goal, use was made of updated stratigraphic, structural, tectonical and paleogeographical evidence (Bruner and Landa, 1991; Fleischer et al., 1993). Another important target was to identify the origin of the brackish waters, to determine the extent of their distribution and to understand the processes that disperse saline waters within the fresh waters of the Judea Group aquifer. Hydrochemical parameters were used as natural tracers and facilitated the elucidation of the regional groundwater flow model.

The essence of the present study is to link the regional model based upon hydrogeological and hydrochemical evidence with the quantitative hydrological model which is presented by Mandell et al. (2001) (published in this same volume).

2. Regional hydrogeological setting

The Judea Group succession is composed of a thick (600–800 m) sequence of hard, karstic and permeable limestone and dolomite interbedded with argillaceous beds of lower permeabilities (Fig. 2). Such low-permeability rocks separate the upper and lower parts of the Judea Group sequence, thereby creating two aquifers: (1) The Yagur Formation of Albian age, composed mainly of massive dolomite and limestone layers forming the lower aquifer and, (2) The Negba (and its equivalent formations) and Bina Formations of Cenomanian–Turonian age which contain dolomite and limestone layers interbedded with subordinate amounts of marl beds. The Negba and Bina Formations form the upper aquifer (Fig. 2). The recharge area of these aquifers are exposures in the western parts of the Judea and Samaria Mountains covering an area of about 1800 km². Within the Judea Group, groundwater flows towards west and northwest to the Yarkon and Taninim springs which are the natural outlets of the two aquifers. Water wells are located mainly on the margins and in the foothills of the high (600–1000 m) Judea–Samaria anticlinorium (Fig. 1).

In the western foothills of the mountains and further westward, beneath the Coastal Plain, the Judea Group aquifer is unconformably overlain and confined by the Mt Scopus Group composed of massive chalk and bituminous chalk of Senonian age and by Early Tertiary (Paleocene) chalk, marl and shales attaining a thickness of 300 m. The sequence of the Mt Scopus Group is subdivided into several formations (Figs. 2 and 3) which are built of chalk, bituminous chalk, marl, shales, brecciated chert with some horizons of phosphorites (Flexer, 1968). The overall thickness of Mt Scopus Group in the study area fluctuates between 50 and 300 m. Because of the prevailing chalky-shaly composition of the lithological ensemble, the Mt Scopus Group was always regarded as a regional aquiclude overlying the Judea Group aquifer (Blake and Goldschmidt, 1947). However, later investigations (Bentor and Vroman, 1960; Flexer, 1968) revealed that the Menuha Formation which occurs at the base of the Mt Scopus Group, consists of hard, highly fractured chalk. This was confirmed by the findings of Buchbinder (1969) who described the Ka’akule member in the lower part of the Menuha Formation or the Har Zefat member of the En Zeitim Formation (Flexer, 1968). Rosenthal et al. (2000) indicated that in certain areas in which the En Zeitim Formation is composed of hard, fractured limestone beds, it acts as a continuous aquifer with the underlying Judea Group. These beds should be considered as permeable and form in many cases, one hydrogeological entity with the underlying aquiferous Bina and Negba Formations (Judea Group).

The chert beds of the Mishash Formation are usually brecciated and may act as local, low-yield aquifers. Although the Mt Scopus Group is built by and large by a uniform succession of chalk and shales and contains several lithological and mineralogical components which are essential for the elucidation of groundwater salinization processes in the study area. The En Zeitim Formation (the equivalent of the Menuha and Mishash Formations) overlying the upper aquifer is characterized by a thick sequence of bituminous chalky marl rich in organic material and containing a high amount of sulfides. The Taqiye Formation (Buchbinder, 1969)
Fig. 1. Location map showing the Kefar Uriya well field located close to the western foothills of Judea Mts and in the northern part of the Hashepela syncline. Line A–A' represents the section shown in Fig. 3. Line B–B' is shown in Fig. 4.
Fig. 2. Hydrostratigraphic columnar section.
Fig. 3. Schematic geological cross section (A–A’, see Fig. 1) of the Kefar Uriya well field indicating the brackish wells (4, 10) located beneath the fissured beds of the Menuha Formation and the accumulation of grumosol and rendzina soils. The eastern water wells producing fresh water are drilled beneath thick sections of Senonian Formations. The Kefar Uriya anticline controls the differential erosion of the Senonian structure forming a topographic depression with a ‘funnel or chimney-like’ structure (TD, total depth, in m).
exposed in the area, contains a profusion of marcasite and pyrite and shales containing bituminous material. Further oxidation processes due to exposure and erosion, brought to the massive formation of gypsum occurring mostly in joints and in veins. The topographic depression extending over the Kefar Uriya well field and particularly over the saline wells, acts as a sink accumulating rock debris and soil which are rich in sulfides and sulfates. The leachates of these components may percolate to the upper aquifer in those places in which the overlying Mt Scopus sequence is of reduced thickness.

The thick sequence of shales of the overlying—mostly Neogene—Saqiye Group and the laterally aligned chalky marl of the Albian Talme Yafe Group, act as impervious barriers along the western boundary of the Yarkon–Taninim aquifer (Figs. 2 and 4). The Saqiye Group is associated with major sedimentary cycles, each commencing with a marine transgression and terminating with a westward regression accompanied by deeply cutting erosional channels and creating unconformities (Gvirtzman and Buchbinder, 1969). One of these sedimentary cycles is represented by the evaporites of the Mavqi'im Formation (containing gypsum and halite) deposited in the Neogene channels and reflecting the regional Messinian desiccation event (Gvirtzman and Buchbinder, 1978). These evaporites are in direct lateral contact with the Judea Group Aquifer (Fig. 4).

3. Findings

The chemical composition of groundwater in the study area is presented in Table 1. Considering their Cl-concentrations, two salinity groups were discerned.

(a) Fresh groundwater which were identified in wells 2, 3, 6, 7 and 9a located along the eastern margins of the study area (Fig. 1) producing water from the upper aquifer, with Cl-concentrations of 170–183 mg/l.

(b) Brackish groundwater occurring in wells 4, 5, 8 and 10 located along the western margins of the area (Fig. 1). The groundwater are produced from the upper aquifer (Fig. 3) with Cl-concentrations as high as 430 mg/l.

The characteristics of these waters are summarized in Table 2. The chemistries of the fresh and brackish waters closely resemble though the brackish waters have higher concentrations of $H_2S$ and slightly higher values for the $SO_4/HCO_3$ ratio.

In the Kefar Uriya area the producing upper aquifer is overlain by strata of Mt Scopus Group which underwent differential erosion.

In those wells which produce fresh groundwater most of the Mt Scopus section remained intact reaching a thickness of 240 m. In well 9a water of high quality are produced from aquifer beds which occur only 46 m below the base of relatively thick section of beds of the Mt Scopus Group. In wells 3 and 6, located beneath thick Senonian beds (140–240 m) and also producing high quality water, the thickness of the interval separating between base Mt Scopus sequence and the top of the perforated casing, is negligible or does not exist at all (Fig. 3, in yellow).

Wells 4 and 10 (Fig. 3) which produce brackish water, most of the Mt Scopus sequence was eroded leaving behind sections of 35 and 67 m of the fissured Menuha Formation which is covered by soils filling in a local depression forming a funnel-like structure (cross section 7 in Buchbinder (1969) and Fig. 3 in the present paper). In this part of the study area, the brackish water are pumped from aquifer beds which are 115–214 m below the base of the thin sequence of Mt Scopus Group beds (Fig. 3, marked in yellow).

4. Sources of groundwater salinization—discussion

According to a traditional postulate, salinization processes in the upper aquifer were attributed to (assumed and chemically unexplained) residual salt sources within the chalk-dominated rock-sequences of the Mt Scopus Group. Kroitoru (1987), Ecker (1995), Livshitz and Katz (1997) and Guttman and Ettinger (1997), suggested that percolating fresh rainwater push the (unidentified) ‘Mt Scopus salts’ downward into the underlying Judea Group aquifer. It was also claimed (though not proven) that
Fig. 4. Regional geological cross section (B–B', in Fig. 1) in the Kefar Uriya region. The erosive Neogene channel is filled with beds of the Saqiye Group including evaporites of the Mavqim Formation which are in direct contact with the Judea Group aquifer (Negba Formation). The deep faults cutting through the Judea Group and through younger beds are potential eastward flow-paths for saline water of the Lakhish type saline waters. Note the significant variations in the thickness of Senonian Formations.
whenever the Judea Group aquifer was underlying thick sections of the Mt Scopus Group, ground-water derived from the upper aquifer, would be brackish. Hence, the thicker the overlying Mt Scopus Group beds, the higher would be the Cl- content of the Judea Group groundwater. However, evidence presented in Fig. 5 points to an inverse situation. The highest groundwater salinities and H₂S concentrations were encountered in those wells (4, 5, 8, 10) in which the thickness of the overlying Mt Scopus is lower than 100 m and the interval separating between base Mt Scopus to the top of the perforated casing (in the Judea Group aquifer) is larger than 100 m. Contrarily, wells (such as 2, 3, 6) that encountered fresh water with much lower concentrations of H₂S were drilled through much thicker beds of the Mt Scopus and the interval between the base Mt Scopus to the perforated casing is rather small or does not exist at all; except well 9a whose salinity is considerably lower, but the depth between Mt Scopus and the perforated casing is 105 m (Fig. 3).

In order to verify the occurrence and chemical composition of soluble salts in the rocks of the Mt Scopus sequence, aqueous leachates were extracted from the main rock types (Rosenthal et al., 1992) and from soils and rock debris overlying these beds.

<table>
<thead>
<tr>
<th>Parameters/wells</th>
<th>Kefar Uriya region—brackish groundwater</th>
<th>Kefar Uriya region—fresh groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>K. Uriya 4</td>
<td>89</td>
<td>76</td>
</tr>
<tr>
<td>K. Uriya 5</td>
<td>87</td>
<td>70</td>
</tr>
<tr>
<td>K. Uriya 8</td>
<td>76</td>
<td>64</td>
</tr>
<tr>
<td>K. Uriya 10</td>
<td>67</td>
<td>64</td>
</tr>
<tr>
<td>K. Uriya 6</td>
<td>66</td>
<td>73</td>
</tr>
<tr>
<td>K. Uriya 2</td>
<td>42</td>
<td>35</td>
</tr>
<tr>
<td>K. Uriya 3</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td>K. Uriya 9a</td>
<td>33</td>
<td>40</td>
</tr>
<tr>
<td>K. Uriya 1</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>K. Uriya 7</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>K. Uriya 10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2
Comparison of chemistries between fresh and brackish groundwaters in the Kefar Uriya and Eshtaol areas

<table>
<thead>
<tr>
<th>Ion</th>
<th>Fresh groundwater</th>
<th>Brackish groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>K. Uriya</td>
<td>Eshtaol</td>
<td>K. Uriya</td>
</tr>
<tr>
<td>Ca (mg/l)</td>
<td>170–183</td>
<td>116</td>
</tr>
<tr>
<td>Mg (mg/l)</td>
<td>63–80</td>
<td>44</td>
</tr>
<tr>
<td>H₂S (mg/l)</td>
<td>0.5–1.0</td>
<td>0.2</td>
</tr>
<tr>
<td>NaCl (meq/l)</td>
<td>0.84–0.99</td>
<td>0.92</td>
</tr>
<tr>
<td>Q</td>
<td>0.3–0.7</td>
<td>0.55</td>
</tr>
<tr>
<td>Mg/Ca</td>
<td>0.7–0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>SO₄/HCO₃</td>
<td>0.23–0.29</td>
<td>0.16</td>
</tr>
<tr>
<td>SO₄/Cl</td>
<td>0.26–0.3</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Table 1
Chemical composition and ionic ratios in groundwaters of the Kefar Uriya area
The leaching of soluble salts from chalk samples taken from formations overlying the Judea Group revealed that the resultant solutions contain low concentrations of Cl and SO\(_4\) and that the chemical composition of these leachates is entirely unlike that of groundwater encountered in the upper aquifer (Rosenthal et al., 1992). On the other hand, the leaching of soils and of accumulated rock debris points to a possible source for solutes.

The significant variations in the thickness of Mt Scopus sequence in the Kefar Uriya area are caused by a local anticlinal uplift (Fig. 3). At its crest, the Paleocene–Campanian Taqiye, Ghareb and Mishash Formations were eroded exposing highly (Table 3). The leaching of soluble salts from chalk samples taken from formations overlying the Judea Group revealed that the resultant solutions contain low concentrations of Cl and SO\(_4\) and that the chemical composition of these leachates is entirely unlike that of groundwater encountered in the upper aquifer (Rosenthal et al., 1992). On the other hand, the leaching of soils and of accumulated rock debris points to a possible source for solutes.

The significant variations in the thickness of Mt Scopus sequence in the Kefar Uriya area are caused by a local anticlinal uplift (Fig. 3). At its crest, the Paleocene–Campanian Taqiye, Ghareb and Mishash Formations were eroded exposing highly

<table>
<thead>
<tr>
<th>Ion (meq/l)</th>
<th>Aqueous leachate</th>
<th>Kefar Uriya—brackish</th>
<th>Hazerim end member</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil and rock debris</td>
<td>Soft chalk</td>
<td>Silicified chalk</td>
</tr>
<tr>
<td>rCa</td>
<td>3.3</td>
<td>2.25</td>
<td>1.9</td>
</tr>
<tr>
<td>rMg</td>
<td>5.4</td>
<td>3.75</td>
<td>0.2</td>
</tr>
<tr>
<td>rNa</td>
<td>36.7</td>
<td>32.6</td>
<td>2</td>
</tr>
<tr>
<td>rK</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>rCl</td>
<td>38.8</td>
<td>33.05</td>
<td>3.1</td>
</tr>
<tr>
<td>rSO(_4)</td>
<td>5.41</td>
<td>4.41</td>
<td>0.36</td>
</tr>
<tr>
<td>rHCO(_3)</td>
<td>1.73</td>
<td>1.85</td>
<td>0.52</td>
</tr>
<tr>
<td>Mg/Ca</td>
<td>1.63</td>
<td>1.66</td>
<td>0.1</td>
</tr>
<tr>
<td>Na/Cl</td>
<td>0.95</td>
<td>0.98</td>
<td>0.64</td>
</tr>
<tr>
<td>Q</td>
<td>0.46</td>
<td>0.35</td>
<td>2.26</td>
</tr>
<tr>
<td>SO(_4)/Cl</td>
<td>0.13</td>
<td>0.13</td>
<td>0.11</td>
</tr>
<tr>
<td>SO(_4)/HCO(_3)</td>
<td>3.12</td>
<td>2.38</td>
<td>0.69</td>
</tr>
<tr>
<td>H(_2)S (mg/l)</td>
<td>2.2</td>
<td>5.9</td>
<td></td>
</tr>
</tbody>
</table>
fractured Santonian Menuha Formation locally covered by debris from rocks building the surrounding hills and by light brown rendzina and brown reddish calcareous grumusol soils. The evidence collected in the present study indicates that in the study area, an important source for groundwater salinization could be due to the flushing of salts from this debris and these soils, which contain high concentrations of solutes (1000 ppm Na, over 1300 ppm Cl and up to 318 ppm SO₄) increasing with depth (Dan and Raz, 1970; Dan, personal communication, 2000).

From data presented in Table 3, the following conclusions could be drawn:

- By comparing the chemical composition and the ionic ratios, no resemblance was found between the aqueous leachates of Mt Scopus rocks and the groundwater from the Kefar Uriya wells (Rosenthal et al., 1992).
- Contrarily, it occurs that the chemical composition of the brackish groundwaters resembles that of the aqueous leachates of soils and of rock debris. Altogether, they seem to be identical to the chemical characteristics of the Hazerim water group as previously defined by Rosenthal et al. (1999).

Water of the Hazerim Group are always encountered in the upper aquifer, in permeable beds within the aquicludal sequence of the Mt Scopus Group and higher up in permeable layers occasionally discerned in the overlying Avedat Group. The Hazerim type is characterized by brackish to saline water in the 823–3453 mg/l Cl with high concentration of sulfates (420–1200 mg/l). H₂S is either absent or of low concentrations (few mg/l). The following molar ratios characterize the Hazerim water type:

\[
\begin{align*}
\text{Na/Cl} & : 0.80–1.21 \\
Q & : 0.23–0.54 \\
\text{Mg/Ca} & : 1.44–2.48 \\
\text{SO}_4/\text{Cl} & : 0.24–0.4 \\
\text{Cl/Br} & : 277–400 \text{ (weight ratios)}.
\end{align*}
\]

The waters are undersaturated with anhydrite, gypsum and halite and oversaturated to the common carbonate species (aragonite, calcite and dolomite).

In order to explain the formation of the brackish waters in certain wells of the Kefar Uriya area, the origin of two chemical components should be accounted for, i.e. the sources of salinity and of H₂S.

Percolation of local natural replenishment waters into the depressions containing soils and rock debris (characterized by high concentration of salts, Table 3) could generate the brackish waters encountered in the investigated wells, Guttman et al., 2001. These leachates penetrate through joints and fissures of the Menuha Formation reaching finally into the underlying aquiferous beds of the Judea Group. The indurated, heavily fractured and fissured Menuha chalks act as permeable ‘chimneys’ facilitating inflow of leachates of overlying soils, rock debris, incrustations and of overlying of caliche crusts as suggested by Rosenthal et al. (1992). The same process would mobilize the sulfides and the abundant organic material occurring in the rock debris originating from the En Zeitim and Taqiye formations. The anaerobic decay of the bituminous material and the abundant presence of leached sulfates will ultimately generate hydrogen sulfide. According to Burg et al. (2001), the irregular occurrence of H₂S in this well field could be related to different groundwater flow conditions. In those parts in which groundwater is confined under thick beds of the Mt Scopus Group, there is almost no percolation of solutions which leached salts and organic material from overlying sources and no H₂S was detected in the waters. In other parts of the well field in which the Mt Scopus overburden is either thin or absent or water flows under non-confined conditions, H₂S concentrations were as high as 5.6 mg/l.

The suggested sequence of hydrochemical events was modeled with the NETPATH computer code (Plummer et al., 1994). The phase list employed in deriving the models and the results are those most appropriate to the lithologic environment in the study area. The results indicate that the investigated brackish waters are mixing products of 31% soil and rock debris leachate with 69% fresh groundwater recharging the upper aquifer (represented by water from well Eshtaol 1). The derived mass transfer model indicates (in mmol/kg) the following:

Degassing

\[
\begin{align*}
\text{H}_2\text{S} & : 1.95 \\
\text{CO}_2 & : 0.15
\end{align*}
\]
Dissolution or disintegration of organic material

Organic material: 0.50

Precipitation

NaCl: 2.19
CaCO3: 0.36

Exchange

Ca/Mg: 0.27.

Previous studies and modeling (Rosenthal et al., 1999; Livshitz and Katz, 1997; Livshitz, 1999) suggested that the salts accumulated in the soils and in the strata overlying the investigated rock-sequences (i.e. of the Hazerim water type), were of marine origin, i.e. relics of the late Pliocene eastward transgression of the Mediterranean.

5. The distribution and formation of Lakhish-type groundwater

Recent evidence from well Kefar Uriya 11 (Fig. 1), suggests the possible existence of another major regional salinization source prominent particularly in the lower aquifer in the western parts of the study area and in the western parts of the foothills area (Rosenthal et al., 1999). These saline groundwaters could be related to deep-seated brines flowing from the west through an intricate system of NE–SW striking subsurface faults displacing pre-Neogene rock units faults connecting to major deposits of Neogene evaporites (Fig. 4). This process generates the Lakhish water type which are characterized by:

- Cl concentrations in the 1205–8350 mg/l range,
- H2S, 26–69 mg/l,
- Na/Cl, 0.82–1.02,
- Q = Ca/(SO4 + HCO3), 0.12–1.42,
- Mg/Ca, 0.64–0.96,
- SO4/Cl, 0.012–0.024.

The waters are undersaturated with anhydrite, gypsum, and halite and oversaturated with calcite and dolomite. Rosenthal et al. (1999) suggested that the Lakhish-type waters originated by landward ingression of the Post Messinian Sea. The suggested chain of events (supported by NETPATH modeling—op. cit. 1999) could be characterized by (1) massive addition of dissolved NaCl, (2) massive bacteriological reduction of sulfates in presence of oil, (3) high pCO2 in presence of oil which might lead to low pH values and to further dissolution of carbonates and release of Ca to solution, (4) formation of dolomite and/or authigenic Mg-minerals as result of Mg deriving from reduction of MgSO4 and, (5) additional supply of Ca to the system following dissolution of anorthite in sandstones.

6. Conclusions

The salinization that occurs in the western part of Kefar Uriya well field is caused by the concerted action of several geological, pedological and hydrological parameters forming a local funnel-like flushing mechanism. This mechanism is well confirmed by the quantitative hydrodynamic model presented by Mandell et al. (2001). These local salinization mechanisms are in addition to the regional salinization process that generates deep-seated saline and brackish groundwater of the Lakhish type deriving from a western source. All sources in which saline Lakhish Group waters were encountered are always located on, or in immediate vicinity of major NE–SW striking subsurface faults displacing pre-Neogene rock units. This conclusion stands true for the whole foothill area of the Judea Mts extending as far northwards as the Lod Plain. The occurrence of Hazerim type groundwater is less dependent on major structural features and is controlled by local lithological and erosional conditions facilitating accumulation and/or flushing of solutions.

Acknowledgments

Thanks are extended to the Israel Ministry of Science for financial support in the frame of
the Infrastructure Research Project on salinization processes of Israel aquifers.

We are highly indebted to Dr Arie Ben Zvi, to Dr Klaus Peter Seiler and to another anonymous reviewer for their important remarks and suggestions improving considerably the paper.

References


Dan, J., Raz, Z., 1970. The Soil Association Map of Israel (scale 1:250,000), Soil and Water Department, The Volcani Institute for Agricultural Research.


