Mapping of Groundwater Vulnerability and Hazards to Groundwater in the Irbid Area, N Jordan

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Grundwasser, Grundwasserverunreinigung, Grundwasserschutz, Regionalplanung, Technische Zusammenarbeit, Irbid, Jordanien.

Abstract

Groundwater quality has been deteriorating in many parts of Jordan in recent years due to rapid urban development, expansion of agriculture, and industrialization. The country, however, can ill afford a situation in which precious water resources are lost due to pollution.

Land use planning is often done without taking aspects of groundwater protection sufficiently into account. Discussions with the relevant authorities clearly showed the need for planning documents that take aspects of groundwater contamination into consideration. For this purpose, a program of mapping the 'intrinsic' groundwater vulnerability in Jordan has been initiated within the framework of a Technical Cooperation Project between the Water Authority of Jordan (WAJ) and the Federal Institute of Geosciences and Natural Resources (BGR) in Germany. The methodology is based on a system developed by State Geological Surveys in Germany.

In Jordan, this methodology has been applied to study groundwater vulnerability and hazards to groundwater in the Irbid area, i.e., from the Yarmouk River in the north to the area north of Ajlun and Jerash. Other areas of Jordan are currently under investigation. ARC/INFO software is applied for the mapping procedure.

The maps prepared during this study are meant to provide planners with tools for a preliminary selection of priority areas for different forms of land use. As environmental problems are increasing, the urgency to take measures for the protection of the groundwater and to improve legislation in this field will grow.

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Kurzfassung

Die Grundwasserqualität hat sich in vielen Gegenden Jordaniens in der nahen Vergangenheit durch die rapide städtische Entwicklung, die Ausweitung der Landwirtschaft und die zunehmende Industrialisierung verschlechtert. Das Land kann es sich jedoch bei der Knappheit der Vorkommen nicht leisten, daß wichtige Grundwasserressourcen durch Verunreinigung für die Versorgung verloren gehen.

Bislang wird Regionalplanung in Jordanien betrieben, ohne den Schutz des Grundwassers hinreichend zu berücksichtigen. In Diskussionen mit betroffenen Behörden zeigte sich der Bedarf an Planungsgrundlagen, die verschiedene Aspekte aufzeigen, welche zu einer Grundwasserverunreinigung führen können. Aus diesem Grunde wurde im Rahmen eines Projektes der Technischen Zusammenarbeit zwischen der Water Authority of Jordan (WAJ) und der Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) ein Programm zur Kartierung der Verschmutzungsempfindlichkeit des Grundwassers durchgeführt. Das Projekt wurde gefördert vom Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (BMZ). Die Methodik basiert auf einem System, welches von den staatlichen geologischen Diensten Deutschlands entwickelt wurde.

In Jordanien wurde diese Methodik angewandt, um die Verschmutzungsempfindlichkeit und die möglichen Verschmutzungsquellen im Gebiet um die Stadt Irbid, vom Jarmouk im Norden bis nach Ajlun und Jerasch im Süden, zu untersuchen. Weitere Kartierungen in Jordanien sind gegenwärtig in der Durchführung. Das Processing erfolgt mit dem Programm ARC/INFO.

Die Karten stellen erste Versuche dar, den lokalen Regionalplanern Planungsgrundlagen zur Verfügung zu stellen, die es ihnen erlauben, Vorzugsgebiete für die verschiedenen Landnutzungen zu definieren. Mit der Zunahme der Umweltprobleme verstärkt sich auch die Notwendigkeit, Maßnahmen zum Grundwasserschutz zu ergreifen und die Gesetzgebung in diesem Bereich zu verbessern.

Introduction

Excessive groundwater withdrawal has caused a severe lowering of the water table of more than 2 m/a in some well fields in central and northern Jordan (MARGANE 1995). Deterioration of groundwater quality became an increasingly serious problem in recent years. Nitrate contents of more than 100 mg/L and the increasing mineralization of the groundwater in some of the intensively cultivated areas indicate that groundwater is already polluted to an alarming extent.

Over the past 20 years, groundwater vulnerability maps have been developed in many countries as a basis for developing land use strategies that take aspects of groundwater protection from pollution into consideration. These maps show the distribution of highly vulnerable areas, in which all polluting activities should be banned, since contaminants can reach the groundwater within a very short time. Areas with a better natural protection of the groundwater against pollution could be suitable as locations for industrial areas, waste water treatment plants, and waste disposal sites. However, such maps do not replace more detailed studies of the geological and hydrogeological conditions in order to ensure the suitability of a particular site for the envisaged use.

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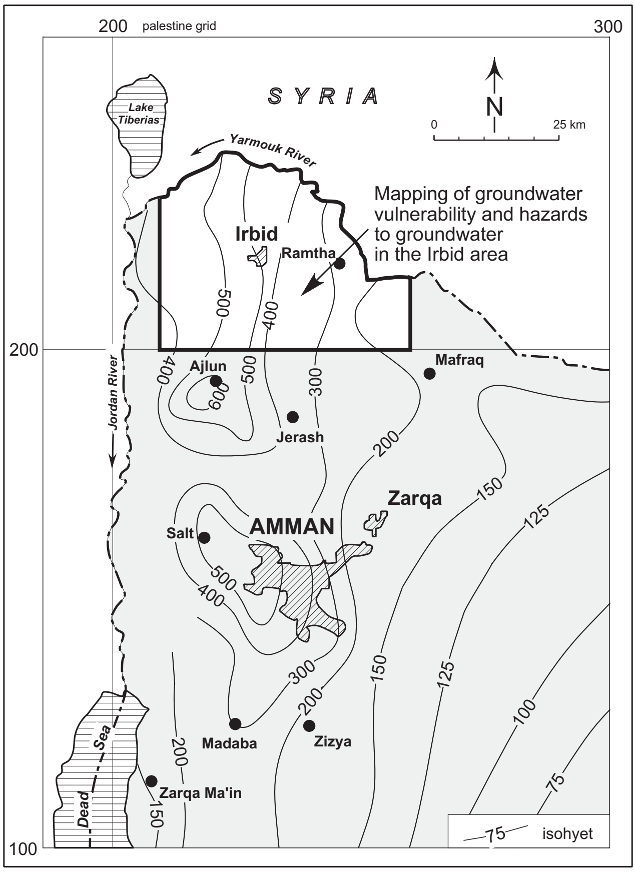


Fig. 1: Location of study area and rainfall distribution (mean annual rainfall 1973/74 - 1992/93 in mm; after MARGANE & AL ZUHDY 1995).

Abb. 1: Lage des Untersuchungsgebietes und Niederschlagsverteilung (mittlerer jährlicher Niederschlag 1973/74 - 1992/93 in mm; nach MARGANE & AL ZUHDY 1995).

When considering vulnerability it has to be borne in mind that all groundwater resources are vulnerable and that uncertainty is inherent in all vulnerability assessments (NATIONAL RESEARCH COUNCIL, 1993).

VRBA & ZAPOROZEC (1994) define groundwater vulnerability as *'the tendency or likelihood for contaminants to reach the groundwater system after introduction at some location above the uppermost aquifer'*. In addition, distinctions are made between 'intrinsic vulnerability' and 'specific vulnerability'. For the determination of 'intrinsic vulnerability', the characteristics and specific behavior of contaminants are not taken into consideration, whereas the term 'specific vulnerability' refers to a specific contaminant, class of contaminants or a certain prevailing human activity.

The Irbid area in the northwestern part of Jordan was selected as an test area where vulnerability mapping could be tested for the first time in Jordan. Part of the selected area is intensively cultivated and industrial development is expected to increase rapidly. The main aim of the map was to give an overview of the 'intrinsic groundwater vulnerability'. In this case the assessment of vulnerability is reduced to the parameters determining the general protective effectiveness of the soil and rock cover. Such simplifications allow for an assessment of groundwater vulnerability of large areas at relatively low cost and in a comparatively short amount of time. Studies of the specific vulnerability could then be performed at a later stage in sensitive areas where groundwater pollution is expected to occur in the near future or already exists.

The Mapping Approach

Different methodologies to determine the intrinsic vulnerability of groundwater have been developed over the past two decades.

The Geological Surveys of the individual states of the Federal Republic of Germany have established their own mapping technique (HÖLTING et al. 1995). Since this technique has been tested in several countries over the past several years and has proven to be useful and effective, it was used for groundwater vulnerability mapping of the Irbid area.

The methodology (HÖLTING et al., 1995) is based on a rating system which takes the unsaturated zone into consideration. The degree of vulnerability is expressed as the protective effectiveness (the ability of the cover above an aquifer to protect the groundwater) of the soil cover down to a depth of 1 m (the average rooting depth) and the rock cover (unsaturated zone). The following parameters are considered for the assessment of the overall protective effectiveness:

Parameter 1: S - effective field capacity (eFC) of the soil (each eFC class is assigned a different rating down to 1 m depth, the average rooting depth);

Parameter 2: W - percolation rate factor;

Parameter 3: R - rock type (R = OF), where Rs stands for consolidated rocks and Ru for unconsolidated rocks, O is a factor for rock type, and F is the degree of faulting, jointing and karstification);

Parameter 4: T - thickness of the rock cover above the aquifer;

Parameter 5: Q - bonus points for perched aquifer systems (500 points);

Parameter 6: HP - bonus points for hydraulic (artesian) pressure conditions (1.500 points).

The overall protective effectiveness (P_T) is calculated using

$$\mathbf{P_T = P_1 + P_2 + Q + HP}$$

the following formula:

where P_1 –is the protective effectiveness of the soil cover, $P_1 = S\ W$, and
P_2 –is the protective effectiveness of the rock cover, $P_2 = W (R_1T_1 + R_2T_2 + \ldots + R_nT_n)$.
andQ, HP as defined above

Calculation of the overall protective effectiveness for the entire study area is complex and requires the use of ARC/INFO or a similar software.

Table 1: Values for the soil factor (S) according to effective field capacity class (HÖLTING et al. 1995).

Tabelle 1: Bewertung der Böden (Punktzahl S) aufgrund ihrer Pflanzen-nutzbaren Speicherkapazität für Wasser (Σ eFC), nach HÖLTING et al. (1995).

Σ eFC [mm] down to 1 m	Soil factor (S)
> 250	750
200 - 249	500
140 - 199	250
90 - 139	125
50 - 89	50
< 50	10

Table 2: Values for the percolation rate factor (W) according to groundwater recharge rate (HÖLTING et al. 1995).

Tabelle 2: Bewertung der Sickerwassermenge (als Faktor W) anhand der Grundwasserneubildungsrate bzw. der klimatischen Wasserbilanz ($P-ET_p$) nach HÖLTING et al. (1995).

Groundwater recharge [mm/a]	$P-ET_p$ [mm/a]	Percolation rate factor (W)
< 25	-	2.25
25 - 49	-	2.00
50 - 99	-	1.75
100 - 199	-	1.50
200 - 299	100 - 199	1.25
300 - 399	200 - 299	1.00
≥ 400	300 - 399	0.75
	≥ 400	0.50

Table 3 : Values for the rock type factor of consolidated rocks (O) according to rock type (HÖLTING et al. 1995).
Tabelle 3: Klasseneinteilung (O) für Festgesteine (nach HÖLTING et al. 1995).

Rock type	Rock type factor (O)
claystone, shale, marlstone, siltstone	20
sandstone, quartzite, massive igneous rocks, metamorphic rock	15
porous sandstone, porous effusive volcanic rock (e. g. tuff)	10
conglomerate, breccia, (tuffaceous) limestone, dolomite, gypsum rock	5

Table 4 : Values for factor F, according to the degree of faulting, jointing and karstification (HÖLTING et al. 1995).
Tabelle 4: Strukturfaktor (F) als Maß für die Wasser-Wegsamkeit im Festgestein (nach HÖLTING et al. 1995).

hydraulic features	factor F
non-jointed	25
slightly jointed	4
moderately jointed, slightly karstic	1.0
moderately karstic	0.5
strongly jointed, fractured or karstic	0.3
not known	1.0

Table 5: Values for the rock factor R_s in the Irbid area (HÖLTING et al. 1995).

Tabelle 5: Bestimmung des Gesteinsfaktors R_s im Gebiet von Irbid (nach HÖLTING et al. 1995).

Formation	rock type factor (O)	degree of faulting, jointing and karstification (F)	rock factor for consolidated rocks (R_S)
B4/B5	5	1	5
B3	20	1	20
A7/B2	5	0.5	2.5

Table 6: Classes of overall protective effectiveness of the soil and rock cover and corresponding residence time of percolating water in the unsaturated zone (after HÖLTING et al. 1995).

Tabelle 6: Klasseneinteilung der Gesamtschutzfunktion der Boden- und Gesteinsdeckschichten und die zugehörigen Verweilzeiten des Sickerwassers in der ungesättigten Zone (aus HÖLTING et al. 1995).

Overall protective effectiveness	Total number of points	approx. residence time in the unsaturated zone
very high	≥ 4000	> 25 years
high	> 2000 - 4000	10-25 years
moderate	> 1000 - 2000	3-10 years
low	> 500 - 1000	several months to 3 years
very low	≤ 500	a few days to one year, in karstic rocks often less

The classifications used for the soil factor (S), the rock factor (O), the factor for the degree of faulting, jointing and karstification (F), and the percolation rate factor (W) are listed in Tables 1 to 5.

Five classes of overall protective effectiveness of the soil and rock cover are distinguished by HÖLTING et al. (1995) (Table 6). The higher the total number of points, the longer the approximate residence time of percolating water in the unsaturated zone and in consequence the overall protective effectiveness.

Description of the Irbid Area

Topographical and Geological Situation

The study area in the northwestern part of Jordan extends from the highland east of the Jordan Valley almost to the city of Mafraq in the east and from the Yarmouk River in the north to the area north of Ajlun and Jerash in the south (Fig. 1). Elevations drop from more than 1100 m in the Ajlun mountains in the south to lower than 200 m below sea level in the lower Yarmouk Valley in the north (Fig. 2). Towards the Yarmouk River and the Jordan Valley, the wadies are deeply incised and slopes of more than 30 % are common (Fig. 2).

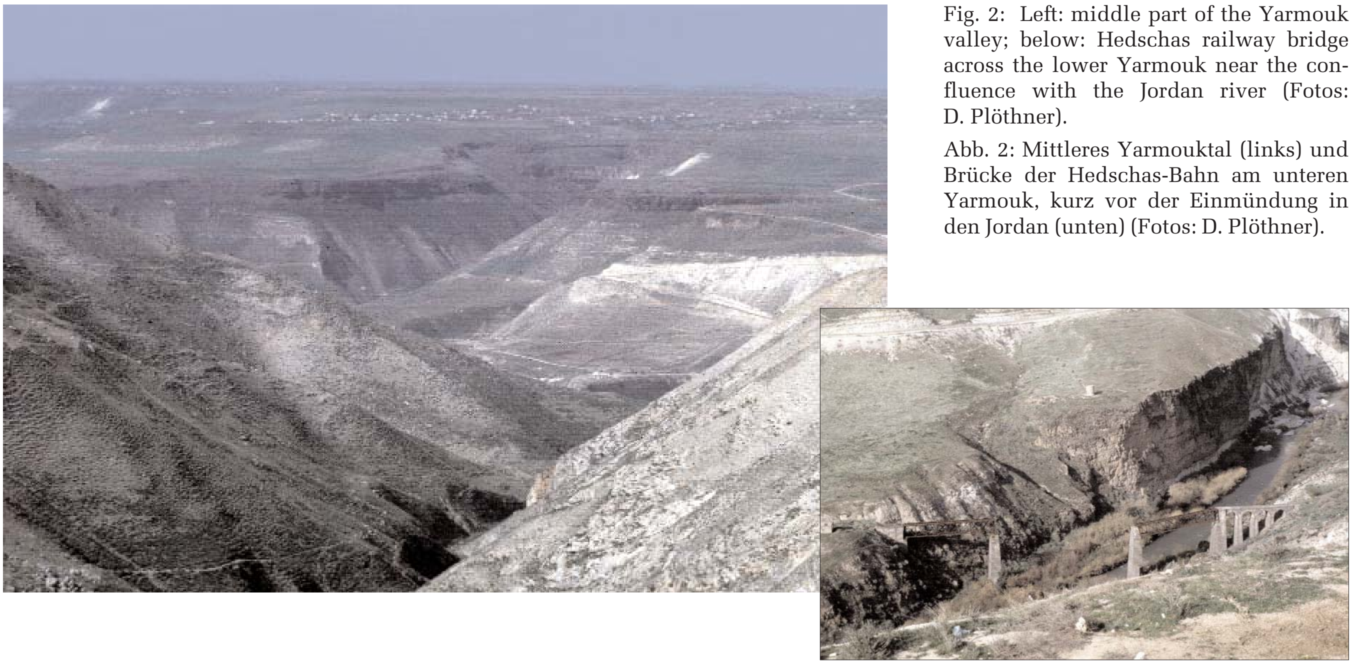


Fig. 2: Left: middle part of the Yarmouk valley; below: Hedschas railway bridge across the lower Yarmouk near the confluence with the Jordan river (Fotos: D. Plöthner).

Abb. 2: Mittleres Yarmouktal (links) und Brücke der Hedschas-Bahn am unteren Yarmouk, kurz vor der Einmündung in den Jordan (unten) (Fotos: D. Plöthner).

Average annual rainfall in the area varies from less than 200 mm/a, in the easternmost part north of Mafraq, to more than 500 mm/a in a narrow strip west of Irbid stretching from Rihaba in the south to Malka in the north of the study area (Margane & Al Zuhdy 1995; for location see Fig. 8).

Figures 3 and 6 show the outcrops of the different hydrogeological units and illustrate the geological setting, which is dominated by the structural high of the Ajlun dome in the southwestern part of the area. Information on the structural setting and detailed lithological descriptions of the formations are given by Hobler et al. (1994).

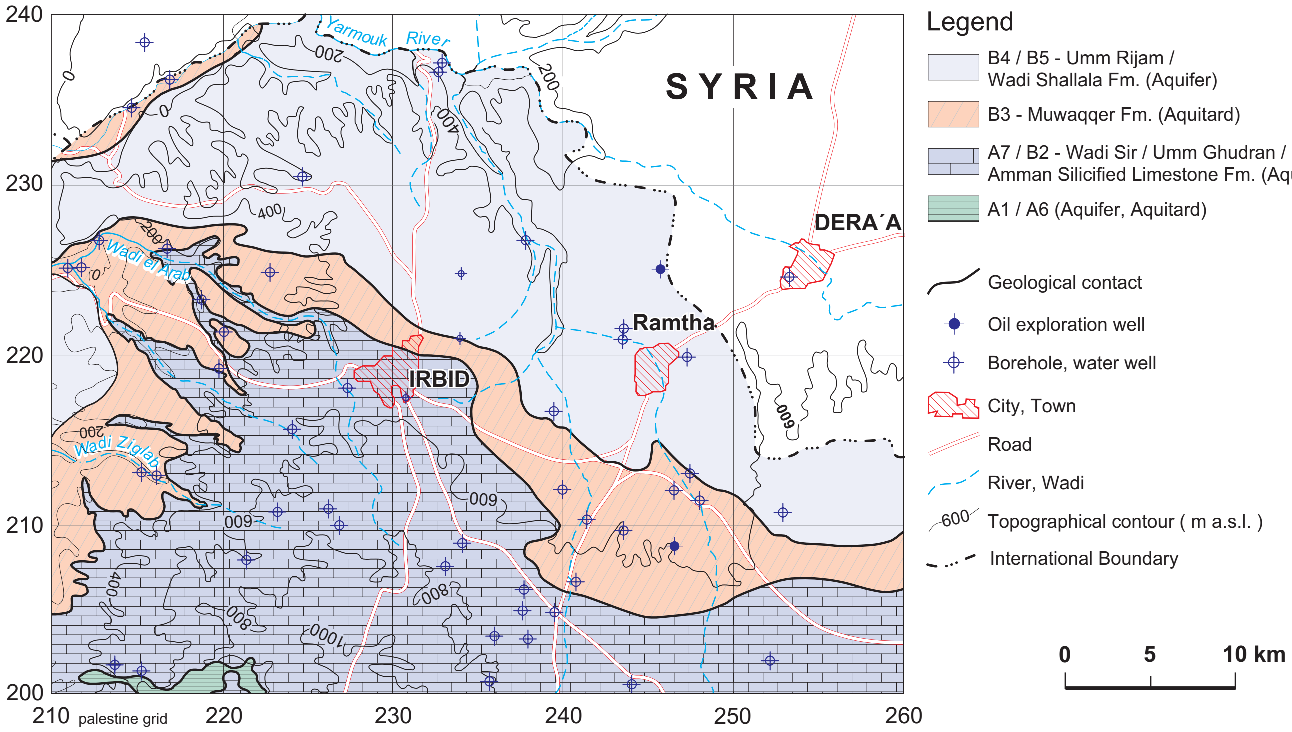


Fig. 3: Surface distribution of the major hydrogeological units in northwestern Jordan.

Abb. 3: Ausstrichgebiete der hydrogeologischen Einheiten Nordwest-Jordaniens.

In small areas in Wadi el Yabis, in the southwestern corner of the study area, limestone of the Upper Cenomanian Hummar Formation (A4) and predominantly marly occurrences of the Lower Turonian Shuayb Formation (A5/A6) have been mapped. Otherwise, outcrops of the overlying Upper Turonian to Campanian Wadi Sir, Umm Ghudran, Amman Silicified Limestone Formations (A7/B2) cover most of the southern part of the study area. The A7/B2 comprises limestone and chert with intercalations of dolomitic limestone, marl and chalk. The base of the A7/B2 dips steeply from elevations of about 900 m above sea level in the area of the Ajlun dome towards the Jordan Valley and the lower reaches of the Yarmouk River, where the base of A7/B2 is more than 100 m below sea level.

The overlying, predominantly marly B3 (Muwaqqar Formation) crops out in a strip reaching from the area south of Ramtha via the city of Irbid to the slopes of the Jordan Rift Valley in the west. Smaller outcrops have been observed in the lower reaches of the Yarmouk River (Palestine Grid East, west of grid line 225 km). The total thickness of the B3 ranges from about 125 m in the eastern part of the study area to > 500 m towards the Jordan Valley in the west and the lower reaches of the Yarmouk River.

The B4/B5 (Umm Rijam, Wadi Shallala Formations) crops out in the area north of Irbid towards the Yarmouk river. It is composed mainly of limestone, chalk and chert and reaches a maximum thickness of more than 200 m.

Hydrogeology

The B4/B5 is the uppermost aquifer in the northern part of the study area. Figure 4 shows the distribution of the aquifer, water table contour lines and depth to the saturated part of the aquifer. The B4/B5 is moderately jointed and fractured and it is only slightly karstified. Groundwater levels are relatively shallow in the plateau area east of Ramtha (in some places only about 10 m below ground level). In other areas, especially the high plateaus in the north, where springs in the deeply incised valleys of the Yarmouk River and its tributaries drain the B4/B5 aquifer, the thickness of the unsaturated zone far exceeds 100 m. In the outcrop areas south and southeast of Ramtha, the B4/B5 aquifer is unsaturated. Hydraulic conductivity ranges between $1*10^{-4}$ and $1*10^{-6}$ m/s, with an average of $5*10^{-5}$ m/s.

Groundwater recharge to the B4/B5 aquifer is estimated at 8-10 % of the mean annual rainfall (HOBLER et al., in prep.). The total average annual spring discharge is approximately 3.3 MCM (MARGANE & AL ZUHDY, 1996).

In the southern part of the test area (and in small areas along the Yarmouk River) the A7/B2 forms the uppermost aquifer. It is the most important aquifer in the mapped area and is used for the water supply of most of the communities. The thickness of the A7/B2 increases from around 300 m in the area of the Ajlun Dome in the south to more

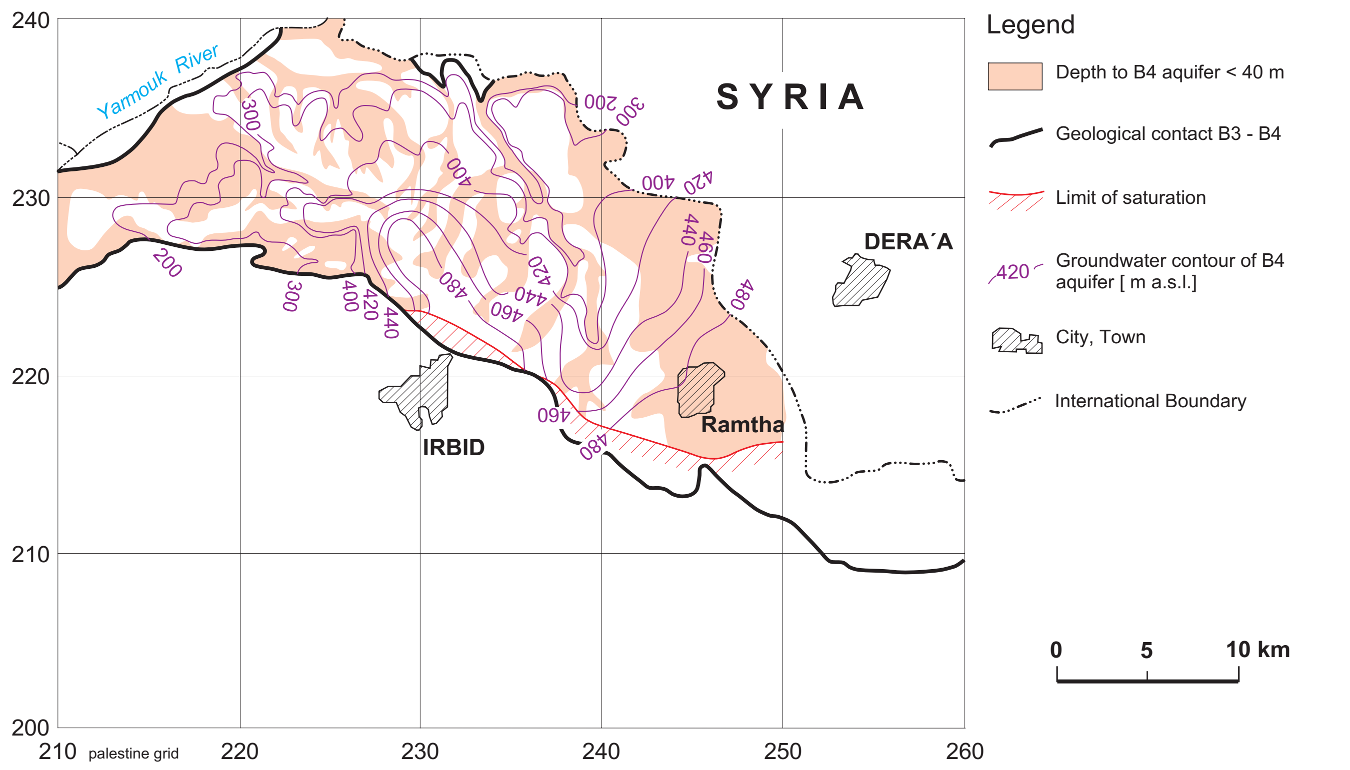


Fig. 4: B4/B5 aquifer: depth to groundwater table and groundwater flow pattern.

Abb. 4: B4/B5 Aquifer: Grundwasserflurabstand und Grundwassergleichen.

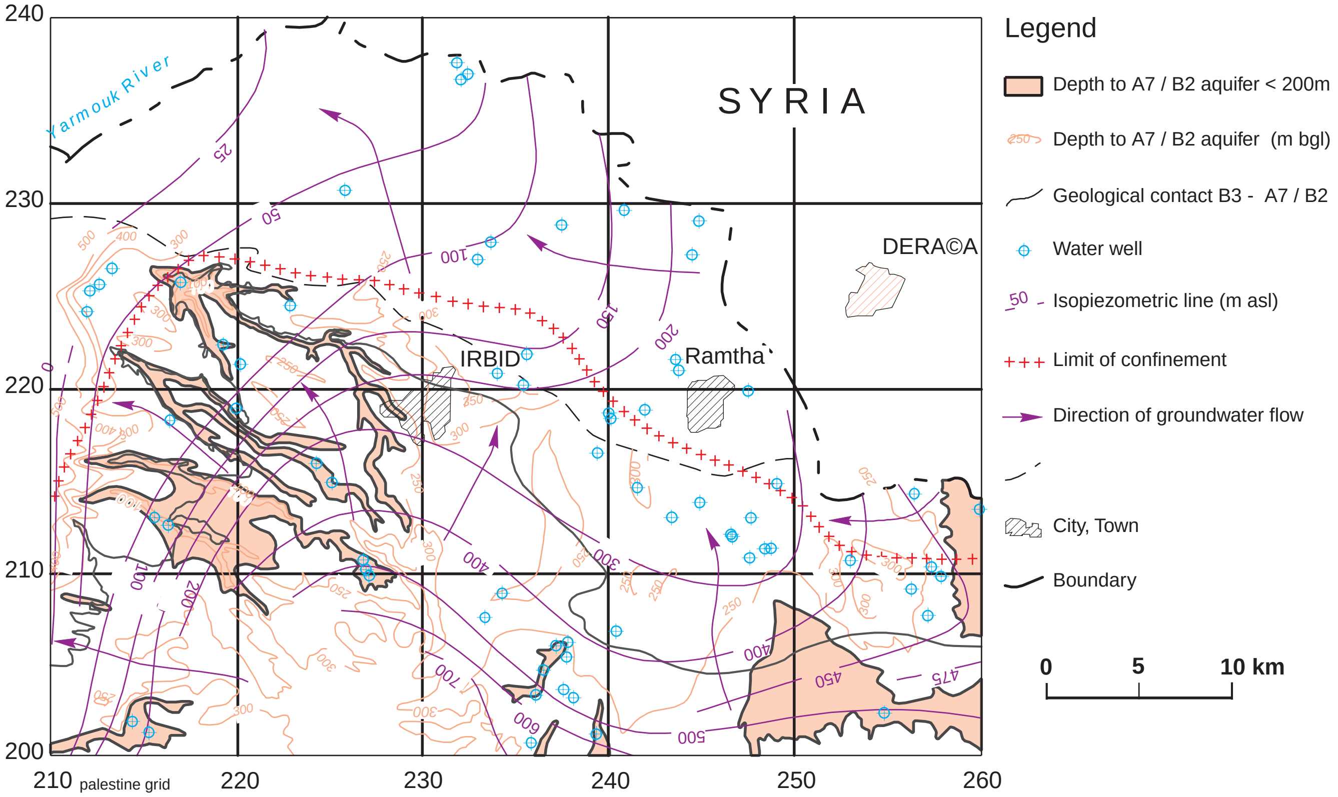


Fig. 5: A7/B2 aquifer: depth to groundwater table and groundwater flow pattern.

Abb. 5: A7/B2 Aquifer: Grundwasserflurabstand und Grundwassergleichen.

than 500 m in the northern and western parts of the study area. Jointing and fracturing is moderate to high and karst has been reported by many authors, especially in the mountain areas. The degree of karstification is regarded as moderate.

The hydraulic conductivity ranges between 1∗10-3 m/s and 1∗10^{-7} m/s. A value of 2∗10^{-5} m/s has been assumed as a regional mean (HOBLER et al., in prep.).

The A7/B2 aquifer is recharged mainly in the Ajlun dome area in the south. Further to the north and west, it is covered by the B3 aquitard and becomes confined. The groundwater flow pattern of the A7/B2 aquifer and the areas in which the aquifer is confined are shown in Fig. 5. Springs in wadies flowing to the Jordan Valley and springs in the Mukheiba and Adassiyeh areas in the Yarmouk Valley provide for natural discharge.

In 1993, total groundwater withdrawal in the study area was almost 50.8 MCM (MARGANE & AL MOMANI, 1995). Of this amount, 1.1 MCM was pumped from the B4/B5 aquifer and 48.7 MCM from the A7/B2 aquifer.
Figure 5 shows the depth to the saturated A7/B2 aquifer. In the deeply incised wadies flowing towards the Jordan Valley, water levels are comparatively shallow (in some places < 100 m below ground level). Towards Mafraq, in the southeastern part of the study area, depth to groundwater is less than 200 m. In other areas, depth to the A7/B2 aquifer ranges between 200 and > 300 m, sometimes reaching depths of > 500 m in the highlands just east of the Jordan Valley.

Hydrochemical Characteristics

The B4/B5 Aquifer

The salinity of water samples from springs and wells in the B4/B5 aquifer varies between 270-1200 mg/L total dissolved solids (TDS) with an electric conductivity (EC) of 420-1840 µS/cm. Under natural conditions, the groundwater is characterized by low contents of TDS (< 450 mg/L) and low EC (< 700 µS/cm) and is mainly of the Ca-HCO_3 type. Total salinity of more than 450 mg/L (>700 µS/cm) usually indicates groundwater contamination.

Nitrate values between 7 mg/L and almost 200 mg/L have been recorded for the B4/B5 aquifer in northwestern Jordan. Though most of the samples are within the desirable limit for drinking water (in Jordan: < 40 mg/L), the elevated nitrate contents clearly indicate that there is a problem of widespread contamination of the B4/B5 aquifer. Many springs in the B4/B5 aquifer cannot be used for the public water supply any more because of chemical or bacteriological contamination (e.g., Rahoob spring, west of Al Mughayyir and northeast of Irbid, Fig.8).

The A7/B2 Aquifer

The salinity of groundwater samples from springs and wells ranges between about 320 and 1660 mg/L TDS (EC: 500 - 2600 µS/cm). In general, groundwater salinity increases in the direction of groundwater flow, from the recharge areas in the south (TDS: < 500 mg/L) towards the Jordan Valley in the west and the Yarmouk River in the north. Elevated salinity of > 650 mg/L (EC: > 1000 µS/cm) occurs mainly in areas where the groundwater is confined by the overlying B3 aquitard.

With respect to its chemical composition, the water in the A7/B2 aquifer is mostly of a mixed type. With increasing salinity the chemical facies changes from earth alkaline water with bicarbonate predominance to alkaline water with chloride predominance.

The tritium values and the stable isotopes ^{18}O and deuterium of groundwater samples from outcrop areas of the A7/B2 aquifer indicate fresh recharge from local precipitation (average tritium values of about 10 TU; Al Momani & Abu Maizer 1989). In the areas where the A7/B2 aquifer is confined by the predominantly marly B3 aquitard, the groundwater contains no tritium. ^{14}C-values in these areas indicate a water age of more than 10,000 years.

In areas where the A7/B2 aquifer is protected by the overlying B3 aquitard, the nitrate contents are usually below 15 mg/L and often even below 1 mg/L. At a few locations close to the A7/B2 outcrop areas, like the spring in Deir Abu Said (WSW Irbid, Fig.8), exceptionally high nitrate values of up to > 80 mg/L indicate contamination from the surrounding villages.

The Groundwater Vulnerability Map of the Irbid Area

Description of the Mapping Procedure

The overall protective effectiveness of the soil and rock cover above the topmost aquifer was compiled from the maps of the following parameters:

– depth to saturated aquifer for the relevant aquifers, i.e., B4/B5 and A7/B2 (Figs. 4 and 5),
– thickness distribution of the relevant hydrogeological units, i.e., B3,
– distribution map of factor S (rating for effective field capacities of the soils),
– areal distribution of factor W (percolation rate),
– areas with artesian groundwater.

Parameter 1, the distribution of soil types and their effective field capacities (S), was determined on the basis of the 1:50,000 soil maps prepared by Hunting Technical Surveys & Soil Survey and Land Research Center (1994). The total effective field capacity of the soil was calculated by multiplying the effective field capacity [mm/m] by the average thickness of the soil down to a depth of 1 m (the average rooting depth), as described by Hölting et al. (1995). The result was used to assign a value to the factor S according to Table 1.

Parameter 2 (the percolation rate factor W): The Ajlun area has one of the highest recharge rates in the study area (probably about 25 % of the precipitation, i.e., up to 130 mm/a). But in large parts of the study area, groundwater recharge is less than 20 mm/a. According to Hölting et al. (1995), the highest value assigned for factor W is 1.75 for a groundwater recharge of less than 100 mm/a. Therefore, a modified scale for Parameter 2 was introduced that reflects the low groundwater recharge in the study area (Table 2). True groundwater recharge varies considerably and depends on factors like topography (slope), soil cover and fracturing. Indirect recharge plays an important role in the study area and might lead to higher recharge in certain areas, such as wadies or morphological depressions. These local differences were taken into consideration by assigning lower values for the percolation rate factor to such areas.

Data on Parameters 3 and 4, the rock type (R) and the thickness of the rock cover above the aquifer (T), was taken from Hobler et al. (1994) and maps of the piezometric head of the B4/B5 and A7/B2 aquifers (Hobler et al., in prep.). In part of the study area, these maps are not very accurate since only very few reference points were available.
Perched aquifers (Parameter 5, Q) are of minor importance in the investigated area and this parameter was, therefore, not used for the assessment of groundwater vulnerability.

Artesian conditions (Parameter 6, HP) exist mainly in the western and northern parts of the mapped area (Fig. 6). In these areas an additional 1500 points were added to the rating of the protective effectiveness for the A7/B2 aquifer.

The effective protectiveness of the rock cover (parameter P2) was calculated by multiplying the rock type factor for consolidated rocks (RS) by the thickness T of the formations above the topmost saturated aquifer and the factor W

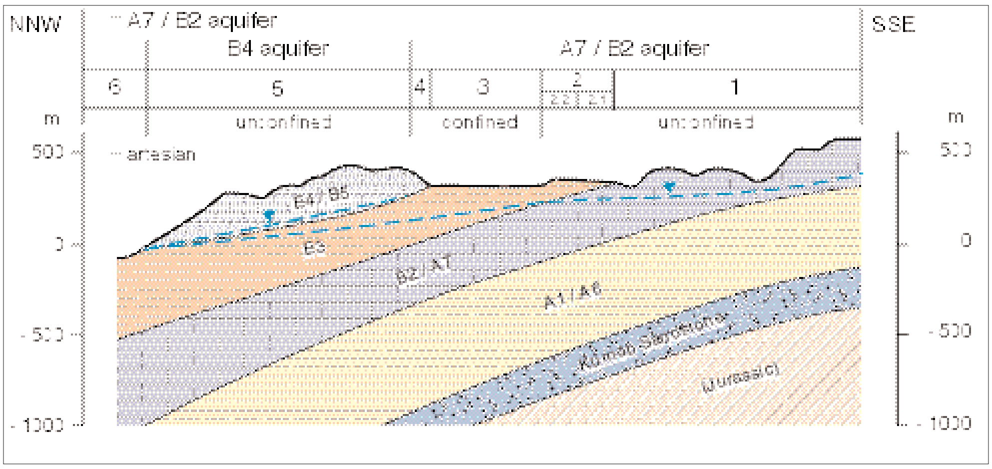


Fig. 6: Schematic cross section through the study area and determination of the *protective effectiveness of the rock cover* (Parameter P2) according to the hydrogeological setting

Abb. 6: Schematisches Profil durch das Untersuchungsgebiet und Bestimmung der *Schutzfunktion der Grundwasserüberdeckung* (Parameter P2) in Abhängigkeit von den hydrogeologischen Gegebenheiten.

(P2 = RS*T*W). Factor RS was determined by multiplying the rock type factor O by the factor F, which describes the degree of faulting, jointing and karstification (RS = O*F). Table 5 shows the rock factor of the formations in the mapped area.

Depending on the hydrogeological conditions, different calculation procedures had to be applied for the calculation of parameter P2, in six distinct areas (Fig. 6):

- Area 1: A7/B2 is the uppermost aquifer. It is unconfined and not covered by the B3 aquitard.
- Area 2: A7/B2 is the uppermost aquifer. It is unconfined and covered by B3. Area 2 has been subdivided according to the thickness of the overlying B3 aquitard:
  - Area 2.1: The thickness of B3 is less than 115 m.
  - Area 2.2: The thickness of B3 is more than 115 m.
- Area 3: A7/B2 is the uppermost aquifer. It is confined by the B3 aquitard.
- Area 4: A7/B2 is the uppermost aquifer. It is confined by the B3 aquitard, which is overlain by the unsaturated B4/B5 formations.
- Area 5: B4/B5 is the uppermost aquifer. It is unconfined.
- Area 6: A7/B2 is the uppermost aquifer. It is confined by the B3 aquitard.

In areas 2.2, 3, 4, and 6 where the thickness of the B3 aquitard above the A7/B2 aquifer exceeds 115 m the calculated number of points for parameter P2 is higher than 4000 for a percolation rate factor W of 1.75:

$$(P2 = W*RS*T = 1.75*20*115 = 4025).$$

Since these areas fall into the category of very high protective effectiveness of the rock cover (P2 > 1000 points), other factors (P1, HP) can be neglected and mapping procedures are simplified.

For the groundwater vulnerability map, the boundaries of the areal distribution of the ratings for the parameters W, S, P2 and HP were digitized and imported into ARC/INFO for the calculation of the overall protective effectiveness of the soil and rock cover (PT). Fig. 7 shows the resulting 'Groundwater Vulnerability Map of the Irbid Area'.

Regional Distribution of Groundwater Vulnerability

Vulnerability of the B4/B5 Aquifer

The protective effectiveness of the soil and rock cover above the saturated aquifer has been classified as low to very low. In the main wadies and in the areas where the groundwater is close to the land surface, the vulnerability of the groundwater is extremely high (e.g. northwest of Irbid, the Ramtha area and the area north of Um Qais and west of Malka).

Only on the high plateaus between the deeply incised wadies flowing towards the Yarmouk River in the north, a moderate protective effectiveness is reached. This is due to the soil cover on the plateaus and/or the high thickness and nature of the unsaturated zone.

Vulnerability of the A7/B2 Aquifer

The groundwater vulnerability of the A7/B2 aquifer is especially high in areas where an effective soil cover is missing, the groundwater table is comparatively shallow and the aquifer is unconfined. The area west of Irbid, the areas around the main wadies flowing towards the Jordan Valley in the west, smaller areas between Irbid and Al Sarieh/Husn (SSE of Irbid), some areas in the surroundings of Nueimeh, and the area west of Al Hamra and south of El Buweida, in the southeastern corner of the study area (near the southern boundary of the Wadi Shallala catchment area), belong into this category.

The widest distribution of areas of medium vulnerability are in the outcrop areas of the A7/B2 aquifer in the southern part of the mapped area. Further north and west, where the A7/B2 aquifer is overlain by the predominantly marly B3 aquitard and well developed soils, the protective effectiveness of the soil and rock cover has been classified as high and in the areas where the groundwater is confined as very high. The Yarmouk Valley in the extreme northern part of the study area, where the B4/B5 unit has been eroded and the highly confined A7/B2 aquifer forms the topmost aquifer, also belongs to this category.

Consequences for Regional Land Use Planning

The groundwater vulnerability map shows the regional distribution of the natural protective effectiveness of the soil and rock cover above the topmost saturated aquifer. In areas of high and very high groundwater vulnerability, waste disposal sites, industrial complexes, effluent treatment plants, and all spillage of contaminating substances must be avoided.

Areas of low to very low vulnerability can be seen as potential sites for activities with high pollution risks. It has to be stressed, however, that contaminated runoff from an area of low vulnerability might pollute an aquifer further downstream in areas where the protective effectiveness of the soil and rock cover is low (for example, in the area where the B4/B5 is the topmost aquifer). A groundwater vulnerability map cannot replace detailed assessment of the risk of groundwater contamination in areas considered for the licensing of high impact activities. Moreover, the mapping approach does not take specific pollution scenarios or individual contaminants into consideration. Due to uncertainties in the assessment process, the map can only give a preliminary and generalized classification.

In the Irbid area, a considerable number of potentially polluting facilities and activities are located in high-risk areas. Examples are

- the Kufr Awan (SW of Irbid, Fig. 8) and Almansourah (NW of Irbid, Fig. 8) dumps for solid waste, which are located on slopes leading directly to areas of high vulnerability to groundwater contamination;
- the existing and planned treatment plants for the Irbid and Ramtha (E of Irbid, Fig. 8) areas, which have been located in wadies for technical reasons;
- some industries, like the Protein Factory north of Al Mughayyir (NE of Irbid, Fig. 8);
- many service stations (storage of oil and fuel, oil spills);
- olive oil producers;
- the slaughterhouse in Irbid;
- animal husbandry (chicken, cattle, sheep);
- agricultural production with abundant use of fertilizers, fungicides and pesticides.

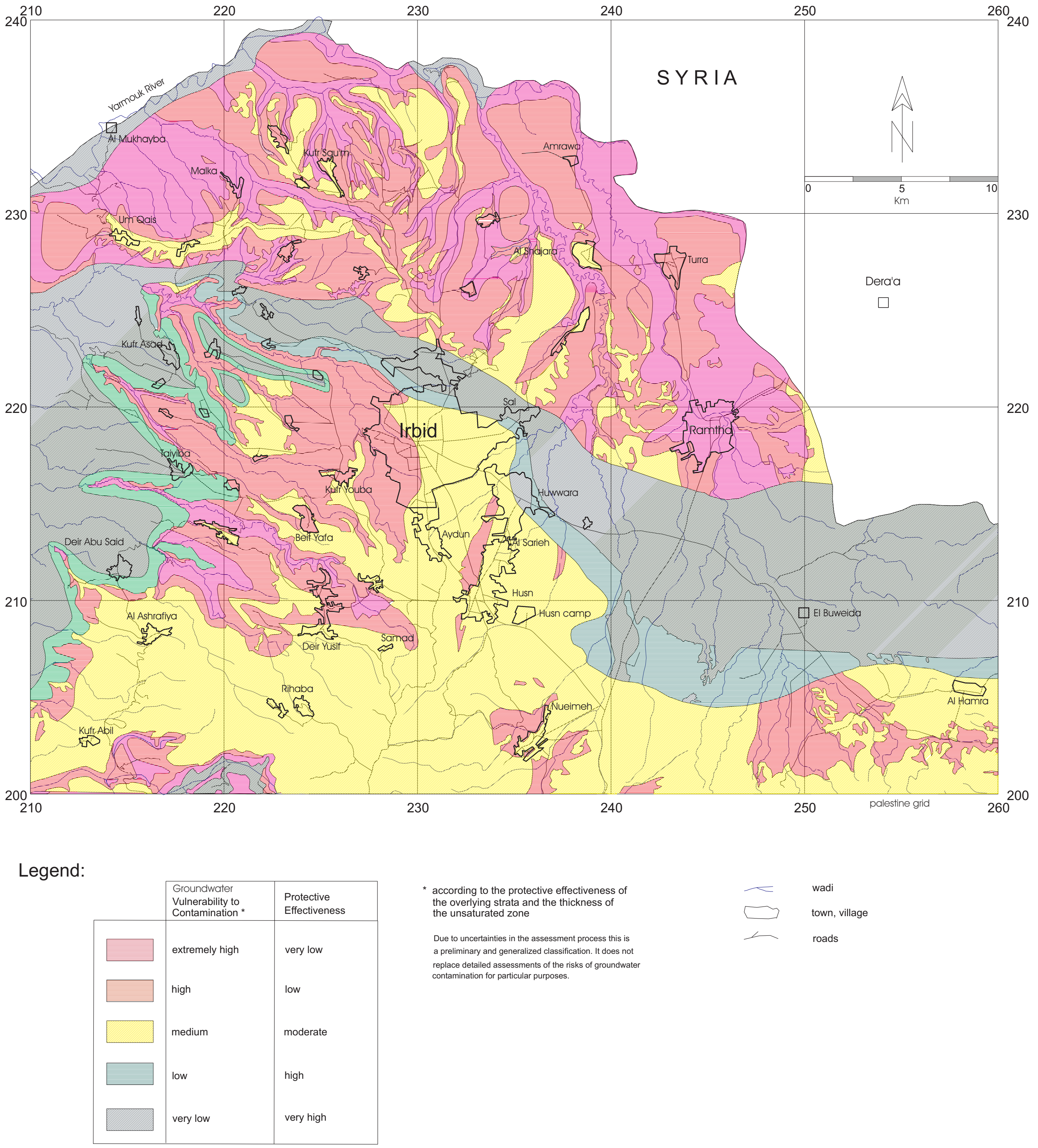


Fig. 7: Groundwater vulnerability map of the Irbid area of Jordan.

Abb. 7: Grundwassergefährdungskarte in der Umgebung von Irbid/Jordanien.

In order to avoid deterioration of the present situation, the following efforts should be made:

– Additional high-risk activities should not be allowed in areas of low protective effectiveness of the unsaturated zone
– High-risk activities should be relocated in more suitable areas, if possible.
– Technical measures should be taken to protect aquifers from high-risk activities, e.g., lining, installation of closed pipe systems for the effluent from treatment plants in high-risk areas, proper waste storage and disposal.
– Farmers should be educated not to apply excessive amounts of fertilizers and pesticides.
– Groundwater protection areas should be delineated for water wells and springs.

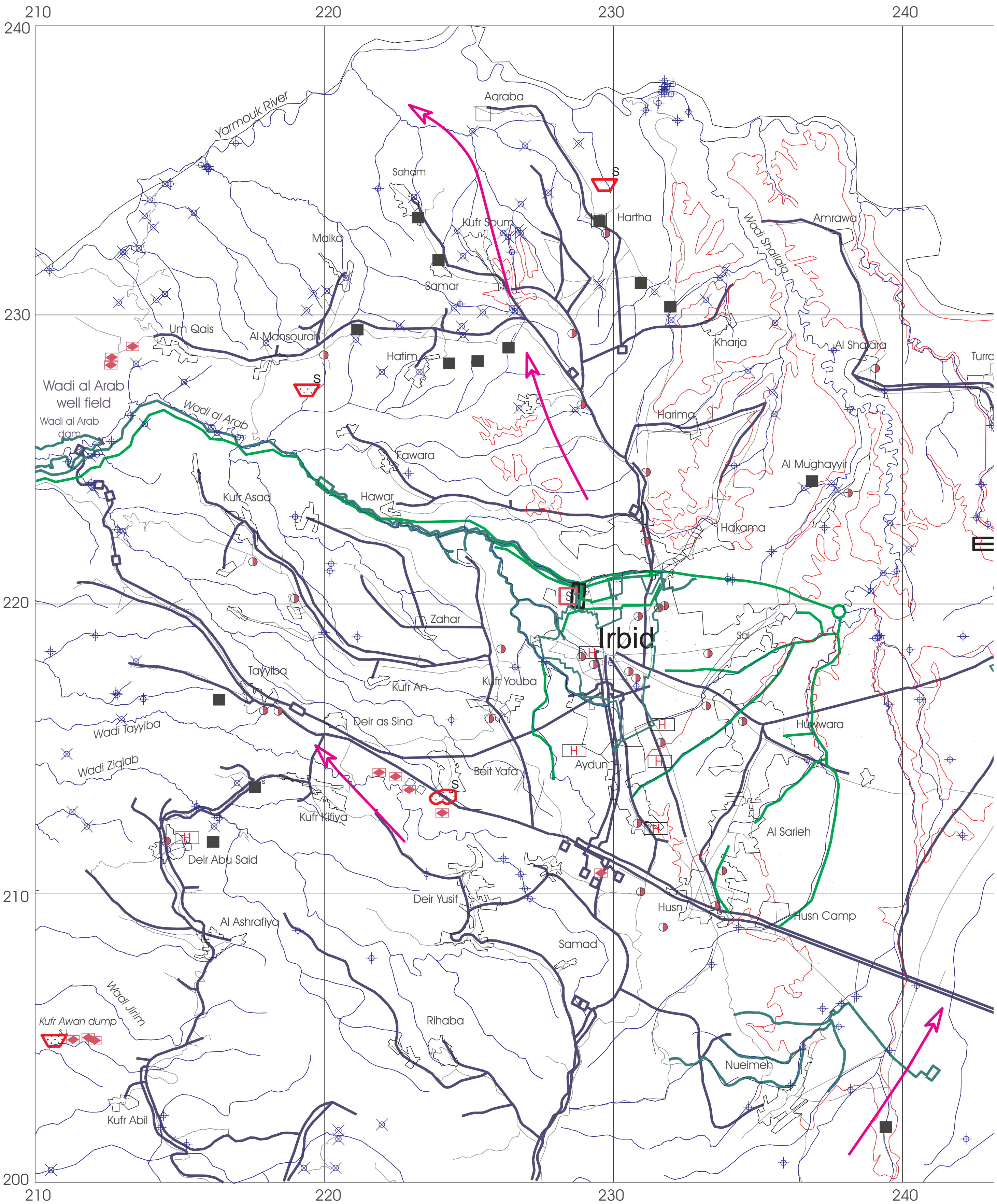
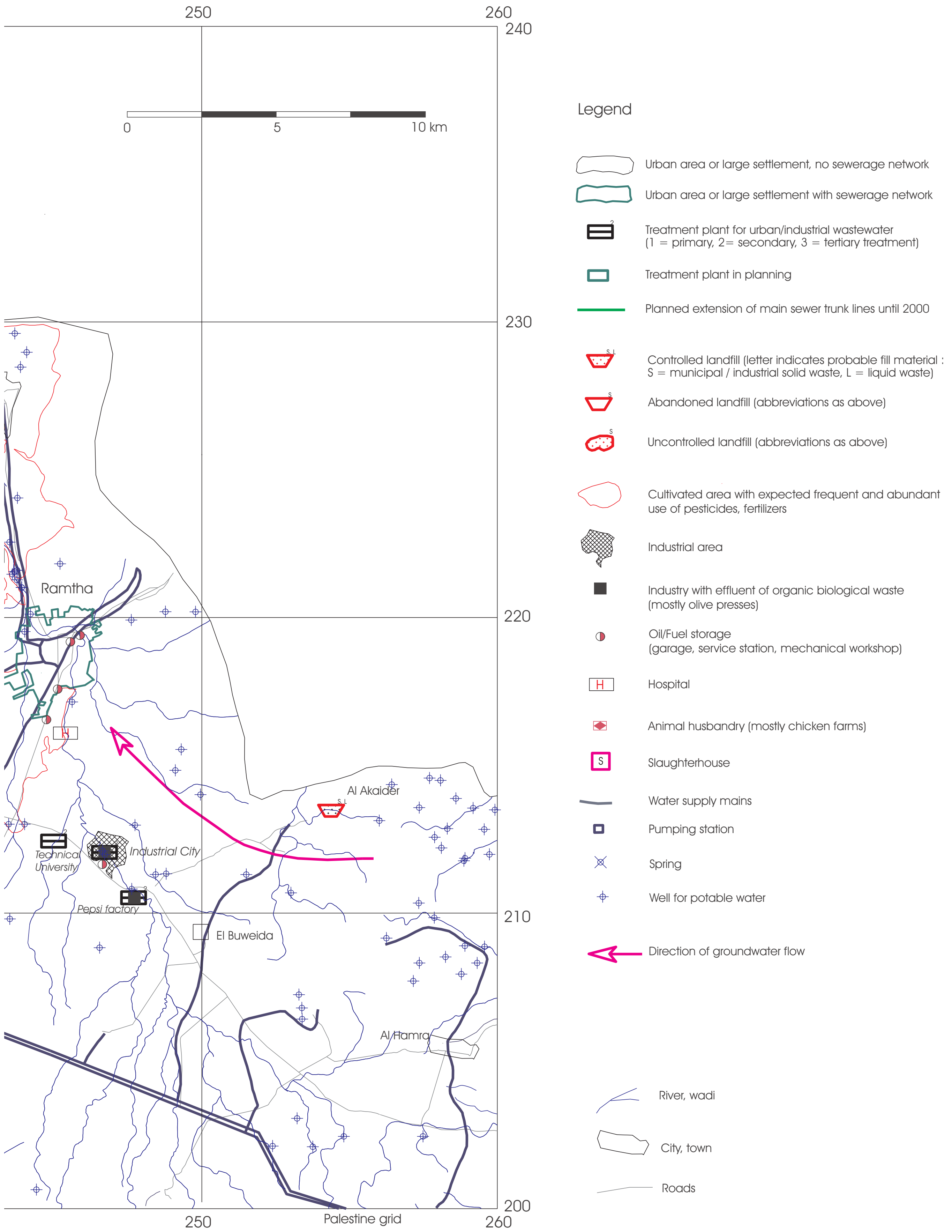


Fig. 8: Map of hazards to groundwater in the Irbid area.

Abb. 8: Mögliche Grundwasserverschmutzungsquellen in der Umgebung von Irbid.



250
260
240
0
5
10 km
230
220
210
200
250
Palestine grid
260
Ramtha
Technical University
Industrial City
Pepsi factory
Al Akaider
El Buweida
Al Hamra
Legend
Urban area or large settlement, no sewerage network
Urban area or large settlement with sewerage network
Treatment plant for urban/industrial wastewater
(1 = primary, 2= secondary, 3 = tertiary treatment)
Treatment plant in planning
Planned extension of main sewer trunk lines until 2000
Controlled landfill (letter indicates probable fill material :
S = municipal / industrial solid waste, L = liquid waste)
Abandoned landfill (abbreviations as above)
Uncontrolled landfill (abbreviations as above)
Cultivated area with expected frequent and abundant
use of pesticides, fertilizers
Industrial area
Industry with effluent of organic biological waste
(mostly olive presses)
Oil/Fuel storage
(garage, service station, mechanical workshop)
Hospital
Animal husbandry (mostly chicken farms)
Slaughterhouse
Water supply mains
Pumping station
Spring
Well for potable water
Direction of groundwater flow
River, wadi
City, town
Roads

The Map of Hazards to Groundwater

A map of potential hazards to groundwater in northwestern Jordan is shown on Fig. 8. The legend of VRBA & ZAPOROZEC (1994) was used for the map. The mapping features are based on a compilation of data in the office and field surveys of hazards to groundwater.

Landfills for Solid and Liquid Waste

The most important landfill for solid and liquid waste is located in Al Akaider, near the Syrian border, in the eastern part of the study area. It serves the entire area from Rihaba, Deir Yousif, Beit Yafa, Irbid, Shajara, and Amrawa to the east. The solid waste is deposited on the northern slope of a shallow wadi and immediately compacted and covered with soil. Al Akaider is the only legal location for the disposal of liquid waste in the entire study area. The liquid waste is released from the tanks of the transport trucks into an open pond above the wadi and from there through further settling and evaporation ponds into the wadi. Part of the water is used to irrigate trees.

The Al Akaider landfill is in an area of very high protective effectiveness of the soil and rock cover above the A7/B2 aquifer. The site is well maintained. However, the destruction of the settlement ponds by flooding of the wadi and spreading of polluted water downstream is a considerable risk. Wadi Al Akaider flows from the disposal area northwest towards the Syrian border (about 2 km) and the city of Dera'a.

The Al-Mansourah dump for solid waste is also located in an area where the vulnerability of the A7/B2 aquifer is very low. The site, however, drains towards areas of very low protective effectiveness of the A7/B2 aquifer in Wadi Al-Arab and towards the Wadi Al-Arab Reservoir. Though the garbage is covered with soil, there is a high risk that contaminants are leached by infiltrating rainwater and transported towards Wadi Al-Arab.

The Kufr Awan dump for solid waste from the towns and villages in the southwestern part of the study area is located in a high-risk area. This landfill poses a high risk of contamination of the A7/B2 aquifer and the springs down gradient of the site, towards the Jordan Valley.

Since none of the waste disposal sites have a leachate collection and treatment system, the leachate can infiltrate into the underground or be washed away by runoff.

Sewer Systems

The central parts of the cities of Irbid and Ramtha are connected to sewer mains and treatment plants for waste water as shown on Fig. 8. The sewer system of Irbid is being expanded to include the entire city and surrounding villages. Sewer systems reduce the risk of groundwater contamination, but the risk of undetected leaks in the sewer mains or treatment ponds remains. Effluent from treatment plants also represents a potential source of pollution.

The Irbid treatment plant discharges its effluent directly into Wadi Al-Arab, where it flows for several kilometers in an outcrop area of the A7/B2, into which it percolates.

The inflow of the treatment plant of Ramtha is overloaded with organic substances and the effluent pollutes the B4/B5 aquifer downstream from the treatment plant (SALAMEH, 1996).

Most villages are not connected to sewer systems. Septic tanks are also potential sources of pollution. Nitrate values around 200 mg/L have been measured in a spring downstream from Hartha (north of Irbid), and in wells north of Ramtha (eastern part of the study area) downstream from the sewage treatment plant (WAJ files and SALAMEH, 1996).

Industrial and Commercial Activities

Industrial development is still rather limited in the study area. Almost all of the industries are in Al-Hassan Industrial City, south of Ramtha. Many of the industries are small and the treatment plant is working at less than full capacity. A considerable part of the wastewater is being recycled and the amount of effluent from the treatment plant is rather small.

The map (Fig. 8) shows the locations of service stations and fuel depots. Leaks may occur from storage tanks or supply lines. Spilling of engine oil on the ground is common and car-washing facilities are gaining in popularity. Since oil is used to clean tires, bumpers, plastic parts, etc., the waste water is often heavily polluted. Storage facilities for heating oil are also sites of potential spills.

Agriculture and Farming

The area between Irbid and Ramtha from the Syrian border in the north to Nueimeh in the south is intensively cultivated. Frequent and abundant use of pesticides and fertilizers poses a risk to the quality of the groundwater. The widespread increase in nitrate concentration in groundwater is related to agricultural activities. Farmers should be educated not to apply excessive amounts of fertilizers and to use pesticides sparingly.

Intensive animal husbandry (mainly chicken farms, some cattle farms) is done without proper care for waste products. Animal droppings are often dumped in nearby wadies. Contamination of springs downstream from farms has been observed, for example, in the Um Qais area northwest of Irbid.

The highlands of northern Jordan are well known for the production of olive oil. The map shows the location of oil presses. None of them has facilities for proper waste disposal. The solid residues from the presses are sometimes used to produce soap or charcoal. The liquid waste is supposed to be transported to the Al Akaider landfill (eastern part of the study area). However, because of the long distance of sometimes more than 40 km, waste products are often dumped in nearby wadies, as field surveys indicate.

Appraisal of the Applied Methodology

The groundwater vulnerability map of the Irbid area (Fig. 7) represents the first attempt in Jordan to provide planners with a tool for a preliminary selection of priority areas for different forms of land use. Taking the availability of data and the purpose of the map into consideration, a scale of 1:100,000 seemed the most appropriate for the representation of the results of the vulnerability assessment. In this paper, the scale was modified for this paper.

Vulnerability mapping in the Irbid area was approached from a pragmatic point of view. Main considerations were

- the use of fairly simple and straightforward methods in order to obtain results within a reasonable time,
- the use of easily accessible existing data and to avoid additional time-consuming and expensive investigations as much as possible,
- to not become involved in scientific details and problems of secondary importance for the purpose of the map and which often cannot be solved anyway because of an insufficient and sometimes unreliable data base,
- to adapt the existing mapping approaches to the situation in Jordan,
- to present the results in such a way that they can be used by nonspecialists.

On the basis of the existing data, it was possible to come to an overall, generalized assessment of groundwater vulnerability in the Irbid area and to show the regional distribution of areas with differing protective effectiveness ratings for the soil and rock cover. Since the map of hazards to groundwater (Fig. 8) shows the location of the main water supply installations, such as springs, production wells and water mains, the combination of the two maps provides an initial indication of potential sources of pollution in the area around wells or springs and allows an initial assessment of the risk of groundwater contamination in a particular area.

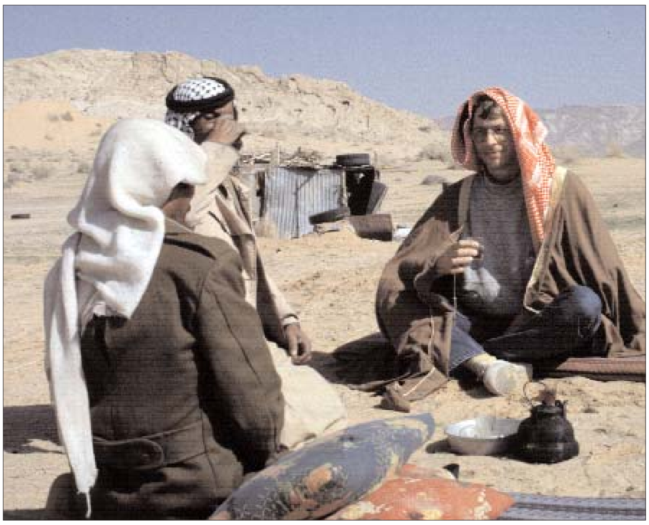


Fig. 9: Teatime (use of groundwater) in the desert near Irbid (Foto: D. Plöthner).

Abb. 9: Teepause (Grundwassernutzung) in der Wüste nahe Irbid (Foto: D. Plöthner).

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