J. ENVIRONMENTAL SYSTEMS, Vol. 26(3) 265-287, 1997-98

AQUIFER GROUND WATER QUALITY AND FLOW IN THE YARMOUK RIVER BASIN OF NORTHERN JORDAN

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ABSTRACT

Nitrate was used as an indicator of ground water pollution caused by contaminated water dumped into the Al Ekader landfill. The build-up of nitrate in the aquifers of the northeastern part of the Yarmouk Basin in Jordan is a cumulative result of Ekader sewage landfill practices. Historical monitoring data of nitrate concentrations in downgradient wells around the Ekader landfill show a gradual increase in concentration subsequent to the establishment of the landfill site in 1981. During the period 1981 to 1985, the increase in nitrate was limited. After 1985, nitrate concentrations rose dramatically, doubling more than ten times in ten years. This indicates that the previously unsaturated zone had become saturated with polluted water.

INTRODUCTION

Water shortage and population expansion are two parameters which at present are greatly affecting the water sector in Jordan. During the last thee decades, industrialization, urbanization, and agricultural activities have been growing at very fast rates. This has lead to large amounts of wastes in the form of wastewater, solid wastes, and emitted gases.

doi: 10.2190/273D-PGGM-0K6P-B8DA
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The use of surface sewage disposal systems, in particular septic tanks and tile bed disposal fields, has long been recognized as one of the most effective means of dealing with domestic-water problems in rural settings [1]. However, leachate plumes from municipal waste-water landfills are potential sources of contamination to ground water supplies [2]. Evaluation of the spatial extent and magnitude of leachate contamination is important because elevated concentrations of inorganic and organic compounds in leachates can degrade groundwater quality and contribute to high treatment costs or abandonment of water supply wells. The occurrence of nitrogen compounds in groundwater is generally an indication of contact with source of pollution from either leakage of waste water or application of fertilizer.

The Ekader open landfill site is a potential pollutant of groundwater in the Yarmouk Basin aquifers in the northern part of Jordan where a gradual buildup of nitrate in the groundwater around this landfill site has been monitored since the landfill site opened.

The main objective of this study is to develop an understanding of the natural groundwater quality in the northeastern part of the Yarmouk Basin. In order to delineate how far ground water quality has been affected by downward progress of leachates from the Ekader open landfill, nitrate concentrations were used as indications of contamination, to define the path of the plume into the deeper aquifer.

AL EKADER LANDFILL SITE HISTORY AND DESCRIPTION

The Ekader landfill site is located 27 km east of Ramtha, just south of the Syrian border (Figure 1). This landfill site has been operated as a waste disposal facility since 1981. It is the only official dump site for northern Jordan, with an area of 60.6 hectares, 8 of which are for contaminated water and the rest for solid waste. Two kinds of waste are dumped in this site: solid municipal and industrial wastes and municipal and industrial wastewater.

The Al-Ekader disposal site receives an average of 2305 m^3/day of wastewater. Tank trucks bring polluted water from houses and factories [3].

The location of this landfill is in a hilly area about 800 m above sea level. This site was chosen to minimize the leakage of contaminants to groundwater; the water table varies from 400 m to 450 m below the surface. The landfill was constructed by the Ministry of Municipal Affairs as a temporary solution for septic tank water in areas not connected to wastewater treatment plants. The lithologic units beneath the Ekader landfill include Quaternary alluvial deposits, Tertiary limestone, and chalky limestone.

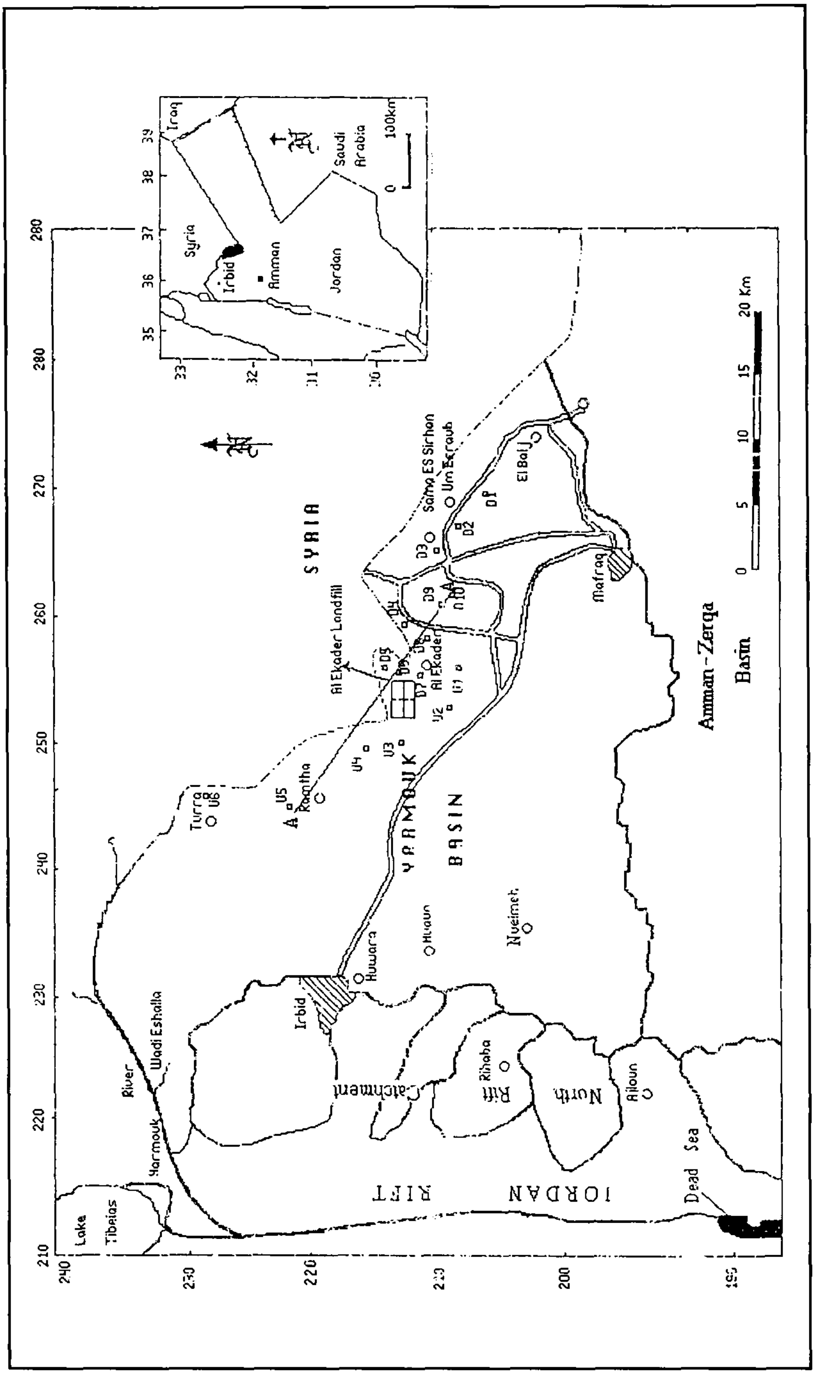

Figure 1. Location map of the study area.

THE SETTING

Three quarters of the Yarmouk Basin is located inside Syrian territory to the north. The Amman-Zarqa basin lies to the south and east, and the Northern Rift catchments to the west. The western part of Yarmouk Basin is highly populated and includes the major cities Irbid and Ramtha, but the eastern part is less densely populated, having only one major city, Mafraq (Figure 1).

The area of the basin is 6700 km^2; some 1514 km^2 are in Jordan and 5186 km^2 in Syria. Topographically as well as hydrologically a major anticline, Ajloun acts as the divide for Yarmouk River Basin and the Northern Rift Side (NRS) catchments.

The Yarmouk Basin lies within a marginal desert area; it occupies a transition zone between the Mediterranean and arid climate. The climate of the basin is generally influenced by the moist Mediterranean air from the west and by the arid desert winds from the east. The annual precipitation varies between more than 500 mm in the west (Irbid area) and less than 200 mm in the east (Sama Es Sirhan area). Two distinct seasons—wet and dry—occur in the area. The rainy season begins in late November and ends in early May, with 80 percent of the 400 mm mean annual rain falling between December and May. The dry season runs from June to October. The ground is more or less bare in the dry season, but covered with sparse shrubs and short grasses during the rains.

GEOLOGY

Structure

Jordan is dominated by the Dead Sea rift valley where thousands of meters of young sediments have accumulated. This rift extends from Wadi Araba and the Dead Sea in NNE direction to the Jordan valley and lake Tiberias. Quennel [4] postulated a left lateral movement of 107 km along the transform system. The formation of the rift began in the Upper Eocene-Oligocene [5]. Vertical displacement at faults on the Eastern flanks of the rift system is high and exceeds a thousand meters. In the rift valley the thickness of Tertiary and Quaternary deposits reach several thousand meters.

Uplift, faulting, and folding has extensively affected the sedimentary sequence in the high lands east of the rift valley. One of the most prominent structural features is the Ajloun Dome, north of the Zerqa River, which extends to the east.

The most important fault systems in the east are associated with the Ramtha-Sirhan fault zone which runs WNW and NW from Wadi Sirhan in Saudi Arabia (Figure 2). The northern arm of the Ramtha Sirhan Fault, which passes east of Ramtha, is believed to intersect with another normal fault which extends eastward across the middle of Yarmouk Basin from the Rift.

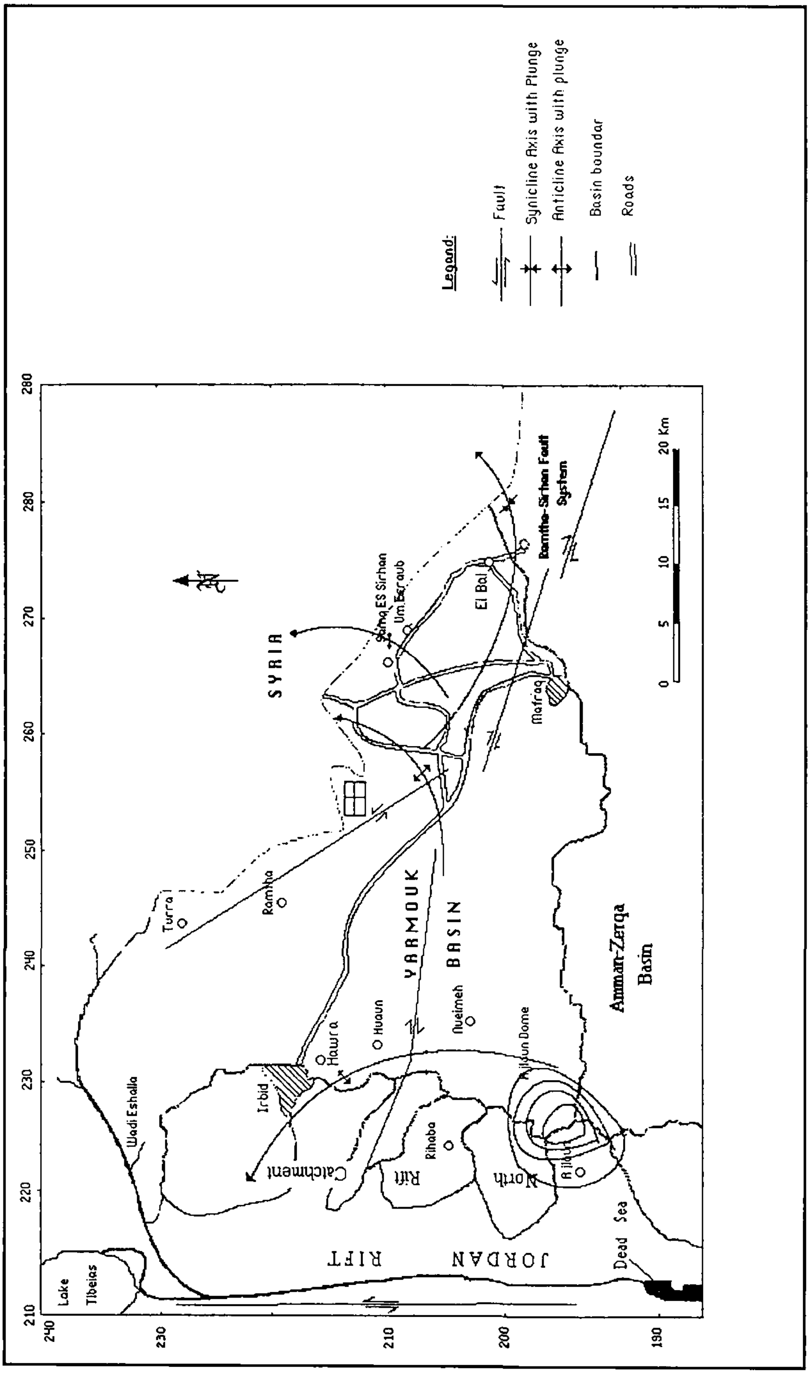

Figure 2. Structural map of Yarmouk Basin.

The major structures in the study area are: the Ajloun Dome (Ajloun anticline), a major fold east of the Jordan Rift, the axis of which strikes north-northwest and then pitches in the same direction. Another anticline extends northeastward and turns north between Sama and Um Essurab where it also pitches to the north. A major syncline extends south-eastward and from the north of Mafraq and turns towards El Baij in Yarmouk Basin.

Stratigraphy

The stratigraphic units of the basin are shown in Table 1. Rock units range in age from Upper Cretaceous to Eocene within the Yarmouk Basin. These rock units form two main groups, the Ajloun and Belqa groups. The Ajloun group consists mainly of marl, marly limestone, and limestone; it is defined more clearly in the south and southeastern parts of the basin. This is where the groundwater recharge occurs. The Ajloun group is divided into seven formations (Table 1), from A1 to A7. The Belqa group overlies the Ajloun group and is divided into five formations, B1 to B5. The group generally consists of chert, chalky marl, and chalky limestone. The most important formation from the hydrologic point of view is the B2 Formation. Generally the thickness of the two groups increases toward the north.

The eastern parts of Yarmouk Basin are covered by basalts (Figure 3), which form the western part of the basaltic Plateau (Quaternary age) which diminishes in thickness in the Yarmouk Basin from 150m at El Baij well (YB4). The basaltic flows cover the B2 Formation.

SAMPLING AND FIELD ANALYSIS

Ground water samples were collected from fifteen operating wells around the Ekader landfill site (Figure 1). These samples were analyzed for major anions and cations. Temperature, pH, and conductivity were measured in the field. In general, chemical analysis was conducted using standard techniques adopted in Jordan [6]. Biocarbonate was measured by titration to the methyl orange indicator end point. Chloride was determined by titration and precipitation of AgCl until silver chromate appears. Sulfate was determined by precipitation of $BaSO_4$ followed by measurement of absorbance with a spectrophotometer. Since the absorbency curve of this technique is relatively short, it is easy to underestimate the true sulfate concentration. Therefore many of the samples had to be duplicated and diluted before rerunning of the samples. We are confident that the error of the numbers reported does not exceed 10 percent.

Sodium, calcium, magnesium, and potassium levels were determined using an atomic absorption spectrophotometer. Phosphate and nitrate were determined using spectrophotometric techniques.

Table 1. Stratigraphy of Yarmouk Basin

Geologic Time Scale			Group	Formation	Symbol	Rock Type	Thickness Range (m)	Aquifer Potentiality
System		Epoch	Jordan Valley	Alluviam	Qa	Soil, Sand and Gravel	?	Good
Quaternary		Holocene		Lisan	JV3	Marl, Clay and Evaporite	300+	Poor
		Pleistocene		Samra Neogene	JV1-2	Conglomerate with Silicious Cement and Sand and Gravel	100-350	Fair
Tertiary		Pliocene						
		Miocene						
		Oligocene						
		Eocene	Belqa		B5	Limestone, Chalky and Marly Limestone	350+	Poor
		Paleocene		W. Shalla				
Cretaceous	Upper	Masterichtian		Rijame	B4	Chert and Limestone	30-50	Good
		Campanian		Muwaqer	B3	Chalk, Marly Chalk, Marl	300+	Poor
		Santanian		Amman	B2	Chert, Limestone with Phosphate	30-120	Excellent
				Ruseifa	B1	Chalk, Marl and Marly Limestone	0-75	Poor
		Toronian	Ajloun	Wadi Sir	A7	Limestone Dolomite Some Chert	65-100	Excellent
				Shueib	A5/6	Limestone, Marly Limestone	70	Fair to Poor
		Cenomanian		Hummer	A4	Dolomite, Dolomite Limestone		Good to Fair
				Fuheis	A3	Marl, Marly Limestone	60-120	Poor
				Naur	A1/2	Limestone, Dolomite, Limestone and Marly Limestone	80-120	Good
	Lower		Kurnub	Subeihi	K2	Sandstone, Shale, Clay and Sandy Limestone	230-270	Poor
				Arda	K1	Sandstone, Marl and Shale		

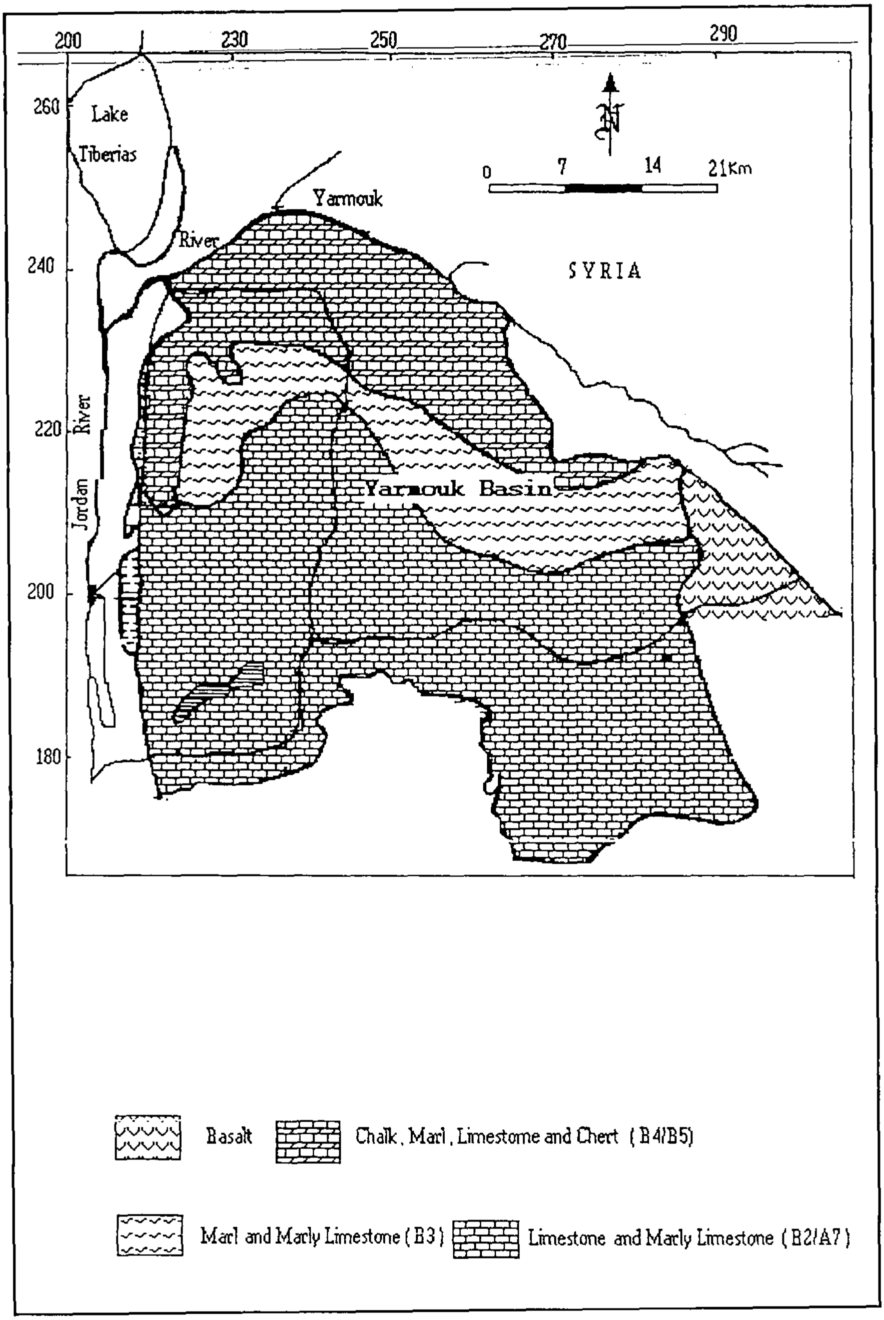

Figure 3. Geological map of Yarmouk Basin.

HYDROGEOLOGICAL SETTING

Surface Hydrology

The entire watershed of the Yarmouk Basin is characterized by poorly developed drainage channels, in spite of relatively high rainfall. Most of the plains are extremely flat and are covered by fertile soils. Good rapid infiltration through the soil and high permeability in the underlying rocks (basalt, chert, and limestone) preclude the development of secondary drainage channels. Consequently this area is considered to be an important recharge area for ground water. Higher drainage density and deep valleys that have been cut into bedrock occur near the Jordan Valley, and in the lower part of the Yarmouk. Deep drainage channels occur where soils are underlain by the less permeable B3 Formation which consists of marl and marly limestone. In these areas infiltration from rainfall decreases, and surface runoff increases [7].

GROUNDWATER HYDROLOGY

Ground water in the north east of Jordan is present in three aquifer complexes termed the shallow, middle, and deep aquifers. In the context of this study, we are primarily interested in the shallow and middle aquifers.

The aquifer systems of Yarmouk Basin are either related to the Ajloun or to the Belqa Groups (Table 1). The upper aquifers (shallow aquifer) consist of two formations: the B4 (Rijam Foundation) and B5 (Shalla Formation). These from one hydrologic unit termed the B4/B5 aquifer. It consists of chalky limestone and marly limestone with chert intercalation: it is a shallow thin aquifer which is recharged from the southern Ramtha and northern Irbid area. Total recharge of this aquifer was calculated in 1989 to be about 5.5 10^6 m^3/yr where 4.25 $10^6 m^3$/yr appears as spring discharge in northern Irbid area.

The quality of the water is generally good in the springs of the northern Irbid area, but the aquifer is polluted around northern Ramtha.

The A7, B1, and B2 are aquifers in the uppermost unit of the Ajloun group and the lower ones of Belqa Group and are considered to be one hydrological unit (Table 1). They consist of the Wadi Sir Limestone Formation (A7), the Ruseifeh Formation (B1), and the Amman Silicified Limestone. This aquifer is primarily limestone, dolomitic limestone, and chert. It has water table conditions in the upstream areas and artesian (or confined) conditions in the downstream areas, particularly in the Yarmouk Basin.

This aquifer is considered to be the main regional aquifer. Its recharge derives from the nearby Ajloun mountains and local catchment areas, as well as from ground water flow from the Syrian territories into Jordan.

GROUND WATER FLOW SYSTEM

The piezometric map (Figure 4), of the shallow aquifer (B4 aquifer) shows that the groundwater moves toward the Yarmouk river and follows the general pattern of the surface drainage.

The aquifer is encountered 12-120 m beneath the surface. The depth of the static water level can range from the surface down to a level of 132 m. The average aquifer thickness is about 100 m and reaches a maximum at 180 m, where some facies change occur in upper part of the Muwaqer Formation (B3).

The Aljoun anticline acts as a ground water divide, causing water movement in two directions: northeast, toward the Yarmouk Basin, and northwest, toward the northern rift side catchments (Figure 1). The ground water at Um Es Surab and at Sama El Sirhan comes from the south, east, southeast, and northeast, and flows northward, northwest, and southwest (Figure 5). However, underflow from across the Syrian border at Dera's city and Yarmouk river moves northwest, west, and southwest.

The B2/A7 aquifer is a free aquifer in the catchment area around Aljoun and Irbid cities Husun, Kitem, Nuaymeh, whereas the piezometric pressure increases to the northwest and west to form confining conditions and artesian flow in the Wadi Arab area.

The B3 Formation (marl and marly limestone) can be considered to be a potential aquitard. When saturated it can provide some water to the underlying aquifer system by leakage, but still acts as a confining bed to the underlying aquifer system. It can create high artesian pressure at certain places in the basin. Due to such high pressure, parts of the lower portion of the B3 Formation which have become saturated by the upward leakage from the main aquifer B2/B7 [7] make it possible for the well to start flowing before the main aquifer B2/A7 is reached.

The hydraulic gradient is low at Sama El Sirhan and Um Essurab areas, and accordingly is indicative of a very productive aquifer, even though the hydraulic gradient is high in the recharge area of Ajloun Dome, Nuaymeh, and El Manshia. So the possibility of contamination of the confined aquifer from leakage of the shallow aquifer seems to be more effective in the Sama El Sirhan and Um Essurab area, where the thickness of B3 Formation is decreasing toward the flow of polluted water from the shallow aquifer formation.

The hydraulics of the ground water system in the northern desert part of Jordan are different from that of the rest of the Yarmouk Basin. This is due to the presence of basalt overlying the B2/A7 Formation, so forming an aquifer system. The basalt thins to the west and is missing in the Suwelmeh area, where it lies above the saturated zone at Um Essurab village, so that the ground water moves toward Yarmouk Basin as underflow within the B2/A7 aquifer only.

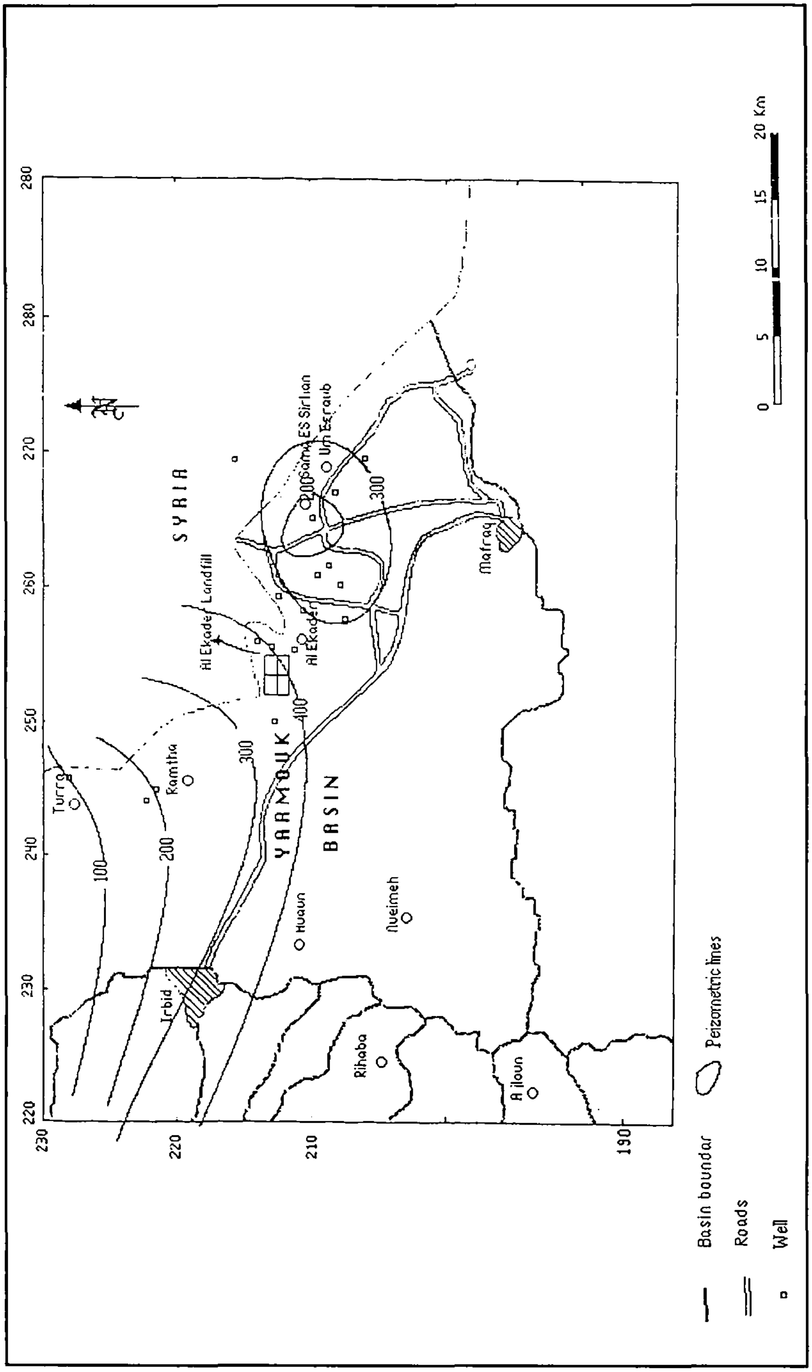

Figure 4. Peizometric map of Yarmouk Basin.

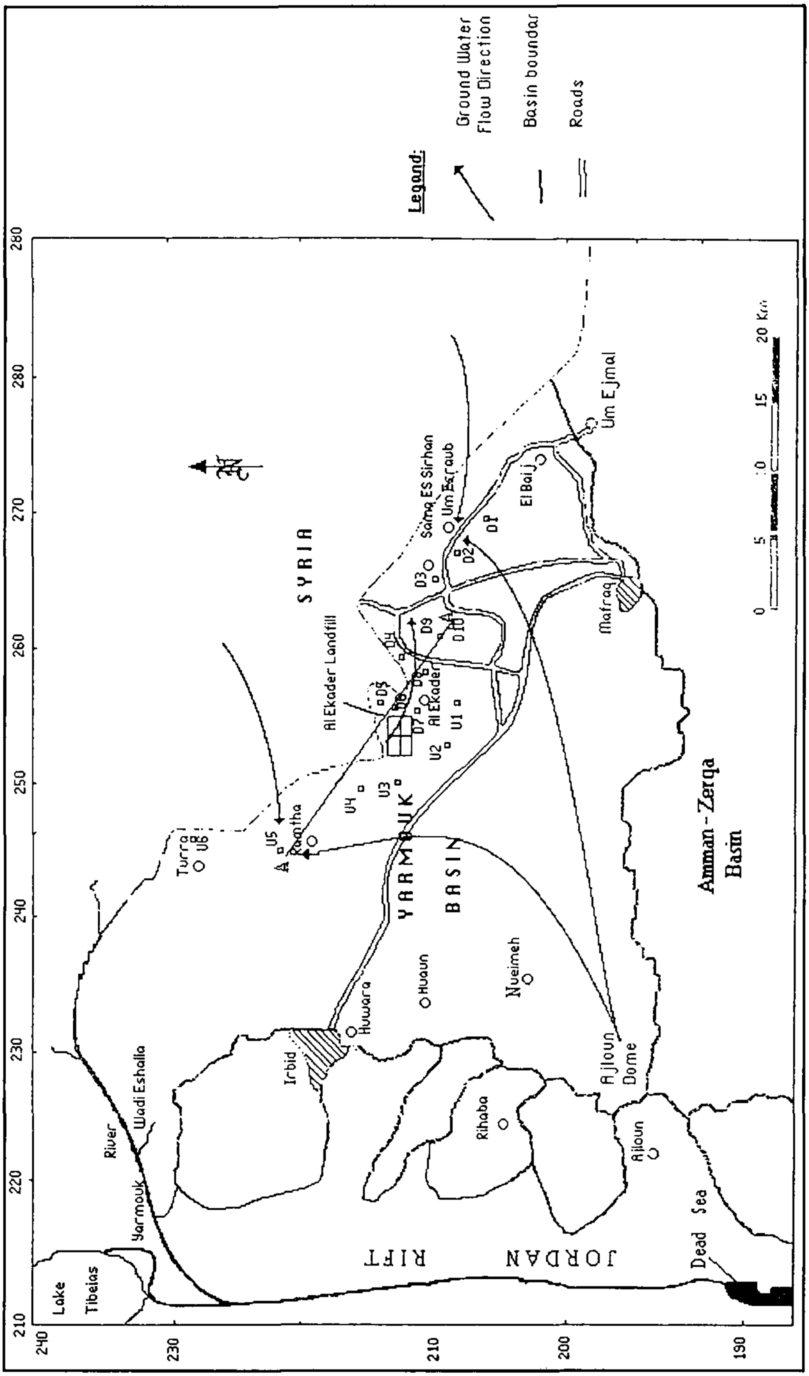

Figure 5. Ground water flow direction.

Depth to static water level ranges from 135 to 170 m in the Um Essurab area. The full thickness of the B2/A7 aquifer is saturated at Ramtha and Yarmouk rivers, but it is only partially saturated in the Sama El Sirhan and Huwwara areas.

The aquifer begins in the recharge area of Ajloun Dome where the lower part of A7 is saturated. Gradually, saturation increases northeastward to the Yarmouk river and northwestward toward the Northern Rift Side catchments. The increase in the saturated thickness can be explained by the outcropping of younger formations and the greater depth bottom of the aquifer, as well as by a decrease in the hydraulic gradient towards the Yarmouk River.

GROUND WATER QUALITY

The Piper diagram of the studied area of Yarmouk Basin shows that it is of the sodium chloride type (Figure 6). The groundwater of the B4/B5 aquifer (shallow aquifer) in the Ramtha area shows high concentration of NO_3^-, increasing in Na^+, Cl^-, HCO_3^-, and TDS. These concentrations increase northward towards Ramtha city. There has been a dramatic increase of NO_3^- in B4 during the last two decades.

The concentrations of calcium Ca^{2+} and bicarbonate HCO_3^- can be interpreted in terms of the lithology of the aquifer itself as attributed to the dissolution of the calcareous aquifer. High concentrations of nitrate are attributed to the pollution caused by the contaminated water brought to this area. Historical data shows a gradual increase of nitrate from nil in 1971 to more than 650 mg/l in 1996 in the Muhasi well. This extends into the ground water flow path by which water moves north and northwest toward Wadi Eshalla. However, the high concentrations of NO_3^- may be attributed to the agricultural activities in the area and to the use of N-fertilizers; or, it may also be due to the effect of the dumping of contaminated water.

Which of these two possibilities is more likely cannot yet be determined. Two wells have been drilled in the Muhasi area. One is within the shallow aquifer (B4) at 70 m depth (static water level 15 m). The other is in B2/A7 at a depth of 702 m (static water level 283). However, the groundwater of the deeper aquifer shows a gradual increase of NO_3^- with depth but lower than that of the upper shallow aquifer.

A geological section A-A$^-$ trends NW-SE along the border between Jordan and Syria (Figure 7). A number of interesting trends can be inferred from the hydrological conditions along this section. The most important is the increase of salinity toward the eastern side of the basin (Sama Es Sirhan and Um Esurab areas). The cause of the salinity increase in this area is the progressive dissolution of the aquifer minerals along the flow path of waters. An examining of the anion variation with salinity in the basin (Figure 8) reveals that the major cause of salinity variation is the variation in chloride concentrations. Bicarbonate

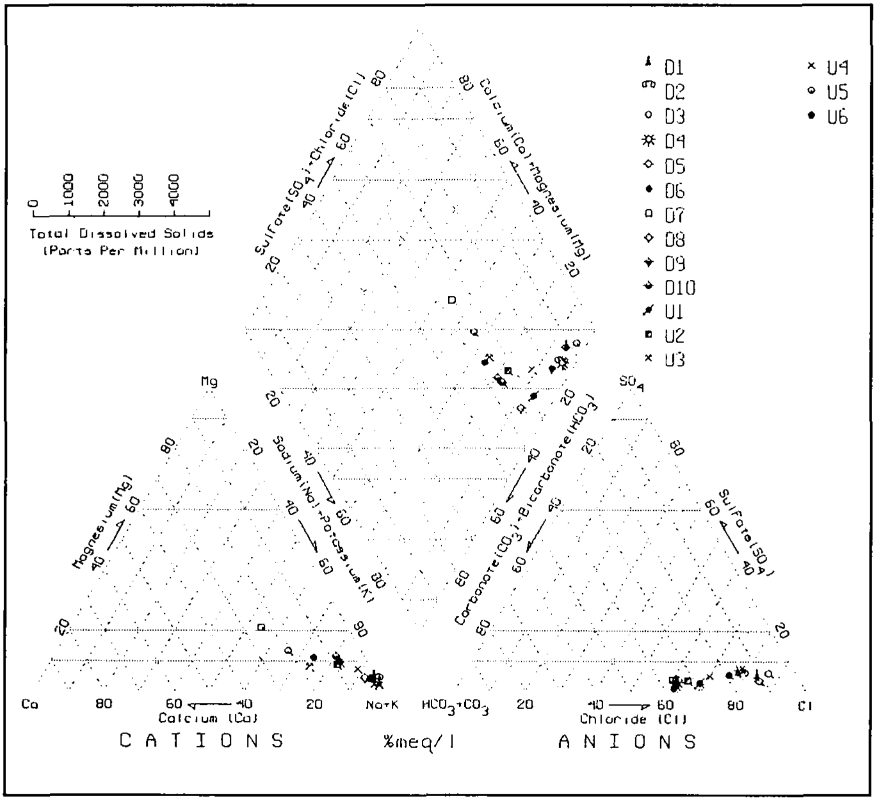

Figure 6. Piper diagram of the downgradient wells.

concentrations show steady decreases with the increase of salinity, whereas the sulfate concentrations are relatively constant. The cation trends show that sodium is the predominant cation (Figure 8). Wells compared in Figure 8 are from the B2/A7 aquifer.

Nitrate concentrations, as shown from the historical data, are highly variable in space and time (Table 2). This variability is due to several factors: the volume of leakage waste water dumped in the landfill and other leakage sources, rainfall, depth of the aquifer, and how far the wells are from the pollution source.

Major Ions

In ground water from Yarmouk Basin aquifers, sodium is the dominant cation, and nitrate, chloride, and bicarbonate are the dominant anions (TDS range from 512 to 1530 mg/l). There are high concentrations in most water samples collected

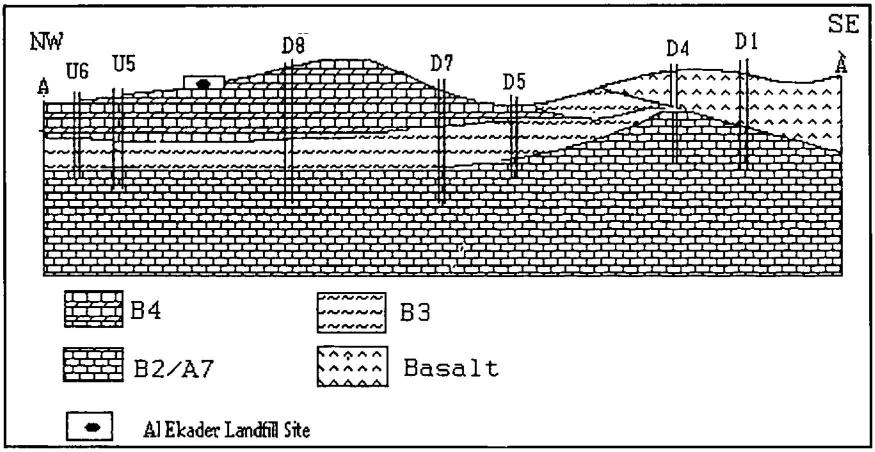

Figure 7. Geological section A-A.

from the study area. These range from 10 to 1133 mg/l. The spatial distribution of nitrate concentration indicates two possible sources. The leakage of contaminated water from the Ekader landfill raises the concentration of nitrate more than 500 mg/l in some wells near the dump site. The other possible source is the contamination from use of N-fertilizers in farming projects in the area. Chloride also shows high concentrations, ranging from 160 to 720 mg/l. In fact, chloride and sodium concentrations increase within the B2/A7 aquifer toward the east, where the aquifer is overlain by basalts. Therefore the increase of chloride and sodium concentration is attributed to the dissolution of basaltic rocks.

Nitrogen Contribution and Transformation

Nitrogen is present in high concentrations in septic tank effluent primarily as ammonium nitrogen (75-80%), with organic nitrogen making up the remainder [8]. Total nitrogen concentrations in such effluent have been reported to vary from 25 mg/l to as much as 100 mg/l, the average generally being in the range of 30 to 45 mg/l [9]. C.E.C. Consult and LG Mouchel & Partners, estimate the total nitrogen concentration in septic tanks discharged in the Ekeder disposal site to be 230 mg/l [3].

The Ekader landfill receives more than 2305 m^3/day of septic tank water. Upon introduction of this water into the landfill, nitrogen may undergo various transformations, the most important being nitrification [1]. Nitrification may be broadly defined as the biological conversion of nitrogen in organic and inorganic compounds from a reduced to a more oxidized state. The predominant end product is nitrate (NO_3^-) because it is a stable ionic species. This also explains its

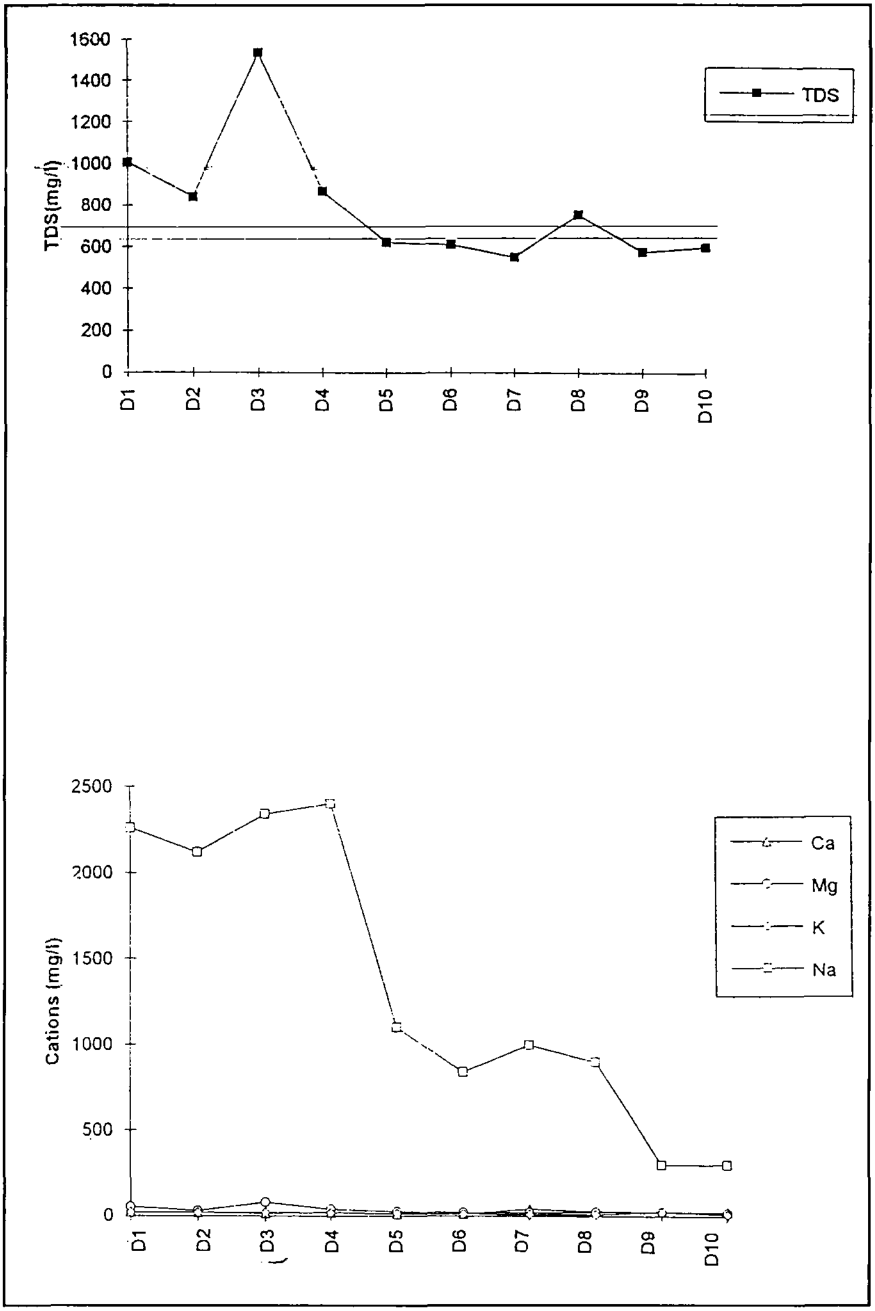

Figure 8. Trends of cations, anions, and nitrate against TDS.

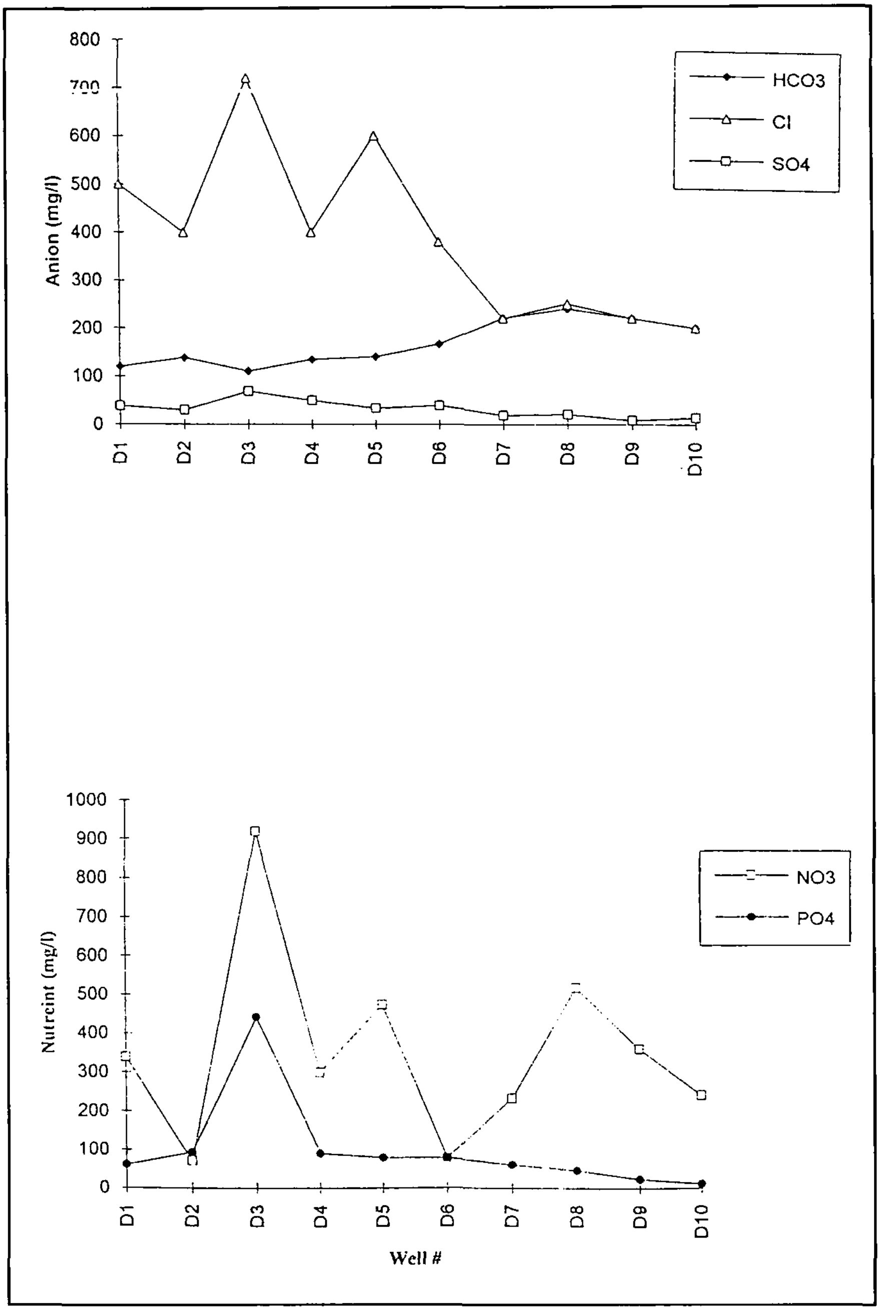

Figure 8. (Cont'd.)

Table 2. Nitrate Concentrations of Downgradient Wells, 1976-1996

Well No.	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1976	0	1	2	0	0	0	0	0	0	0
1978	2	1	15	6	2	0	2	6	3	2
1980	10	9	20	4	19	7	3	18	17	5
1981	7	6	16	5	16	9	5	4	5	3
1982	13	5	32	28	22	11	7	10	7	10
1985	34	22	102	18	32	35	31	29	30	14
1987	40	35	118	49	40	45	48	41	41	26
1988	66	53	138	74	51	54	52	89	50	42
1990	140	54	405	107	103	68	120	218	104	97
1992	98	35	350	73	97	44	88	76	99	62
1994	179	64	502	147	182	82	176	160	185	150
1995	207	54	570	195	217	94	180	185	195	174
1996	338	70	920	297	474	78	234	519	361	242

high degree of mobility in the soil. This resultant nitrate may then pass easily through the soil along with percolating effluent and other recharge waters.

LEACHATE GENERATION AND LEAKAGE

The gradual increase of nitrate concentrations in the ground water wells around the Ekader landfill suggests that saturation of the vasodose zone (400 m) with septic tank water takes a long period of time before contamination of the ground water is recognized.

The initial moisture content of the unsaturated zone below is field capacity, so that during the early stages drainage and potential leakage is limited to localized channeling. Water from infiltration gradually builds up the moisture content of the unsaturated zone, until the general effects of gravity are felt. Eventually, leachate builds up until an approximate hydrologic balance is reached in which average outflow equals average infiltration, and leachate levels stabilize. Defining the ground water flow direction made it possible to interpret the geochemical characteristics of the leachate plume as it moved downgradient from the landfill source (Figure 9).

In the B2/A7 aquifer, upgradient and downgradient wells were distinguishable relative to the flow path through the landfill. The distinction between upgradient (Table 3), and downgradient wells (Table 4) was clear, because the geochemical composition of samples from downgradient wells D1, D2, D3, . . . , and D10 differ from that of the other wells. Upgradient wells are sealed by the ramtha fault from the downgradient wells, which show different chemical composition.

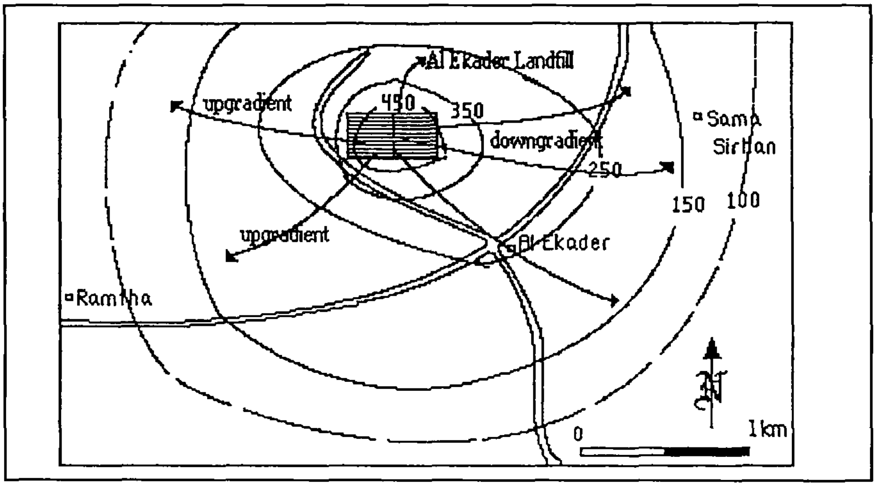

Figure 9. Leakage of leachate from Al Ekader landfill.

Table 3. Chemical Composition of Downgradient Wells

Well No.	pH	TDS	Temp.	HCO_3	Cl	SO_4	Ca	Mg	K	Na	NO_3	PO_4
D1	7.6	1005	35	120	500	38	22	53	22	2260	338	61
D2	8.1	838	29	138	400	30	20	33	20	2120	70	93
D3	7.9	1530	33	110	720	69	16	81	20	2340	920	441
D4	7.8	864	27	134	400	50	20	40	18	2400	297	89
D5	8	621	22	140	600	34	14	26	16	1100	474	79
D6	8.2	608	25	166	380	39	14	20	14	840	78	79
D7	7.8	550	28	220	220	19	42	22	10	1000	234	61
D8	7.5	755	38	240	250	21	30	23	10	900	519	46
D9	7.8	576	24	220	220	9	28	24	24	300	361	23
D10	7.9	600	28	200	200	15	26	19	12	300	242	12

Table 4. Chemical Composition of Upgradient Wells

Well No.	pH	TDS	Temp.	HCO_3	Cl	SO_4	Ca	Mg	K	Na	NO_3	PO_4
U1	8.2	634	31	208	300	17	18	23	14	920	36	50
U2	7.7	690	32	230	270	21	40	23	10	400	42	55
U3	7.6	666	28	240	250	13	70	20	8	340	47	46
U4	8	634	28	180	300	30	16	18	10	400	25	23
U5	7.8	743	26	248	250	23	56	22	6	200	10	32
U6	7.4	860	28	320	310	7	70	33	10	400	15	12

Samples collected from downgradient wells near the Ekader landfill had significantly high specific conductance values and elevated values of nitrate, chloride, and sodium. Historical monitoring of the wells around the Ekader landfill reveals that the leakage of septic water was very limited during the early period of the operation on the landfill between 1981-1985. Nitrate concentrations during this period ranged from 8 mg/l in 1981 to 35 mg/l in 1985 (Table 5) [10, 11]. After 1985, a dramatic increase in nitrate concentrations can be recognized (Figure 10). Nitrate concentrations increased from 0 mg/l (1976) to 47 mg/l (1987), 67 mg/l (1988), 142 mg/l (1990), 204 mg/l (1995), and the most recent measurement of 423 mg/l (1996). These are average nitrate concentrations of ten downgradient wells. High concentrations of nitrate have been recognized in well D3 (920 mg/l) in the Um Essrab area, in a cone of depression within the downgradient wells.

SUMMARY AND CONCLUSION

Concentration of nitrate, chloride, and sodium were used to identify the leachate plume enimating from the Ekader landfill in the northern part of Jordan. In the B2/A7 aquifer, nitrate concentrations in samples from downgradient wells were elevated at a statistically significant level above the concentrations measured in upgradient samples. Elevated concentrations of nitrates persisted as the leachate plume moved away from the landfill toward a depression in the potentiometric surface of the B2/A7 aquifer.

Table 5. Average Concentration of Nitrate, 1976-1996, in Ground Water Wells in Al Ekader Landfill Area

Date	Average NO_3 (mg/l)
Oct-76	0
Nov-78	4
Sep-80	11
Dec-81	8
Aug-82	14
Oct-85	35
Sep-87	47
Nov-88	67
Oct-90	142
Dec-92	102
Oct-94	183
Nov-95	204
Nov-96	423

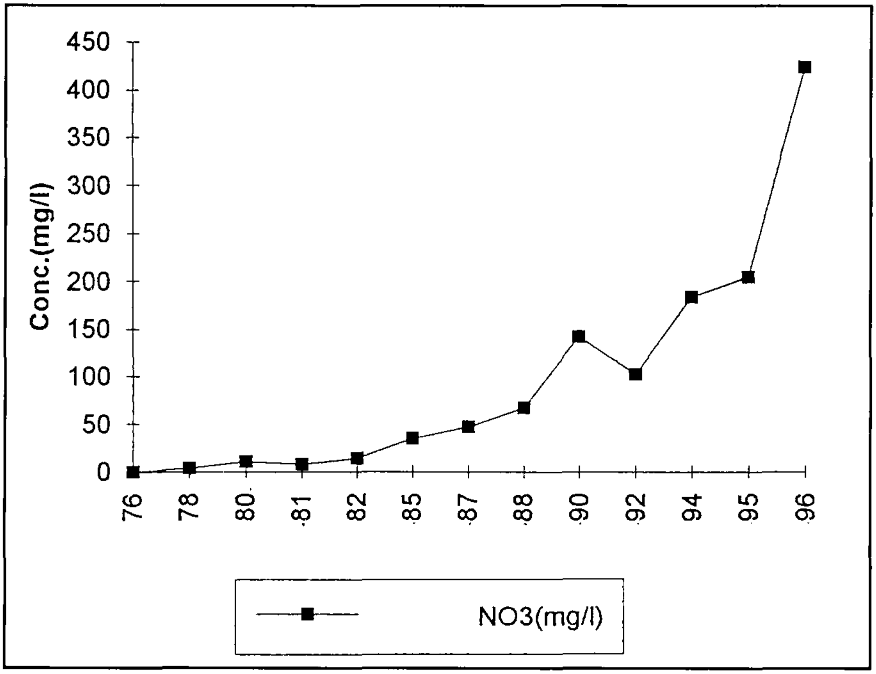

Figure 10. Average nitrate concentration changes, 1976-1996, in ten downgradient wells in the Al Ekader landfill area.

Contaminated water did not seep continuously through the landfill at the same velocity as in the B2/A7 aquifer, which appear from different nitrate concentrations in different wells. During the first four years after the opening of the landfill, percolation to ground water was very limited, because during this period most of the contaminated water was used to saturate the unsaturated zone. After saturation, a sharp increase in percolation of contaminated plumes was recognized.

ACKNOWLEDGMENT

The authors deeply thank Professor J. Petter Johnson (Carleton University, Canada) for reading the manuscript and for his valuable suggestions.

REFERENCES

1. N. N. Hantzsche and E. J. Finnemore, Predicting Groundwater Nitrate-Nitrogen Impacts, *Ground Water, 30*:4, pp. 250-267, 1992.

2. Friedrich Ebert Stiftung Geothe-Institute Amman and Water Research and Study Center, University of Jordan (1991). *Water Pollution in Jordan: Causes and Effects. Proceedings of the 2nd Environmental Pollution Symposium*, p. 76, September 29, 1990.
3. C.E.C. Consult and LG Mouchel & Partners, *Al-Ekader WasteWater Treatment Plant, Technical Report,* Amman-Jordan, 1993.
4. A. M. Quennell, Tectonics of the Dead Sea Rift, *Proceedings of the 20th International Geology Conference*, Resumenes de las trabjos presntados. Mexico, pp. 385-403, 1959.
5. F. Bender, *Geology of Jordan, Contribution to the Regional Geology of the Earth*, Supplementary Edition of Volume 7, Berlin-Stuttgart, 1974.
6. Khawaj et al., *Water Analysis Manual,* Water Research and Study Center Newsletter, University of Jordan Press, 1985.
7. O. Joudeh, *Water Resources of the Yarmouk River Basin,* Water Authority, Amman-Jordan, 1985.
8. R. J. Otis et al., The Performance of Household Wastewater Treatment Units Under Field Conditions, *Proceedings of the National Home Sewage Disposal Symposium*, American Society of Agricultural Engineers, pp. 191-201, 1975.
9. U.S. Environmental Protection Agency (EPA), *Design Manual: On-Site Waste Water Treatment and Disposal Systems*, Report No. EPA-625/1-77-008, 1980.
10. Water Authority of Jordan, *Yarmouk Basin. Internal Technical Report,* Water Authority-Amman, p. 160, 1989.
11. Water Authority of Jordan and Federal Institute for Geosciences and Natural Resources, *Ground Water Resources of Northern Jordan*, Internal Technical Report. Project No. 89.2105.8, p. 94, 1989.

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