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CHEMICAL AND ISOTOPIC COMPOSITION OF WATER FROM SPRINGS AND WELLS IN THE DAMOUR RIVER BASIN AND THE COASTAL PLAIN IN LEBANON

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A hydrochemical and isotopic study was carried out on spring waters of the Damour River Basin and groundwaters from wells in the coastal Mediterranean plain in Lebanon. The aim of this study was to determine the origin, the age, and the quality of groundwater resources in the limestone aquifer. The results showed that most of the groundwater pumped from wells for irrigation and drinking water supply is directly recharged in the coastal plain. It contains up to 30 percent of groundwater recharged in the high mountains. The elevated solute content of the groundwater in the coastal plain compared to that of the spring waters is due to different intensive agricultural activities rather than seawater intrusion. The relatively long mean residence time of the spring waters of about ten years contradicts the previous hydrogeological assumption that the low magnesium/calcium ratio is due to the fact that hydrochemical equilibrium has not been established.

INTRODUCTION

The groundwater resources in the coastal plain in Lebanon serve for the supply of drinking water to municipalities and irrigation water to farmers. The pumping has already lowered the groundwater table, and hydrogeologists have assumed that salty water from the Mediterranean Sea has entered the aquifers.

Pollution by irrigation return flow from intensive agricultural activities may also deteriorate the quality of these economically important fresh water resources in the coastal plain. Spring water in the upper parts of the Damour River Basin might have become affected by dissolution of salty soil in the recharge areas and salt deposition by precipitation, as well as seepage of irrigation return flow.

The growing population, agriculture and industry have competing interests in a steady increase of fresh water supply. There are still sufficient resources in Lebanon for a future development; however, they have to be protected against pollution and over exploitation. Suitable measures for an optimized management of groundwater resources have to be elaborated based on a comprehensive knowledge of the hydrological situation, especially the location and rate of groundwater recharge, and the age or mean residence time of the groundwater.

Hydrological studies applying both analyses of environmental isotopes and hydrochemistry are still rare in Lebanon (Geyh, 1998; Wagner and Geyh, 1999) although they are often indispensable as contributions to the hydrological knowledge on groundwater resources.

The Damour River Basin and the coastal plain near the capital, Beirut, are the most important regions for abstraction of groundwater. Hence, these regions were selected for this isotope hydrology and hydrochemical study of the groundwater budget within the scope of the IAEA Regional Technical Co-Operation Project entitled "Isotope Application for Improved Groundwater Utilization" (RAW/8/007). One objective was to determine the mean residence time of exploited groundwater resources in the coastal plain as well as of waters discharged from the major springs of the Jurassic limestone aquifer in the Damour River Basin. Another objective was related to the vulnerability of the groundwater in the coastal plain to pollution by irrigation return flow from agricultural activity, as well as by industrial and domestic wastewater and seawater intrusion.

LOCATION AND GEOLOGY

Lebanon is located on the eastern shore of the Mediterranean sea. It is bordered by Syria in the north and east and by Israel in the south. The country comprises four narrow geographically well-separated N-S regions stretching parallel to the sea from west to east. The flat coastal plain is about 170 km long and between 10 and 60 km wide. Further to the east the Lebanon mountains rise to about 2800 m. They drop steeply to the third region, the Beka'a Valley, which is the richest agricultural area in Lebanon (Sinu, 1982). The valley is bordered on the east by the Anti-Lebanon Mountains, which rise to 1800 m.

The western slopes of the Lebanon mountains are drained by a number of rivers which directly discharge into the Mediterranean Sea. A large one is the Damour River, which runs south of Beirut. Its catchment surface extends over an area of 290 km² and is bordered by the Nahr-Beirut Basin in the north, the Nahr-Awali Basin in the south and the Nahr-Litani Basin in the east (Figure 1).

The Lebanon and Anti-Lebanon mountains are two massive horsts; the Beka'a valley is a folded synclinal basin. The mountains are tectonically uplifted fault blocks. They consist of Jurassic limestone and dolomite surrounded by folded and faulted deposits of Cretaceous, Tertiary, and Quaternary age (Dubertret, 1948).

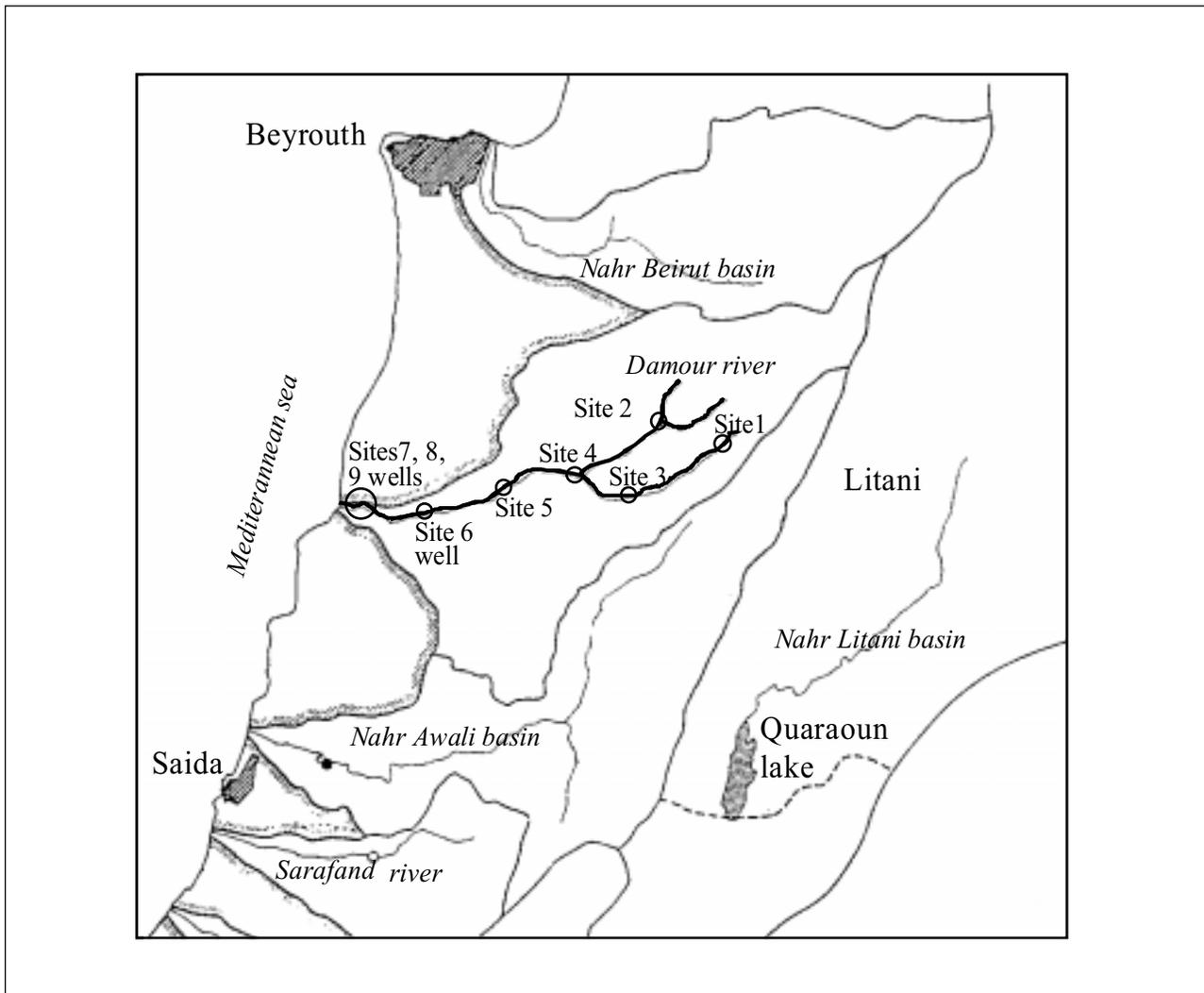


Figure 1. Map of the study area and sampling sites. Spring water: sites 1 to 5 (Site 1, 1060 m; site 2, 1045 m; site 3, 921 m; site 4, 827 m; site 5, 500 m). Wells: sites 6 to 9 (corresponding depths under sea level: site 6, 140 m; site 7, 105 m; site 8, 80; site 9, 60 m).

Both limestone and dolomite dominate in Lebanon beside Quaternary sandstone and clay-like lacustrine deposits. Marly limestone with varying amounts of calcareous clay and dolomite are prevalent in the Upper Jurassic and Cretaceous formations. Thick layers of karstic limestone with large and hydraulically interconnected voids form the major aquifer systems. Groundwater from Jurassic formations is the source of the major springs in the upper Damour River Basin. Faults interconnect the aquifers in the mountain area with those of the coastal plain.

APPLIED HYDROCHEMICAL AND ISOTOPIC METHODS

The combined hydrochemical and environmental isotope survey included five major karst springs and four deep wells. Water samples were collected every two months between 2000 and 2001 .

The pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature of the water samples were measured during the sampling campaigns in the field. The chemical analyses of the water samples were done immediately after their collection. Anions and cations were analyzed with atomic absorption spectroscope (Perkin Elmer AA 100) and an ion chromatograph (Dionex IC 25). $\delta^{18}\text{O}$, $\delta^2\text{H}$ and ^3H values were determined in the Laboratory of Amman, Jordan.

RESULTS AND DISCUSSION

Hydrochemical results

Table 1 contains all results of the chemical analysis (temperature, pH, EC, TDS, hardness and major cations and anions) of groundwater and spring water samples. According to these results, spring waters from the most elevated Sites 1, 2 and 3 have a lower solute content (TDS = 200-315 mg/l) than those from Sites 4 and 5, as well as groundwater from the pumped wells (200-590 mg/l). Figure 2 shows the variation of TDS as a function of spring altitude. The range of TDS progressively increases from the mountainous area towards the coastal Beirut region. This is attributed to an increasing influence of the seawater salt in the precipitation and intensified agricultural activity.

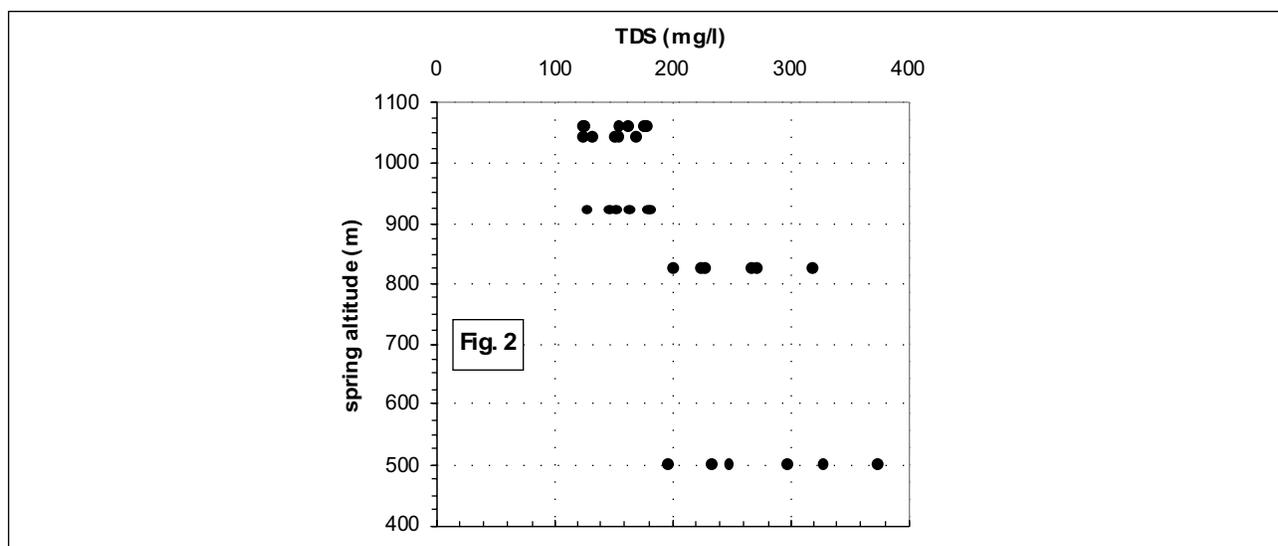


Figure 2. Increase of TDS with the altitude of the springs in the Damour River Basin.

The average temperature of water samples from the spring Sites 1 to 3 (mean 11°C) is lower than that from the Sites 4 and 5 (mean 14°C). This can be explained hydrologically as a result of the different altitudes of the recharge areas. The average temperature of the groundwater pumped from wells (mean 19°C) is considerably higher (Table 1) and is attributed to the geothermal gradient. The pH ranges from 7.1-7.8. The concentration of HCO_3^- ranges from 110 to 340 ppm and that of calcium from 41 to 160 ppm.

The chemistry of the majority of water samples is of the calcium/magnesium/bicarbonate type with the following ionic sequence: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-}$. The average concentration of Ca^{2+} and Mg^{2+} exceeds that of Na^+ and K^+ . These hydrochemical compositions reflect the geochemical properties of the aquifer rocks consisting of calcium carbonate and dolomite. The $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio from 0.05 to 0.4 of the spring waters is low compared to 0.5-0.9, which is representative of karst waters of limestone and dolomite aquifers (Schoeller, 1956; Rosenthal, 1987). Hydrogeologists explain this difference by a different long mean residence time (MRT) of the spring waters and the groundwater in the aquifers. The MRT appears to be too short to allow the establishment of chemical equilibrium in the aquifers of the Damour River Basin.

The variation in time of the concentration of cations, anions, the electrical conductivity and TDS during the study period was small. Minimum values belong to the rainy season. This phenomenon is explained by mixing of groundwater of relatively long-term storage and high solute content with

Table 1. Results of the Hydrochemical Analyses of Water Samples from Springs Collected in 2001

Source (Altitude)	Date	T (°C)	pH	EC (µS cm ⁻¹)	TDS (mg/l)	Na ⁺ (mg/l)	K ⁺ (mg/l)	Mg ²⁺ (mg/l)	Ca ²⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	NO ₃ ⁻ (mg/l)	HCO ₃ ⁻ (mg/l)
Albarouk Site(1) (1060 m)	Apr 01	11.0	7.37	212	283	3.21	0.97	12.7	50.1	18.0	7.9	9.7	180
	Jun 01	11.0	7.45	271	305	2.52	0.12	1.1	68.9	15.0	11.2	11.0	195
	Aug 01	11.0	7.50	267	202	2.74	0.12	2.2	46.7	10.0	19.4	1.8	120
	Oct 01	12.6	7.70	289	240	5.32	0.45	5.8	53.2	13.0	7.4	9.1	145
	Dec 01	12.0	7.42	153	220	6.03	0.83	4.5	43.3	11.0	7.2	7.0	140
	Feb 02	10.0	7.51	280	269	3.07	0.85	11.4	46.4	19.5	9.1	17.6	160
Alkaa Site (2) (1045m)	Apr 01	12.0	7.64	215	252	3.41	0.12	14.0	45.2	13.1	6.1	5.3	165
	Jun 01	12.2	7.68	274	293	2.7	0.16	2.2	70.3	14.6	4.5	7.8	190
	Aug 01	12.0	7.60	275	205	2.7	0.15	2.7	45.7	9.0	13.5	1.0	130
	Oct 01	11.0	7.80	295	255	4.12	0.37	5.1	52.1	11.0	13.6	17.3	150
	Dec 01	11.0	7.30	280	249	5.68	3.19	4.7	45.0	13.0	15.8	10.0	150
	Feb 02	10.0	7.85	205	243	2.87	0.16	12.5	42.5	16.7	7.9	15.8	145
Alrihan Site (3) (921m)	Apr 01	11.0	7.47	227	270	3.02	0.10	15.3	48.4	13.5	8.3	8.3	172
	Jun 01	11.8	7.36	289	266	2.52	0.21	3.2	60.7	15.3	2.2	1.7	180
	Aug 01	12.0	7.20	134	197	2.92	0.22	3.9	45.8	10.0	22.4	1.2	110
	Oct 01	11.0	7.45	215	313	3.56	0.69	4.2	65.1	14.2	12.3	11.1	200
	Dec 01	12.0	7.54	195	267	2.67	0.42	3.2	56.0	13.7	18.9	20.7	150
	Feb 02	9.0	7.60	221	233	2.76	0.14	10.9	41.2	16.7	17.4	13.7	130
Deir Elkamar Site (4) (827 m)	Apr 01	16.0	7.40	312	452	6.23	0.47	38.7	64.2	36.0	9.5	12.3	285
	Jun 01	15.0	7.20	504	444	7.14	0.68	16.3	80.5	34.5	11.9	12.7	280
	Aug 01	18.0	7.10	411	347	6.35	0.75	15.8	65.7	16.2	42.5	8.7	190
	Oct 01	14.0	7.30	375	343	7.32	0.93	14.8	66.3	22.9	8.6	16.2	205
	Dec 01	13.0	7.15	297	327	7.98	0.63	12.5	60.2	27.0	29.1	9.4	180
	Feb 02	13.0	7.70	303	441	7.89	0.73	29.5	60.3	38.0	10.3	18.0	275
Akoat Site(5) (499 m)	Apr 01	16.0	7.43	217	535	6.98	0.89	46.2	74	38	15.4	17.8	335
	Jun 01	17.8	7.56	531	354	6.71	1.28	17.8 15.8	90	43	5.3	17.1	260
	Aug 01	16.0	7.50	502	363	6.17	1.21	18.4	67	15	35.1	6.6	210
	Oct 01	15.0	7.80	590	381	6.50	2.01	13.0	69	23	13.2	16.5	230
	Dec 01	13.0	7.61	550	343	7.45	1.89	39.5	57	16	15.7	14.7	215
	Feb 02	14.0	7.68	280	520	5.71	1.02		67	33	13.7	20.3	340
Michref (140m)	Apr 01	14.5	7.50	698	532	40.21	2.94	28.2	88	130	2.6	5.8	241
	Jun 01	17.8	7.47	768	525	32.52	1.65	24.0	85	160	0.8	3.8	220
	Aug 01	20.0	7.26	803	562	16.51	1.52	28.4	61	120	8.6	4.6	180
	Oct 01	19.0	7.52	820	475	17.21	2.07	26.4	76	105	7.1	6.3	202
	Dec 01	17.0	7.23	723	582	19.60	1.59	21.9	71	105	45.1	3.5	180
	Feb 02	15.3	7.43	840	530	25.50	2.37	26.0	91	140	5.6	9.5	260
N3 (105m)	Apr 01	19.0	7.10	1361	698	45.16	7.82	38.0	122	190	16.1	18.4	261
	Jun 01	21.0	7.24	1229	680	42.20	5.17	41.3	120	195	13.6	13.3	250
	Aug 01	22.0	7.12	2350	614	18.00	4.70	37.1	121	170	19.7	13.3	220
	Oct 01	21.0	7.23	2450	627	15.76	5.48	40.3	126	180	16.9	17.4	225
	Dec 01	19.0	7.20	2290	680	25.18	5.19	34.9	122	160	102.7	9.1	220
	Feb 02	18.02	7.01	1563	695	36.40	6.98	38.0	126	180	16.7	19.6	270
N1 (80m)	Apr 01	19.1	7.26	2104	796	46.72	6.60	42.7	140	191	47.7	21.2	301
	Jun 01	22.0	7.19	2080	902	60.45	5.52	45.3	160	270	51.6	29.2	280
	Aug 01	21.0	7.19	1960	572	20.36	4.57	45.7	91	160	20.0	10.2	220
	Oct 01	20.0	7.21	1950	603	19.23	5.54	47.5	96	125	23.4	15.7	270
	Dec 01	19.0	7.11	2850	691	22.31	6.49	50.4	100	145	117.9	23.2	226
	Feb 02	18.0	7.31	1989	811	42.04	7.02	42.8	150	190	42.2	36.1	300
D4 (60m)	Apr 01	20.0	7.42	830	664	44.19	6.38	34.2	118	170	15.7	5.2	270
	Jun 01	22.0	7.64	564	633	40.51	2.58	30.1	120	180	10.1	9.0	240
	Aug 01	22.5	7.19	2370	521	19.22	3.06	31.7	81	145	17.5	13.9	210
	Oct 01	21.6	7.31	2380	567	20.13	5.93	46.7	87	150	16.9	14.6	226
	Dec 01	19.0	7.35	2290	626	33.61	2.04	24.9	129	135	88.7	12.7	200
	Feb 02	18.0	7.38	2110	648	35.71	2.98	27.4	111	190	20.4	9.0	251

infiltrated rainwater of low solute content. Generally, groundwater pumped from wells has a higher concentration of anions and cations than the spring waters.

The Ca^{2+} concentration in spring waters fluctuates little and slightly decreases during the rainy season. In contrast, the Mg^{2+} concentration decreases considerably during this season. The higher solubility of calcium with respect to magnesium is believed to be the cause. Consequently, the variation of the $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio is similar to that of calcium.

Figure 3 shows a slight increase of the chloride concentration with well depth in the coastal area. This may be due to seawater intrusion of maximum 1 percent. An admixture of irrigation return is more or less excluded, as it would preferentially affect the shallow rather than the deep groundwater.

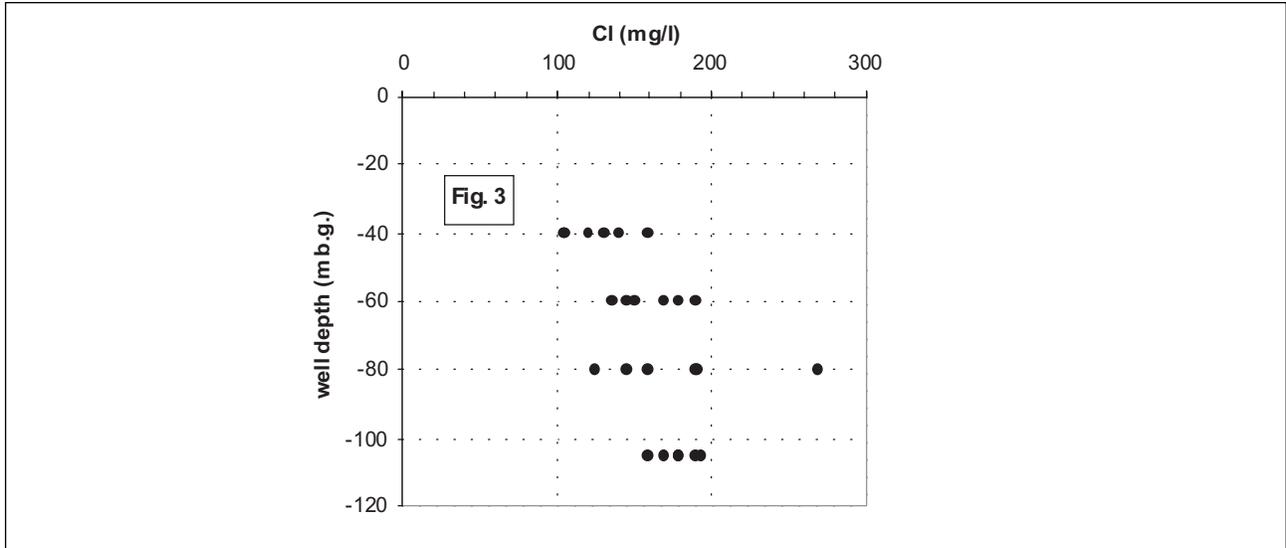


Figure 3. Increase of chloride concentration of groundwater with depth.

The relationship between Na^+ and Cl^- concentration of spring waters and groundwater is shown in Figure 4. It is obvious that the chloride concentration of groundwater has a bias of about 90 mg Cl^-/l with respect to spring waters. This is attributed to the agricultural activity rather than seawater intrusion (maximum 1 percent).

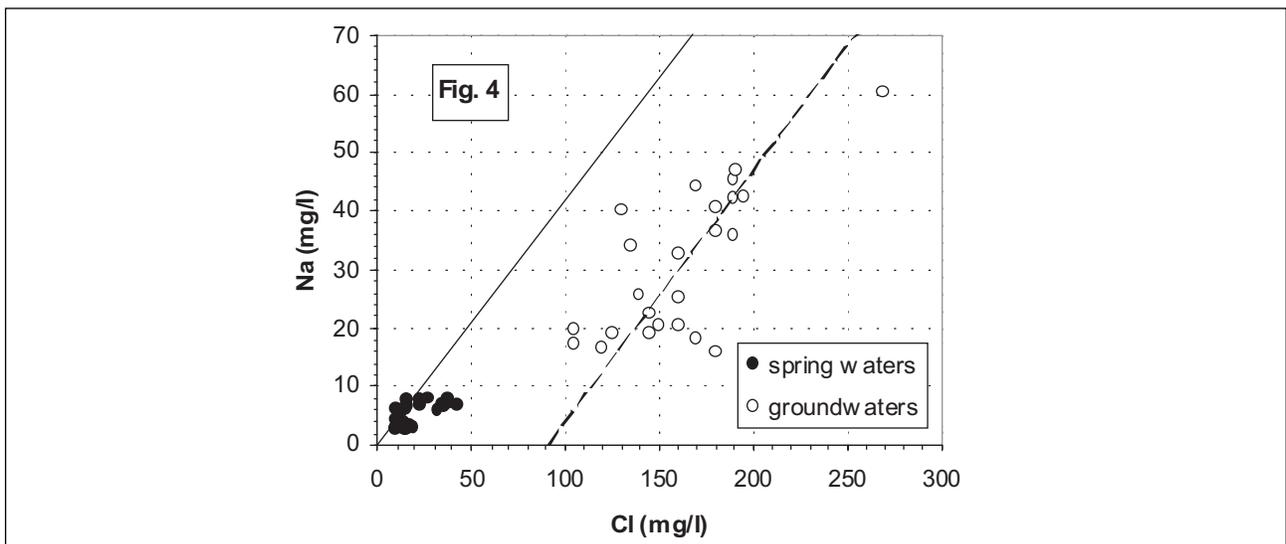


Figure 4. Relationship between sodium and chloride concentration in spring waters and groundwater

Figure 5 shows the relationship between the nitrate and chloride concentrations in both groundwater and spring waters. It is weak for the groundwaters due to the fast infiltration of nitrate from fertilizers, as well as the short lifetime of nitrate of one or two decades in the aquifer. This interpretation follows that by Hachache and Aranyosy (IAEA/SR-185/7) of their study on the Sarafand River (in the same area as the Damour River). A mean residence time of around 10 yr is sufficient for the biological degradation of nitrate. It follows that both nitrate and chloride have their origin in the agricultural activities (Figure 5).

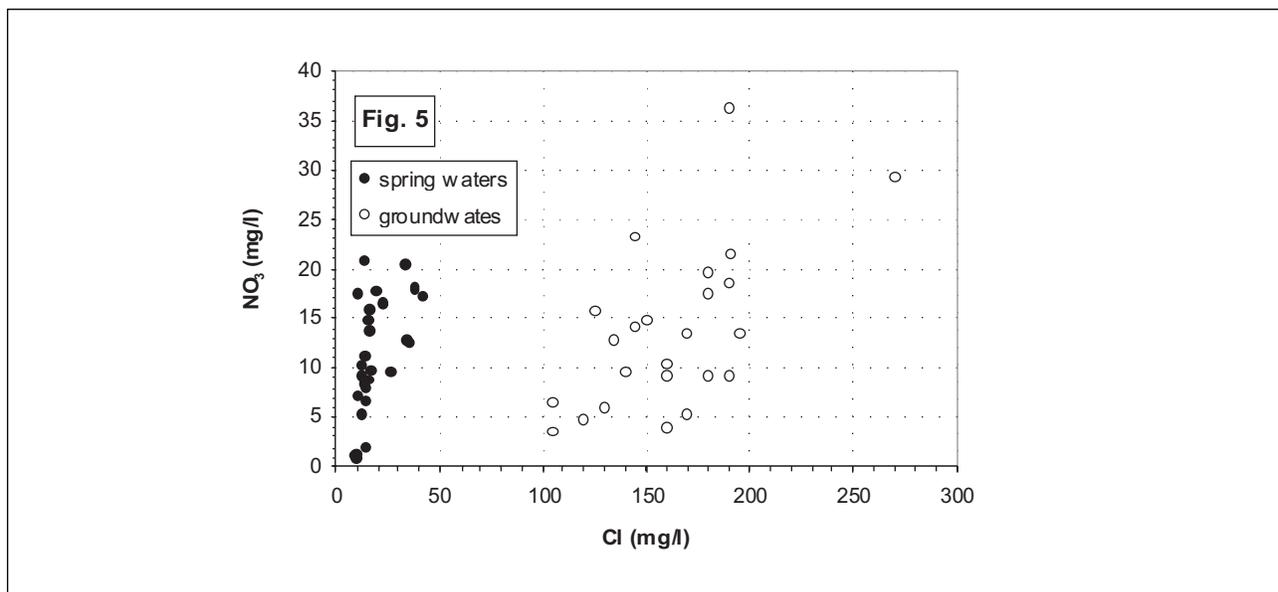


Figure 5. Relationship between chloride and nitrate concentration in groundwater

The mean value for the Na^+/Cl^- ratio was used to explain the origin of chloride in water (Figure 6). The Na^+/Cl^- mean ratio was found to be less than 0.5. This indicates that chloride has sources other than the evaporated seawater. In fact, the Mediterranean Sea spray has a Na^+/Cl^- ratio of 0.84 (Katzet et al., 1981). The Na^+/Cl^- ratio, as high as 0.84, was also reported from a site near the Eastern Mediterranean Sea (Kattan, 1997 and Singer, 1993). The increase in chloride concentration might be attributed to seawater input combined with anthropogenic sources like the runoff of fertilizers in extensively cultivated agricultural regions (Hem, 1985).

The aquifer formation of the Damour River basin extends from Jurassic to Cretaceous limestones (Zaatiti, 1983). Thus Ca, Mg ions are mostly derived from the dissolution of carbonate rocks. This interaction between groundwater and mineral matter supplies calcium and magnesium to water. In limestone aquifers, the $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio normally ranges from 0.5 to 0.9 (Rosenthal 1987) (Figure 6). Thus, the waters with low $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio may indicate that the contact time with the rocks was too short to approach chemical equilibrium (Kattan, 1997). It appears that the contact time is not high in spring waters at high altitude, whereas it is much higher at the other stations, especially the wells. This is shown by a $\text{Mg}^{2+}/\text{Ca}^{2+}$ ratio (calculated from the mmol l^{-1} concentrations) of water samples that was found to be less than 0.4 in the high altitude spring waters, and higher than 0.5 in the other stations.

In the spring waters, $\text{SO}_4^{2-}/\text{Cl}^-$ varies between 0.3 and 0.4 (Figure 6), values far from the ratio in seawater (0.11) (Hem 1985). This elevation is due to variation in sulfate that could be originating from different anthropogenic sources like agricultural activities. On the other hand, the $\text{SO}_4^{2-}/\text{Cl}^-$ ratio in wells is around 0.08 (less than the seawater value of 0.11). This low ratio corresponds to the increase of chloride in groundwater due to the high contact time with the aquifer (Table 1).

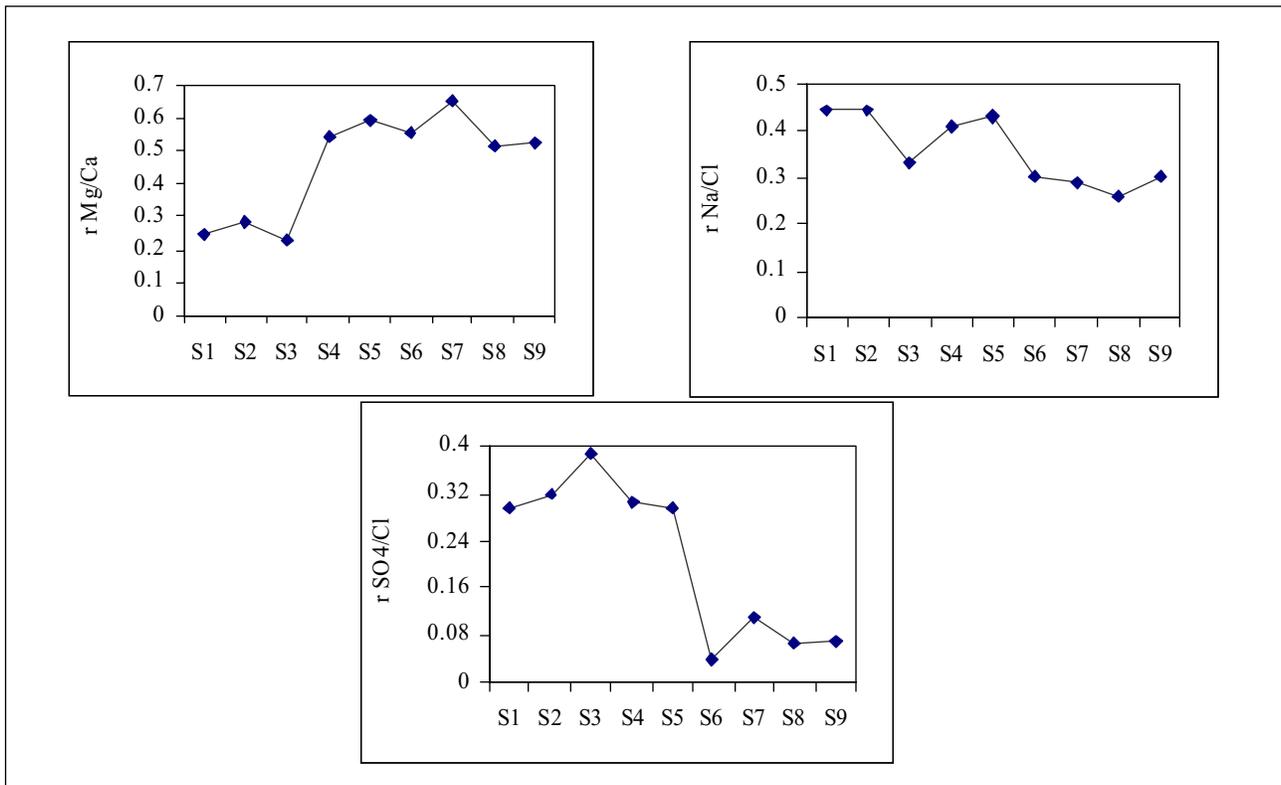


Figure. 6. Variation of mean concentration ratios of some anions and cations.

Isotopic compositions of spring waters and groundwaters

The results of environmental isotopes are compiled in Table 2.

The $\delta^{18}\text{O}/\delta^2\text{H}$ diagram (Figure 7) shows that about 70 percent of all points fit within the 1-s interval the Mediterranean Meteoric Water Line (MMWL) with a slope of 8 and a deuterium excess of +22‰ (Gat and Carmi, 1970). There may be a slight trend of elevated $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values of the groundwater pumped from the wells, which may indicate evaporative isotope enrichment.

The altitude effect allows the identification of groundwater recharge areas (Figure 8). It describes the decrease of the $\delta^{18}\text{O}$ value in water with rising altitude. The corresponding points lie above the sloped line of an altitude effect of $-0.23\text{‰}/100\text{ m}$, as recharge areas are located always higher than the spring pools. Kattan (1997) determined this altitude effect from the isotope compositions in precipitation of the anti-Lebanon mountains of the western part of Syria (near the Lebanese border) in the altitude range from 0 to 1540 msl. This gradient is similar to corresponding data determined worldwide. Isotope data from precipitation were, however, not available from Lebanon. Only $\delta^{18}\text{O}$ values of spring waters and the altitude of the spring pools were available.

From this altitude effect follows a $\delta^{18}\text{O}$ value of about -5.5‰ of the groundwater recharged in the coastal plain. The altitude effect for $\delta^2\text{H}$ should be eight times larger ($-2\text{‰}/100\text{ m}$) corresponding to slope of the MMWL of 8. Then, a $\delta^2\text{H}$ value of -22‰ is expected for the groundwater recharged within the coastal plain, but -26‰ was found. We concluded that up to 30 percent isotopically light groundwater recharged at high altitude is admixed with the isotopically relatively heavy groundwater recharged in the coastal plain. This phenomenon is shown in Figure 8. The points of the pumped groundwaters are located to the left of the sloped line.

To investigate whether seawater intrusion occurs or not, the chloride concentration was plotted

Table 2. Results of the Isotope Analyses of Samples Collected During 2001

No.	SITE	depth/altitude (m/m a.s.l.)	Date	$\delta^{18}\text{O}\text{‰}$ ± 0.15	$\delta^2\text{H}\text{‰}$ ± 1.0	$\text{d}\text{‰}$ $\pm 1,0$	^3H (TU)	
1	Barouk	-/1060	5/4/01	-7.54	-35.5	23.54	6.2	
			10/6/01	-7.55	-36.9			5.3
			1/8/01	-7.56	-38.2			5.9
2	Alkaa	-/1045	5/4/01	-6.81	-30.7	23.11	5.4	
			10/6/01	-7.62	-37.7			6.2
			1/8/01	-7.56	-38.2			6.9
3	Rihan	-/921	5/4/01	-7.57	-36.6	23.97	6.7	
			10/6/01	-7.50	-37.3			6.7
			1/8/01	-8.04	-39.0			7.3
4	Dier	-/827	5/4/01	-7.51	-35.5	24.14	5.8	
			10/6/01	-6.95	-30.6			4.7
			1/8/01	-6.69	-30.7			5.3
5	Akaot	-/499	5/4/01	-6.65	-32.1	21.97	5.1	
			10/6/01	-6.63	-31.4			4.6
			1/8/01	-6.83	-31.7			5.6
6	Well Michref	140/-	10/6/01	-6.15	-29.0	20.01	3.3	
			1/8/01	-6.30	-30.5			5.4
7	Well N1	105/-	10/6/01	-5.54	-24.5	19.9	5.3	
			1/8/01	-5.66	-25.3			6.2
8	Well N3	80/-	10/6/01	-5.55	-25.9	19.94	5.3	
			1/8/01	-6.01	-26.7			4.1
9	Well D4	60/-	10/6/01	-5.48	-25.8	19.71	5.0	
			1/8/01	-6.01	-26.7			4.1

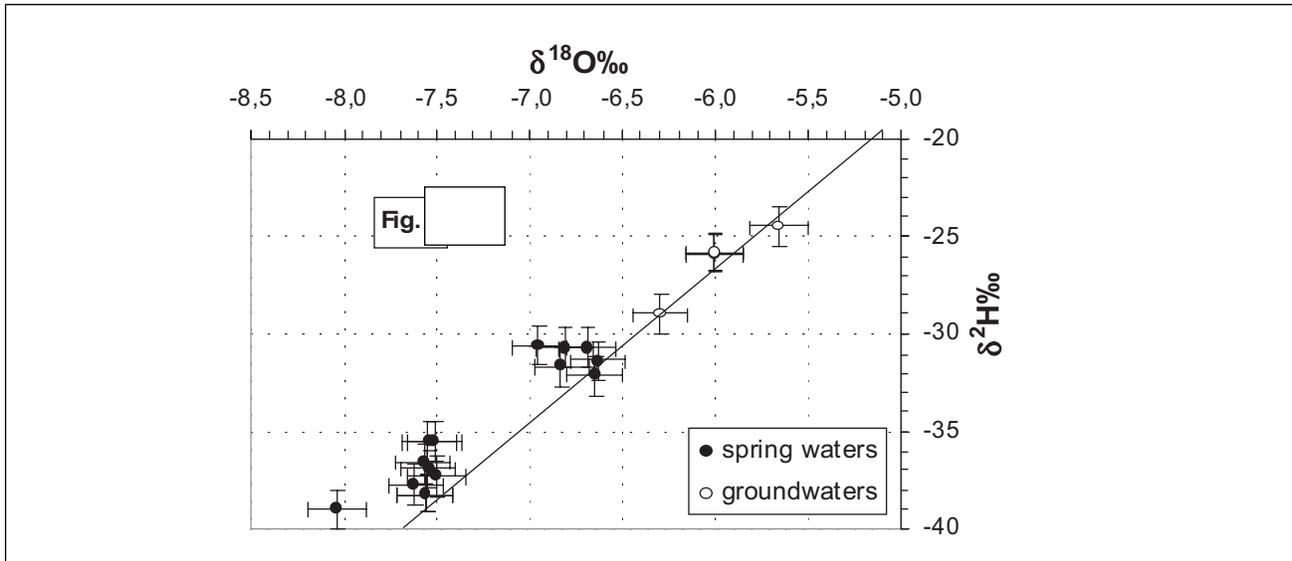


Figure 7. $\delta^{18}\text{O}/\delta^2\text{H}$ plot with the Mediterranean Meteoric Waterline (MMWL)

against the $\delta^{18}\text{O}$ value (Figure 9). As seawater from the Mediterranean Sea has a chloride concentration of about 19,000 mg/l and a $\delta^{18}\text{O}$ value of about +1‰, the mixing line of both (dashed line) has a slope of about 2200 mg Cl/‰ $\delta^{18}\text{O}$. Only one point most to the right of the diagram may account for an admixture of 3‰ seawater. The regression line of the other points has, however, a slope of only 215 mg/l Cl/‰ $\delta^{18}\text{O}$. It is a mixing line between groundwater recharged in both the coastal plain and the high mountains. The wide scatter of the data may be the result of the admixture of saline irrigation return flow with both an elevated chloride concentration and TDS. In any case, seawater intrusion cannot be dominant.

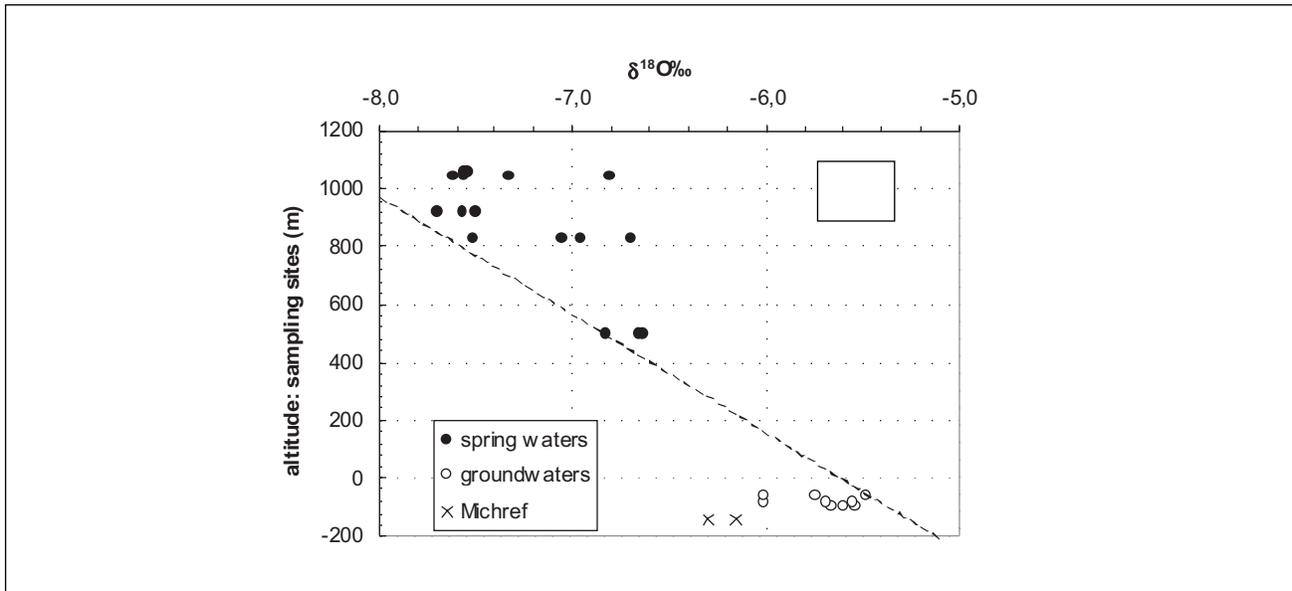


Figure 8. Apparent altitude effect of the $\delta^{18}\text{O}$ values in the studied area.

Based on the results shown in Figures 8 and 9, the deep well Michref in the coastal plain pumps a proportion of 30 percent of groundwater recharged around 1060 m above the sea level. The rest is recharged in the coastal plain. The more shallow wells pump such isotopically light groundwater up to 12 percent only during the summer.

The presence of tritium in all samples confirms that most groundwater has been recharged after 1963. As open aquifers are studied, the exponential model is suited to estimate mean residence times of the water samples. But, only the tritium values of spring water samples collected during the dry season are representative .

The ^3H values of the mountain spring waters range from 5.3 to 7.3 TU and are slightly higher than those of the coastal groundwaters (4.1-6.2 TU). This already means that the MRT of the spring water

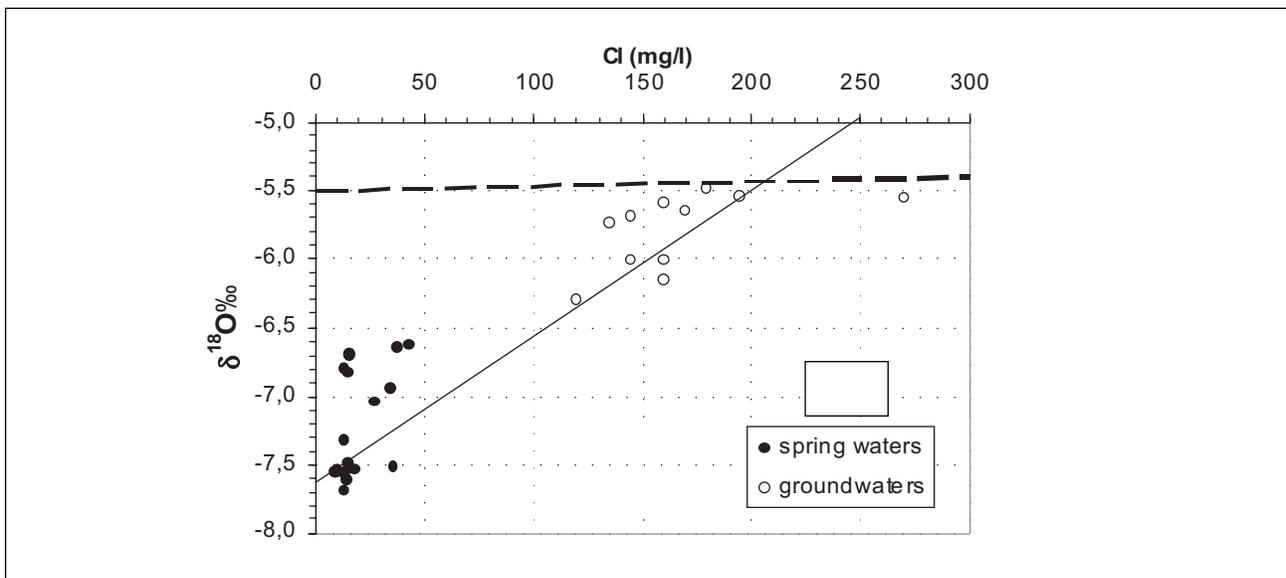


Figure 9. Chloride concentration versus $\delta^{18}\text{O}$ values. Hatched line shows the expected increase in case of seawater intrusion. Solid line reflects a mixture between groundwater recharged in both the coastal plain and the high mountains.

is slightly higher than that of the pumped groundwater, as the ^3H value in precipitation has decreased since the beginning of the 1960s. Obviously young groundwater is mobilized by the pumping. The naturally discharged spring water still contains a relatively high proportion of old groundwater.

For the calculation of the MRT, the ^3H input function of the rainwater in Lebanon was estimated. It was extrapolated from isotope data of precipitation collected at the IAEA stations in Bet Dagan, Israel, and Adana, Turkey. The program MULTIS (Figure 10) yielded a linear relationship between MRT and tritium values. We obtained the results shown in Table 3.

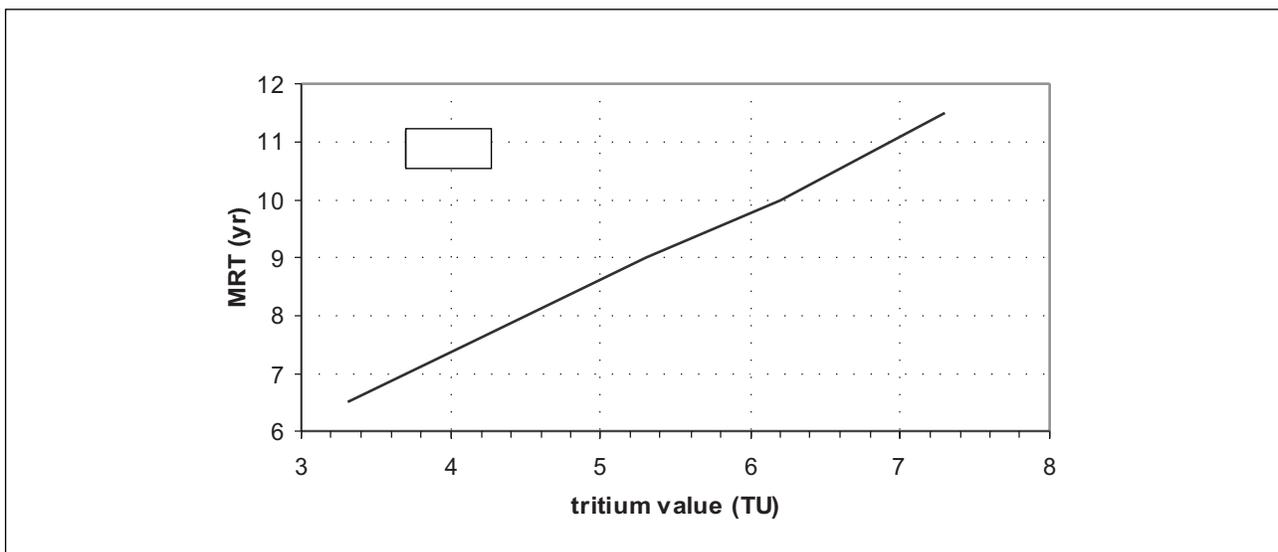


Figure. 10. Relationship between the MRT and ^3H value according to the program MULTI applying the exponential model

Table 3. Tritium and Mean Residence Time for Selected Springs and Wells

No.	site name		depth (m)	^3H (in August) (TU)	MRT (yr)
1	Albarouk	spring		5,9	9,7
2	Alkaa	spring		6,9	10,9
3	Alrihan	spring		7,3	11,5
4	Deir Elkamar	spring		5,3	9,0
5	Akoat	spring		5,6	9,3
6	Michref	well	140	5,4	9,1
7	N3	well	105	6,2	10,0
8	N1	well	80	4,1	7,4
9	D4	well	60	4,1	7,4

The MRT between 9 and 11 yrs of the spring waters is similar to that of karst waters from other regions in the world but slightly higher than the MRT of the groundwaters. It is an open question, however, whether the exponential model is applicable to ^3H data from the pumped groundwater samples.

As expected there is no relationship to the geology of the aquifers (Jurassic, Cretaceous, Tertiary and Quaternary aquifers). The hydraulic conductivity is not related to the type of these rocks.

There is an expected trend of increasing MRT with depth. Exceptions are the samples from the Michref well. The reason may be a fast hydraulic connection to the high altitude.

According to the hydrochemical and isotopic findings, most pumped groundwaters are directly recharged in the coastal plain and contain a maximum 30 percent of groundwater from higher elevations. The elevated Mg^{2+}/Ca^{2+} ratio of the groundwaters compared to that of spring waters is due to the intensified dissolution of dolomite in the coastal plain rather than a different MRT. Elevated CO_2 concentration in the top soil of the coastal plain compared to that in the mountains may be responsible. This reflects the different densities of the plant cover.

CONCLUSIONS

The results of the combined hydrochemical and isotopic study in the Damour River Basin and the coastal plain yielded new hydrological insights:

Most of the groundwater in the coastal plain and pumped from wells for irrigation and drinking water supply is directly recharged in this area. It contains up to 30 percent of groundwater recharged in the high mountains. The pumped groundwater from shallow wells contains this water only during the summer season.

The pumped groundwater is not polluted by seawater intrusion. This is confirmed by the Na^+/Cl^- and SO_4^{2-}/Cl^- ratios.

The elevated solute content of the groundwaters in the coastal plain compared to that of the spring waters is mainly due to the different intensive agricultural activities. There is no relationship to the MRT of the water.

The temperature of the spring waters is related to the altitude of the recharge area. The temperature of the groundwater decreases with depth and reflects the admixture of groundwater recharged in higher elevations. The geothermal gradient does not play any role.

The relatively long mean residence time of the spring waters of about ten years contradicts the assumption that their low Mg^{2+}/Ca^{2+} ratio is due to a non-established hydrochemical equilibrium. The reason may be a lower CO_2 concentration in the topsoil of the mountainous region compared to that in the coastal plain.

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