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HYDROCHEMICAL CHARACTERISTICS OF THE JORDAN AND YARMOUK RIVERS: EFFECTS OF NATURAL AND HUMAN ACTIVITIES

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Water chemistry was used to assist in understanding the effect of human and natural activities on the Jordan and Yarmouk Rivers. Eighty-eight water samples were collected from different locations along both rivers and analyzed for major ions. The Yarmouk River samples were predominantly alkaline, with prevailing chloride and sodium, and low TDS values. The Jordan river samples are alkaline earth, with prevailing chloride, increased alkalies, and high TDS. The sampling took place in different time periods between April and July 1996 to determine the effect of changing seasons on the water chemistry. From the upper to lower reaches of both the Jordan and Yarmouk rivers, a systematic increase of most of the measured major ions concentrations is reported in July 1996. Strong variations were observed in the water chemistry between the different locations. As the distance increased from the mouth of the rivers, so did the salinity of the water. The study found that the Jordan River is affected by groundwater and the related anthropogenic activities on both sides of the Jordan Valley. The saline groundwater is from ancient trapped sea water or brine of deep seated origin. The water which dilutes the Yarmouk river is a $\text{Ca}^{+2} - \text{HCO}_3^-$ type. The increase in the ion concentrations in 1996 compared to 1969 is due to the increase of the anthropogenic effects.

INTRODUCTION

The Jordan River and its major tributary, the Yarmouk River, flow through the Jordan valley, where many important agricultural activities are located. The headwaters of the Jordan River originate from three main springs: the Hasbani in Lebanon; the Dan in southern Lebanon, and the Banias in Syria. It begins its journey through Lake of Tiberias (Figure 1) and flows through the valley until it reaches the Dead Sea (Dajani, 1957; Sahawneh, 1970; Salameh and Banyanne, 1996). The Yarmouk River flows through a deep volcanic gorge westward where it joins the Jordan south of lake Tiberias (Sahawneh, 1970; Mas'ad, 1987).

The area adjacent to the Jordan River is called the Jordan valley. It is a part of the geological fault which extends from Syria down to the Red Sea, as a part of the Great African Rift extending from Ethiopia through the Red Sea into Jordan and Syria. The rift created a new base level for the surrounding surface and groundwater (Quenelle, 1959; 1983). In the late Pleistocene the Jordan river came into existence cutting into the Lisan Marls and gradually working backward until it captured the Yarmouk river and Tiberias lake for the Dead Sea Drainage (Quenell, 1959).

The climate of the study area is influenced primarily by both moist Mediterranean air from the West, and arid desert wind from the east. The average annual rainfall in the Jordan Valley ranges from 400 mm in the north to about 100 mm near the Dead Sea (Mas'ad, 1987, Rimawi et al., 1990).

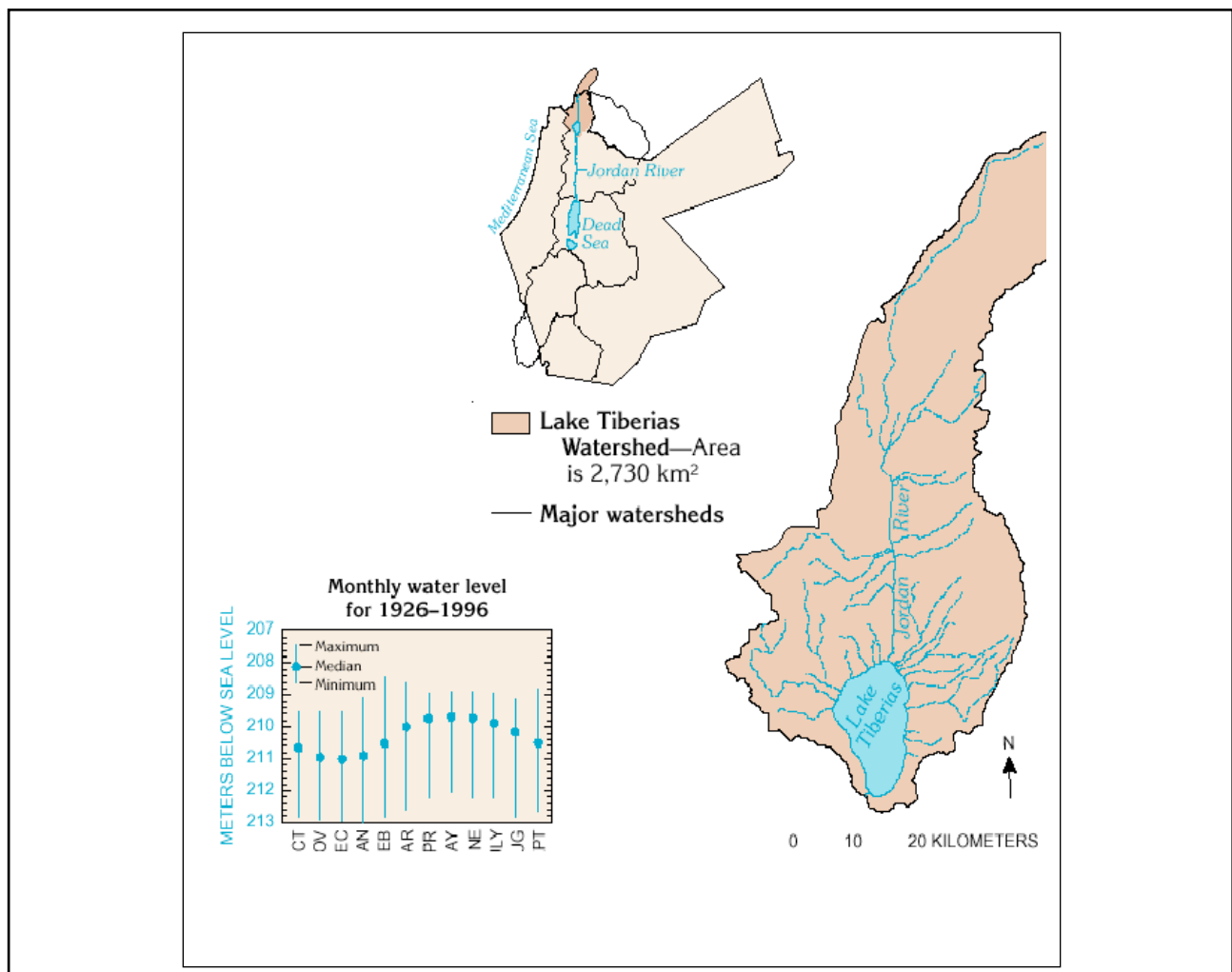


Figure 1. Location map of the Jordan River watershed.

The potential evaporation increases from a minimum of 200 mm/yr in the north to 2500 mm/yr in the south, near the Dead Sea. The Jordan River watershed yields a total of 1880 million cubic meters of water annually, with 77 percent of the water originating in Syria, Lebanon and Jordan.

The area adjacent to the Jordan river is defined by two distinct physiographic features: (i) Quaternary alluvial deposits with illite, kaolinite, illite-smectite mixed layers, and smectite as their most abundant clay minerals; and (ii) a mountainous sector of late Cretaceous - early Tertiary age extending from the north to the flat area below sea level composed mainly of siliciclastics, carbonates, evaporites and phosphate deposits.

This study investigated the effect of the natural sources and anthropogenic activities on the fluvial hydrogeochemistry in the semi-arid Jordan Valley. In this paper we summarize the chemistry of both the Jordan and Yarmouk rivers to understand and evaluate the different processes and mechanisms leading to the degradation of water quality, and to identify environmental factors that control their hydrochemistry.

METHODS OF STUDY

Eighty-eight water samples were collected from the Jordan and Yarmouk rivers at two different time intervals (forty-four each), in April and July, 1996. The samples were analyzed for major cations and anions. The sampling stations were selected to be representative of the river's course and selection depended on the distribution of agricultural activity and apparent sources of pollution. Samples were collected in polyethylene bottles and sample duplicates were obtained. Samples were transferred to the laboratory 3-4 hours after collection (USEPA protocol, 1983) for chemical analyses of waters and wastes, and standard methods for the examination of water were followed. Calcium, magnesium, sodium and potassium were determined by direct aspiration of the samples into Atomic Absorption (PYE UNICAM, SPQ, Phillips AA). Nitrate, ammonia, and sulfate were determined by a Spectronic 2000 Spectrophotometer. Titration methods were used for the determination of both chloride and bicarbonates. Chloride was determined by using potassium chromate (K_2CrO_4) as an indicator and silver nitrate as a titration solution, whereas bicarbonate concentrations were determined by titrating the samples with 0.02N H_2SO_4 , using methyl orange as indicator. The electrical conductivity (EC) and the total dissolved solids (TDS) were measured for the water samples by a digital conductivity meter, and the pH of the samples was measured by a pH meter.

RESULTS AND DISCUSSION

Seasonal variations of major ion chemistry are seen between late winter (April, 1996) and summer (July, 1996) and are accompanied by geographical variations between the upper and lower reaches of both rivers (Figure 2). The differences in the concentrations of the major ions along the flow paths of both rivers are attributed either to the mixing of various water types of different tributaries and springs located adjacent to both rivers, or due to the interaction between the river water and different lithologic units exposed along their flow paths. The variations in the concentrations of the major ions between April and July 1996 is likely to be related to the strong evaporation in July, and to the inputs of dissolved salts from both the Mediterranean and the Dead Seas by means of atmospheric transport. The poor correlation between the different measured ions

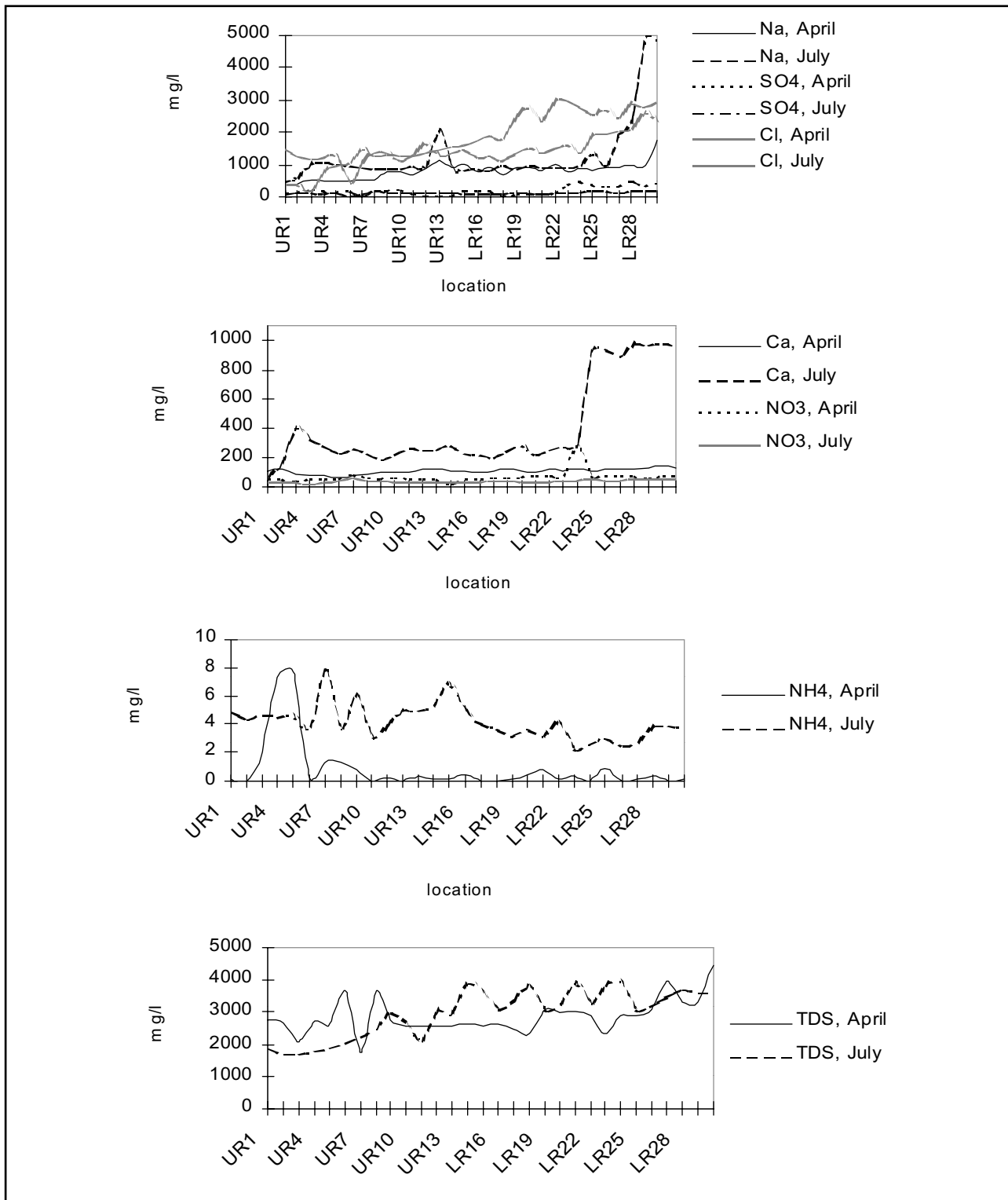


Figure 2. Variation pattern of major ions in the water samples collected from Jordan River.

in the river water (Table 1) may indicate that these ions were derived from different sources and/or different processes influencing their distribution.

Natural effects

The mixing process between the Jordan river water and Tiberias lake water seems to be the major cause of salinity in Jordan river water. Once it enters Tiberias lake, its characteristics are changed

Table 1. Correlation Coefficients for Chemical Components of Both Jordan and Yarmouk Rivers

	Jordan River						Yarmouk River					
	Mg ⁺²	Na ⁺	Ca ⁺²	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²	Mg ⁺²	Na ⁺	Ca ⁺²	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻²
Na ⁺	0.189						0.77					
Ca ⁺²	0.082	0.27					0.61	0.4				
Cl ⁻	-0.54	-0.035	0.33				0.6	0.71	0.33			
HCO ₃ ⁻	0.174	0.3	.00	-0.339			-0.1	0.93	0.2	-0.031		
SO ₄ ⁻²	-0.237	-0.048	0.42	0.37	-0.4		0.54	0.2	0.6	0.49	0.2	
NO ₃ ⁻	-0.180	-0.181	0.31	0.209	0.24	0.22	0.28	0.26	-0.007	0.178	0.09	-0.23
NH ₄ ⁺	0.00	0.139	-0.47	-0.05	0.18	0.25	0.26	0.47	0.055	0.316	-0.04	0.095

completely from essentially a Ca⁺²-HCO₃⁻ water type to Na⁺-Cl⁻ type (Oren, 1992; Nissenbaum, 1969; Gophan, 1991; Stiller, 1994). The relatively high values of salinity recorded in the water samples from the Jordan river in the present study compared with those given by Wilson and Wazob (1954) and Nissenbaum (1969) partly result from the ever increasing influx from saline springs near the Tiberias and Bessian areas. The water of these saline springs have been drawn through channels adjacent to the shore of Tiberias Lake to the Jordan River (Barghothi, 1987).

The average maximum value of salinity in the Jordan River water recorded at a site 4-5 km north of the Dead Sea in both April and July 1996 is extremely high and equal to 34,383 mg/l. This may reflect the effect of the Dead Sea on the salinity of the Jordan River, which resulted in a marked increase of sodium, chloride and magnesium concentrations in its lower reaches. The effect of the Mediterranean Sea is reflected in the increase of chloride concentration in the collected water samples during the winter of 1996, especially in the upper reaches of the Jordan river, and in both the upper and lower reaches of the Yarmouk river (Figures 2 and 3). Stallard and Edmond (1987) and Zhang et al., (1995) have pointed out that chloride is the most useful indicator of marine inputs to the river water by means of atmospheric deposition.

The salinity of the Jordan River water increases from the upper to the lower reaches (i.e. from 1067 mg/l to 4171 mg/l), accompanied by the obvious increase of sodium, chloride, calcium, magnesium and sulfate concentrations southward. This pattern follows the same lateral distribution of evaporites and brackish water deposits of the previous Lisan Lake. The excessive dissolution of evaporite deposits, especially the gypsum of the Lisan Marl, is clearly reflected in the increasing sulfate concentrations in the lower reaches of the Jordan River. Potassium and bicarbonate exhibit, however, a different pattern. Bicarbonate concentration decreases as the Jordan River flows to the south (i.e. from 340 mg/l to 167 mg/l). This can probably be attributed to the increase of salinity downstream along the river, which leads to an increase of carbonate dissolution. The relatively high concentrations of potassium in both rivers should be due to the almost total absence along the rivers of clay beds, which are potential natural source of potassium.

Various thermal hot springs are distributed along the eastern and western flanks of the Jordan Rift Valley (Abu Ajameh et al., 1990; Howari, 1997). Their impact on the water of the Jordan River

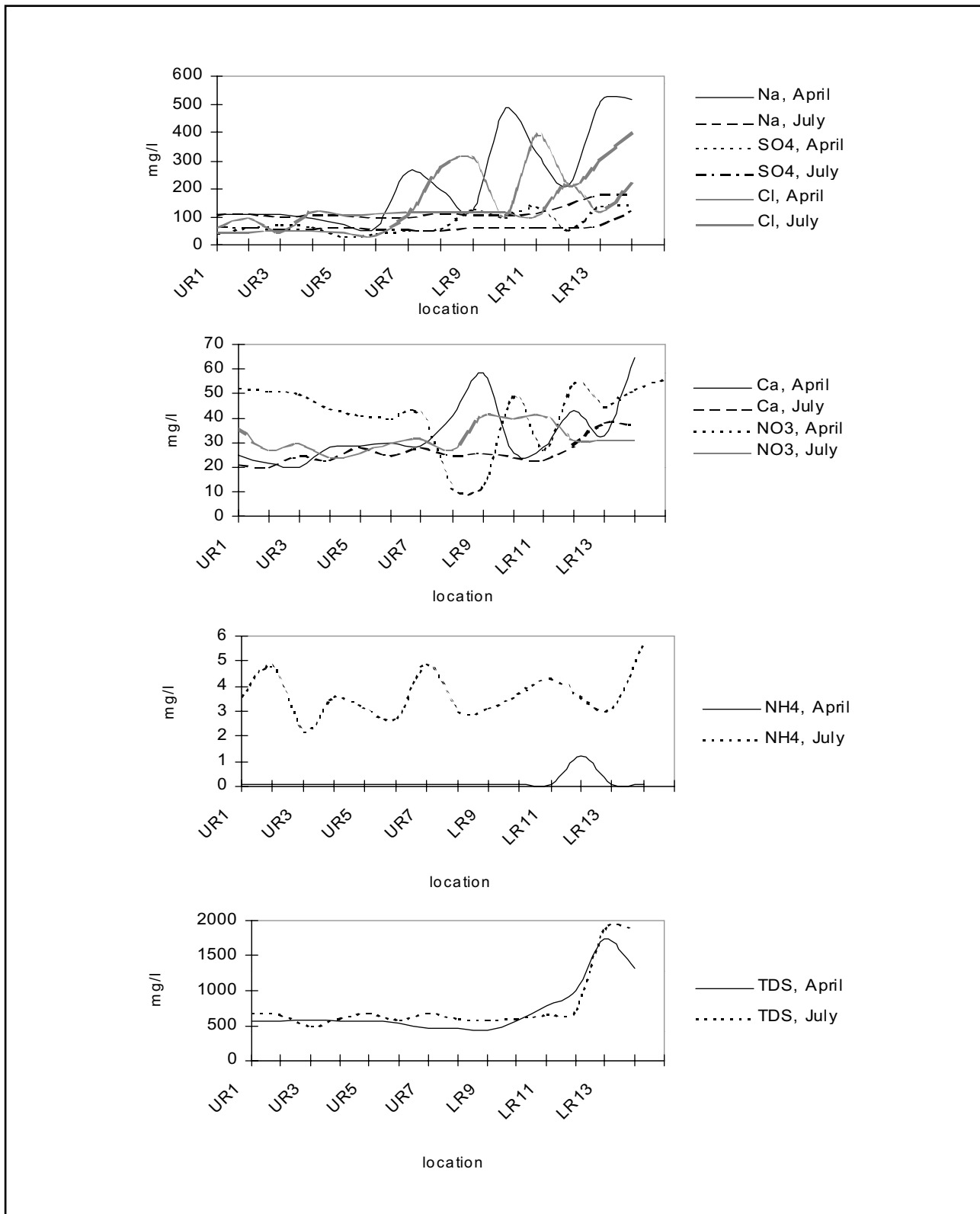


Figure 3. Variation pattern of major ions in the water samples collected from YarmoukRiver.

and lower reaches of the Yarmouk River is clearly reflected in the increasing concentrations of sodium, chloride, potassium, bicarbonates and sulfates in different localities, including El-Hamma, Wadi El-Arab (north Shuna), Wadi Abu Saleh (Hammam Abu-Thableh), Bessian and Dier Alla (Table 2).

Table 2. The Average Concentrations of Cl⁻ and Na⁺ in the Main Springs Adjacent to Jordan and Yarmouk Rivers (mg/l)

Ion	El-Hamma	North Shuna	Hamman Abu Thableh	Dier Alla
Cl ⁻	158	77	273	882
Na ⁺	36	37	132	403
K ⁺	79	4	18	402
HCO ₃ ⁻	271	396	427	894
SO ₄ ⁻²	189	91	-	891

Anthropogenic effect

The average TDS values encountered in the present study are higher than those given by Nissenbaum (1969), which may reflect the ever-increasing anthropogenic impacts (Figure 2). Leaching of the top soil by irrigation water, as well as the changes induced on the natural regime of the rivers, such as channeling of the water and the continuously increasing amount of water that has been drawn and is being drawn by other riparian states, are the possible anthropogenic causes which lead to increasing salinity in both rivers. Sulfate concentrations display relatively elevated values in both rivers, especially in the winter time. This may be related to the use of fertilizers and to the impact of domestic sewage water input to the river, and probably to the atmospheric deposition of sulfates by the winter rains.

The concentrations of nitrates and ammonia are significantly higher in the Jordan in comparison to the Yarmouk river water. This is probably linked to the increasing usage of nitrogen fertilizers and manure in the area adjacent to the Jordan River. Both nitrate and ammonia contents in the Yarmouk River water are obviously affected by the untreated waste water dumped in Al-Abider, east Ramtha city (Ta'ani, 1989).

Water Type

Trilinear diagrams of major cations and anions provide a convenient method of plotting the evolution of the waters (Fetter, 1982; Bayari, 1995; William et al., 1995; Sukhija, 1996). By plotting Jordan and Yarmouk water samples on trilinear diagrams, shown in Figure 4, and raising them to the center of their interpretative parts, it is clearly seen that the Jordan river water samples are closely grouped on the right hand side of the central diamond, whereas the Yarmouk river waters are located near the lower corner of the diamond. However some samples that belong to both rivers occupy a distinct position on the trilinear diagrams i.e. along the mixing line.

The predominant water type of the Jordan River is alkaline earth with prevailing chloride and an increased portion of alkalis; this type of water is characterized by high concentrations of chloride. The ionic ratios of the Jordan River waters are $Na^+ + K^+ > Ca^+ > Mg^+$; $Cl^- > HCO_3^- > SO_4^{-2}$. The predominant water type of the Yarmouk River is alkaline water with prevailing chloride and sodium; this type of water is characterized by low salinity. The ionic ratios of the Yarmouk river

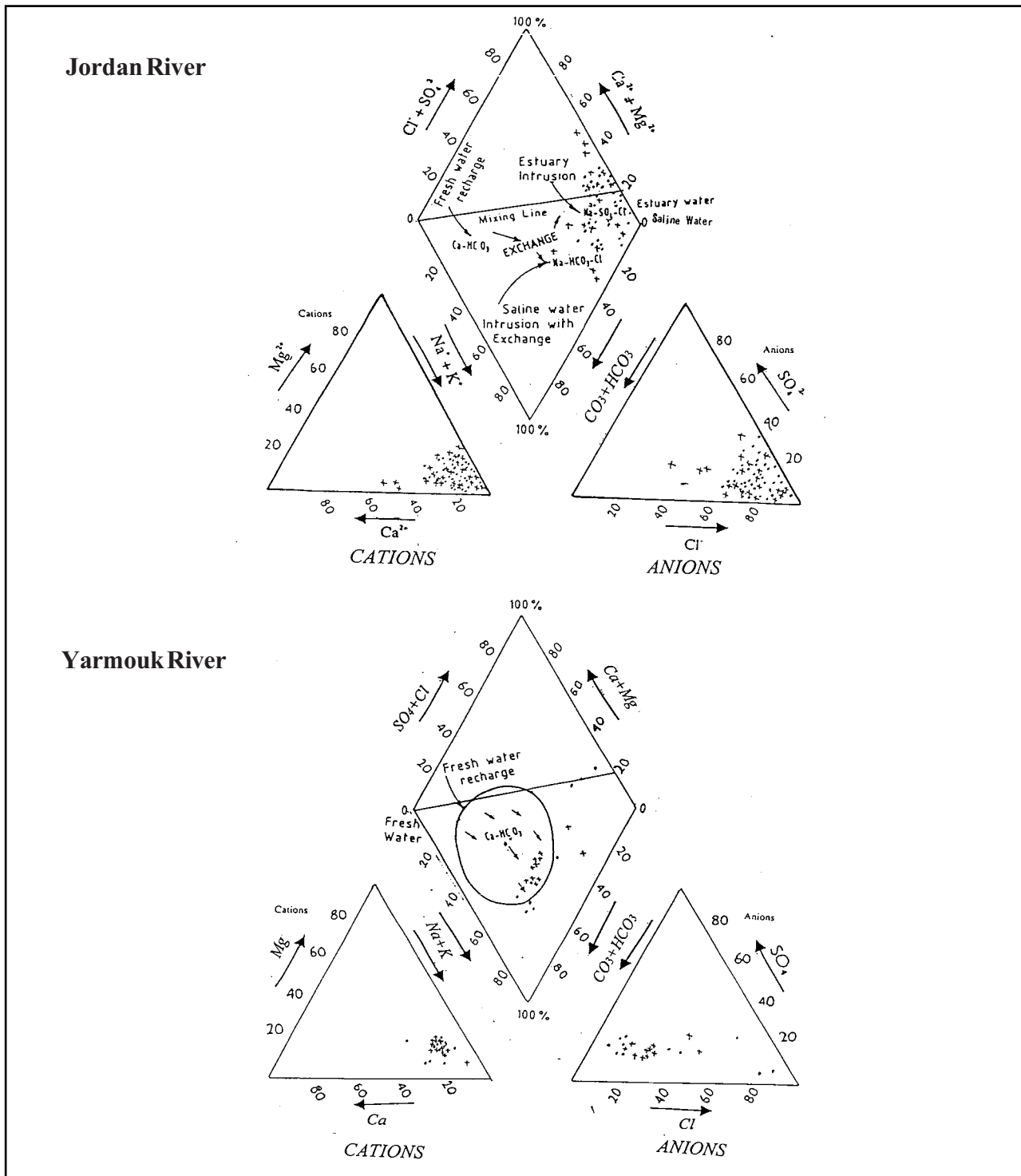


Figure 4. Trilinear diagram of major ions in the collected water samples from Jordan and Yarmouk river in both April, 1996 (x), and July, 1996 (o).

waters are: $\text{Na}^+ + \text{K}^+ > \text{Mg}^{+2} > \text{Ca}^{+2}$; $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{-2}$. Yarmouk river water is strongly influenced by the rain water over the seasons. According to Nissenbaum (1969), the water which dilutes the Yarmouk river could be a $\text{Ca}^{+2}\text{-HCO}_3^-$ water type, indicating a rain water origin, or rain water after reaction with calcium carbonate.

In many arid and semi-arid regions, the occurrence of salinity in coastal and inland groundwater is a common phenomenon. Saline water may occur in geologic formations by any of the following

processes: retention of ions from salt water trapped at the time of ancient marine transgressions and intrusions of salt water after deposition owing to the changes in sea or estuarine level or discharge (Sukhija, 1996). As shown in Figure 4, the Jordan River has an ionic ratio similar to sea water, which may be due to the fact that it is an effluent river gaining water from the groundwater system on both sides of the Jordan valley (Hawi, 1989). Arad and Kaufri (1979) have found that the saline groundwater within the adjacent area of Jordan river results from either an ancient entrapped sea water or brine of deep seated origin, in addition to the current infiltrating sea water i.e. there are mixing processes between the groundwater and the Mediterranean Sea water with the river head waters. Furthermore, the effects of the northern ends of the Dead Sea water itself, and its evaporite sediment, have an obvious influence on increasing the major ion concentrations (Nissenbaum 1969; Bender, 1974; Lerman, 1974; Mazor et al., 1995, Howari, 1997)

CONCLUSION

The water of the Yarmouk River can be classified as fresh since its average TDS values range from 571 to 801 mg/l; whereas the water of the Jordan River can be classified as fairly brackish water since its TDS values range from 2914 to 3224 mg/l. The study found that the ionic ratios are: $\text{Na}^+ + \text{K}^+ > \text{Mg}^{+2} > \text{Ca}^{+2}$; $\text{Cl}^- > \text{HCO}_3^- > \text{SO}_4^{-2}$ in the Jordan River, and $\text{Na}^+ + \text{K}^+ > \text{Mg}^{+2} > \text{Ca}^{+2}$; $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{-2}$ in the Yarmouk River. The study reported a systematic increase of the concentrations of measured ions in both April and July 1996 from upper to lower reaches of both rivers. This was attributed to 1) the interaction between the river water and the different lithologic units exposed along their flow paths, 2) the mixing of various water types of different tributaries and springs located in the Jordan Valley with the river water, and 3) the increase of evaporation downstream. The variations in the concentrations between April and July 1996 are related to the effect of washing out by rain water of natural and anthropogenic sources of the ions within the watershed areas of the rivers. The increase of the reported ion concentration in 1996 compared to those reported in 1954 and 1969 is due to the increase of anthropogenic effects such as urban and agricultural activities in the watershed areas. The study concluded that the highly saline groundwater zones which extend from the northern end of the Dead Sea, and the Dead Sea evaporite sediments have increased the concentrations of the ions in the lower reach of the Jordan River. The study found that the water which dilutes the Yarmouk River is a $\text{Ca}^{+2}\text{-HCO}_3^-$ water type, indicating a rain water origin, or rain water after reaction with calcium carbonate.

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