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Groundwater in Haddat Al Sham-Al Bayada Area, Western Saudi Arabia

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ABSTRACT. Haddat Al Sham - Al Bayada area is situated about 100 km to the east-northeast of Jeddah. The average annual rainfall within the study area is about 100 mm. Groundwater occurs within the alluvial deposits of the wadi system and also within the clastic members of Cretaceous - Tertiary sedimentary succession. The alluvial aquifer is characterized by a hydraulic gradient of $1.6 \times 10^{-2} - 8.8 \times 10^{-2}$, an average transmissivity of 390 m^2/day, average permeability of 34 m/day and a storage coefficient of $1.12 \times 10^{-3} - 1.28 \times 10^{-1}$. The groundwater within the clastic members moves under a hydraulic gradient of $6.0 \times 10^{-4} - 1.4 \times 10^{-2}$, an average transmissivity of 180 m^2/day, and an average permeability of 10 m/day. Its storage coefficient is about $5.4 \times 10^{-2} - 1.1 \times 10^{-3}$.

Groundwater chemical composition and ionic relationships are as well discussed in this paper. Each of the aquifers is characterized by its own water quality.

The study area lies in proximity to the Arabian coast of the Red Sea. It is situated some 100 km to the east-northeast of Jeddah between latitudes 21° 30′N and 22° 00′N, longitudes 39° 20′E and 39° 45′E (Fig. 1). From east to west it includes Haddat Al Sham, Wadi Madsus, Al Bayada and Al-Shamiyah. The average depth of rainfall, is about 100 mm year^{-1}. Rainfall occurs mainly in winter (December-January). Spring rains occur on the highlands during April.

The main rock units building up the area are (Table 1):

– Pre-Cambrian Cambrian Basement Complex,

– Cretaceous Haddat Al Sham Formation,

– Upper Cretaceous - Tertiary Usfan and Shumaysi Formations,

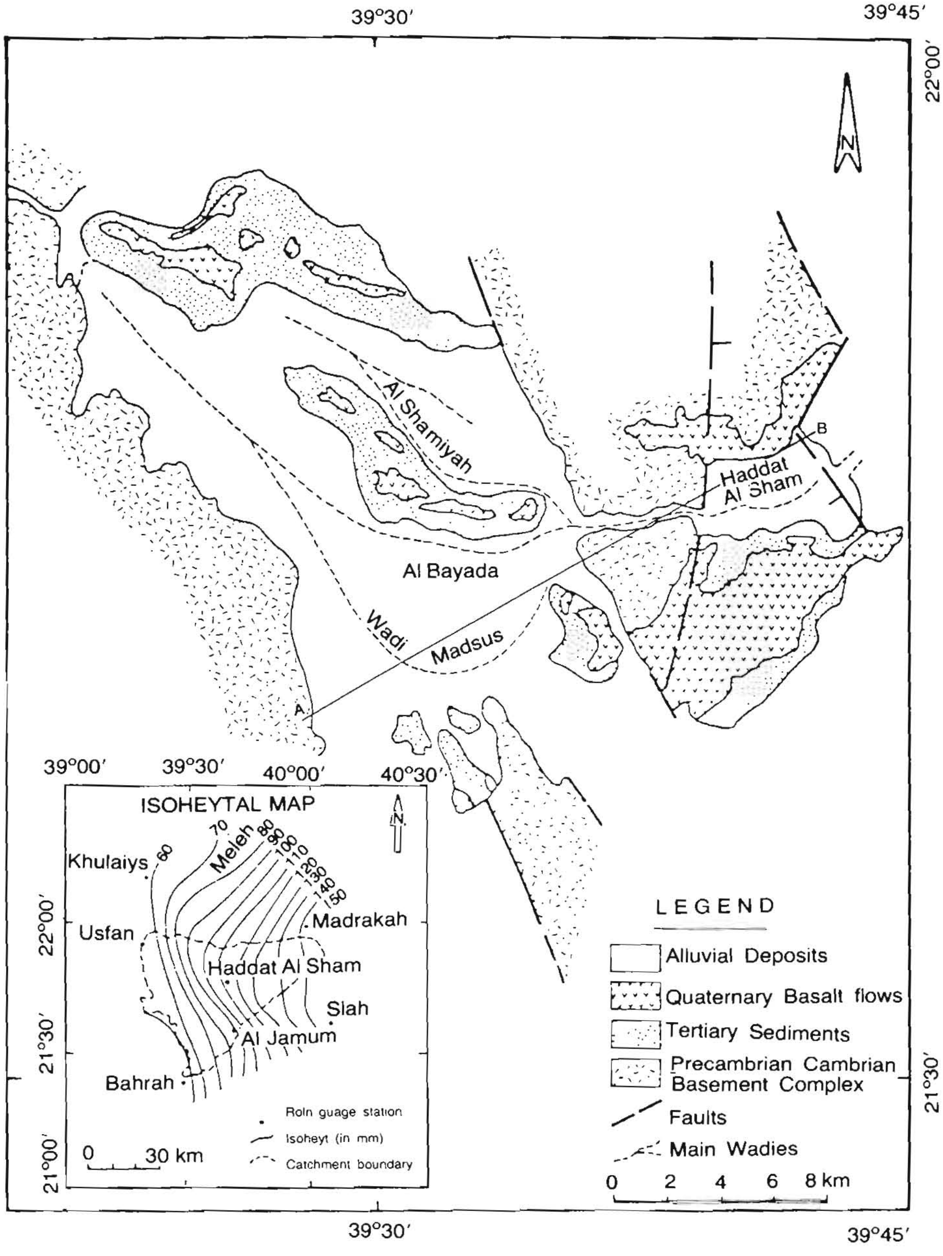

Fig. 1. Location map of the study area with an Isoheytal map including the surrounding areas

- Quaternary basalt flows,
- Alluvial Deposits.

The Basement includes a complex assemblage of igneous and metamorphic rocks intruded by basic, aplitic and pegmatitic dykes. Haddat Al Sham Formation consists mainly of varied sized sandstones, conglomerates and claystone (Bahafzalla *et al.* 1983). It rests unconformably on the Basement Complex. Usfan Formation consists mainly of sandstones, shales, marls and fossiliferous carbonate wedges (Karpoff 1955). In Haddat Al Sham area it overlies Haddat Al Sham Formation, elsewhere, and where it is found, it rests unconformably on the Basement rocks. Shumaysi Formation is composed of sandstones, siltstones and oolitic ironstone bands (Al Shanti 1966). It lies conformably on Usfan Formation. In Al Bayada area, Shumaysi Formation lies unconformably on the Basement Complex. The basalt flows form non-continous caps overlying the upper levels of the previous rock units. Alluvial deposits form a heterogeneous assemblage of gravels, sand, silt and clayey silt.

From Cambrian through Quaternary the area had been subjected to different tectonic activities. These activities were accentuated with the opening of the Red Sea (Oligocene-Eocene). The prominant structural features in the area are

Table 1. Geological succession of Haddat Al Sham area (after Bahafzalla *et al.* 1983)

Age	Formation	Lithology	Thickness (m)
Quaternary - Recent	Surficial deposits including Alluvial deposits of the wadi system	heterogeneous assemblage of gravels, sands, silt and clay	≤ 30
Tertiary - Quaternary	Basalt flows	basalts and andesite	≤ 60
Eocene - Oligocene	Shumaysi Formation	sandstone, siltstone with oolitic ironstone bands	20-200
Maestrichtian -	Usfan Formation	sandstone, shales, marls and carbonate ledge	
Cretaceous	Haddat Al Sham Formation	conglomerate, sandstone, breccia with claystone and siltstone	250
Cambrian-Precambrian	Basement Complex	Igneous and metamorphic complexes	

faulting and jointing. NE-SW faults form elongate grabens and horsts in the area (Basahel *et al.* 1983). Fig. 2 is a conceptual cross-section simplifying the geological succession in the area.

Groundater Occurrence and Movement

The groundwater occurs in the area within two geological units: the alluvial deposits of the wadi system and the clastic coarse members of the Cretaceous - Tertiary sedimentary succession (Fig. 3).

Within the wadis groundwater occurs in the heterogenous assemblage of gravels, sand, silt and clay that make the wadi-fill deposits. The depth to the water level in the wadi-fill deposits varies between 7 metres in the upstream areas (Haddat Al-Sham) to some 13 metres in the downstream areas. This depth fluctuates according to the time of the year and recharge conditions wherever available. The general groundwater flow within the wadi system follows the surface drainage *i.e.* from the upstream to the downstream of the wadis. A lateral component of flow occurs as we go away from the main channel of the wadi and this lateral component might contribute towards the recharge of the sedimentary units below. Fig. 4 explains this situation explicitly. The water-level ranges from 90 m to 230 m above mean sea level and the hydraulic gradient varies between 1.6×10^{-2} and 8.8×10^{-3}. The transmissivity in the wadi-fill ranges between 72 m^2/day and 713 m^2/day, the storage coefficient varies from 1.28×10^{-1} to 1.12×10^{-3} (Table 2). Local semi-confined conditions are present due to facies changes and local abundance of clay lenses within the wadi-fill deposits. The hydraulic permeability of the wadi-fill deposits measured in the lab. reveals a range of 5.6 - 62.6 m/day.

Groundwater occurs as well within the clastic members of the sedimentary succession in the study area. A number of wells have penetrated the wadi-fill deposits and the upper clays of the Shumaysi Formation and tapped groundwater from the clastic coarse member in Haddat Al Sham area, Al Bayada, Al Shamiyah and in the vicinity of wadi Madsus. Groundwater has been struck in these areas at depths between 23, 25, 33 metres respectively. Water has risen above these depths for some 2-5 metres above the confining clay member. Groundwater occurring in the upper members of the sedimentary succession is largely controlled by a complexity of geological elements including the block faulting mechanism that effects the sedimentary succession and the lithological facies variations. Thus a complicated picture for the underground flow exists (Fig. 5). The situation needs more understanding of the geometries of the water-bearing horizons and this

Table 2. Field and Laboratory measurements of Permeability, Transmissivity and Storage Coefficient

Pumping Test Results												Grain-size Analysis	Constant Head Parameter	Average		
Method	Theis		Jacob		Boulton		Papadopulos & Cooper		Slop-Matching		Recovery					
Test No.	T (m^2/day)	S	T (m^2/day)	S	T (m^2/day)	S	T (m^2/day)	S	T (m^2/day)	S	T (m^2/day)	K (m/day)	K (m/day)	T (m^2/day)	K (m/day)	S
1					38	0.086			140	0.194	–	17.12	17.17	108	17.15	1.4×10^{-1}
2					71	0.058			217	0.364	141	21.16	21.18	143	21.17	2.1×10^{-1}
3					120	0.049			171	0.163	237	5.59	5.60	176	5.60	1.6×10^{-1}
4*					36	0.16			88	0.356		4.79	4.80	62	4.80	2.58×10^{-1}
5									408	0.859	1018					8.59×10^{-1}
6									35	0.128	197			116		1.28×10^{-1}
7					72	0.037						38.25	62.64	72	50.45	3.7×10^{-2}
8					161	0.093						22.42	38.44	161	30.43	9.3×10^{-2}
9			282	–					300	7.2×10^{-3}	133	14.46	28.97	713	21.72	7.2×10^{-3}
10					186	0.17			378	5.6×10^{-5}	86	5.76	4.49	217	5.13	8.5×10^{-2}
11					126	0.89			263	3.8×10^{-4}	122	5.76	5.50	212	5.63	4.4×10^{-1}
12*											316	21.29	9.84	316	15.57	
13*			86	–			72	4.6×10^{-3}			115	4.21	8.24	91	6.23	4.6×10^{-3}
14*			43	–			58	5.4×10^{-4}				4.20	3.21	51	3.71	5.4×10^{-4}
15	260	1.03×10^{-3}	245	1.2×10^{-3}							273	7.84	7.60	259	7.72	1.12×10^{-3}
16	84	1×10^{-3}	345	4×10^{-3}							173	8.91	5.25	201	7.08	2.5×10^{-3}

Tests Nos. 1, 2, 3, 5, 6, 7, 8, 9 are tapping unconfined aquifer
10, 11, 15, 16 are tapping semiconfined aquifer
4, 12, 13, 14 are tapping confined aquifer

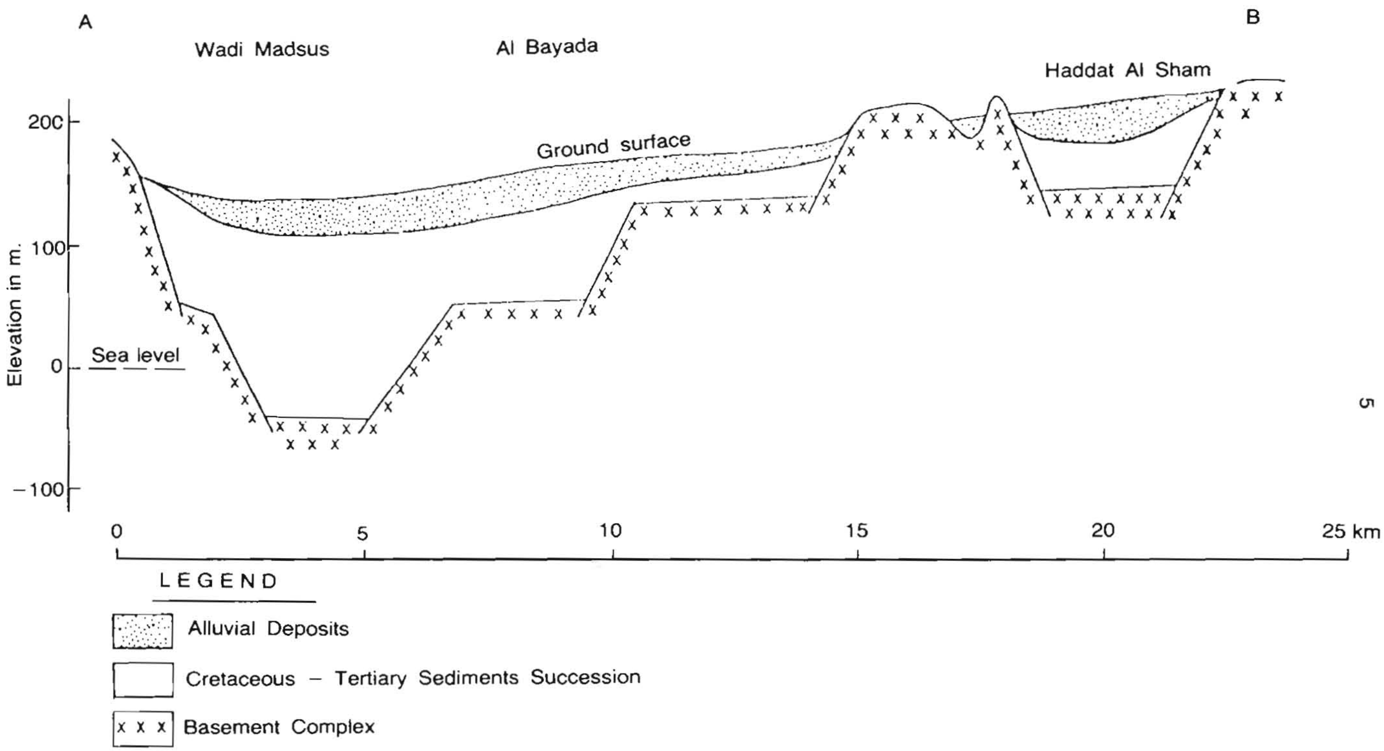

Fig. 2. Generalized geological cross-section (Basement complex configuration is based on DGMR 1966).

needs detailed gravity and resistivity surveys in the area. The average hydraulic gradient for this case is ranging between 1.4×10^{-2} and 6.0×10^{-4} (Fig. 5). The transmissivity values obtained are between 51 m^2/day and 316 m^2/day (Fig. 6). The storage coefficient ranges from 5.4×10^{-4} to 1.12×10^{-3}. Some values of the storage coefficient reflect semi-confined conditions which can be explained as follows: in some areas the upper clayey member might be reduced, eroded or it could be silty in nature or that this aquifer is hydraulically inter-connected with the upper unconfined wadi-fill aquifer. Laboratory measurements on the hydraulic conductivity gave average values between 3.7 and 156 m/day (Table 2). Recent recharge to this lower aquifer is limited to outcrop areas and in places where there is interconnection with the upper unconfined alluvial deposits of the wadis (Fig. 4).

Groundwater Quality

102 water samples were collected from the study area to shed light on the groundwater chemical composition of the two aquifers. Table 3 summarizes the analytical methods used in this study. Table 4 includes the results of the chemical analysis. The groundwater of the confined aquifer is generally characterized with higher electrical conductivity values (2760 to 13400 micromhos/cm) while those of the unconfined aquifer have relatively lower electrical resistivity values (679 to 7920 micromhos/cm) *i.e.* the total mineralization of the groundwater tapped from the clastic members of the sedimentary succession is relatively higher than that of the groundwater tapping the wadi-fill deposits. The relative ionic concentrations in the confined aquifer are generally as follows:

$$(Na^{+} + K^{+}) > Mg^{++} > Ca^{++}$$

and $$Cl^{-} > SO_4^{--} > HCO_3^{--}$$

When the confined aquifer is interconnected with upper unconfined aquifer of the wadi-fill deposits exceptions to the above mentioned generalization may occur. The relative cationic concentrations in the unconfined aquifer are as follows:

$$(Na^{+} + K^{+}) > Ca^{++} > Mg^{++}$$

The anionic concentrations are:

$HCO_3^{--} > Cl^{-} > SO_4^{--}$ in the upstream of Haddat Al Sham, while in the other sub-areas anionic concentrations are: $Cl^{-} > SO_4^{--} > HCO_3^{--}$

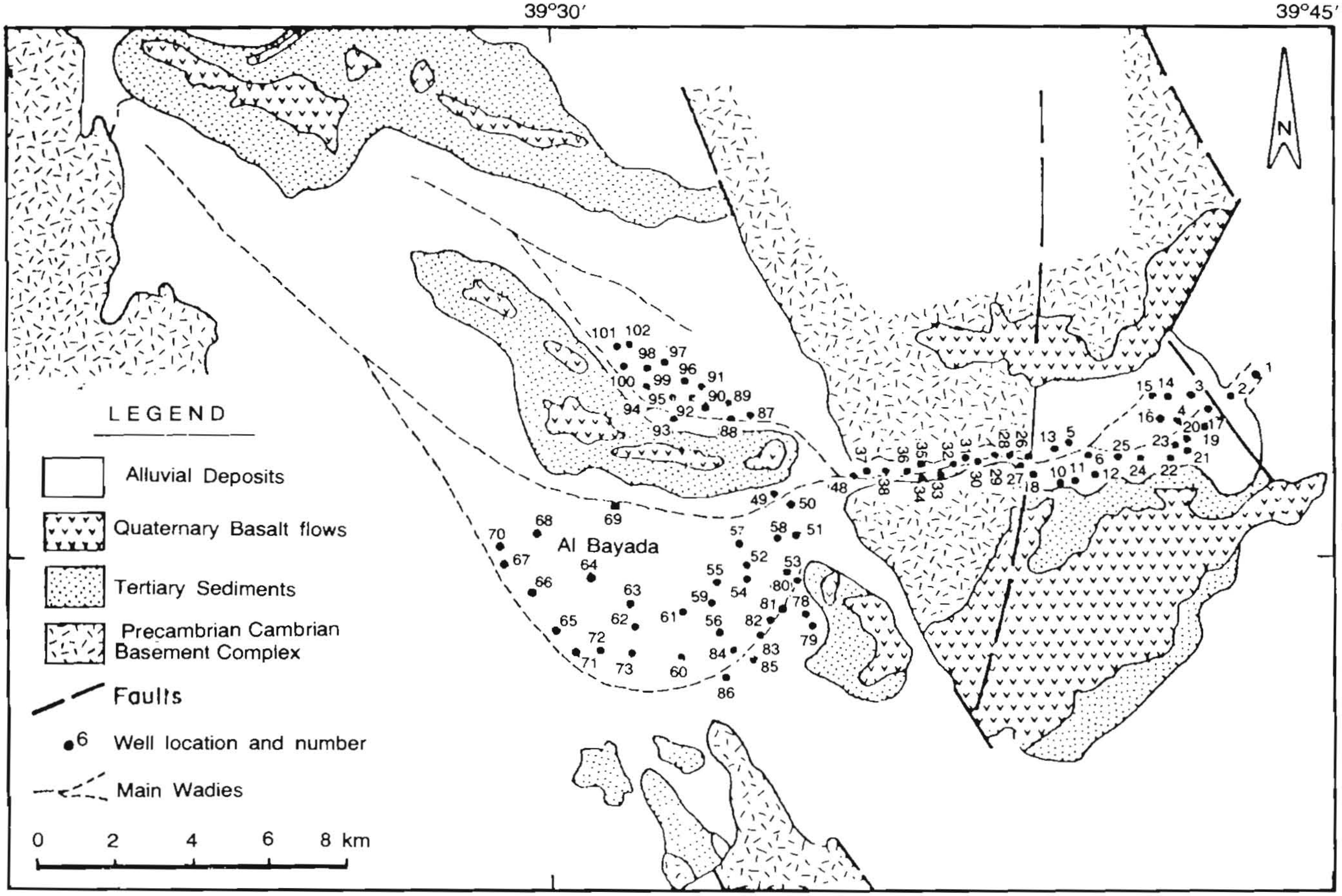

Fig. 3. Well-location map.

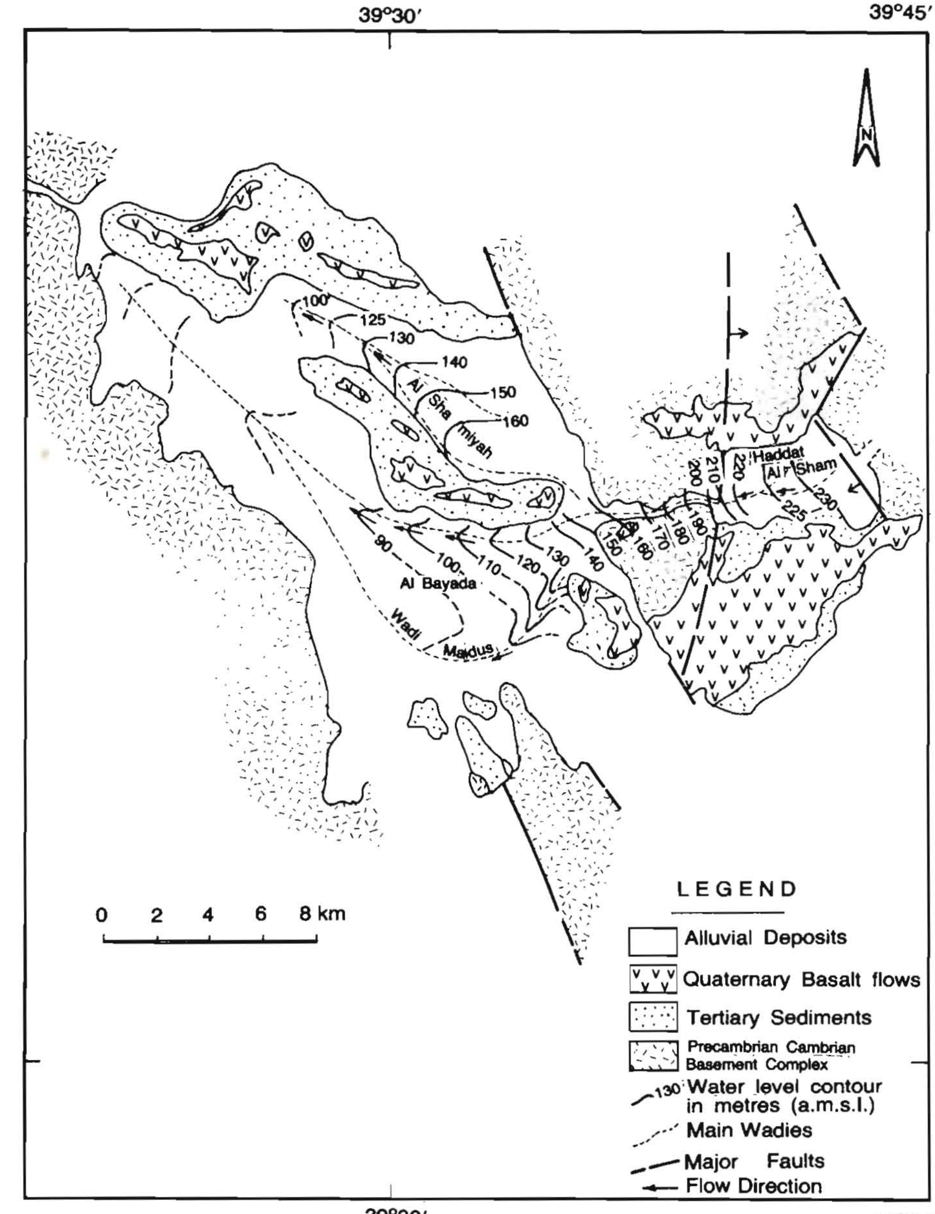

Fig. 4. Water-table map for the alluvial aquifer in Haddat Al Sham - Al Bayada area.

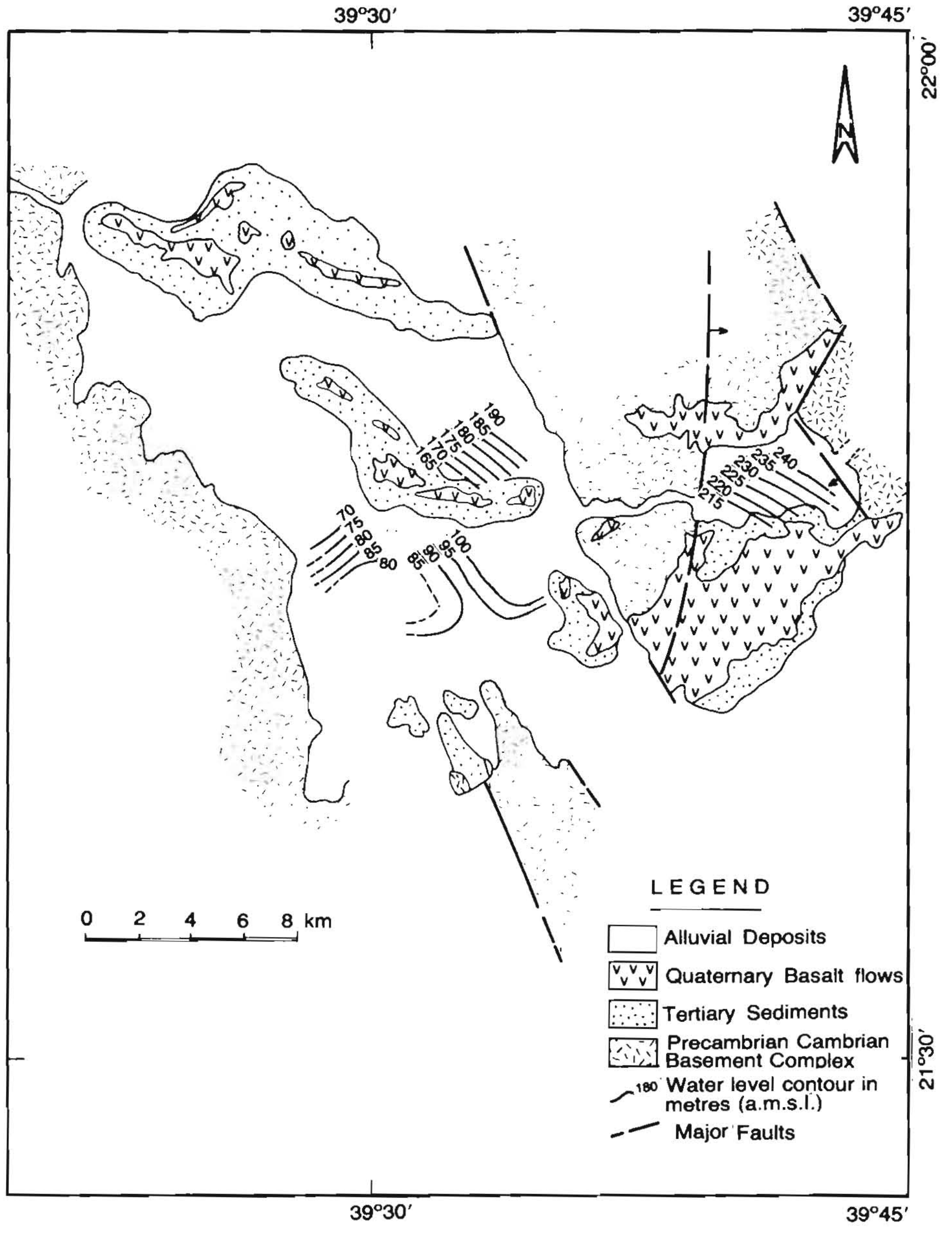

Fig. 5. Piezometric surface map for the confined aquifer in the study area.

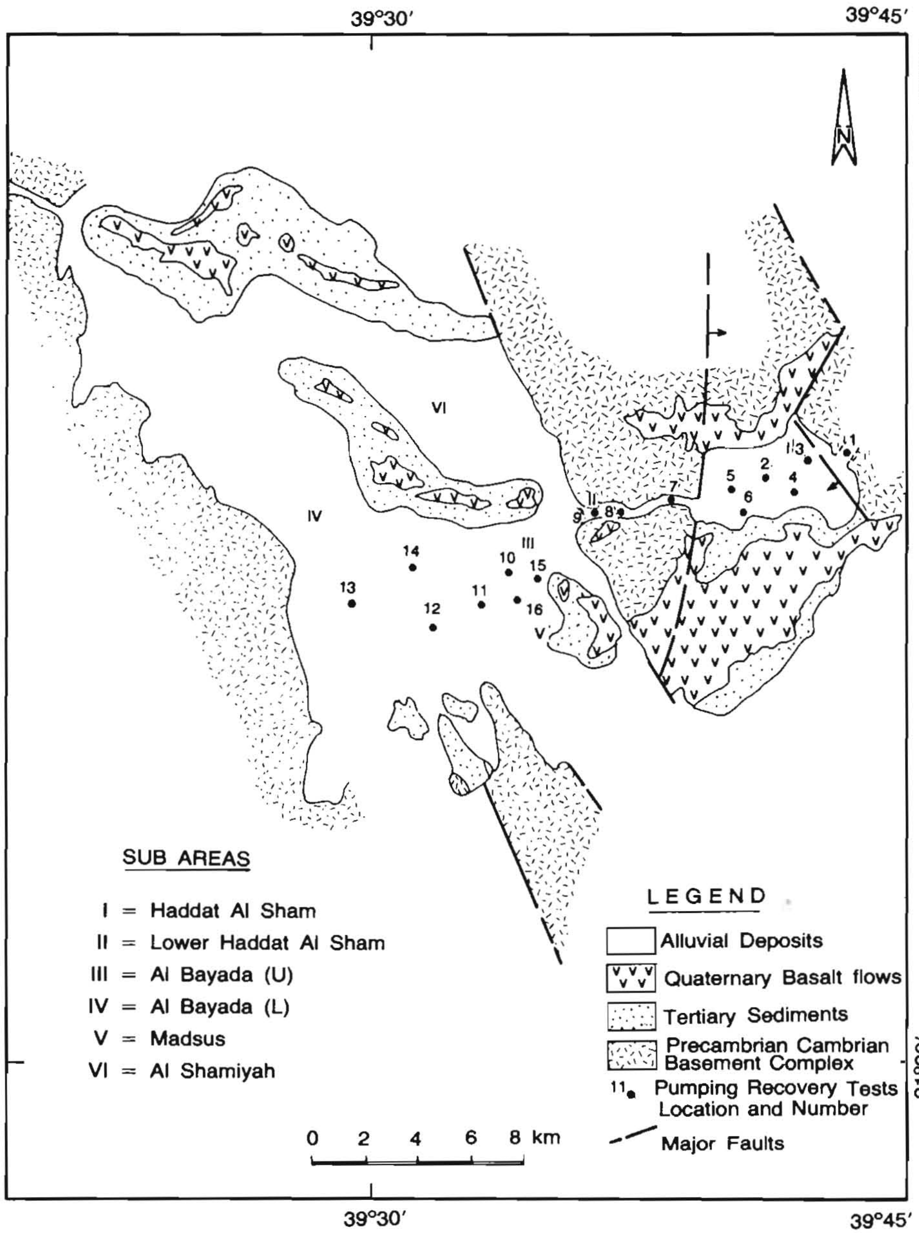

Fig. 6. Locations of Pumping and Recovery Tests.

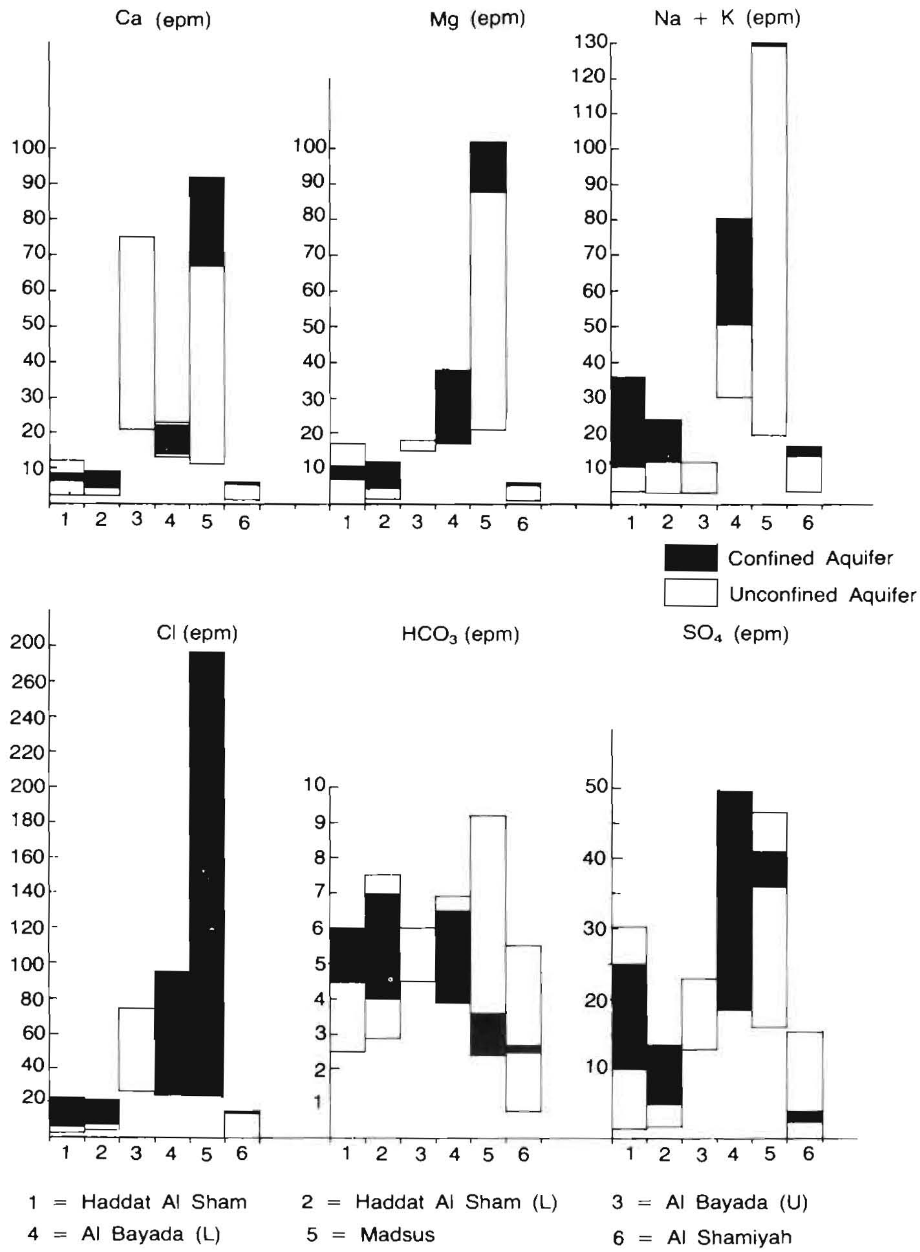

Fig. 7. Ionic concentration for the different sub-areas.

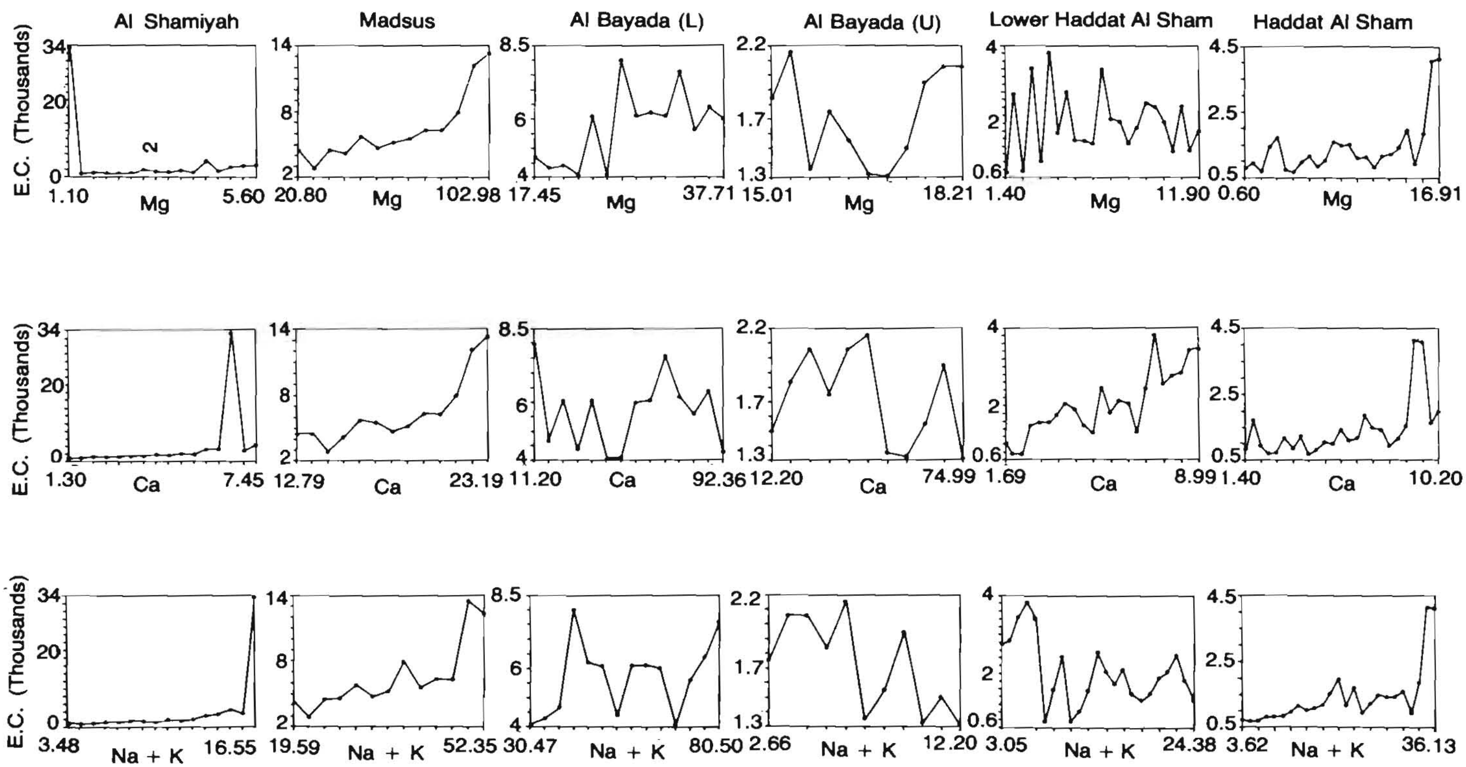

Fig. 8. Electrical Conductivity/cation relationships. (E.C. in micromhos/cm, cations conc. in epm)

In dealing with individual ion concentration for the different sub-areas (Fig. 7) it is difficult to visualize a certain pattern.

The relationship of each ion concentration with the electrical conductivity is shown in figures 8 and 9. In the upstream area, Haddat Al Sham, the relationship is direct while in lower Haddat Al Sham and Al Bayada sodium has been substituted by calcium and to a lower extend by magnesium. In these areas the relationship of the electrical conductivity with the chloride and sodium has became indirect; with the sulphate and calcium the electrical conductivity is directly related *i.e.* the soil is getting more colloidal. In Al Shamiyah the relationships resemble those of the upstream in Haddat Al Sham. From our field observations the intermediate sector of Al-Bayada is lying within a plain where evaporites are available. However, the bicarbonate concentration did not show any effect and its values remained nearly constant. This can be explained that it formed the media of the reaction.

It can thus be concluded that the water quality of each well shown in Table 4 depends on the penetration through the aquifer.

Conclusions

Groundwater occurs in Haddat Al Sham - Al Bayada area within two water-bearing horizons: an upper unconfined aquifer formed mainly of alluvial deposits of the wadi system in the area, and a lower confined aquifer formed by

Table 3. Analytical Methods

Electrical Conductivity	(Field)	E.C. meter, WTW D 812 WEILHEIM type.
pH	(Field)	Digital pH-meter, Knick Portamess 651-2 type.
Na, K, Ca, Mg,	(Laboratory)	A A S (Perkin - Elmer 50000). To minimize matrix effect from different elements, a mixture of the standards was used to have the same conditions as in the water sample.
Cl	(Laboratory)	Titration against Ag NO_3 in presence of potassium chromite as indicator.
SO_4	(Laboratory)	Turbidimetric method using barium chloride - compared spectrometrically with standard conc.
HCO_3	(Laboratory)	Titration with sulphuric acid using methyl-orange as indicator.

Table 4. Chemical Analysis: Major ions concentration (epm) of Haddat Al Sham - Al Bayada groundwater

Location	Sample No.	pH	Ca	Mg	Na+K	Cl	HCO_3	SO_4
Haddat Al Sham	1	7.93	3.560	1.001	3.8430	3.000	3.500	1.637
	2	7.71	5.520	2.501	3.8710	4.000	4.500	4.468
	3	7.74	3.360	1.210	4.0430	3.750	2.500	2.545
	4	7.69	4.000	2.101	6.3850	5.250	4.000	3.420
	5	7.63	3.880	1.401	3.6260	3.250	3.500	2.348
	6	7.65	8.160	2.201	10.1840	5.500	4.000	10.703
	7	7.60	5.160	2.001	4.4350	4.250	3.500	3.839
	8	7.83	6.480	1.101	10.1580	5.250	2.500	8.947
	9	8.04	5.120	2.402	6.6270	4.250	3.500	5.639
	10*	7.93	7.700	11.007	36.1310	23.251	6.000	25.434
	11*	7.83	7.400	16.911	35.2350	23.251	5.000	30.396
	12	7.70	5.520	7.205	11.1440	8.000	5.000	11.972
	13	7.86	6.500	7.205	9.7350	7.500	4.500	10.138
	14	7.87	1.840	1.401	7.9440	3.500	4.000	3.591
	15	8.03	1.400	3.002	4.3500	2.750	3.500	2.939
	16	7.34	2.001	1.001	7.9440	3.250	4.000	3.359
	17	7.62	10.200	6.404	8.7150	13.251	3.000	7.610
	18**	7.61	7.300	2.203	8.6000	9.000	2.500	5.784
	19	7.35	6.600	2.502	5.7420	6.250	2.500	4.542
	20	7.47	3.100	2.001	4.4010	3.250	4.500	2.674
	21	7.64	5.700	2.201	9.4550	6.750	4.500	6.667
	22	7.32	3.200	3.502	9.3790	5.750	4.400	5.456
	23	7.52	4.200	4.403	10.0820	7.500	4.400	5.356
	24	7.39	3.300	1.601	3.6850	3.250	3.200	2.125
	25	7.40	3.000	3.302	8.7510	4.750	4.200	3.445
Lower Haddat Al Sham	26	7.64	4.239	2.501	10.7720	7.500	3.999	5.313
	27	7.69	4.079	2.301	10.7337	7.000	3.999	5.655
	28	7.70	4.799	1.401	9.6467	6.750	4.499	4.173
	29	7.75	5.919	3.702	13.1267	9.500	5.498	7.086
	30	7.53	3.519	2.901	10.0817	6.250	4.499	5.347
	31	7.71	5.599	2.901	11.1940	8.750	4.499	6.658
	32	7.70	4.639	2.701	11.8187	8.750	3.999	5.998
	33*	7.59	8.159	4.803	15.9790	9.250	7.498	10.429
	34	7.54	7.199	5.302	14.2130	14.000	4.998	8.655
	35	7.50	6.879	5.103	13.5870	14.500	4.998	7.155
	36	7.72	5.199	9.005	13.5617	15.000	5.498	7.849
	37*	7.68	8.999	10.206	18.3210	19.500	5.498	13.608
	38*	7.60	8.899	11.907	18.7560	19.500	5.498	13.291
	39	7.73	4.699	4.703	12.6370	8.500	6.998	5.655
	40*	7.59	7.099	10.206	24.3850	22.500	6.498	12.057

* confined aquifer

** semi-confined aquifer

Table 4.–*(Continued)*

Location	Sample No.	pH	Ca	Mg	Na+K	Cl	HCO_3	SO_4
Lowe Haddat Al-Sham *(Contd.)*	41*	7.64	8.699	7.304	11.4370	12.000	3.999	10.394
	42	7.60	6.399	6.604	10.2980	10.500	4.499	6.821
	43	7.82	1.699	2.543	7.3950	3.750	4.998	2.116
	44	7.67	4.699	5.403	11.3100	9.500	4.998	6.598
	45	7.66	3.199	1.701	3.0520	3.500	2.999	1.851
	46	7.60	5.399	2.801	5.7310	5.800	2.999	4.293
	47	7.78	2.899	3.502	9.1860	5.400	5.998	3.564
	48	7.64	4.999	2.501	6.1410	6.500	4.499	2.562
Al Bayada (Upper)	49	8.00	74.990	16.410	12.2056	75.470	5.000	22.880
	50	8.10	57.800	16.910	9.1912	56.480	5.000	21.840
	51	7.70	25.800	15.010	6.5256	27.000	5.000	16.710
	52	7.30	54.990	16.010	7.4512	55.480	4.500	18.960
	53	7.40	41.800	15.210	6.9856	42.480	4.500	17.680
	54	7.70	41.200	15.210	6.5556	43.980	4.500	13.810
	55	6.50	33.590	18.210	5.2456	34.500	5.000	17.950
	56	7.20	28.380	17.410	4.6060	28.990	6.000	15.040
	57	6.60	21.200	16.410	10.8256	27.490	6.000	15.600
	58	7.70	46.890	16.010	9.6212	47.480	4.500	20.440
	59	7.50	33.200	15.610	2.6612	34.500	4.500	13.090
Al Bayada (Lower)	60*	6.40	14.080	17.450	50.0250	25.000	6.460	49.290
	61*	6.60	22.160	24.090	54.4106	75.000	4.490	21.320
	62*	6.80	20.080	29.290	80.5006	89.500	5.490	32.340
	63*	7.20	12.790	21.050	54.4006	55.000	5.490	24.750
	64*	7.10	15.990	20.890	58.7506	48.000	4.990	41.590
	65*	7.40	18.720	37.710	63.1006	80.000	3.990	34.160
	66*	6.50	14.880	23.130	63.1006	72.500	4.490	23.560
	67*	6.80	19.990	25.820	60.9256	72.500	5.990	28.430
	68*	6.60	22.390	29.620	69.6256	97.500	5.990	18.650
	69*	6.80	18.190	21.010	30.4756	40.000	4.990	23.200
	70**	6.90	17.790	20.210	67.4486	75.000	4.990	24.400
	71**	6.90	15.790	18.420	60.9256	65.000	5.990	26.430
	72**	7.50	23.190	17.810	41.3506	40.000	5.990	24.970
	73**	7.10	22.390	32.820	69.6256	85.000	6.990	31.470
Wadi Madsus	74	7.90	14.000	20.800	39.1556	43.430	5.600	23.300
	75	7.21	24.600	35.400	43.5056	66.400	9.200	27.310
	76	7.13	20.600	29.200	19.5906	43.090	4.800	20.420
	77	7.34	22.000	33.200	41.3256	68.205	5.200	22.135
	78*	7.92	11.200	24.200	34.8056	43.875	6.400	19.735
	79*	7.51	92.355	102.980	130.4606	276.157	3.600	46.933
	80	7.33	67.030	88.730	130.6140	242.216	2.400	41.165

* confined aquifer

** semi-confined aquifer

Table 4.–*(Continued)*

	Sample No.	pH	Ca	Mg	Na+K	Cl	HCO_3	SO_4
Wadi Madsus *(Contd.)*	81	7.12	23.000	38.000	58.7256	81.460	4.800	32.590
	82	7.11	14.400	22.200	21.7656	36.600	4.800	16.310
	83	8.01	34.000	52.400	67.4412	110.206	4.800	37.714
	84	7.21	24.800	37.400	52.3019	75.840	5.600	32.230
	85	7.32	33.000	48.400	65.3479	108.934	6.400	30.756
	86	7.41	51.000	75.400	52.3530	145.599	6.000	26.711
Al Shamiyah	87	7.72	2.030	1.500	6.1112	4.998	4.500	1.120
	88	7.63	2.130	1.100	4.3756	1.199	4.250	0.980
	89	7.72	1.890	1.700	3.4800	2.409	4.000	1.044
	90	7.61	1.304	1.700	5.2200	2.749	5.502	0.022
	91	7.24	2.160	1.800	5.2200	4.198	4.500	0.950
	92	7.32	3.780	2.100	7.8556	7.990	4.250	2.000
	93*	7.33	3.599	2.700	6.9856	8.997	3.500	1.170
	94*	7.31	6.500	5.600	14.8156	12.500	4.000	11.200
	95	7.43	5.9998	5.900	16.5556	12.700	2.500	13.900
	96	7.62	2.970	2.300	6.9856	6.250	3.500	2.780
	97	7.44	2.560	2.400	6.9856	5.500	5.002	2.130
	98	7.32	3.960	2.400	7.0556	8.500	3.000	3.300
	99	7.61	7.450	4.000	11.3356	12.500	2.500	7.900
	100	7.34	3.780	2.000	9.5956	8.300	5.000	3.400
	101	7.21	6.750	1.100	16.5556	14.995	3.000	7.200
	102	7.21	18.199	2.602	15.7368	20.500	0.800	15.500

* confined aquifer
** semi-confined aquifer

the clastic members of the Cretaceous - Tertiary sedimentary succession. The alluvial deposits are characterized with an average permeability of 34 m/day, an average transmissivity of 390 m^2/day and an average storage coefficient of 6.5×10^{-2}. The confined aquifer is characterized by an average permeability of 10 m/day, and average transmissivity of 180 m^2/day and an average storage coefficient of 8.3×10^{-4}.

Electrical conductivity within the unconfined aquifer ranges from 679 to 7920 micromhos/cm while in the confined aquifer it ranges from 2760 to 13400 micromhos/cm. The ionic composition of each of the two aquifers is generally distinguished.

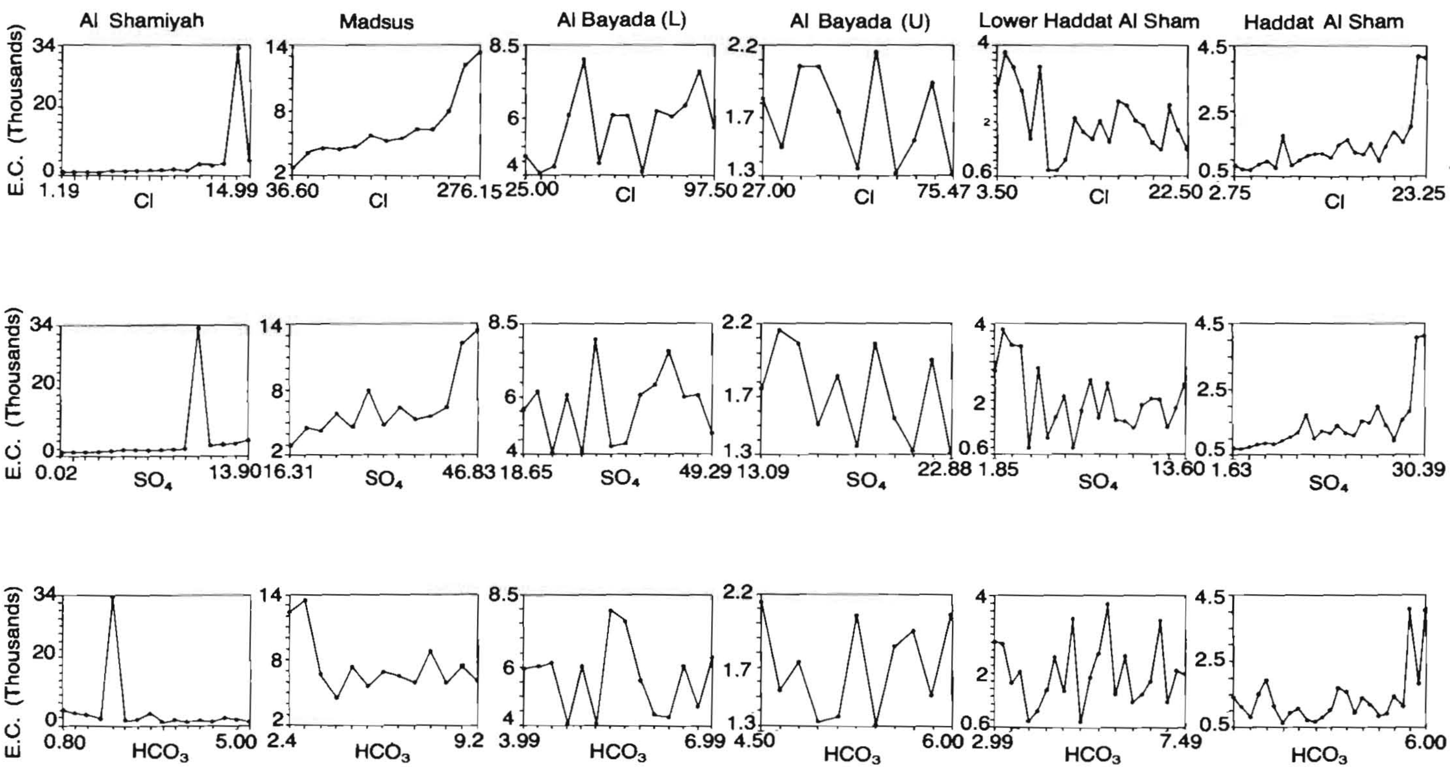

Fig. 9. Electrical Conductivity/anions relationships. (E.C. in icromhos/cm, anions conc. in epm).

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المياه الجوفية في منطقة هدى الشام ـ البياضة غرب المملكة العربية السعودية

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المملكة العربية السعودية

تقع منطقة هدى الشام ـ البياضة على مسافة نحو ١٠٠ كم شرق ـ شمال شرق مدينة جدة . وتكتسب هذه المنطقة أهمية خاصة لتواجد المياه فيها إلى حَدٍ ما مقارنةً ببقية أجزاء الدرع العربي . ونتيجةً لهذه الظروف السائدة يتواجد عدد من المزارع الصغيرة للخضروات وعدد من مزارع تربية الحيوانات حيث تشكل هذه المزارع مصدراً محلياً مهماً للخضروات لمدينة جدة وضواحيها .

هدف هذا البحث هو دراسة المياه الجوفية في المنطقة من حيث تواجدها ، حركتها ، خواص الطبقات الحاملة لها ، نوعيتها وعلاقات الأيُونات الرئيسية المذابة فيها .

يبلغ متوسط هطول الامطار في منطقة هدى الشام ـ البياضة حوالي ١٠٠ ملم / سنة . تتواجد المياه الجوفية في طبقتين حاملتين للمياه هما :

١ ـ طبقة الرواسب الوديانية والتي تشكل خزاناً حراً غير محصور في مجمله .

٢ ـ طبقة الصخور الرسوبية الحتاتية التي تتبع للعصر الكريتاسي الثلاثي في خزان محصور .

تتميز طبقة الرواسب الوديـانية بميـل هيدروليكي يـتراوح بين ١,٦ × $١٠^{-٢}$ إلى ٨,٨ × $١٠^{-٢}$ ، متـوسط إنتقاليـة يبلغ ٣٩٠$م^{٢}$/ يوم، ومتـوسط نفـاذيـة يبلغ ٣٤ م/ يـوم ومعامـل تخـزين يـتراوح بـين ١,١٢ × $١٠^{-٣}$ إلى ١,٢٨ × $١٠^{-١}$. تتحـرك المياه الجـوفية المـوجـودة في طبقـات الصخـور الـرسـوبيـة تحت أثـر ميـل هيدروليكي يتراوح بـين ٦,٠ × $١٠^{-٤}$ إلى ١,٤ × $١٠^{-٢}$ ، متوسط إنتقـالية يبلغ ١٨٠$م^{٢}$/ يوم، متوسط نفاذية يبلغ ١٠م/ يـوم. يتراوح معـامل التخـزين في هذا الخزان بين ٤,٥ × $١٠^{-٢}$ إلى ١,١ × $١٠^{-٣}$.

كما يناقش هذا البحث المحتوى الكيميائي للمياه الجوفية في كل من الخزانـين (الخزان الحر والخزان المحصور). وقد مثلت نتائـج التحاليـل الكيميائيـة للعناصر الرئيسية على أشكال بيانية مختلفة ميزت المياه الموجودة في كل خـزان على حـدة من ناحيتي التركيب وكيمياء المياه كما بينت الخصائص الكيميائية العامة لأجزاء منطقـة الدراسة المختلفة.