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Geology and Hydrogeochemistry of Al-Quwayiyah Area, Saudi Arabia

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ABSTRACT. Geological and hydrogeochemical studies were carried out on 60 km^2 in Al-Quwayiyah area that consists mainly of igneous and metamorphic rocks. The former group includes extrusive and intrusive rocks of different ages and assorted compositions ranging from calc-calkaline to strongly alkaline affinities. The latter sequence has, at least, four metamorphic phases containing foliated and nonfoliated rocks of ortho and para origins. They have N-S strikes with eastern dip to vertical foliation. The area suffers several major and minor structures and shear zones where some Phanerozoic sedimentary cover also occurs.

Ten shallow hand-dug water wells exist in Wadi Al-Faydhiyah in Al-Quwayiyah zone with depths of 20-40 m. The groundwater is of a reasonably good quality for all uses, although its quality changes downstream due to the extensive pumping in the drought seasons and becomes more mineralized. Regional geology with cross sections and other shallow wells in different areas from this zone were studied for comparison.

Al-Quwayiyah area occurs in the central part of Saudi Arabia at the eastern-central edge of the Precambrian Arabian Shield where these crystalline rocks are overlain by the western border of the Phanerozoic sedimentary cover. This zone is located in the arid region at longitude 44° 50′E-45° 30′E and latitude 23° 45′N-24° 15′N (Fig. 1). It slopes gently from the western crystalline shield at 850 m above sea level to 620 m at the south-eastern border of the sedimentary belts. The basement complex is composed of a heterogeneous mixture of metamorphic country rocks that are traversed by various types, compositions and ages of volcanic and other igneous intrusions. The metamorphic group belongs to ortho and para origins of greenschist facies of at least four phases.

Search for reasonably good water for domestic, irrigation and light industry is the main and most costly problem in Saudi Arabia. The aim of this paper is to study the quantity and quality of the groundwater in a small sector in the central part of

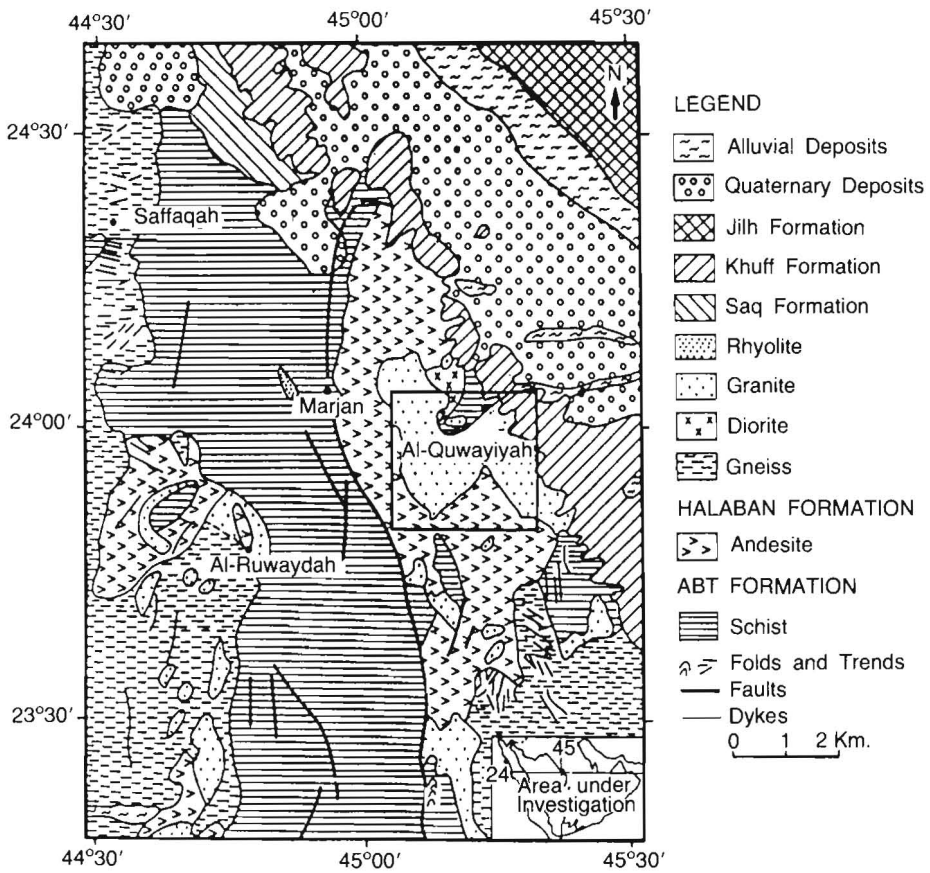
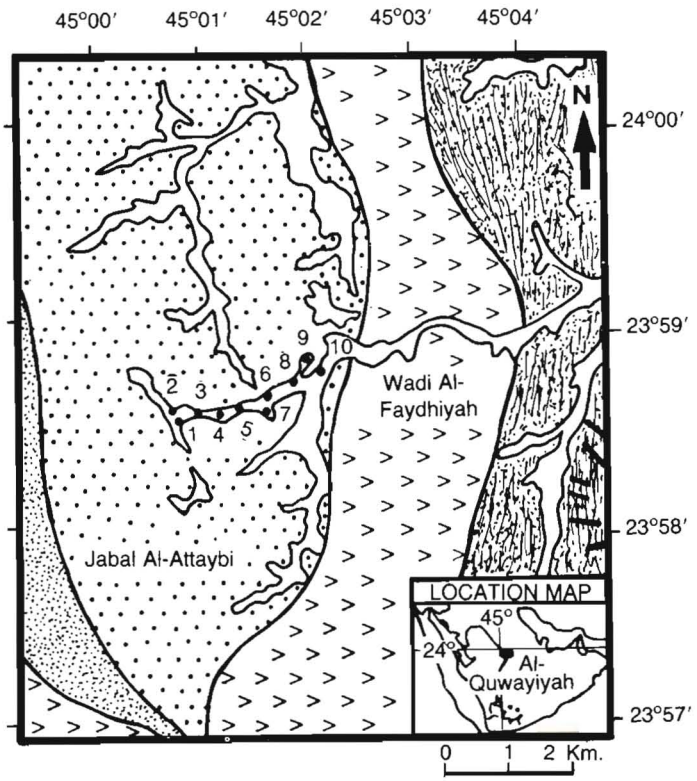


Fig. 1. Geological map of part of the Arabian shield.

Saudi Arabia lacking water. The main water-bearing horizons in the greater Al-Quwayiyah zone are the alluvial deposits and the sedimentary rocks of the Jilh (Triassic), Sudair (Upper Permian-Lower Triassic), Khuff (Upper Permian) and Saq (Lower Paleozoic) Formations. These formations have interstitial and fracture porosity that bear sizeable groundwater bodies. Some of the wadis have dendritic pattern and follow the major structures of the area. In the west, the intermittent streams flow eastward, while in the east they cut through cliffs of the Khuff and Tuwaiq mountains.

In the cultivated areas, the water demand for irrigation and domestic uses plus the hydrostatic levels of the dug wells and dams were studied. The selected representative Wadi Al-Faydhiyah is located in the central part of Al-Quwayiyah

zone where the Halaban Group occurs (Fig. 2). This wadi has ten hand-dug water wells where the fissures, cracks, weathered and fractured granites and wadi alluvium are water-bearing. Here, pebble deposits alternate with medium to coarse grains of sand, some of which are of eolian origin. Recommendations assessing the water quantity and quality for domestic and irrigation usages in the region were made.



LEGEND

Quaternary eolian sand and alluvial deposits

Dykes of dacite, andesite or basalt

Postorogenic granite

Border zone of postorogenic granite

Andesite

Metamorphic rocks (lines showing trend of planar structures)

1-10 Sample location

Fig. 2. Geological map of Wadi Al-Faydhyiyah area in Al-Quwayiyah region.

Methods of Study

Field and laboratory studies were completed intermittently over a period of five months from 5/5/82. Water, soil and rock samples were collected and analysed by X-ray fluorescence and atomic absorption methods as used by Sindi (1981 and 1985). Total dissolved solids (TDS) were obtained by weighing the residue dried at 105°C. The sodium residue (SAR) was calculated for the sodium hazard to the soil by the equation:

$$SAR = Na^{+} / \{ \sqrt{(CA^{++} + Mg^{++})/2} \} \text{ meq/L}$$

The alkalinity percentage (A%) can be calculated by the equation:

$$A\% = (Na^{+} + K^{+}) / (Na^{+} + K^{+} + Mg^{++} + Ca^{++}) \times 100$$

which explains the reaction of sodium with the soil and the reduction of the permeability. The biological studies were carried out by studying the presence of protozoa or other primitive cells under the microscope. The presence of bacteria was studied by the presumptive test for the presence of Coliform (bacilli) following the method prepared jointly by the American Public Health Association and the American Water Works Association (1976) and described by Freeman (1979). Bacteria dilution plate count method, with suitable media and agar, was performed by the procedure of Harrigan and McCance (1974). The result was compared with similar findings within Saudi Arabia and also with the analyses of the U.S. National Academy of Science (1972).

Geology

Oldest units in Al-Quwayiyah area are the Abt and Halaban Groups which contain several shear zones and tectonic movements that can be identified from the aerial photographs and/or traced in the field (Fig. 1). Marjan (Al Amar-Idsas) high-angle fault started as a thrust fault and was later reactivated as a strike-slip fault trending NNW-SSE, dipping 75°-80° and plunging 10° SSW. It has recent movements involving eastward displacement of the Abt schist over the Halaban Formation, giving the difference in elevation. This fault separates the eastern Halaban volcanic rocks from the western Abt Formation where the gap is filled by cherty materials (Nebert 1970).

The Abt Group has a flat magnetic pattern with moderate intensity and gentle gradient while the Halaban Formation and the granitic rocks are distinguished by a patchy pattern with low and high magnetic anomalies and steep gradient with circular pattern. The calc-alkaline Abt schist strikes N10°E and N30°W dipping

50°-90°W to SW. In some places, it dips toward the east. It is fine to medium grained, massive with schistose structure and a pale green colour due to the sericite. It has N-S bedding with vertical dip. The fractures are N45°W/75°SW, N65°SE and less commonly N35°/55°NW and are filled with calcite and quartz veins. This group may represent mixing of materials from both island-arc and continental sources and composed originally of calcareous and pelitic greywacke and tufaceous rhythmically bedded shale that were deposited upon a juvenile oceanic island-arc tholeiitic series. This series is altered to greenschist during regional metamorphism. The Halaban Group consists of dioritic to gabbroic, metavolcanic, quartzite, calc-silicate, marble lenses and typical ocean-floor sediments and fine-grained turbidities.

After periods of erosion following some Precambrian depositions, the basement rocks were overlain by some crescent belts of Phanerozoic sedimentary sequences facing the west (*e.g.* the Jilh, Sudair, Khuff and Saq Formations). These exposures, their discussion is included for completion, are dissected by several wadis. The Khuff Formation is 20 km wide bordering the eastern part of the shield and is dominated by 150m high irregular cliff. The strata dip gently 5° to the east with 300 m in breadth. The lower units of this formation are composed of coarse grained, cross bedded, heterogeneous with various types of pale reddish-brown sandstone, limestone, shales and thin lenses of marl and evaporites. The upper units are mainly formed of impure limestone and/or dolomite containing some gypsiferous and shale horizons. It is overlain by the Sudair shale and gypsum and it is underlain by a red clay layer compacted into shale (Bramkamp *et al.* 1956). This Khuff Formation has no porous sediments, although rocks that have only fractures may be water-bearing, and due to poor permeability with no aquifer its groundwater is not favourable.

Jado and Zötle (1984) have studied the Quaternary sediments in Saudi Arabia that includes a brief description of the wadi alluviums. The main surficial deposits in the Al-Quwayiyah area are the colluvial and alluvial deposits. The former precipitations occur at the foot of the hill slopes and in the upstream courses of the wadis. The latter deposits are the extensive blanket covering most of the area and consist mainly of pebbles, gravel, sand and silt. So the name alluvial deposit has been given to all the superficial sediments in this zone.

Hydrogeology and Wadi Deposits

The average annual rainfall based on 20 years (1965-1985) of the M.A.W. record at Al-Quwayiyah city is 148 mm/year though amount of rain is small and scattered with mainly no rain during April-November. The depth of water on rainy days is > 10 mm for several days/year. The frequency of rainfall and the duration

curves show that rainfall intensities for this area are below the world's greatest observed values. Temperatures are −2°C at night, 15°C during the day in the shade; 20°C in the sun during the winter and 40°C-47°C in the shade during the summer. Average water temperature is 25.5°C (21/1/83 and 15-25/2/84), relative humidity (R.H.) is 26%, and total evaporation is 300 mm/year.

All the wells at the basement section of the western side of Al-Quwayiyah zone are large diameter wells, hand-dug to the solid granitic rocks where the groundwater occurs in the wadi deposits and the weathered and fractured rocks. These aquifers (8-10 m depth) govern the productivity and yield (Fig. 3) while the

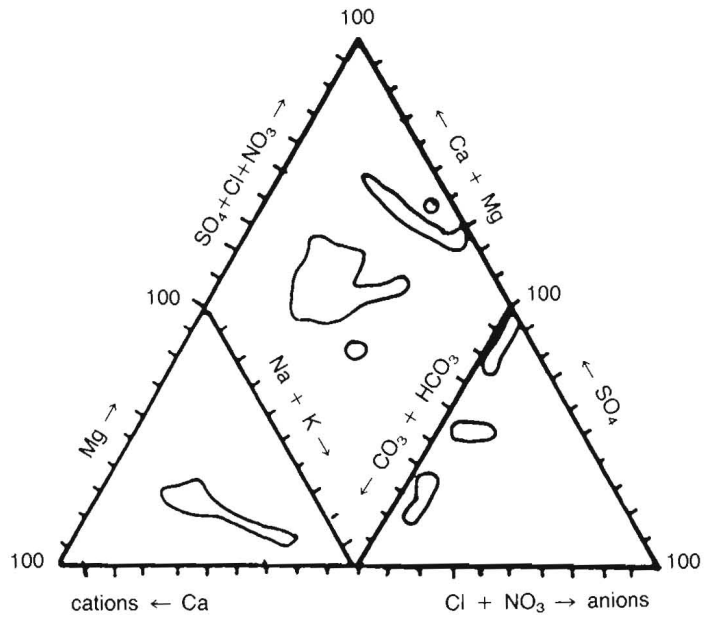


Fig. 3. Piper diagram shows the water composition of the twenty samples from the Khuff formation in Al-Quwayiyah zone.

recharge consists mainly of the rain that infiltrates downward. 90% of the rainfall is lost by runoff, evapotranspiration, infiltration and evaporation. When wells are pumped dry, they recover their original water-level in about 12-15 hrs. Since Wadi Al-Faydhiyah alluvial deposits (fairly permeable) constitute the main potential aquifer, the early time drawdown measurements of the selected wells (Table 1) give a linear relationship. In this wadi, the groundwater flow is from the western fractures and joints of the granites of the Jabal Al-Attaybi. Since the water flows

slowly, its salinity is increased. This excess of salinity is due to the sulphate ions probably derived from NaCl, the dissolution of gypsum and excessive recycling. Soil, plus ground and surface water quality, deteriorate from one year to the next. The flood plain and channel alluvium, which are suitable for tube and open wells, were distinguished with some isolated patches of gravel. These alluvial deposits extend 20 km, a broad belt between the Khuff-Jilh and the crystalline basement and have good recharge and potential. Sandstone is the most promising aquifer and the sand has been reworked and redeposited.

Table 1. Relationship between time of pumping and the drawdown (m) in 7 selected large diameter wells

Time of pumping (min)	Well numbers						
	1	2	3	4	5	6	7
1	0.06	0.05	0.07	0.10	0.12	0.08	0.09
2	0.12	0.10	0.15	0.18	0.20	0.24	0.20
3	0.20	0.20	0.23	0.29	0.30	0.35	0.29
4	0.28	0.27	0.31	0.35	0.39	0.41	0.39
5	0.35	0.38	0.49	0.55	0.58	0.45	0.50
6	0.40	0.44	0.55	0.60	0.65	0.47	0.76
7	0.51	0.53	0.65	0.71	0.76	0.55	0.79
8	0.65	0.62	0.72	0.78	0.79	0.69	0.85
9	0.75	0.73	0.78	0.85	0.75	0.80	0.90
10	0.89	0.83	0.85	0.88	0.81	0.89	0.95
Average well radius (rw)	1.4	1.1	1.2	1.3	0.9	1.14	1.1

Average pumping rate is about 9 L/sec.

Some of the drilling in the wells at the sedimentary section pass through the aquifer layer; so the water is wasted by passing through the other layer underneath. Other wells need casting as water also flows through the other layers above the aquifer bed.

Description of the Wadis

Wadi Marjan (600 km^2) is the main wadi in the terrain that runs north-south and has an 8 stream order following the methods of Scheiddegar (1967). Some branches at the eastern side of the area are the wadis called Abu-Alrahi (350 km^2), Al-Khenigah (400 km^2) and Al-Faydhiyah (200 km^2). Most of the branches at the

western side of Wadi Marjan run along the metamorphic Abt Group having less aquifer permeability than those run in igneous rocks. Due to the deposition of altered metamorphic minerals along the fractures and foliation planes the porosity decreases with depth of the wadis. Generally, 50% of the wadis in the area cut through sedimentary deposits, 30% through igneous bodies and 20% in metamorphic rocks. The drainage density is 1.8 following Horton (1954). The stream tortuousity is 1.5 as defined by Sribnyi (1962). The lithologic log of the middle zone (between Abu-Alrahi and Marjan village) illustrates the thickness of the alluvium (Table 2) that makes a reasonable water reservoir and circulation as it is the main aquifer exploited in the closed basin of Wadi Al-Faydiyah. This wadi continues to inhabited Wadis Marjan and Al-Khenigah which have thicker alluvium deposits and have gorges where several ground dams were built by the M.A.W. to provide

Table 2-a. Lithologic log of the Quaternary deposits in Al-Quwayiyah zone

Depth (m)	Lithology
0-3	Yellowish sand and silt alternating with gypsum, gravel and brown dolmite
4	Fine sand
5	Sand and gravel
6	Shale, sand, gravel, gpysum and brown dolomite and marl
8.5	Brown shale, marl, sand and gravel
10	Fine to coarse sand, gravel and shale
12	Fine gravel, shale and light brown sand
14	Calcrete
19.5	Medium sand and gravel, gypsum, brown limestone, pebbles and calcrete
25	Brown sand, gypsum, coarse gravel, clay, siltstone, calcrete and quartz
28	Highly weathered rocks
32	Fractured rocks
35	Sound rocks (bottom of the section)

Table 2-b. Lithologic log of the upper valley of Wadi Al-Faydhiyah (well No. 1)

Depth (m)	Lithology
0-1.5	Boulders, gravel, pebbles, yellowish silty sand (top of the section)
2.1	Weathered and fractured crystalline rocks and clayey sands
3.5	Highly weathered rocks with indian red colour
4.6	Fractured and fissured metamorphic rocks
5.9	Open fissures (75°) with oxidation, high rate of water absorption
7.1	Weathered granitic rocks with open fissures
8.5	Granitic sands with pebbles
9.8	Fractured unaltered granitic rocks
18.9	Unaltered massive granitic rocks with fractures and fissures
23.0	Unaltered massive sound granite (bottom of the section)

Table 2-c. Lithologic log of the wadi sediments at Wadi Al-Faydhiyah bank

Depth (m)	Lithology
0-0.15	Gravels (bottom of the section)
0.31	Clay
0.38	Fine-medium grained sand
0.42	Clay
0.50	Coarse sand
0.63	Clay
0.70	Medium grained, reddish, sand and gravels
0.84	Very coarse grained reddish sand and gravels
0.97	Pebbly sand
1.1	Clay and clayey sand
1.2	Medium grained, brownish, sand
1.3	Gravels and pebbles with some white sand in places
1.4	Boulders and large gravels
1.5	Breccia
1.6	Gravels
1.7	Clay (top of the section) (ground surface of the wadi)

(The surface is the datum reference)

water for this area for industrial, irrigation and domestic use. These basement alluvial wadis are the best places to search for reasonably good water although limited. Each well in Wadi Al-Faydhiyah alluvium averages 9 L/sec.

Physical and Chemical Properties

Physical Properties

Petrology of the different rocks at this area will be presented in a forthcoming paper. Quartz is subangular with medium sphericity and undulose extinction. Plagioclase (9%) is altered to sericite. The frequencies of the iron oxides are 60%, amphibole 15%, epidote 75%, garnet 10% and zircon 5%.

Fifty soil samples were collected from Al-Quwayiyah wadi deposits (Table 3-a and 3-b). The grain size (M_z) is coarse (0.13) to medium (1.84) with an average of coarse sand (0.98) according to the Wentworth scale (1922). According to Folk's parameters (1965) the sorting (σ_I) is moderate (1.49) to poorly sorted (1.90) with an average of (1.70). The skewness (SK_I) is symmetrical (+0.04) to fine skewed (+0.268) with an average of fine skewed (+0.20). Kurtosis (K_G) studies give a range from very platy kurtic (0.51) to leptokurtic (1.33) with an average of mesokurtic (0.90). Applying this data on Moiola and Weiser's diagram (1968), it

Table 3-a. Stratigraphy of some well beds in the Wadi Al-Faydhiyah area

Material	Well numbers					
	1	2	3	4	5	6
	Thickness in meters					
Surface level	0.4	0.6	1	3	3	3.6
Alluvial deposits	5.6	5.9	6.0	15.8	16.0	11.9
Highly weathered granite	10.0	6.6	3.0	8.0	15.0	11.1
Fissured granite (above the water surface)	6.0	7.9	13.0	9.6	6.0	7.8
Total depth from surface to the water table	22.0	22.8	23.1	27.0	40.0	41.9

Table 3-b. The main different Folk's parameters for samples collected from:
i) Wadi Al-Faydhiyah at the mid of the wadi stream; and
ii) Wadi Abu-AlRahi area (where water samples have been collected)

Type of Parameters	i) Wadi al-Faydhiyah						ii) Wadi Abu-AlRahi					
	1	2	3	4	5	6	7-1-A	7-1-B	7-1-C	7-1-D	7-2-A	7-3-A
Graphic mean $M_z\phi$	1.83	1.84	1.56	1.50	1.10	0.80	0.13	0.33	0.40	1.30	0.23	1.27
Inclusive graphic standard deviation σ_I	1.63	1.59	1.53	1.50	1.50	1.49	1.43	1.49	1.60	1.90	1.44	1.87
Inclusive graphic Skewness SK_I	0.07	0.06	0.04	0.05	0.06	0.04	0.55	0.63	0.68	0.41	0.63	0.40
Graphic kurtosis K_G	0.85	0.90	0.97	1.02	1.02	1.03	1.28	1.06	1.16	0.54	1.33	0.51

(Based on Folk's parameters 1965).

shows a river origin from the wadi blankets that originate from the local crystalline rocks (Fig. 4).

The Khuff Formation has a geophysical resistivity sounding of 20-150, while the Pre-Khuff Formation (fractured and weathered basement rocks) is 20-30 and the basement complex is 200 (ARGAS, 1974 and MAW and BRGM 1982). This may indicate that the Pre-Khuff rocks have good water occurrences related to a steep plunge of the basement complex. The infiltration rate of the Khuff Formation is 12 mm/year, the Jilh Formation is 10 mm/year and 8 mm/year for the Minjur, Saq and the Quaternary deposits.

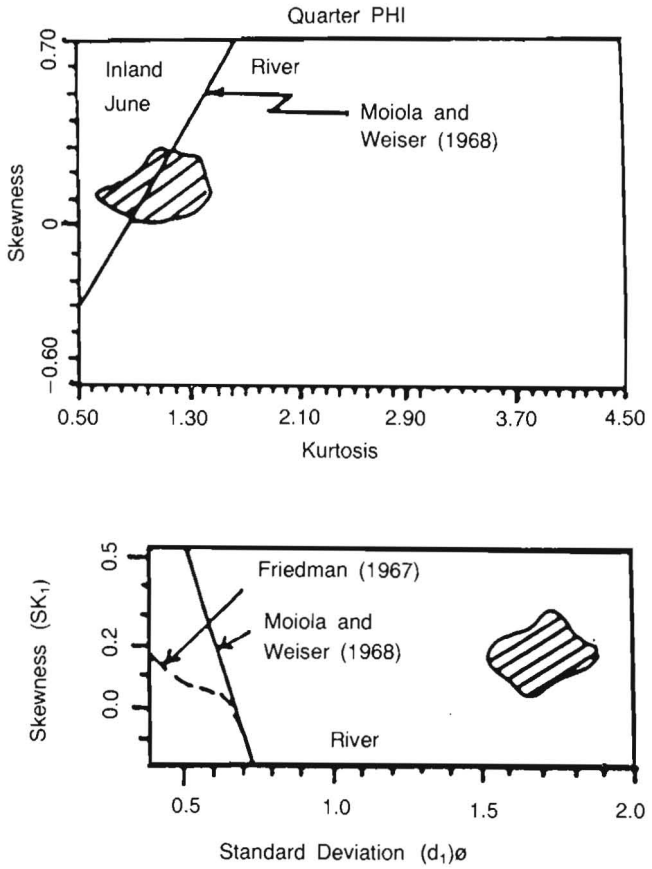


Fig. 4. Maltivariant plot of the mean size vs. inclusive standard deviation of twenty samples from Al-Quwayiyah zone.
(after Moiola and Weiser 1968)

Chemical Properties

The average TiO_2 = 2% and the T.FeO/MgO = 2 for the Abt tholeiitic amphibolite. TiO_2 = 0.8% for the Abt calc-alkaline Group. The alkalinity ratio $K_2O/(K_2O+Na_2O)$ = 0.47-0.54 in the post tectonic granite, 0.16-0.4 for the gneissic granodiorite and 0.27-0.41 for the Muhayrigah calc-alkaline metavolcanic rocks. The Halaban carbonate rocks have Ca/Mg ratio = 2.7-89.0 with an average of 42.0, Ca/Sr ratio = 593, Mn = 0.037-2.20% and Fe = 0.112-2.12%, while the averages of Sr = 741 ppm, Ni = 150 ppm, Cr = 72 ppm, Pb = 59 ppm and Co = 56 ppm.

Twenty alluvium samples have averages of Cu = 40 ppm, Co = 20 ppm, Ni = 10 ppm, Cr = 100 ppm, Mg = 2%, Ca = 8% and Fe = 2%. The P_H value for the soil paste samples is 6.8-7.9 while for the water specimens it is 7.0-8.0 with an average of 7.5. The washed up soil, by rain water, contains 20% clay, 0.5% organic material and Carbon/Nitrogen ratio = 10. A Chi-square test has been applied for the area where the data is plotted on Gumbel probability paper, and control curves were drawn which confirmed each of the data points contained within the control interval.

The absorption ranges from 0 L.V. in the massive unaltered, fine-grained, non-fissured igneous rocks to 26 L.V. in the highly permeable fissured crystalline rocks and it increases to higher values in some parts of the alluvium deposits and sedimentary rocks (MAW and BRGM 1976 and 1982). The evaluation of the groundwater resources and aquifer hydraulic parameters can be determined by any of the analytical methods (*e.g.* Papadopulos and Cooper 1967) assuming a constant pumping discharge and taking into account the groundwater flow in fractured rocks as discussed by Jenkins and Prentice (1982). By these methods, it is possible to find the ability of an aquifer to store and transmit water.

Hydrogeochemistry

The excess of salinity in Al-Quwayiyah area is due to the dissolving gypsum that is directly related to the TDS (*i.e.* TDS is >4 gm/L) and the E_c (TDS = $C.E_c$, where C is a constant factor = 0.5-0.54 as defined by Hem, 1970). The TDS for the Khuff Formation is >7.5 gm/L, for the Sudair Formation is >13.7 gm/L and for the Jilh Formation is 4.4. The average E_c for the Khuff Formation is 4 m mho/cm with an average discharge of 5 L/sec. Mee (1983) recorded the relation between the TDS and the E_c to be:

$$\text{TDS (ppm)} = (850 \times E_c \text{ m mho/cm}) - 200 \text{ at } 25^\circ\text{C}.$$

Both the E_c and the SAR values put the Al-Quwayiyah water samples in a low-medium salinity and alkalinity hazard (C_1-S_2, C_1-S_1, C_2-S_1, C_2-S_2) to the plants (Fig. 5) as defined by Hem (1970) where NaCl is one of the dissolved salts from these sedimentary rocks. The Quaternary, Sudair and Khuff Formations have the highest Sodium-Adsorption-Ratio (SAR), TDS, Na^+, K^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^{--} and E_c and the lowest P_H value and HCO_3^-, while the Ca^{++}/Mg^{++} ratio is 1.2-3.5 (Table 4).

The TDS content in Wadi Al-Faydhiyah = 290 mg/L ranging from 75-550 mg/L in the recharged zone, 100-850 mg/L in the discharged zone at Wadi Al-Khenigah (Table 4). The total hardness of water samples = 0.2-0.4 mg/L and the specific gravity at 20°C is 1.003. The average CO_3^{--}, HCO_3^- and total organic

Table 4. Hydrogeochemical analyses for some water samples from some formations of the Al-Quwayiyah zone

Formations		No. of Samples	Temp. °C	Turbidity N T U	SAR	P_H value	E_c m mhos at 25°C	Ca/Mg	mg/L								
									T D S	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	SO_4^{--}	CO_3H^{-}	NO_3^{-}
Saq*	Mean	15	33.6	9	5.1	7.7	3.5	4.5	2400	270	59.9	402	12.4	688	670	121	80.5
	S.D.			1	4.7	0.7	3.9	–	2590	237	4.8	525	20.4	889	609	60	107
Khuff*	Mean	20	31.2	10	8.6	7.7	10.1	3.5	7500	817	231	1420	20.8	2910	1860	123	35.5
	S.D.			2	1.0	0.4	10.6	–	7340	544	175	2140	20.3	4430	716	64	46.0
Minjur*	Mean	5	29.8	8	3.4	7.9	2.1	3.8	1430	173	45.9	196	20.1	256	480	156	35.8
	S.D.			3	0.6	0.4	0.4	–	264	42	4.7	45	6.1	63	97	82	46.0
Jilh*	Mean	10	30.1	11	4.3	7.8	5.3	1.6	4390	452	279	460	48.1	908	1710	289	2.0
	S.D.			2	0.2	0.3	1.4	–	1607	180	142	111	9.3	460	609	46	1.4
Sudair*	Mean	7	29.1	9	16.7	7.9	17.4	1.2	13750	745	617	2820	110	6400	3840	249	7.3
	S.D.			1	2.5	0.3	1.0	–	373	69	87.2	221	4.7	468	657	33	5.5
Quaternary*		1	25.0	7	8.2	7.5	26.8	2.1	19	1300	625	4830	39.3	8690	3930	51	0.9
Wadi Al-Faydhiyah Quaternary alluvial deposits‡	Well no. 1	3	25.8	N.D.		8.1	0.8	7.1	2250	753	106	950	8.0	660	910	1550	1.0
	Well no. 2	2	25.5	N.D.		8.2	0.9	7.5	1970	906	120	101	8.5	912	950	1660	1.1
	Well no. 3	1	25.6	N.D.		8.3	1.1	8.1	2490	1110	137	1160	8.7	1150	980	1780	1.0
	Well no. 4	2	25.4	N.D.		8.5	1.4	6.7	13.50	1470	218	1750	14.2	1740	990	1800	0.9
	Well no. 5	1	25.2	N.D.		8.3	2.3	8.5	3060	2790	327	2040	14.2	3630	1010	1640	1.1

* See Fig. 1 for formations' localities in the Phanerozoic sedimentary cover. ‡ See Fig. 2 for samples' localities.
N.D. Not determined.

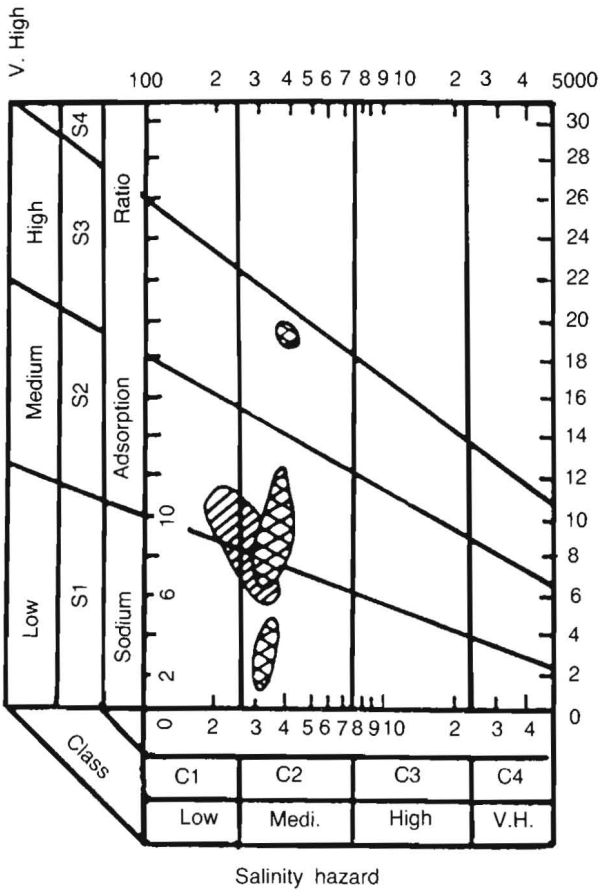


Fig. 5. The salinity hazard vs. SAR diagram for the Al-Quwayiyah zone with comparison with samples from the Wadi Fatimah area.

carbon in this zone is 35 mg/L, 150 mg/L and zero respectively. Na^+, K^+ and Ca^{++} are 20.2 ± 15 mg/L, 7 ± 0.5 mg/L and 59 ± 15 mg/L respectively , S, F and the Residual-Sodium-Carbonate (RSC) are below the detection limit. Cl, SiO_2 and nitrate are 30 ± 20 mg/L, 10.2 ± 2 mg/L and 8 ± 5 mg/L respectively. Mg = 10 ± 5 mg/L, Ba = 0.1 mg/L, Mn = 0.001, Sr = 1.5 mg/L and each of the Cr, Cu, Zn and total and soluble iron are 0.01 mg/L. The sulphate and N-Ammonia are 40 ± 35

mg/L and 0.1 mg/L. Some wells (Nos. 1-5) in Wadi Al-Faydhiyah have nonpotable water as its analyses show CO_2 = 20 m moles/L, O_2 = 0.3, Fe = 0.4, Mn = 0.01, Cl = 13 m moles/L. Biological studies show the existence of Coliform bacteria ranging from 13000 to 27000/cm^3, but no protozoa or any primitive cells were found in this area.

The water chemical analyses of the Wadi Nukhaylan (44° 59′ 55″E, 24° 00′ 00″N) show TDS = 2 gm/L, Mg^{++} and HCO_3^- = 10% each, Cl = 20%, Na + K = 40% and Ca and SO_4 are > 50%. The inferred rainfall isohyet is 100 mm and F = 1.8 mg/L (Cottez *et al.* 1984).

The reduction-oxidation (REDOX) potential (E_h) values of samples from the upstream plateau are −50 to −280 mv becoming positive at the downstream areas where these samples are exposed to the air in the shallow wells. The saturation indices and $Fe(OH)_3$ were calculated by the MAW and BRGM (1982) suggesting the source of iron in the water samples to be the dissolution of pyrite involving the oxidation of sulphide to sulphate which reduce E_h and P_H values according to the equation:

$$2FeS_2\ (s) + 7O_2 + 2H_2O \rightleftharpoons 2Fe^{++} + 4SO_4^{--} + 4H^+$$

Since the area is highly mineralized, the dissolution and redox rate are high and affect the water especially near the old mines, mineralized veins and tectonic zones. Isotope studies were carried out for this area by measuring ^{14}C and $\sigma^{13}C$ where the age of water ranges from recent (evidenced by Tritium tracing) to about 30000 years, and so the Khuff aquifer has an age of 1500-2000 years (MAW and BRGM, 1976 and 1982).

A comparison between the composition of the water samples from Wadi Al-Faydhiyah and the recommended upper limits of the U.S.N.A.S. and N.A.E. for irrigation purposes (1972) indicates that these samples are acceptable. However, the saline water and carbonate rocks and fragments from the sedimentary formations will destroy the land by increasing the salinity of the soil in the future (*e.g.* 30-50 years). The farms, therefore, should be washed periodically (≅ 5−7 years) to leach the salts.

Conclusion

Al-Quwayiyah area consists of metamorphic, igneous and sedimentary rocks of several ages; bisected by wadis covered by alluvial deposits, with a river origin indicating a good permeability factor for the aquifer. Sparse rainfall occurs and most is reserved in the alluvial deposits, fissures, cracks, and weathered rocks although evapotranspiration and evaporation is high due to the arid climate. The

saturation indices suggest that the main source of iron in the water is the dissolution of pyrite with the oxidation of sulphide to sulphate. Since water flows slowly in the sedimentary section, it increases its salinity by dissolving NaCl and gypsum illustrating that the soil and the groundwater quality are deteriorating each year and neither will be suitable for agricultural purposes in the future. Periodic leaching of the land by farmers is needed to reduce deterioration. Additional fertilizers to replace the leached nutrients, without affecting the E_c or the P_H values of the soil, are necessary. In the igneous rock zone, the E_c is reduced giving a better quality of water than at the sedimentary section, so the wadi alluvium is the best place to locate water.

The shale below the Khuff Formation has low resistivity (E_c = 1.36 m mho/cm) with strong gamma activity (MAW and BRGM, 1982) which may indicate that this layer contains little water. Due to the high salinity, the Sudair Formation underground water (E_c = 17 m mhos/cm) should be avoided for use (*op. cit.*). Water in the Jilh and the Saq Formations becomes more saline than the Khuff Formation as E_c = 4 m mho/cm (*ibid.*); so, the underground water has limited potential. Test wells were dug to the Saq sandstone aquifer and produced a good quality water up to 40 L/sec with E_c <4 m mhos/cm making it probably the best water type in this sedimentary section (*op. cit.*).

Recommendations

1. Different aquifers should be found by using different exploration methods (*e.g.* Side Looking Airborne Radar).
2. More underground and surface dams are needed.
3. Full regular maintenance of the water pipes, wells and dams.
4. Water should be treated for pollution, chemical materials and excessive salt and sand.
5. Soils should be washed and nutrients replaced.
6. Priority rotation of pumping for irrigation is necessary to avoid draining the aquifers and destroying the wells.
7. Trickling methods should be used for irrigation.
8. Effective drilling and casting should be performed to protect the water flow.

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جيولوجية وهيدروجيوكيميائية منطقة القويعية المملكة العربية السعودية

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أجريت دراسات جيولوجية وهيدروجيوكيميائية على منطقة بحدود ٦٠ كم^2 في القويعية والتي تتكون من صخور نارية ومتحولة، حيث تحتوى المجموعة الأولى على صخور جوفية متداخلة وسطحية ذات أعمار مختلفة وتراكيب متباينة تتدرج من الكلس القلوي إلى القلوي الشديد، بينما تحتوي المجموعة الثانية والتي تتكون من الصخور المتحولة المتورقة وغير المتورقة ذات أصل ناري ورسوبي ومرت على الأقل بأربع مراحل تحولية، كما يتجه مضرب هذه الصخور إلى اتجاه الشمال الجنوب بينما يأخذ ميل التورق من اتجاه الشرق إلى الوضع العمودي. وتوجد في المنطقة عدة تراكيب جيولوجية رئيسة وثانوية، كما توجد في المنطقة بعض رسوبيات حقب الحياة القديمة.

توجد في وادي الفيضية بالقويعية عشرة آبار ضحلة حفرت يدويا وتتراوح أعماقها ما بين عشرين وأربعين مترا تحت سطح الأرض. وكمية مياهها الجوفية جيدة على الرغم من أن نوعية هذه المياه تتغير في أسفل الوادي بسبب الضخ الشديد من هذه الآبار وبالذات خلال فصول الجفاف حيث تصبح المياه أكثر معدنية من أعلى الوادي.

كما درست الجيولوجية الإقليمية ومقاطع صخرية ومقاطع لآبار ضحلة أخرى في مناطق مختلفة لمنطقة الدراسة ومن المناطق المجاورة للقويعية وذلك لغرض المقارنة.