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Electrical Resistivity, Geochemical and Hydrogeological Properties of Wadi Deposits, Western Saudi Arabia

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ABSTRACT. Six main wadi systems within the Arabian Shield, filled with a heterogeneous, strongly anisotropic assemblage of alluvial deposits, were investigated with Schlumberger resistivity soundings. Aquifer electric resistivities were determined for 39 vertical electrical soundings at these wadies where pumping and recovery tests were also performed. The hydrogeophysical properties of the wadi deposit exhibit a wide range in all its individual characters. The hydraulic conductivity varies from 3 to 166 m/day, the aquifer resistivity is between 1.4 and 176Ω m, the transmissivity values are 40-5800 m^2/day, the apparent formation factor is 0.17-26, and the electrical conductivity of the groundwater varies from 610 to 19000 μ S/cm. The major ionic composition shows a wide variation in the hydrochemical properties of the groundwater of the wadi deposits. The results of this study also indicate that electric resistivities determined from soundings and aquifer properties have a relation of the type: $Y = aX^b$.

The comparison of the results of the present study with previous published work (largely from temperate zones) has shown that wadi deposits have different hydrogeological properties.

Introduction

The Arabian Shield lies within the North African-Eurasia dry province, a typical arid zone that extends from North Africa eastwards to the arid region of Afghanistan and Pakistan. The weather in the Arabian Shield is characterized by a transitional climatic zone between the monsoon and the Mediterranean region. The climate in the area is greatly modified by the presence of the Red Sea, the mountainous nature of the Shield towards the escarpment, and the basaltic lava flows or Harrat in the east. Orographic rainfall takes palce in winter (December-January), spring (April-May) and in fall (October-November). Generally, the rain events are scarce, irregular, and the rainy days are very rare and scanty. Rainfall is generally characterized by its high annual and spatial variability though much of high intensity, short duration rains are able to produce flash floods. Figure (1) shows the general distribution of rainfall within the study area.

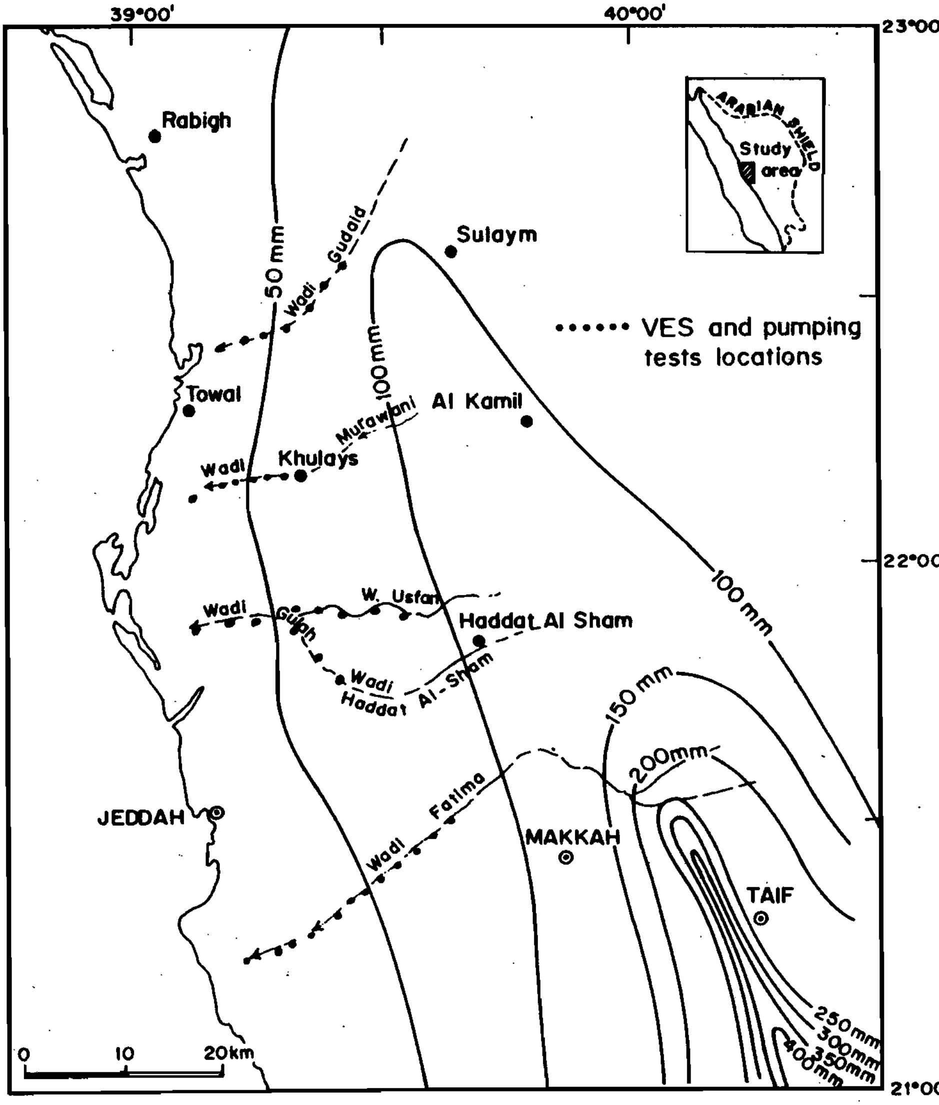

FIG. 1. Location of major wadies and average rainfall ditribution over the study area, showing the locations of pumping test and VES in the study area.

The main drainage system in the study area comprises the wadies of Gudaid, Murawani, Usfan, Haddat Alsham, Gulah and Fatima. All these wadies drain towards the Red Sea. Wadi Murawani and Wadi Gudaid are important sources for Jeddah water supply system. A number of wells were drilled in these two wadies and water is pumped directly into the supply system after being chlorinated. Wadi Fatima has always been an important source for water for both Makkah and Jeddah cities, especially during pilgrimage (Haj). The other above mentioned wadies are the only sources for water on which local rural population depend completely for their various needs. These including drinking, general household and agricultural purposes.

The primary objectives of this study is to outline and define the electrical resistivity, geochemical and hydrogeological properties of the alluvial deposits in the courses of the wadies that drain the study area. These deposits are the main water-bearing horizons in the Arabian Shield. Relationships between the electrical, geochemical and hydrogeological characteristics of these deposits are also evaluated.

Geology of the Study Area

Various aspects of geology of the study area have been studied by many previous workers. However, the most recent works that we refer to are those of Ramsay (1986), and Moore and Al-Rehaili (1989). A modified map from both references is illustrated in Fig. 2. According to these works, the study area is covered by Precambrian and Cambrian basaltic to rhyolitic volcanic and pyroclastic rocks and epiclastics of primitive island-arc type that have been deformed and metamorphosed. In some places, multiplied and injected by intrusive bodies of diverse ages and composition.

Tertiary rocks are present in many parts of the study area forming in some places thick sequences of clastic sediments. The clastic sedimentary succession is believed to have been deposited in fault bounded troughs. The succession consists of sandstones, limestones, siltstones, gravels, clays and shales of Eocene-Oligocene age. Tertiary sediments are covered in most of the study area by Tertiary-Quaternary basaltic flows (Harrat Rahat).

Pleistocene-to-Holocene deposits are widely spread, especially along the coastal plain. It includes raised terraces, reef limestone, Quaternary sand, alluvial deposits, gravels, and Recent evaporitic deposits.

The most outstanding structural features in the study area are the NE trending overthrusts which were believed to belong to the Precambrian E-W compressionals. Numerous other trends were formed as a consequence of this compression. Tertiary tectonics, in addition, brought about the NNW and EW faulting as well as the NNW trending flexure with its long fracture set as the source of the Tertiary to Recent plateau basaltic lava flows.

The main wadies in the study area follow in general the main fracture system, *i.e.*, they run perpendicular to the orientation of the Red Sea. The drainage system is generally of a rectilinear nature with subordinate orientation parallel to the Red Sea. A typical main wadi channel is characterized by a width that ranges from about 100 m to 1000 m or more, the average thickness of the water-bearing unit varies from about 3 m in the upstream part to about 30 m or more in the downstream. The alluvial deposits making up the aquifers are a heterogeneous assemblage of unconsolidated blocks, cobbles, gravels, sand, and silt. The coarser units predominate in the upstream areas and grain size decreases in the downstream direction, towards the coastal plain. Water levels vary from about 1100 m above mean sea level (a.m.s.l) in the head waters to about 5 m in the coastal plain. It is worth mentioning that most of the surface runoff of these wadies does not reach the Red Sea. The wadies spread and disappear in the coastal plain (Fig. 1).

Methodology

a) Geophysical investigations

Electrical resistivity methods are frequently used as investigation tools in water exploration (Zohdy *et al.*, 1974) to obtain, quickly and economically, details about the location, depth, and resistivity of the subsurface layers. Estimation of hydraulic parameters such as hydaulic conductivity (*K*) and transmissivity (*T*), by surface electrical resistivity measurements has been studied by many researchers. Of these we mention Zohdy *et al.* (1974), Kelly (1977), Worthington (1977), Kosinski and Kelly (1981), Niwas and Singhal (1981), Urich (1981), Ponzini *et al.* (1984), Kelly and Frohlich (1985), Mazac *et al.* (1985), Egboka and Uma (1986), Hussein and Ibrahim (1990), and Hussein *et al.* (1994).

In this study Schlumberger vertical electrical sounding measurements were conducted using a portable ABEM SAS-300 instrument with booster transmitter capable of producing a maximum of 500 volt D.C. voltage, large enough to ensure a penetration depth of about 100 m for a separation of 300 m between the current electrodes. The soundings were made at sites where pumping test data were collected. The measurements were made in a direction parallel to the axes of the wadies along the strike direction. These measurements are then converted to apparent resistivity values by scaling them by a geometrical factor that depends on the type of array as well as the spacing between the electrodes. The results were then plotted on a bi-logarithmic paper, and an appropriate method of interpretation was then used to compute the true resistivities and thickness of the layers. These values were subsequently used to estimate the aquifer transmissivity and hydraulic conductivity (Bear, 1972). The water resistivity values were then corrected to field temperature (Keller and Frischknecht, 1966). The apparent formation factor (*AFF*), which is a modification of the original formation factor defined by Archie (1942), includes the effect of surface conductance and is obtained by dividing the measured resistivity of the saturated thickness by the porewater resistivity corrected to field temperatures (Croft, 1971).

b) Hydrogeological investigations

The hydrogeological investigations carried out in the study area aimed to determine both the hydraulic and the hydrochemical properties of the aquifers. The hydraulic properties were determined through both laboratory and field measurements. The laboratory measurements included the determination of hydraulic conductivity with the help of constant-head permeameter measurements and through grain size analysis. The transmissivity and hydraulic conductivity were also determined in the field with the help of

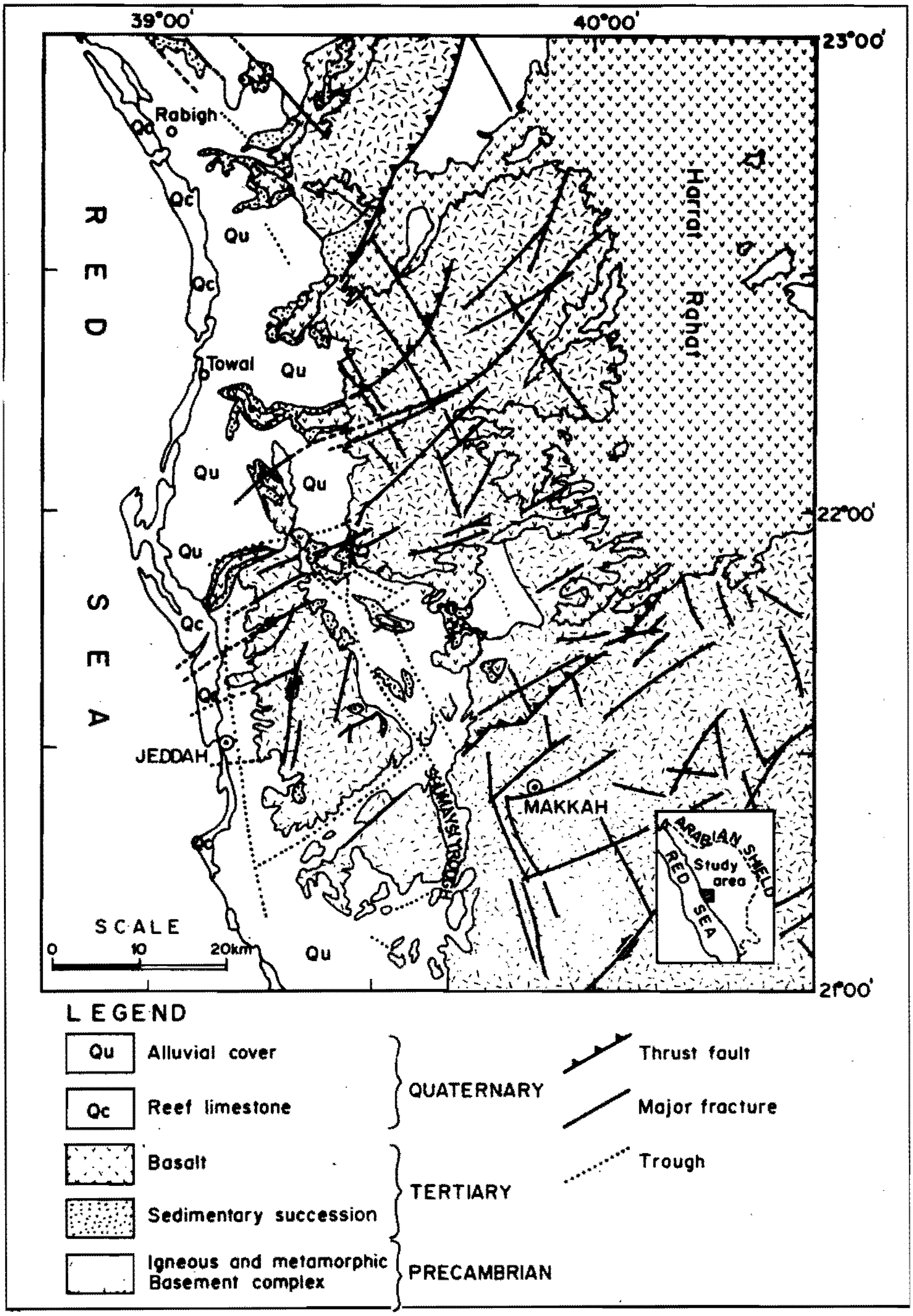

FIG. 2. General geology map of the study area (modified after Ramsay (1986) and Moore and Al-Rehaili (1989)).

controlled pumping and recovery tests for a fairly long time. The hydrochemical characteristics dealt with in this study are the electrical conductivity (*EC*), pH, HCO_3^-, Cl^-, SO_4^{--}, Na^+, Ca^{++}, Mg^{++}, and K^+ contents in collected groundwater samples. Table 1 summarizes the methodology and analytical techniques adopted in this study. The degree of accuracy for each determination is also indicated. The accuracy of chemical analysis was evaluated through the summation of the total anions and the total cations in addition to the calculation of the ionic balance. The data were collected from six wadies within the Arabian Shield, namely: Gulah, Usfan, Gudaid, Murawani, Fatima and Haddat Alsham.

TABLE 1. Methods and Analytical Techniques adopted in this study.

Item	Method and Analytical technique	Accuracy
ρ	VES interpretations	5%
ρ_ω	(Field) Direct measurements on water samples	5%
AFF	Computations from ρ and ρ_ω	5%
T	(Field) controlled pumping and recovery tests	5%
K	(Lab.) measurements (apparatus plus seive analysis)	10%
EC	(Field) *EC* meter, WTW D812 WEILHEIM type	0.05%
pH	(Field) Digital pH meter, Knick Portamess 651-2 type	5.0%
Na^{++}	(Lab.) Flame photometer CORNING M 410	0.1 ppm
K^+	(Lab.) Flame photometer CORNING M 410	0.1 ppm
Ca^{++}	(Lab.) Volumetric method using EDTA	0.1 ppm
Mg^{++}	(Lab.) Volumetric method using EDTA	0.1 ppm
Cl^-	(Lab.) Titration against $AgNO_3$	0.5 ppm
HCO_3^-	(Lab.) Titration with sulphuric acid	0.5 ppm
CO_3^{--}	(Lab.) Titration with dilute hydrochloric acid	0.5 ppm
SO_4^{--}	(Lab.) Turbidimetric method using Barium Chloride	0.5 ppm

ρ = Aquifer resistivity, ρ_ω = Porewater resistivity, *AFF* = Apparent formation factor,
T = Transmissivity, *K* = Hydraulic conductivity, *EC* = Electrical conductivity.

Results and Discussion

Aquifer resistivities were determined in the study area from the results of the Schlumberger's electrical sounding measurements. A total of 46 soundings were made. Only 39 of them, at pumping test sites, were interpreted and analyzed. (see Fig. 1 for the locations of the VESs and the pumping tests). Interpretations were initially made by curve matching (Compagnie Generale de Geophysique, 1955). The final interpretation was made by using a one dimensional inversion computer program (GRIVEL). The automatic fitting was accomplished by the Dar Zarrouk algorithm. An accuracy of fit of 5% was achieved for most of the sounding curves, which was considered satisfactory (Fig. 3).

The field sounding curves within the study area were a four layer type curve resulted from a four layer geoelectric section consisting of a top soil composed of dry alluvium and sand having a resistivity ranging between 170 to 250 ohm·m. This layer is under-

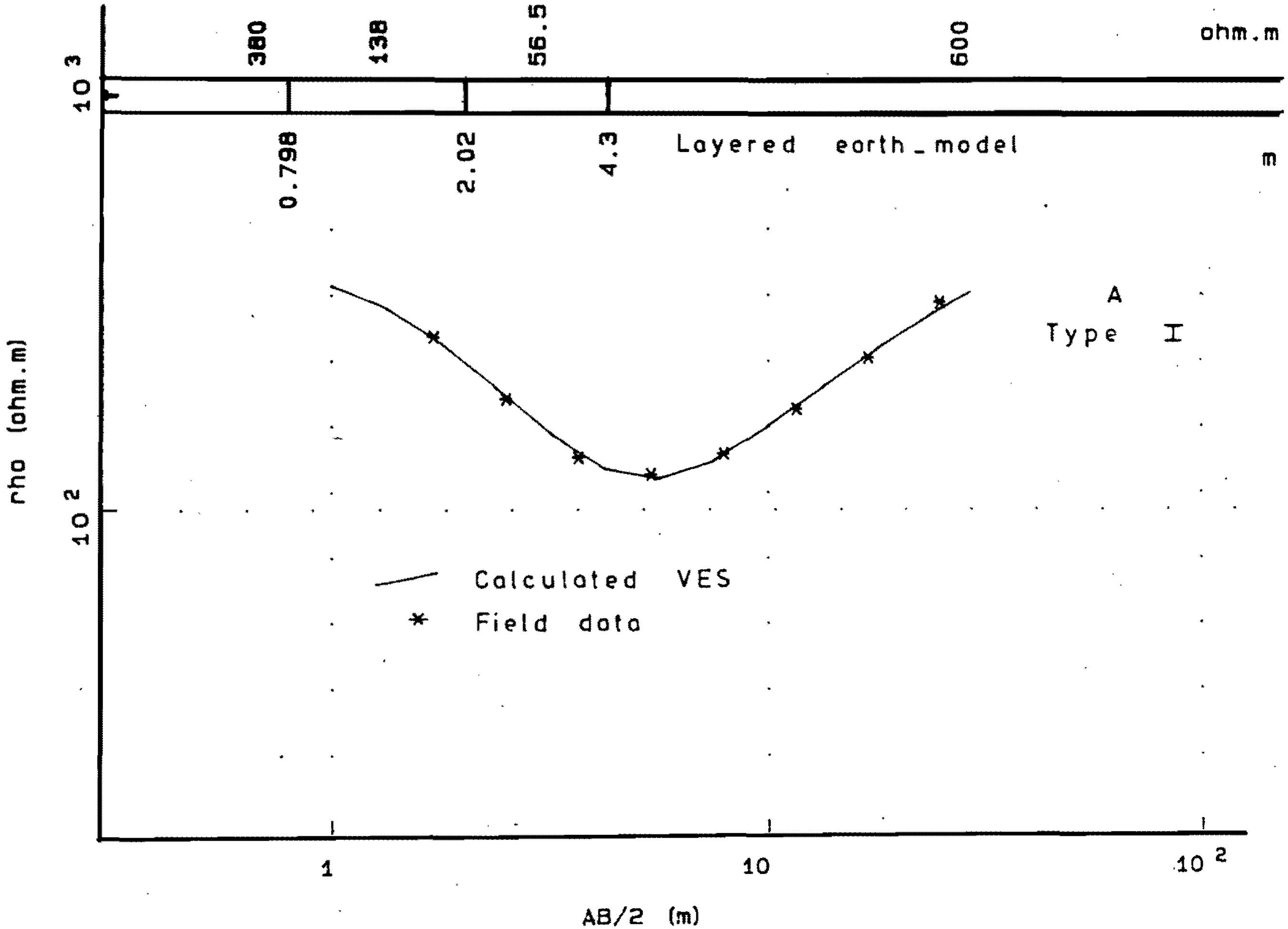

FIG. 3. A representative four-layer resistivity curve in the study area with its possible geological interpretation.

lain by a layer of dry sands and gravels with a resistivity between 110 to 900 ohm·m and represents the unsaturated aquifer. The saturated aquifer consists of wet gravel and sand or probably clays, with a resistivity between 10 to 60 ohm·m depending on the quality of the contained water. The bedrock is represented by fresh granitic rocks with resistivity greater than 500 ohm·m and a depth to its top ranging between 40-60 m. The depth to the water table is 8-10 m deep.

Table 2 summarizes the hydrogeophysical parameters of the investigated wadies, while the average values of these parameters are indicated in Table 3. The transmissivity of the wadi deposits varies from 42 to 5813 m^2/day, the saturated thickness is in the range of 2.3-50 m, the hydraulic conductivity is about 3-166 m/day, the aquifer resistivity is between 1.4 to 176 m, the apparent formation factor (*AFF*) varies from 0.17-25.62, the electrical conductivity (*EC*) ranges from 610 to 19000 μ S/cm and the pore-water resistivity varies from 0.15 to 16.4 ohm·m. The total dissolved solids (*TDS*) varies from 340 to 9677 ppm. The major ionic composition of the water is as follows: Ca^{++} is between 30 and 288 ppm, Mg^{++} varies from 7 to 224 ppm, Na^{+} ranges from 46 to 871 ppm, K^{+} is between 1 and 11 ppm, HCO_3^{-} varies from 4 to 183 ppm, CO_3^{--} between 2 to 24 ppm, SO_4^{--} between 70 and 1953 ppm, Cl^{-} varies from 130-1045 ppm and sodium adsorption ratio (*SAR*) between 1.46 to 19.28.

A correlation matrix was generated for different pairs of the 11 parameters indicated in Table 3 using the Statgraph Package. The data were fitted to a linear regression model utilizing least square minimization. The linearization was achieved by logarithmic transformation and the fitting equation was of the type:

$$Y = a X^b$$

where

b : Represents the slope of the regression line,
log a : Is the intercept.

The above equation was chosen from a number of models including the linear model $y = bx + a$, based on the judgment and experience of the authors. Other factors for favoring this model are: The wide range of the original data, and the relatively higher correlation factors as compared with the results of the linear model. The correlation matrix of Table 4 shows high correlation among 14 different pairs, 8 of which will be considered for further investigation based merely on the authors judgment and experience in the study area.

Figures 4-10 depict the relations between Na^{+} and Cl^{-}, Ca^{++} and Cl^{-}, *TDS* and SO_4^{--}, *EC* and SO_4^{--}, *TDS* and Ca^{++}, *TDS* and Cl^{-}, and *TDS* and Na^{+}, respectively. It is important, however, to mention that the relations are only reliable within the investigated ranges. The relations are strong and linear (see Table 3). This pattern can be explained by the high rates of evaporation and evapotranspiration that dominate the study area. Together with the low rainfall, these high rates of evaporation lead to the concentration of salts in the soil and when runoff occurs it leaches the soil. The chemical reactions that take place are simple dissolution of salts and mixing (Eriksson, 1985).

TABLE 2. Summary of the hydrogeophysical parameters of the investigated wadies.

	T m/d	*K* m/d	ρ ohm·m	*AFF*	*EC*	ρ_{ω} ohm·m	*TDS*	Calcium	Sodium	Sulphate	Chloride
Wadi Gudaid	259	64.75	10.8	1	5000	1	3538	288	280	868	828
	173	27.46	30.3	1	2400	1	1698	97	198	353	519
	59	9.37	32	1	2100	1	1486	112	194	449	421
	331	42.44	42.2	1	1250	1	884	60	98	266	249
	2700	465.52	20.2	1	4000	1	2830	225	234	618	1032
	173	29.83	30.3	1	2100	1	1486	152	102	296	437
	1380	600	22.9	1	3000	1	2120	199	176	459	818
Wadi Marawani	132	10.15	61	9.76	1600	6.25	1200	107.2	166.9	195.7	374.8
	325	10.83	121	11.49	950	10.53	713	64.3	89	88.3	159
	730	28.07	70	4.55	650	15.4	437	35.7	63.1	70	138
	2606	118.4	28	2.52	900	11.11	675	67.9	122.4	74.8	246.4
	2074	103.7	176	16.71	950	10.53	713	71.5	126.1	123.7	253.3
	5813	166.08	69	5.18	750	13.33	975	57.2	144.7	134	208
	1307	36.31	115	14.94	1300	7.7	600	42.9	81.6	74.3	135.3
Wadi Usfan	78	15.57	15	1.7	1140	8.8	652	62	150	247	158
	282	21.72	2.1	1	4800	2.1	2658	148	680	756	957
	116	7.72	2.1	8.09	4750	2.1	2869	156	871	311	1459
	27	7.08	2	5.4	4900	2	2987	214	803	424	1449
Wadi Haddat Al Sham	283	17.15	29	1.77	610	16.4	340	42	46	82	130
	466	21.17	1.7	0.17	990	10.1	581	49	110	142	223
	129	5.6	27	2.84	1050	9.5	630	66	135	171	194
Wadi Fatima	78	14.18	80	6.5	810	12.3	464	30	102	158	130
	3390	67.8	5.8	0.54	935	10.7	542	49	92	182	168
	2800	80	49	5.38	1100	9.1	799	129	85	293	234
	120	26.67	83.3	10.41	1250	8	775	97	100	269	242
	3800	152	18	2.37	1505	6.6	915	74	172	336	261
	1050	87.5	34	4.1	1200	8.3	488	66	67	116	196
	30	12	15.14	6.06	4000	2.5	2406	259	346	775	857
	211	4.4	25	13.89	5550	1.8	3697	323	728	1031	1434
	200	5	19	14.62	7700	1.3	5068	437	1027	1364	1993
	200	5	33.3	25.62	8000	1.3	5458	479	1188	1953	1676
	83	12.77	9	18	19000	0.5	9677	886	2430	1074	5077
	60	5	5	2.27	4500	2.2	2552	236	590	588	1062
	31	3	4.3	2.69	6300	1.6	4656	521	890	1919	1136
	3800	40	1.4	0.45	3250	3.1	1351	175	160	755	168
Wadi Gulah	149	4.8	2.1	0.36	1690	5.9	1039	70	270	412	243
	159	5.13	7	1.84	2625	3.8	1647	74	400	629	456
	42	5.63	7	2.41	3400	2.9	1878	156	344	556	681
	112	6.23	2	1.05	5250	1.9	3227	175	728	1179	969

TABLE 3. Summary of the electrical, geochemical and hydrogeological properties of the investigated wadies, (averages).

	Wadi Gulah (4)			Wadi Usfan (4)			Wadi Gudaid (7)			Wadi Murawani (7)			Wadi Fatima (14)			Haddat Alsham (3)		
Variable	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average
T (m^2/d)	42	159	115.5	27	282	125.75	59.0	2700	725	132	5813	1855.29	30	3800	1132.36	129	466	292.67
b (m)	7.5	31	21.87	3.8	15	9.2	2.3	7.8	5.46	13	36	26.0	2.5	50	22.64	16.5	23	20.50
K (m/d)	4.8	6.23	5.45	7.08	21.72	13.02	9.37	600	177.05	10.15	166.08	67.65	3	152	36.81	5.6	21.17	14.64
ρ (Ω m)	2.0	7.0	4.52	2.0	15.0	5.3	10.8	42.2	26.96	28.0	176.0	91.43	1.4	83.3	27.30	1.7	29	19.23
AFF	0.36	2.41	1.44	1	8.09	4.05	–	–	–	2.52	16.71	9.31	0.45	25.62	8.06	0.17	2.84	1.59
EC (μ S/cm)	1690	5250	3012.50	1140	4900	3897.5	1250	5000	2835.71	650	1600	1014.3	810	19000	4650	610	1050	883.33
ρ_{ω} (Ω m)	1.9	5.9	3.62	2	8.8	3.75	–	–	–	6.25	15.4	10.70	0.5	12.3	4.95	9.5	16.4	12.00
TDS (ppm)	1039	3227	1947.70	652	2987	2291.5	884	3538	2006	437	1200	759	464	9677	2774.86	340	630	517
Ca^{++} (ppm)	70	175	118.70	62	214	145.0	60	288	161.86	35.7	107.2	63.81	30	886	268.64	42	66	52.33
Mg^{++} (ppm)	9	145	80.5	7	79	43.75	33	130	68.57	16.9	70.8	32.43	18	224	91.36	7	30	19.0
Na^{+} (ppm)	270	728	435.5	150	871	626	98	280	183.14	63.1	166.9	113.4	67	2430	569.79	46	135	97.0
K^{+} (ppm)	1	5	2.5	1	4	2.5	3	11	6.86	4.2	6.6	5.06	2	12	6.07	2	5	3
HCO_3^{-} (ppm)	18	30	23.0	14	29	25	73	183	137.0	117.1	251.8	195.34	4	88	16.93	9	31	19.67
CO_3^{--} (ppm)	3	9	6.25	8	12	9.5	2	6	3.14	–	–	–	–	–	–	6	24	12.0
SO_4^{--} (ppm)	412	1179	694.00	247	756	434.5	266	868	477.71	70	195.7	108.69	116	1953	772.36	82	171	131.67
Cl^{-} (ppm)	243	969	587.3	158	1459	1005.75	249	1032	614.85	135.3	374.8	108.69	130	5077	1045.29	130	223	182.33
SAR	5.21	9.86	7.86	4.81	16.61	11.31	–	–	–	2.1	3.9	3.08	1.74	19.28	6.52	1.46	3.44	2.65

T = Transmissivity, b = Aquifer thickness, K = Hydraulic conductivity, ρ = Aquifer resistivity, AFF = Apparent formation factor,
EC = Electrical conductivity, ρ_{ω} = Pore water resistivity, SAR = Sodium absorption ratio. (7) Number of samples.

TABLE 4. Correlation Coefficient Matrix.

	T	K	ρ	AFF	EC	ρ_w	TDS	Ca^{++}	Na^+	SO_4	Cl^-
T	1.00	0.840	0.157	–0.146	–0.271	0.336	–0.281	–0.236	–0.302	–0.255	–0.266
K		1.00	0.030	–0.147	–0.093	0.362	–0.586	–0.046	–0.201	–0.116	–0.050
ρ			1.00	–0.493	–0.358	0.448	–0.361	–0.313	–0.343	–0.404	–0.311
AFF				1.00	0.443	–0.269	0.463	0.477	0.488	0.322	0.474
EC					1.00	–0.999	0.981	0.952	0.966	0.893	0.979
ρ_w						1.00	–0.668	–0.616	–0.699	–0.704	–0.585
TDS							1.00	0.942	0.926	0.891	0.961
Ca^{++}								1.00	0.904	0.787	0.908
Na^+									1.00	0.687	0.919
SO_4^{--}										1.00	0.583
Cl^-											1.00

Explanations :
T = Transmissivity, *K* = Permeability, ρ = Aquifer resistivity, *AFF* = Apparent formation factor,
EC = Electrical conductivity, ρ_w = Water resistivity, *TDS* = Total dissolved solids, Ca^{++} = Calcium,
Na^+ = Sodium, SO_4^{--} = Sulphat and Cl^- = Chloride.

Figure 11 shows a direct relation between transmissivity and hydraulic conductivity. This is understood in cases where the saturated thickness does not vary, *i.e.*, almost constant (Bouwer, 1978). In the present study the correlation between *AFF* and *K* was not considered because of the low correlation factor (– 0.147). This week relation can be explained by the great difference in grain size from the upstream to the downstream areas of the wadies, which ultimately resulting in a noticeable variation in porosity.

The relations involving the correlation of apparent formation factor and hydraulic conductivity had been investigated by many researchers. Croft (1971) had established an empirical positive relationship between *AFF* and *K* for a constant porosity of 41.5%. Kosinski and Kelly (1981), in a similar study for a glacial outwash aquifer in Rhode Island, observed a relationship between the two parameters which is opposite to what had been reported by Croft and other researchers. They attributed that, in part, to the high resistivity of the ground water. Kelly and Frohlich (1985) presented data from Rhode Island showing a direct relationship between the two parameters. In their study, they considered a variable porosity. Urish (1981), in his study emphasized the role played by surface conductance at small grain size and high porewater resistivities. His relationship was of the type:

$$Y = aX + b,$$

where a is the slope and b is the intercept.

The results of the present study and the relationships obtained ($Y = aX^b$) are specific to wadi deposits in aird regions, especially under the aforementioned geological environment. Other models including the linear model suggested by Urish (1981) among other models were tested with the data but with some experience and judgment we believed that the logarithmic model adequately represents a best fit.

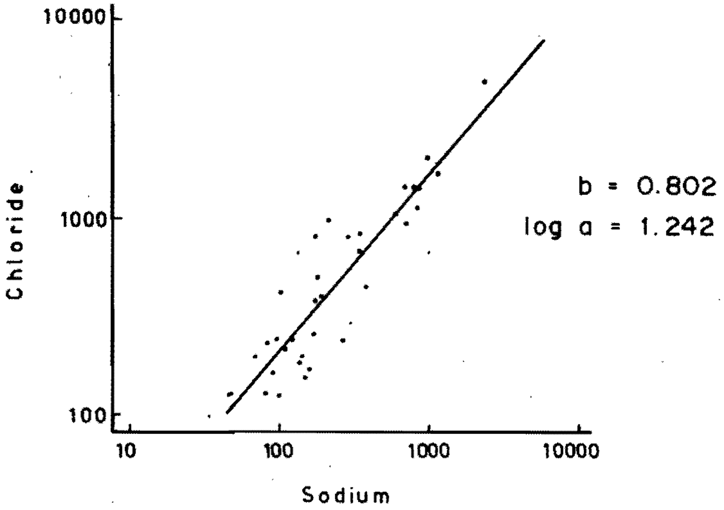

FIG. 4. Plot of Na^{++} versus Cl^{-}.

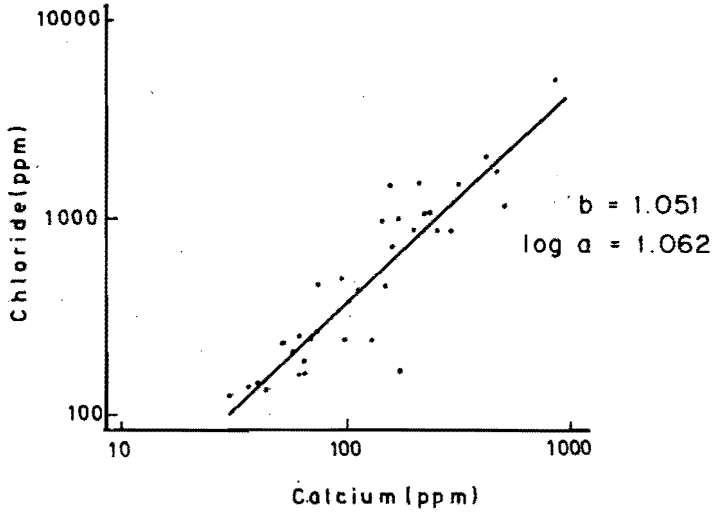

FIG. 5. Plot of Ca^{++} versus Cl^{-}.

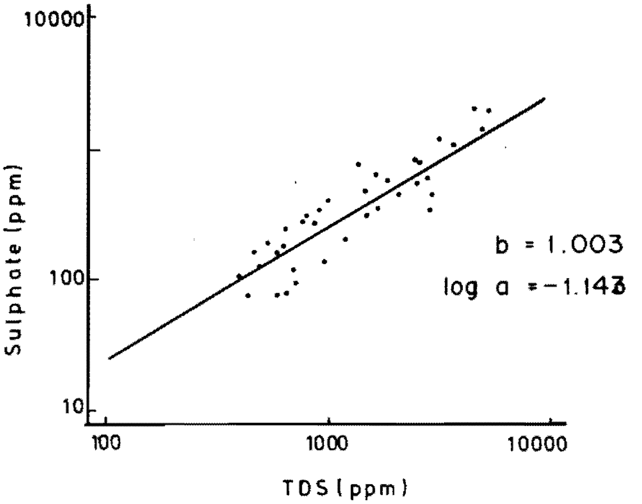

FIG. 6. Plot of *TDS* versus SO_4^{--}.

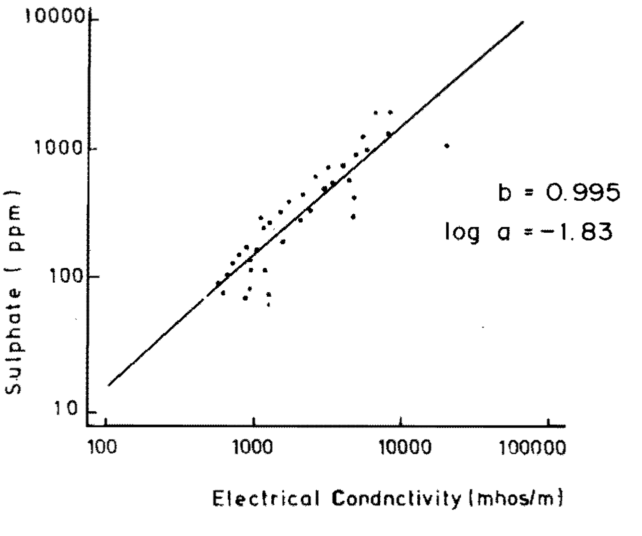

FIG. 7. Plot of *EC* versus SO_4^{--}.

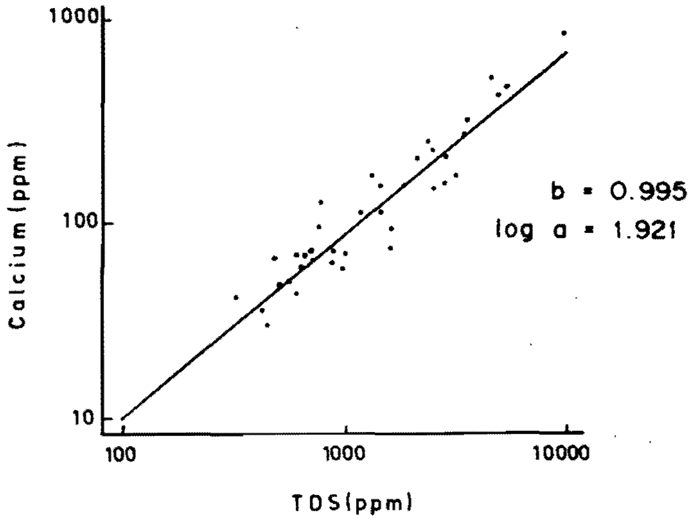

FIG. 8. Plot of *TDS* versus Ca^{++}.

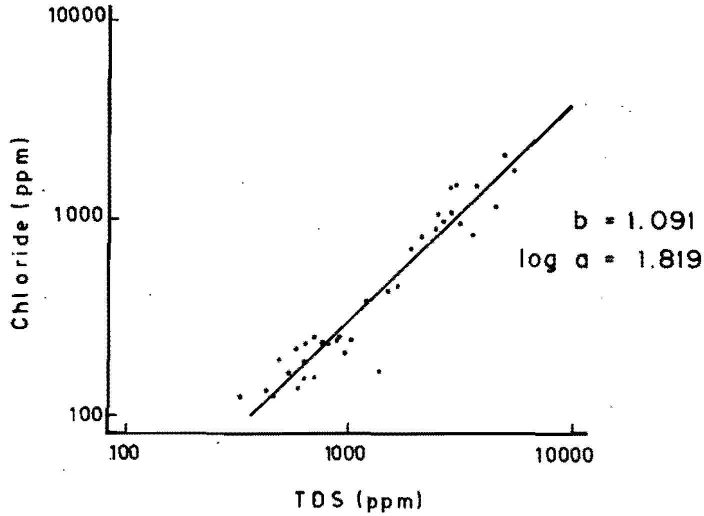

FIG. 9. Plot of *TDS* versus Cl^{-}.

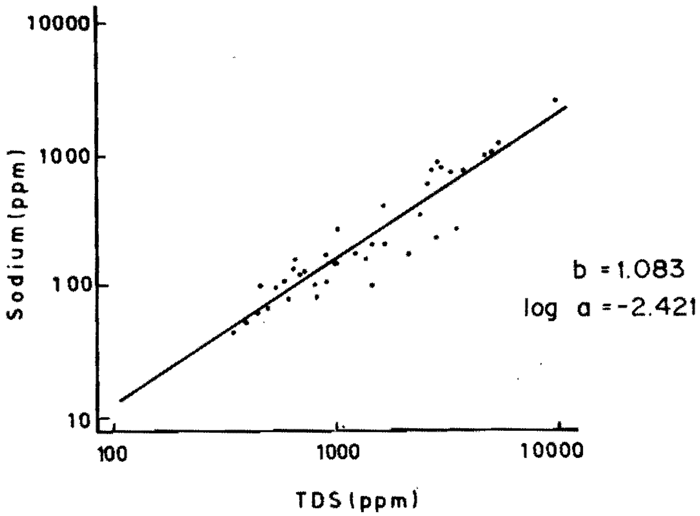

FIG. 10. Plot of *TDS* versus Na^+.

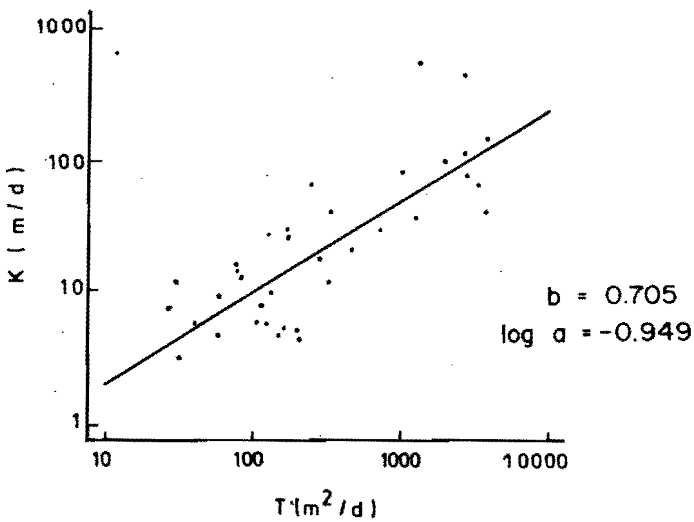

FIG. 11. Plot of transmissivity (m^2/d) versus hydraulic conductivity (m/day).

Conclusion

The aluvial deposits of the main wadi systems in the Arabian Shield are a heterogeneous, strongly anisotropic assemblage of detrital sediments mainly gravels and sands. These deposits are characterized by a wide range of hydrogeophysical properties. The average hydraulic conductivity is 52.43 m/day, the average aquifer resistivity is about 29 ohm·m, the average apparent formation factor is 4.89, the average electrical conductivity is of the order of 2715.56 S/cm and the average total dissolved solids is 1716 ppm. The major ion concentrations averages are: Ca^{++} is about 135 ppm, Mg^{++} is 56 ppm, Na^{+} is 337 ppm, K^{+} is 4.3 ppm, HCO_3^{-} is 53 ppm, CO_3^{--} is 8 ppm, SO_4^{--} is 403 ppm and Cl^{-} is about 607 ppm. The sodium absorption ratio varies from 1.46 to 19.28.

The relations between these properties gave strong linear correlation when fitted to a linear regression model of the type $Y = a\,X^b$. It should be mentioned that the above stated relationships are valid in areas under similar climatic, geomorphological and geological conditions of wadi deposits and with similar water chemistry.

References

Archie, G.E. (1942) *The electrical resistivity as an aid in determining some reservoir characteristics*, Petroleum Technology, Technical Report 1422, Amer. Instit. of Mining and Metallurgical Engineering.

Bear, T. (1972) *Dynamics of Fluid in Porous Media*, Elsevier, New York, 764 p.

Bouwer, H. (1978) *Groundwater Hydrology*, McGraw-Hill, New York, 480 p.

Compagnie Generale de Geophysique, (1955) *Abaques de Sondage electrique (Master curves), Geophysical Prospecting*, **3,** Suppl. no. 3. Amesterdam.

Croft, M.G. (1971) A method of calculating permeability from electric logs, *In: Geological Research*, 1977. *U.S. Geol. Surv. Prof. Paper* **750-B**.

Egboka, B.C.E. and **Uma, K.O.** (1986) Comparative analysis of transmissivity and hydraulic conductivity values from the Ajali aquifer of Nigeria, *Hydrol.*, **83:** 185-196.

Eriksson, E. (1985) *Principles and Applications of Hydrochemistry*, Chapman and Hall, Ltd. London. 187 p.

Hussein M.T. and **Ibrahim K.E.** (1990) Empirical relations between hydraulic properties and geoelectric properties of shallow alluvial aquifer in the Arabian Shield of Saudi Arabia, *Hydrol. Sci. Tech.*, **6:** 24-37.

Hussein M.T., Ibrahim, K.E. and **Adam, E.G.** (1994) Comparison of hydrogeological and electrical properties of a consolidated sandstone aquifer, Arab Gulf. *Scient. Res.*, **12**(2): 221-229.

Keller, G.V. and **Frischknecht, F.C.** (1966) *Electrical Methods in Geophysical Prospecting*, Pergamon Press, London, 519 p.

Kelly, W.E. (1977) Geoelectric sounding for estimating aquifer hydraulic conductivity, *Ground Water*, **15** (6): 420-425.

Kelly, W.E. and **Frohlich, R.K.** (1985) Relation between aquifer electrical and hydraulic properties, *Ground Water*, **23**(2): 182-189.

Kosinski, W.E. and **Kelly, W.E.** (1981) Geoelectrical sounding for predicting aquifer properties, *Ground Water*, **19**(2): 163-171.

Mazac, O., Kelly, W.E. and **Landa, I.** (1985) A hydrogeophysical model for relations between electrical and hydraulic properties of aquifers, *Hydrol.*, **79:** 1-19.

Moore, T.A. and **Al-Rehaili, M.H.** (1989) *Geologic Map of the Makkah Quadrangle*, sheet 21 D, Kingdom of Saudi Arabia, Saudi Arabian Deputy for Mineral Resources Geologic Map GM-107C, scale 1:250000 with text 62 p., Jeddah, Saudi Arabia.

Niwas, S. and **Singhal, D.C.** (1981) Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media, *Hydrol.*, **50:** 393-399.

Ponzini, G., Ostroman, A. and **Molinari, M.** (1984) Empirical relation between electrical transverse resistance and hydraulic conductivity, *Geoexploration*, **22:** 1-15.

Ramsay, C.R. (1986) *Geologic Map of the Rabigh Quadrangle*, sheet 22 D, Kingdom of Saudi Arabia, Saudi Arabian Deputy for Mineral Resources Geologic Map GM-107C, scale 1:250000, with explanatory notes, 49 p., Jeddah, Saudi Arabia.

Urish, D.W. (1981) Electrical resistivity-hydraulic conductivity relationships in glacial outwash aquifers, *Water Resour. Res.*, **17**(5): 1401-1408.

Worthington, P.E. (1977) Geophysical investigations of groundwater resources in the Kalahari Basin, *Geophysics*, **42**(4): 838-849.

Zohdy, A.A.R., Eaton, G.P. and **Mabey, D.R.** (1974) *Application of Surface. Geophysics to Ground-Water Investigations*, U.S.G.S. 116 p.

الخصائص الكهربائية (المقاومية) والجيوكيميائية والهيدروجيولوجية لرواسب الوديان في غرب المملكة العربية السعودية

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المستخلص . تم استخدام طريقة الحفر الكهربائي في دراسة الرواسب السطحية غير المتجانسة التي تشغل قيعان الأودية الرئيسة بغرب المملكة العربية السعودية ، إذ جرى تحديد مقاوميات الخزان الجوفي من قياسات ٣٩ جسة للحفر الكهربائي ، بالإضافة إلى عمليات الضخ التجريبي في نفس المواقع .

وقد أظهرت نتائج الدراسة اختلافًا واضحًا في الخصائص الهيدروجيوفيزيائية لهذه الأودية ، إذ تتراوح الموصلية الهيدروليكية ما بين ٣ إلى ١٦٦ مترًا في اليوم ، في حين تتراوح قيم مقاومية الخزان الجوفي بين ٤ , ١ و ١٧٦ أوم.متر ، وقيم الإنفاذية بين ٤٠ إلى ٥٨٠٠ مترًا مربعًا في اليوم ، وقيم معامل التكوين الظاهري وصلت إلى ٢٦ ، وأخيرًا كانت الموصلية الكهربائية للمياه الجوفية ما بين ٦١٠ إلى ١٩٠٠٠ ميكروسيمن/ سم . كما أظهر التركيب الأيوني لعينات الماء تباينًا في الخصائص الهيدروكيميائية لرواسب الوديان في منطقة الدراسة . بالإضافة إلى ذلك ، فقد أشارت نتائج الدراسة إلى أن المقاومية الكهربائية المستخلصة من الحفر الكهربائي وخصائص الخزان الجوفي يمكن تمثيلهما بالعلاقة الرياضية :

$$Y = a X^b$$

وقد اتفقت نتائج هذه الدراسة مع دراسات سابقة (في مناطق مدارية) في تأكيد تباين الخصائص الهيدروجيولوجية لرواسب الوديان .