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THE USE OF THE RESISTIVITY METHOD FOR GROUNDWATER INVESTIGATIONS IN A SEMIARID REGION (A CASE HISTORY)

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ABSTRACT

The hydrogeophysical investigations play a very important role in the assessment of groundwater in Wadi Ranyah since there is a considerable lack of hydrogeological and hydrological information. Significant and detectable contrasts in resistivity values of the lithological units have enabled the application of the electrical resistivity method. The survey consisted of 10 vertical electrical soundings (VES) and 10 horizontal electrical profiling (HEP), using Schlumberger and Wenner arrangements, respectively. The analysis of VES curves and HEP contour map in conjunction with the results of groundwater parameters indicates that the groundwater aquifers occupy the saturated part of the alluvium and the weathered part of the basement rock. The groundwater potentiality occurs mainly in the downstream of Wadi Ranyah because of its low clay content and highly fractured rocks underlying the Wadi alluvium. The VES in the order of preference for the sequence of drilling which demonstrate relatively better groundwater potential are VES 7, 8 , 9, 3 and 6 respectively.

INTRODUCTION

The area of investigation (Wadi Ranyah) lies in the central part of the Arabian Shield between latitudes 21.22° - 21..25° N. and longitudes 42.92° - 42.97° E. (Fig. 1) and cuts across the Precambrian basement complex. It can be considered as a semiarid terrain in which the groundwater plays an important role in cultivation activities and for the inhabitants.

Information on the Precambrian rocks was obtained from the 1: 100,000-scale maps (Ramsay 1982). Much of the information on the Cenozoic volcanic rocks was obtained from Green (1985) ; Al-Muallem and Smith (1987).

Previous geological and hydrological surveying (SADM 1991; Majil 1994; Al-Amri 1994) strongly recommend a detailed subsurface structural mapping to evaluate the potential existence of an abstractable water resource available from the fractures.

In order to fully understand the subsurface hydrogeologic conditions, the main objective of the proposed study is to investigate the subsurface structural features obtained from the resistivity data (VES & HEP) and delineate any potential water-bearing fractures in the bedrock. Thus locating the most suitable sites for constructing new wells in the Wadi area.

This paper presents an example of the application of a Zohdy (1989) n-layers model and layering model (Parasnis 1979) to produce the corresponding subsurface resistivity sections. In addition, the contour section was employed to reveal more information about the subsurface lateral variations. The subsequent borehole drilling confirmed most

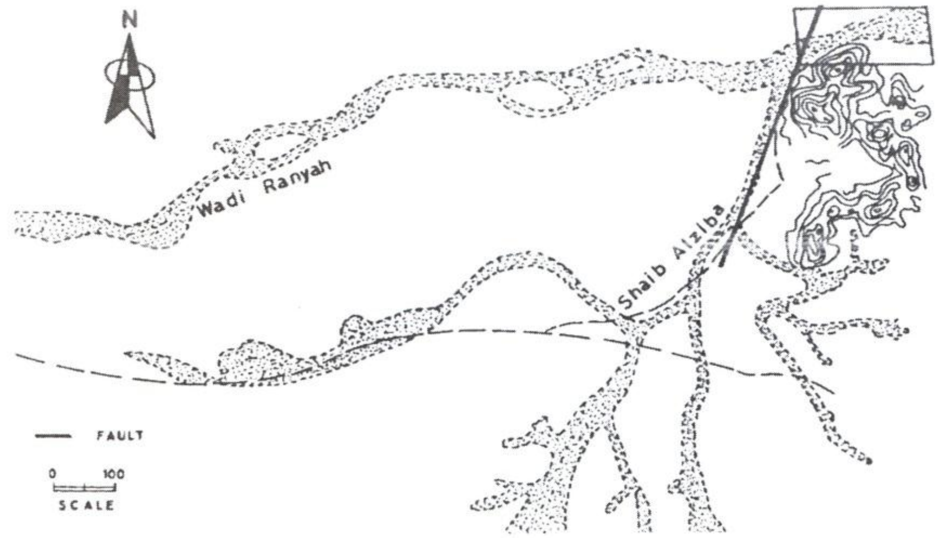

Fig. 1: Location Of The Study Area

of the previous conclusions.

GEOLOGY & HYDROLOGY

Ranyah is located within the area of Precambrian basement shield of the Arabian Peninsula, a complex lithological and structural massif which has remained relatively stable since the onset of Paleozoic sedimentation. Two distinct orogenic episodes are recognized, the Hijaz (600-1000 Ma) and the most recent Najd Orogeny (520-540 Ma).

The area has been subjected to a number of metamorphic and intrusive episodes. It contains Precambrian metasedimentary and metavolcanic rocks intruded by a wide range of ultramafic to felsic plutonic rocks. In fact, andesitic metavolcanics and granite - granodiorite rock units dominate the study area. These are all underlain by the Precambrian basement unit everywhere in the area (Fig. 2).

The upstream of Wadi Ranyah extends from the Hijaz plateau in the Arabian Shield. The moist air masses originating from continuous evaporation from the Red Sea give rise to intensive orographical rainfalls leading to surface runoff over the plateau. This runoff is carried toward the study area by channels of surface depressions. The channel of Wadi Ranyah is about 200 m wide where the Wadi cuts through the hard granitic bedrock. This constriction zone has caused the Wadi to erode a deep, relatively narrow channel and infill it with coarse alluvial sands, gravels cobbles and boulders.

Important sources of water in Wadi Ranyah are to be found in two aquifer systems (SADM 1991). The shallow aquifer system comprises coarse alluvial deposits. The second aquifer system is that associated with fractures in the underlying diorite and granodiorite. The water sources for the shallower and deeper aquifers are the limited rainfall accumulations over recent years.

GEOPHYSICAL SURVEY & DATA PROCESSING

In order to delineate the geometry of the aquifer and to determine the subsurface geological and hydrological conditions, the resistivity method was carried out applying two different electrode spacing arrangements, namely Schlumberger and Wenner to create vertical electrical soundings (VES) and horizontal electrical profiling (HEP) respectively.

The object of VES is to deduce the variation of resistivity with depth and correlate it with the geological information in order to infer the depths and resistivities of the layers present. The Wenner Arrangement was used in HEP to detect lateral variations in the resistivity and to mark the structures with near - vertical boundaries, such as faults, dikes and fractures.

The ground geophysical field work carried out in the Wadi alluvium plain, consisted

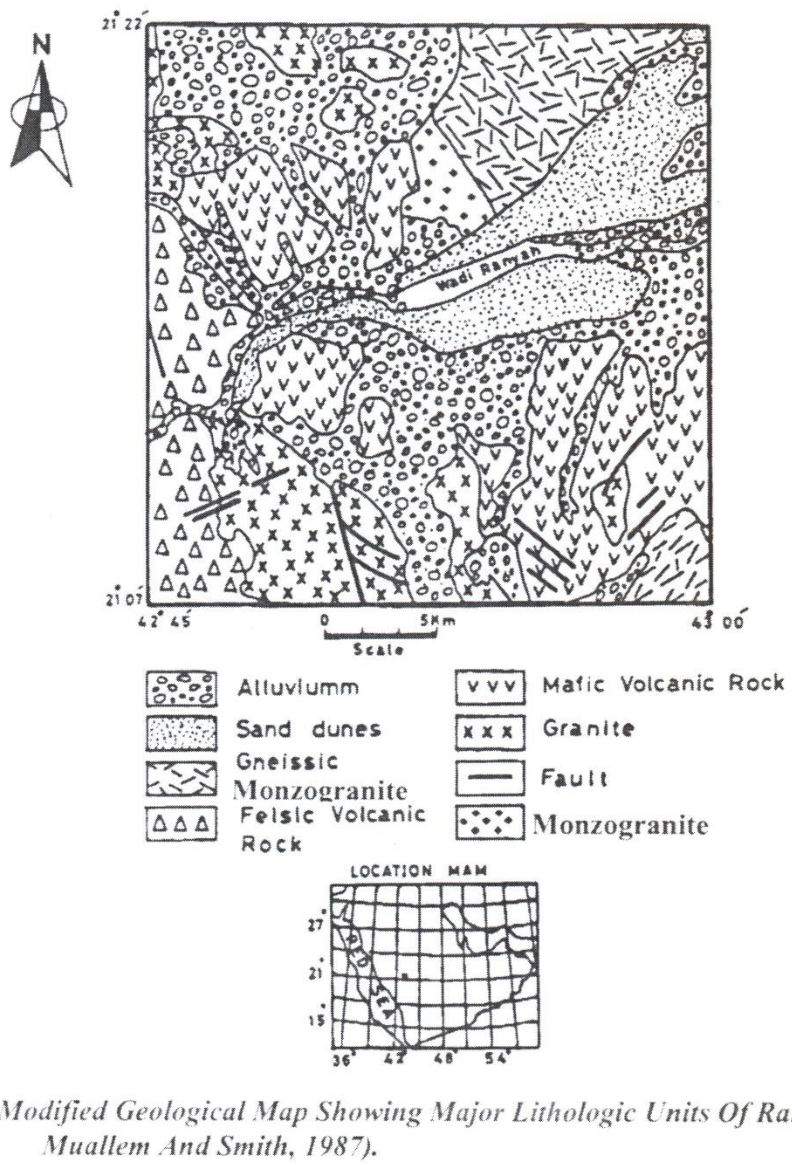

Fig. 2: Modified Geological Map Showing Major Lithologic Units Of Ranyah Area Muallem And Smith, 1987).

of 10 VES and 10 HEP; perpendicular to the trend of the Wadi , covering an area of 1000 m width and 2000 m length (Fig.3). The distance between the two adjacent VES and HEP was 200 m.

An ABEM - SAS 300B terrameter was used to obtain the measurements. The maximum half current electrode spacing (AB/2) in the Schlumberger arrangements reached almost 200 m, while the intensity of the measurements was about 7 readings per decade at AB/2 values of 1.5, 3, 4, 5, 7, 9, 10, 12, 15, 30, 45, 60, 90, 120, 150, and 200 m. The Wenner configuration was applied using AB / 3 = 10 m and a station spacing of 15 m. This configuration was based primarily on the results of VES curves which indicate that the average depth to the water table is 8 m. Consequently, AB/3 = 10 m was used in the HEP to delineate, if any, the shallow subsurface structure and lateral inhomogeneity.

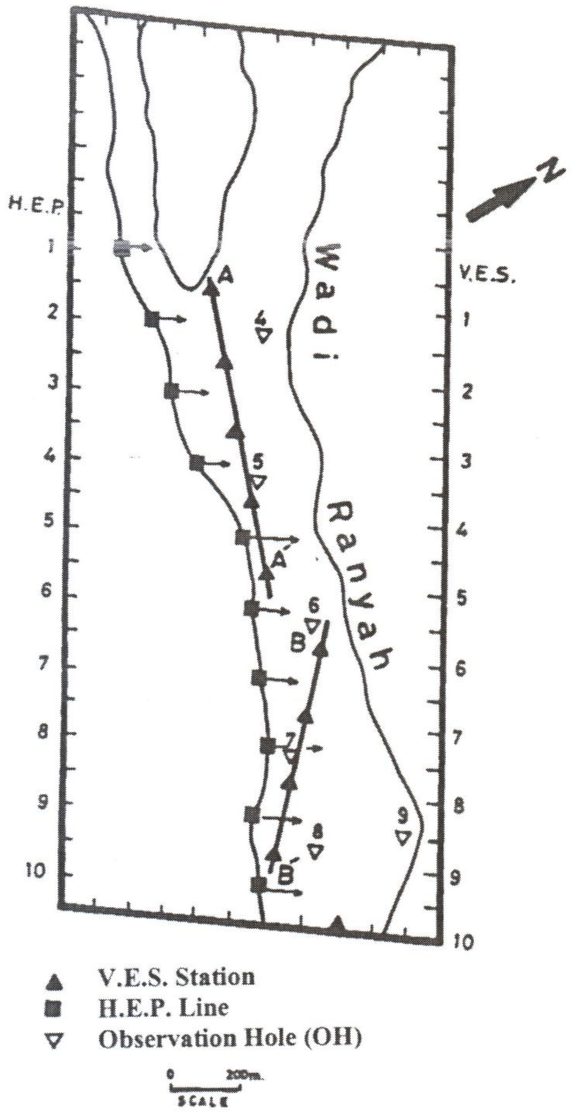

Fig. 3: Location And Distribtion Of VES, HEP, And Observation Well Sites.

Some sounding curves indicated noise interference particularly at larger AB/2. The main causes of such noise could be the low power of the instrument used in this survey which cannot provide sufficient signal strength to exceed the required signal to noise ratio. The noise also increases when the current passes through good conductors (e.g clays).

The apparent resistivity values computed in the field were reduced using automated inversion computer programs (Zohdy 1989 ; Parasnis 1979) to allow either automatic correction or user-defined corrections. The final corrected resistivity curves were then re-digitized for subsequent data analysis and interpretation.

The first technique adopted by Zohdy (1989), used to obtain the so-called n-layers model equivalent to each of the corrected apparent resistivity sounding curves. It does not require a suggested input model to start the automatic iteration for calculating the final model. Instead the number of AB/2 in a sounding is considered as the number of layers while the apparent resistivity values are considered as the equivalent input resistivity for each layer. The resistivity values and the sampling intervals on the curve were used automatically to create the first approximation of the corresponding multilayer model. Hence, this model has been modified in layer thicknesses and resistivities through a number of iterations until the best-fit between the calculated curve and the apparent resistivity curves is reached.

The second technique is based on the mathematical solution suggested by Parasnis (1979) to describe the apparent resistivity curve according to the equation:

$$\rho_a (r) = r^2 \int_0 T(\lambda)\, J_1 (\lambda r)\, \lambda d\lambda$$

where:

J_1: the Bessel's fbnction of order 1;

r: half electrode spacing (*AB/2*)

$T(\lambda)$: the resistivity transform

ρ_a: the apparent resistivity

The application of this equation is to fit the same layer thicknesses and / or resistivities with the apparent resistivity curves through a number of layers, which describes the lithology variation beneath the sounding site. The number of layers is related mainly to the geological layers that might occur beneath the sounding and not to the number of resistivity measurements in the sounding as considered in the Zohdy method. The advantage of this method is that it can be expressed directly using the lithological layering model in a straight forward interpretation and does not require as high a skill in the interpretation as does the Zohdy method.

VES curves were subjected to both techniques of sounding analysis. A multi-layer model and an absolute layering model corresponding to each sounding were then obtained using advanced software. Figure 4 shows an example (VES 5) of the interpreted resistivity using the absolute layering model (Fig. 4a) and the n-layers model (Fig. 4b).

RESULTS & INTERPRETATION

In Wadi Ranyah, significant and detectable contrasts in physical properties of the lithological units enabled the application of VES and HEP for groundwater exploration.

The general features of the interpreted resistivities in Figs. 5 and 6 ranged from low (< 20 ohm.m), to high (> 150 ohm.m). Specifically, on the basis of typical resistivities of materials in similar geological environments, the interpreted resistivity ranges in Wadi Ranyah can be classified into 4 geoelectric layers (GEL) as follows

GEL 1 with low resistivities of less than 20 ohm.m,

GEL 2 with moderate resistivities of 20 to 50 ohm.m,

GEL 3 with moderate-to-high resistivities of 50 to 150 ohm.m, and

GEL 4 with high resistivities of greater than 150 ohm.m.

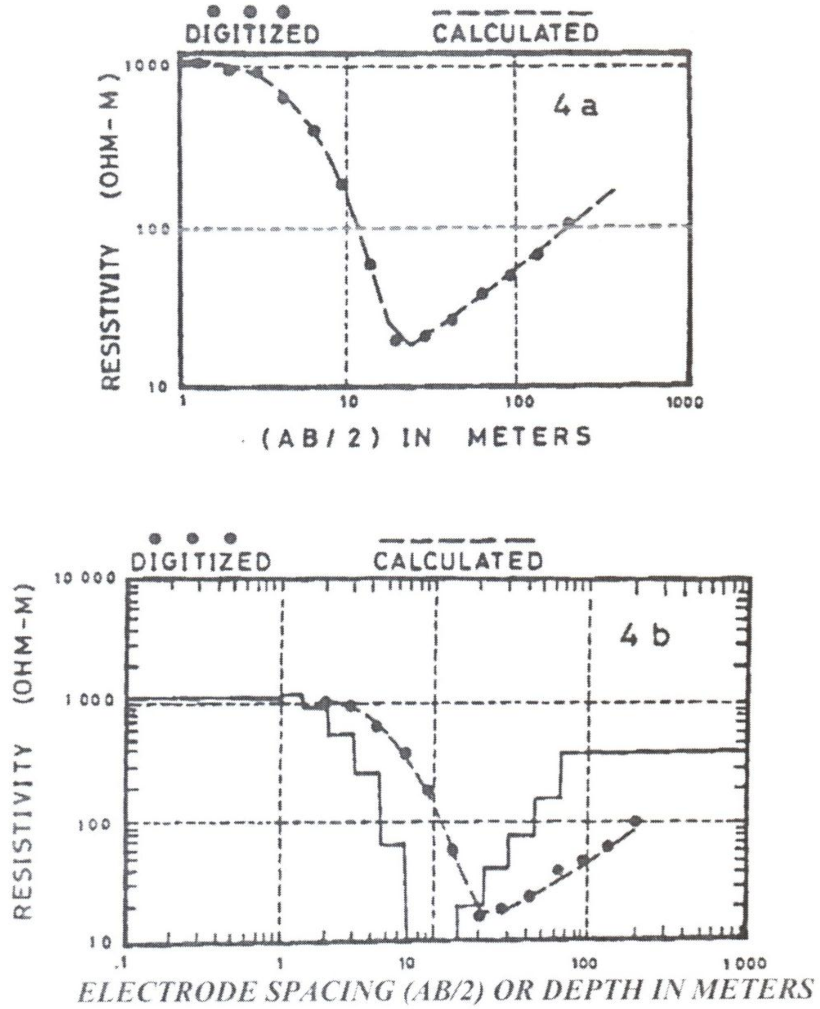

Fig. 4: An Example On The Sounding Curve Analysis Of VES 5 Using Layering Model (A) And N - Layers Model (B).

Boundaries between geoelectric layers (GEL) were determined by the midpoint method (Stodghill 1983). The boundary separating the shallow, high resistivity zone from the shallow, low resistivity zone was determined by finding the midpoint between the maximum value of the first peak and the minimum value of the trough. Except for the lower limit of the deep layer , all other boundaries were determined similarly.

The interpretation of the vertical subsurface resistivity contour sections was carried out after the careful examination of the resistivity contour behavior, taking into account the resistivity value of each of the n-layers model as plotted at the midpoint beneath the corresponding sounding location. The contour gradient was used to locate the boundary between two geoelectric layers, while the closed contour was used to describe the thickness of any interpreted layer. Using this criteria, it was possible to construct the equivalent subsurface geological sections from the contour sections This procedure was used to prepare two sections namely, A - A' and B - B' (Figs. 5 and 6, respectively).

Section A - A' of Fig. 5 consists of the results of VES 1 , 2 , 3 , 4 and 5. The dry alluvium near the surface is characterized by high resistivity values (540 - 850 ohm.m). The contour section also reveals the extent of a water-bearing layer along the profile. This layer is associated with the moderate resistivity values (20 - 50 ohm.m) at depths ranging from 8 - 25 m. The clay content decreases beneath VES 4 and 5. This section also demonstrated lateral lithological variations, such as clay lenses beneath VES 1 , 2, and 3 at a depth ranging from 8 to 20 m having an average thickness of about 8 m. This clay layer is associated with the lowest resistivity values in the section (< 20 ohm.m). The intermediate-to-high resistivity values (>50 ohm.m) at depths greater than 25 m are associated with the weathered bedrock which is believed to contain substantial amount of water in some fractures and joints.

Section B - B' of Fig. 6 consists of the results of VES 6, 7 , 8 , and 9. This section indicates that the upper surface layer is dry alluvium because it is associated with high resistivity values (460 1200 ohm.m) and has a thickness of about 5 m. The water-bearing layer is distinct and obvious beneath all the soundings with moderate resistivity values (20 - 50 ohm.m) reflect lower clay content and salinity The sharp increase in the resistivity values beneath the entire section is probably due to the existence of the bedrock at depths greater than 20 m.

Generally, the two geoelectric sections show three subsurface geologic layers. The uppermost layer consists of gravel and unconsolidated dry sediments which are associated with high resistivities. The middle layer is composed of clayey fine materials intermixed with gravel and water. This layer probably constitutes the water -bearing zone in the Wadi with resistivities range from 20 to 50 ohm.m. Evidence from these measurements indicates that the water-table varies in depth between 7 - 10 m. The unconformable surface between the weathered bedrock rocks and saturated deposits is clearly identified from the sharp contrast in resistivity values above and below it. The lowermost layer may represent the weathered bedrock. Depths to the bedrock range from 20-25m.

The HEP contour map (Fig.7) is characterized by more or less homogeneous resistivity of moderate to-high values (00 - 250 ohm.m). In this range of resistivities, the low clay content, the existence of weathered granite and gneiss with water flows, gravely sand with freshwater and fractures saturated with water are expected. It is well known in the semi arid areas that the uppermost part of the wadis are characterized by a sequence of dry alluvial deposits (high resistivity) overlying the moist alluvium which is associated with a remarkable drop in resistivity values. In Wadi Ranyah, the water table occurred at an average depth of 8m where resistivity values are relatively low. Therefore, the average resistivity values for the uppermost 8m range from high to -low will produce an average resistivity of moderate values as indicated in the HEP contour map (Fig. 7).

The salinity variation is quite broad, indicating a complex flow system within the aquifer system. Higher salinities were found in wells 4, 5 and 6 (Table 1). They suggest a source of older groundwater is being drown into the flow system, possibly from the weathered zone in the granite where mobilization of ions is occurring through oxidation and solution. High TDS concentrations in these wells occurred at shallow depths (<8m) which probably saturate the porous formations, leading to moderate resistivities.

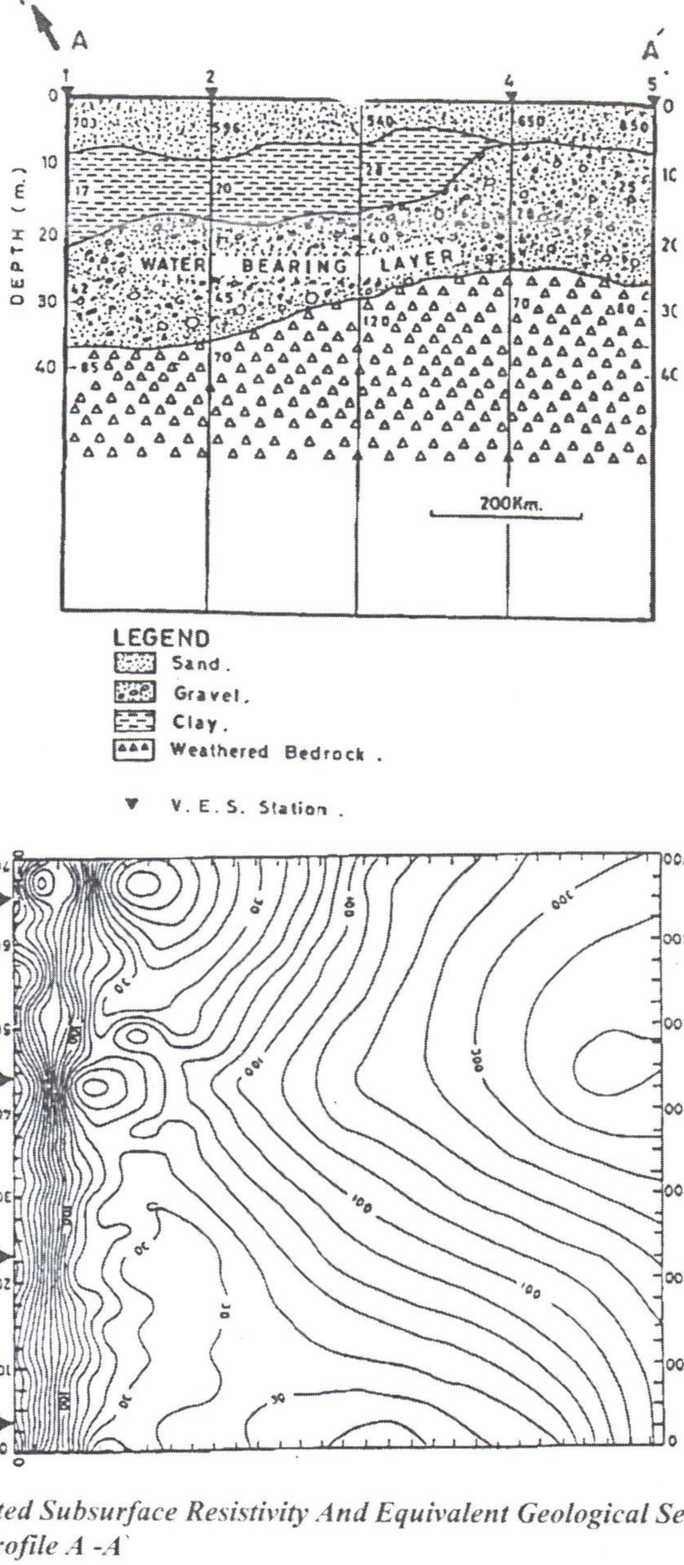

Fig. 5: Interpreted Subsurface Resistivity And Equivalent Geological Sections Along Profile A -A`

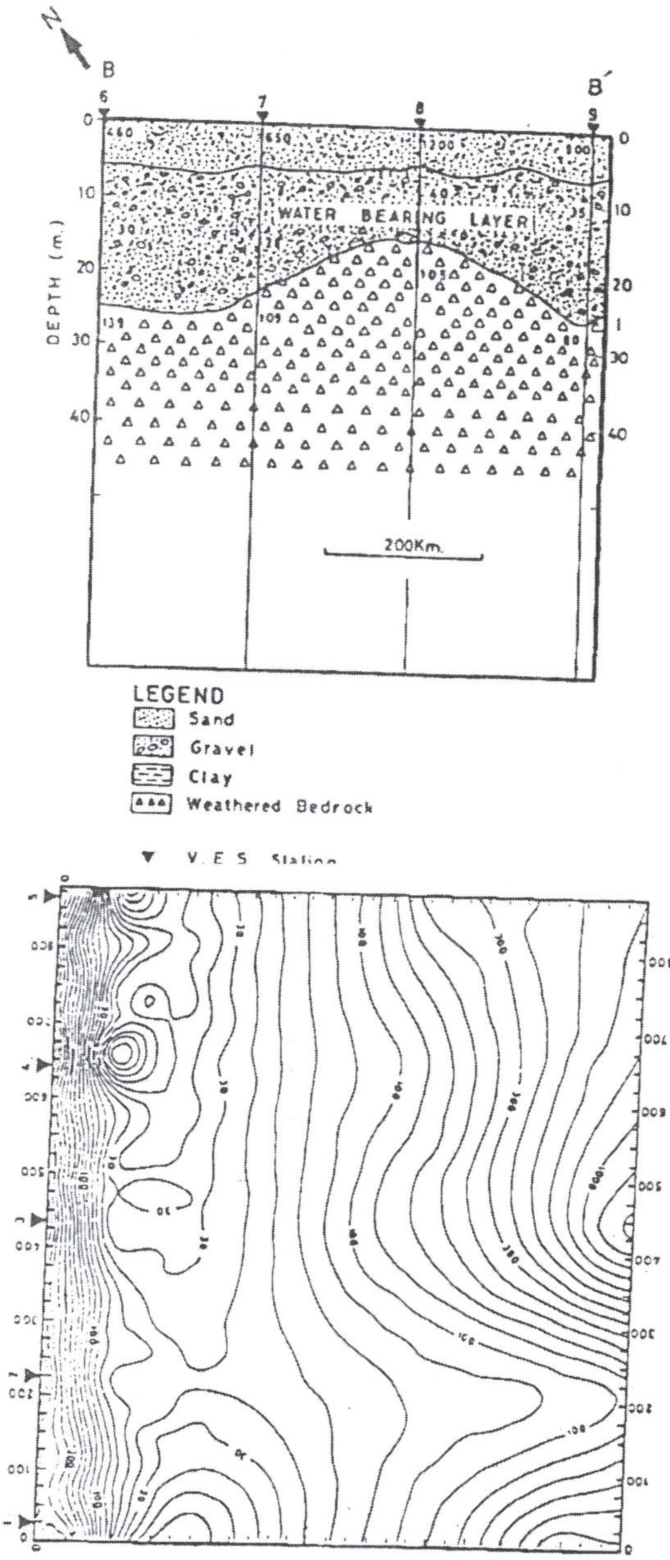

Fig. 6: Interpreted Subsurface Resistivity And Equivalent Geological Sections Along Profile B - B`.

In order to obtain reliable results and check the validity of the application of *VES* and the HEP in Wadi Ranyah, six lithological boreholes (Wells 4, 5, 6, 7, 8 and 9) were drilled (Fig. 3). The information obtained from these wells are shown in Table 1.

The lithology at these wells were correlated with the previous sounding interpretation. The average depth to the water-table (5 - 8 m) and the thickness of the saturated zone (15 - 20 m) show excellent correlations with the corresponding values obtained from the resistivity interpretation. The most conspicuous feature beneath VES 4 is the termination of clay-rich layer at depth of about 7m (Fig. 5). This termination was substantiated by the data from well 5 which is located near to VES 4. Drill cuttings collected at a depth of 8 m are predominantly saturated sand and gravel. Groundwater samples of these wells show gradual decrease in the salinity and TDS concentrations which confirm that the downstream of Wadi Ranyah especially at wells 7, 8 , and 9 contains freshwater. However, the groundwater quality in all the drilled wells can cover both the domestic and agricultural water needs in this desert semi-arid area.

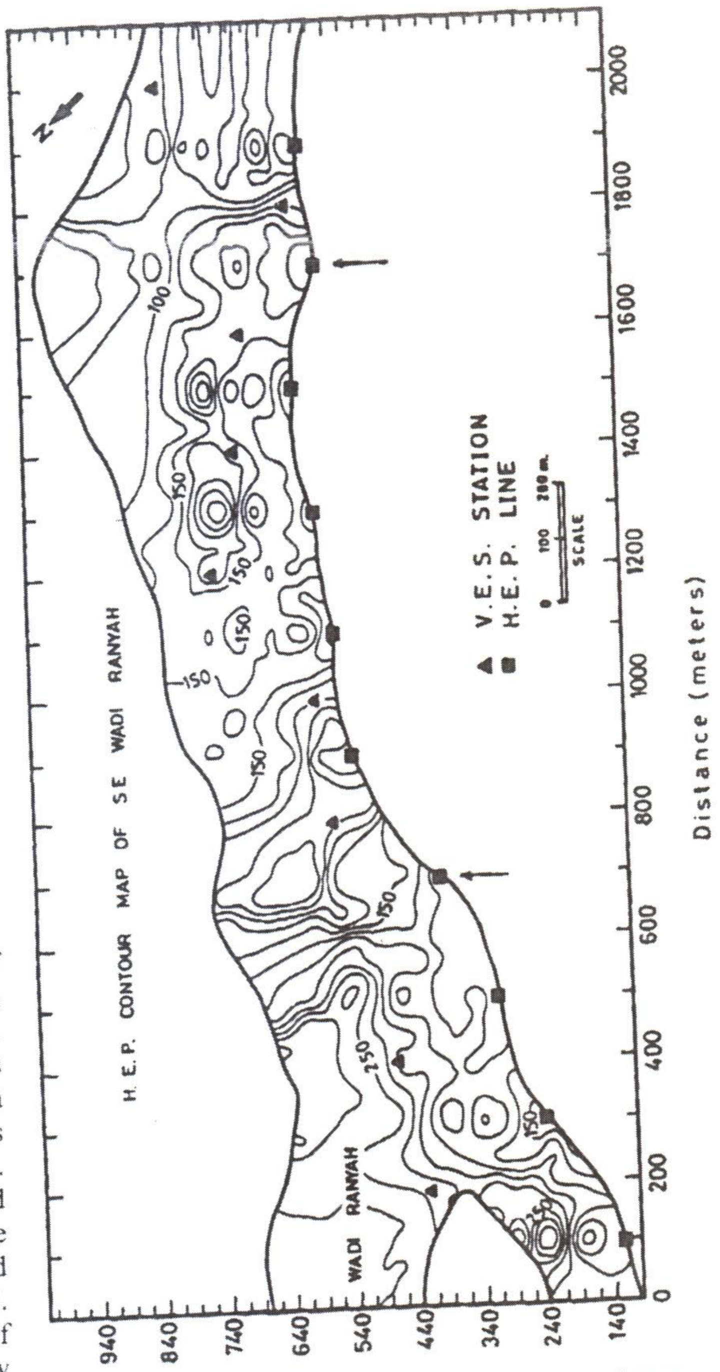

Fig. 7: HEP contour map of the investigated area.

Table1 : The Hydrogeological Parameters Obtained From The Observation Holes.

Well No	Deplk to Ike W. T (m)	Depth 10 the bedrock (m)	T:D.S (Mg/ l)	Salinity conditions
4	8	24	1810	High
5	6	18	870	Moderate
6	6	22	1576	High
7	5	19	517	Low
8	6	20	531	Low
9	5	21	553	Low

SADM (1991) suggested that the groundwater in Wadi Ranyah occurs in two separate aquifers separated by an impervious layer. The shallow aquifer system comprises the coarse alluvial deposits overlying the fractured bedrock. This aquifer is unconfined and receives a recharge from sporadic flows in Wadi Ranyah. The second aquifer system is the one associated with the fractures in the underlying diorite and granodiorite. The granite is considered to be tight and unlikely to yield significant quantities. The water in these deep fractures is recharged through the Wadi alluvium.

Generally speaking, the interpreted subsurface resistivity, equivalent geological sections and borehole data confirm the existence of the shallow aquifer system which overlies the weathered bedrock. The resistivity values within this aquifer suggest that the groundwater in the downstream area is almost fresh. Information obtained from this study does not allow to delineate, with confidence, the deeper aquifer which is believed to occur at greater depths (> 40 m).

CONCLUSIONS

It can be concluded from the integration of HEP maps, VES and the true resistivity contours that the groundwater potentiality occurs mostly in the downstream area of the Wadi Ranyah because of its low clay content and highly fractured rocks underlying the Wadi alluvium . The groundwater aquifers occupy the saturated part of the alluvium and the weathered part of the bedrock. The VES in the order of preference for the sequence of drilling which demonstrate relatively better groundwater potential are VES 7, 8 9, 3 and 6 respectively. The maximum depth of penetration for dug wells, based on VES modeling is in the range of 25 - 35 m below the ground surface.

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