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Research Article

Resistivity survey investigating salinity hazard and aquifer system in the alluvial fans in central Jordan Valley

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Abstract

In the course of this study geological and geophysical resistivity survey were conducted in the area extended from Deir Alla to Suleikhat (Middle Ghor Area) in Jordan valley. In order to evaluate the potential and characteristic of the groundwater quality and distribution of the aquifer in the alluvial in the area. The aquifer system in the area consists of Ajlun and Belga Group, in addition to the Plateau Gravel Group and the Alluvial Aquifers.The resistivity survey encounter an average thickness of the alluvial fans of about93 meters. The source of salinity in the alluvium aquifers was predicted to be Lisan Formation, which underlies the Whole alluvium in the area.Quantitative interpretation of VES data coupled with field and preexisted electrical conductivity reading work out the following characteristic for water bearing layer in the alluvial fan deposits: The alluvial fans exhibit recurrently lateral variation, even in the same area.The continuity of static water table may be interrupted by mud dominated area. These facts forearm to conclude that the aquifer system in the alluvial fans are lenses to micro-aquifers bodies of saturated gravel and sand dominated layers, with resistivity range between 30-60 ohm.m, with apposite thickness range of 8-42 meters.Calculated Porosity ofsuch aquifers is approximated to be in range of 20-27%. In addition to these layers there is a mud gravel layerswith resistivity ranges from 20 to 30 ohm.m, their thickness are in range of 5-23 meters, and their porosity is approximated to 33%.

Key words; Hydrogeology, Resistivity, Jordan Valley, Alluvial fans

Introduction

Deterioration of groundwater in term of quality and quantity is the direct consequence of disturbing the balance between its natural recharge and discharge.Groundwater resources in the Middle East surrounding areas were deteriorated noticeably in the last 50 years Shoqeir (2014)

Exploitation of groundwater in the study area, has been substantially increased in recent decades due to the great development in both drilling and pumping techniques, another related factor is the increasing demand for domestic and irrigation water.More than 60% of the water demand in Jordan is covered by groundwater Alraggad *et al* (2012).

Location

The study area is located between longitudes 35^{o} $36'$ – 36^{o} E, and latitudes 32^{o} $15'$– 32^{o} $35'$ N in Jordan Valley (Al-Ghor), which is of great importance since it represents the main farms area in the Hashemite Kingdomof Jordan fig (1).

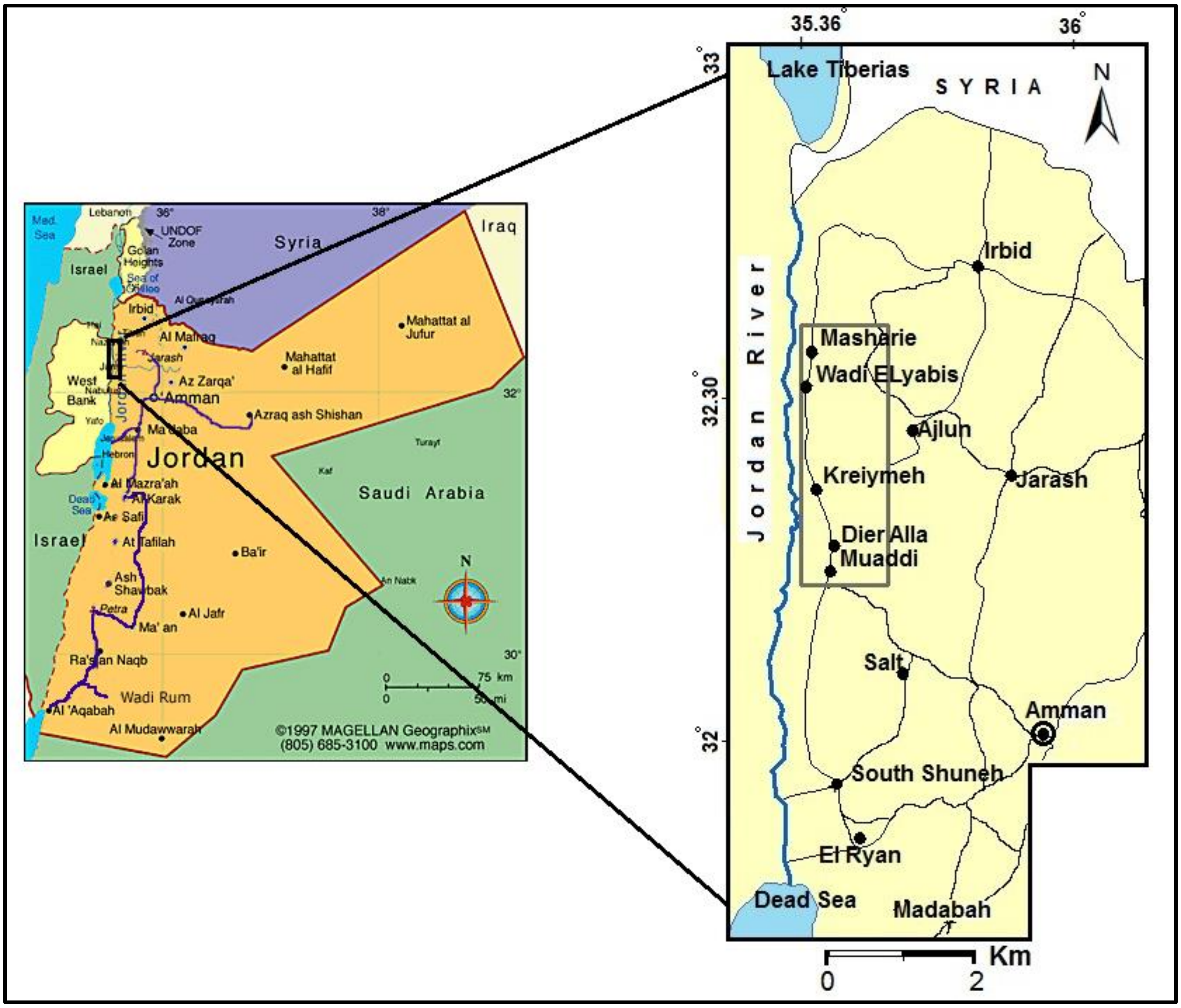

Fig (1) location map of the study area.

Previous works

The area has been studied for different purposes, the following are the most related topics: Quennell (1951) discussed the regional geology of the study area, Wilson and Wozab (1955) studied the chemical quality of water in Jordan Valley. Both Tleel (1967) and Hirzalla (1973) evaluate the water resources of Jordan Valley. Rimawi (1985) studied the isotopic composition of the thermal spring along the Jordan Rift Valley. Shatanawi *et al*, (1993) proceeding of a regional seminar on potential of artificial recharge of groundwater. El Hassan (1999) study the potential of groundwater recharge in Deir Alla - Suliekhat area, Al Amoush *et al* (2012)study the potential stoarativity of groundwater in the alluvial deposits along the

King Abdullah Canal- Deir Alla Area/Jordan. Al Farajat (2015) study, an effective and time-saving strategy for groundwater exploration in alluvium basins in arid-semiarid lands in Petra-Region, Jordan.

The following technical reports were conducted in and nearby the study area were closely related to the topic of the present study these were: Bender *et al* (1964) result of hydrogeological and geoelectrical survey in the southern Jordan Valley. Peter, and Worzyk (1984) conducted geoelectrical investigation in Jordan Valley Adaseiya area. These studies did not include specific interpretations, evaluation, and conclusions describing the situation in the area but include useful information as a background for the present study.

Geology of study area

Stratigraphy and aquifer system

The area is covered byMesozoic marine Cretaceous and Cenozoic, Neogene sedimentary rocks, and recent alluvium deposits dominate the area, from older to youngerthese are;

Kurnub sandstone formation which is of lower Cretaceous age.

Ajlun Group which is consist of five formations. The fifth (lower most), third, and first formation constitute the major aquifer system within this group.Ajlun Groupis of Cenomanian – Turonian age. It overlies Kurnub sandstone and constitutes an alteration of limestone, marly limestone and dolomite sandstone strata.

Belqa Group overlies Ajlun group, consist of alternating beds of chalk, chalky limestone, marl, chalky marl, and chert. These were of Santonian to upper Eocene age. This group has two main aquifer systems (Rimawi, 1985). These are Amman aquifer, which is lies within the study area, the second one Rijam aquifer is located out of limit of this study.

Jordan Valley Group includes the sediments deposited in Jordan Valley, and along the rift sides. The age of these sediments ranges from Pleistocene to Miocene. McDonald (1965) subdivided this group into three formation, which are Conglomerate, Lisan, and Dymma siltstone Formations. Lisan formation, which constitutes repeated finally intercalationsof chalky and gypseous lake sediment horizon of coarse clastic that reflect water levelfluctuations of Lian lake in the Pliestocene age. This formation play an important role in groundwater deterioration in the area as this study well elaborate.

The alluvium aquifers are restricted to Jordan Valley area and its major side wadis.The existence of appropriate underground space in the alluvial deposits for water storage and that the water/water and water/rock interactions are also be minimal and will not present and detriment to the different groundwater,Al-Amoush *et al* (2012). Groundwater in the alluvial fans occurs at relatively shallow depths, interbedding with lacustrine marl and clay. Successive muddy, and sandy gravels alluvial sedimentation of contrasting permeability gives rise to a local artesin condition, suchinterbedding phenomenon decreases towards the mountain slopes El Hassan (1999).

Plateau Gravel Group consists of cemented conglomerate and sandsintercalated with limestone, marly limestone, and chalk. Formations within this group is of upper Pleistocene age. The sand gravel facies of these deposits constitute an aquifer of good potential, especially when they are adjacent to escarpment foothill, and when having continuous sources of recharge El Hassan(1999).

Recent Alluvial Sediments: deposits at the mouth of Wadis, their age is Pleistocene to Holocene. They are consisted of poor sorted alluvium. The alluvial fans of the side Wadis covers the older Jordan Valley escarpments. These are mainly composed of gravels and sands of limestone, dolomites, and chert with intercalations of clays and marls.

Structure; the main structural feature in the area is the Jordan Rift Valley (JRV), which has been studied and discussed by many geologists; Quenell, (1956), Burden (1959), and Bender (1974), the latter author discussedthe fault in detail and suggest differential uplift to explain the structure in the area instead of the inveterate, dominate concept of strike slip displacement in the area i.e. Bender interpretation may be attributed to transpression structure usually associated with conjugate faults such strike slip movement.The JRV extends about 360 Km, which constitute part of a regional fault system. It had been developed, as a result of sub continentaldrift that is the rotational movement of Arabian block counter clockwise. The main consequences of this movement is the JRV and the Dead Sea Graben.

Methodology

This study conducts resistivity survey in order to establish;

The vertical thickness of the water bearing strata and their horizontal variation,in addition to water table level in the alluvial fan formation.

Explore the source of salinity anddeterioration in groundwater quality.

Calculate approximations for porosity of water bearing strata in alluvial fan.

Schlumberger electrode configuration was implemented via fifteen vertical electrical sounding (VES). These were conducted, with maximum current electrode spacing of 400 metersof maximum 36 reading for each VES including check points fig (2).

During this study electrical conductivity (EC)measurements from Aian El Buwiab and Nakhiel El Buwiab in summer and winter were collected. This study use these EC readingsaddset bywater authoritymeasurements data to calculate the porosity of aquifer within alluvial fans.

This study investigate well log from water Authority to clarify, and inhance resistivity data intrpretation forsratification characteristic of saturated horizons in the alluvial fans.

Data processing include the folowing major steps:

The field data were plotted in the usual manner in log-log paper.

The second step is producing initial model by manual fitting of field data curve using two layer case standard curve, and point auxiliary curve.

Computing the final model was accomplished using VES-32 program from Atlas, ABEM, and University of Luleh, Sweden, 1984.

The initial manually produced model and two well log from Deir Alla No.2 and No.6 were used to control computer calculating final models. The results are listed in the tables (1 and2).

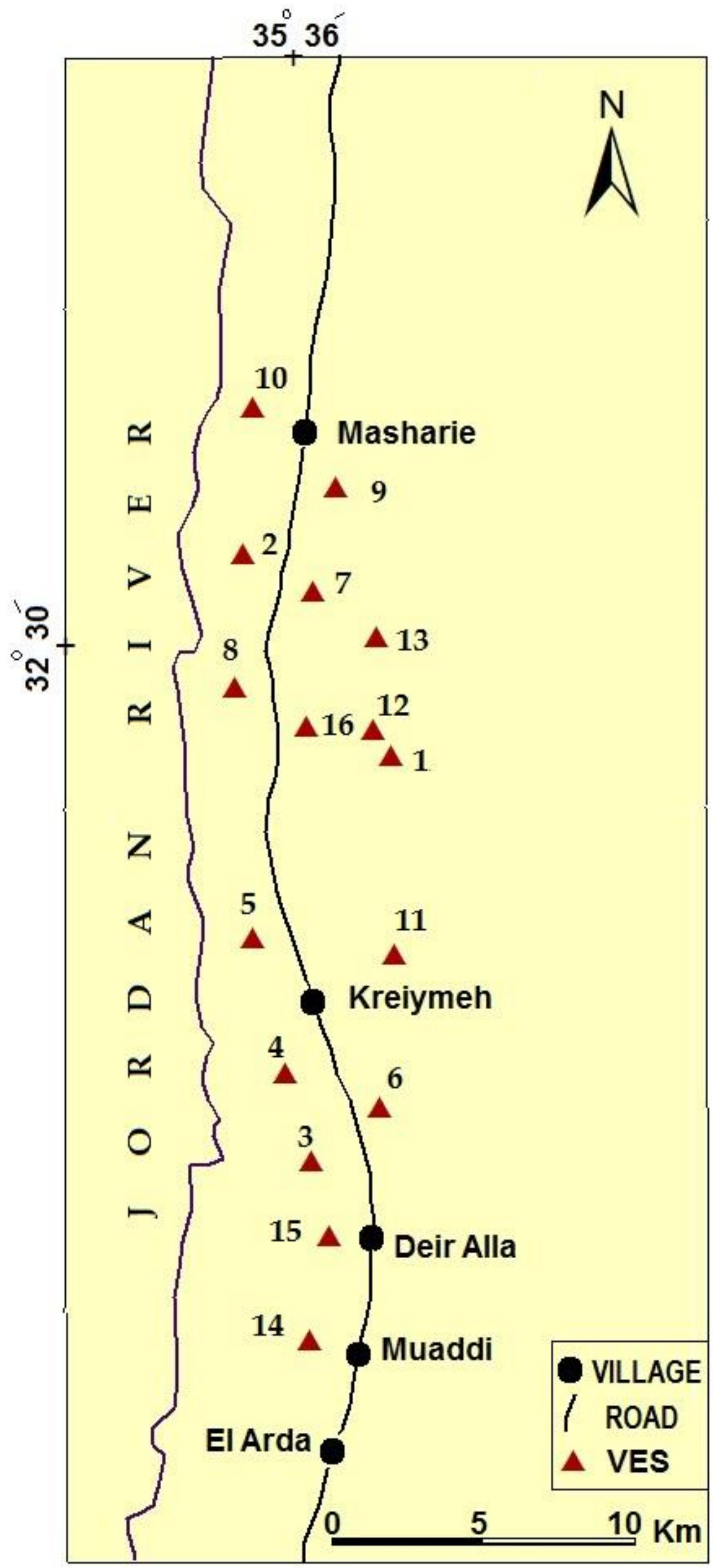

Fig (2) Vertical Electrical Sounding location map.

Results and discussion

General comments in the resistivity data interpretation

The stratification of the alluvial fan is hardly correlated and/or generalized over the area that is because of both topographic complications, and inhomogeneity nature of the alluvium sediments. That is to say the alluvial fan exhibit recurrently lateral variation, even in the same area.

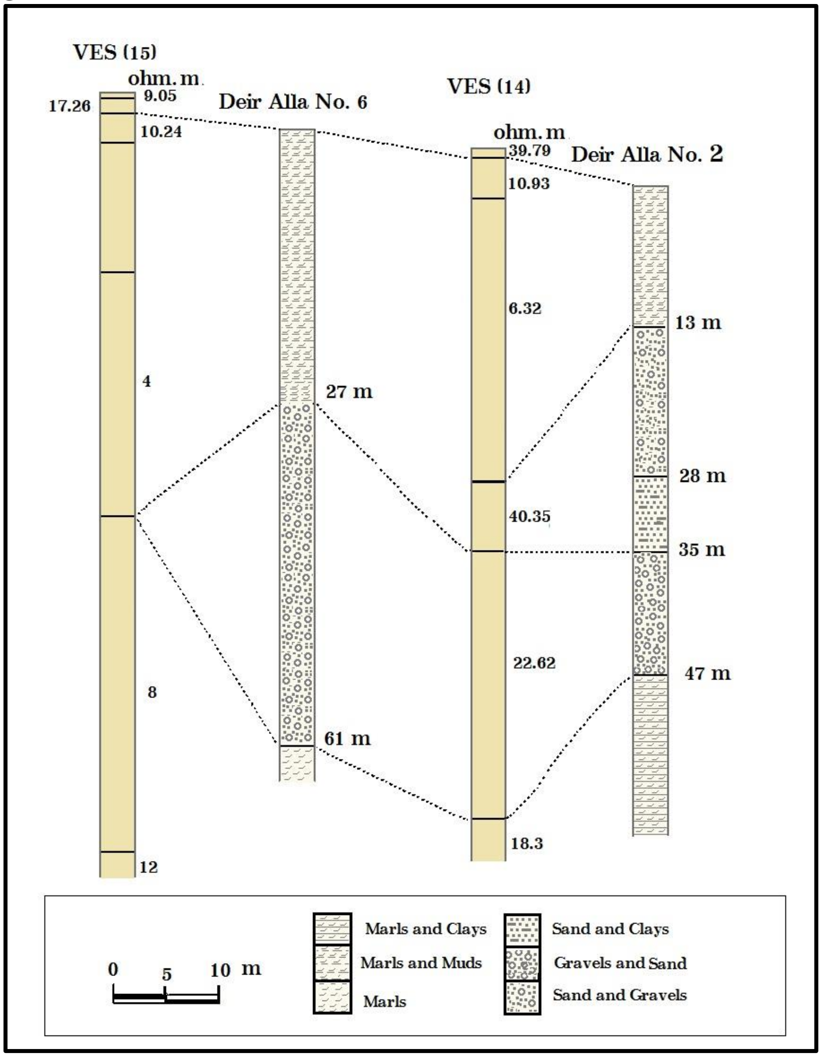

Fig (3) Correlation between [VES (14) and VES 15] to [wells log NO.2 and NO.6] both in Deir Alla area.

The continuity of static water table may be interrupted by mud dominated area. This fact forearm to conclude that the aquifer system in the alluvial fan are lenses and/or micro-aquifers bodies of saturated gravel and sand dominated layers. Their resistivity range from 20-60 ohm.m, which characterized these aquifers.

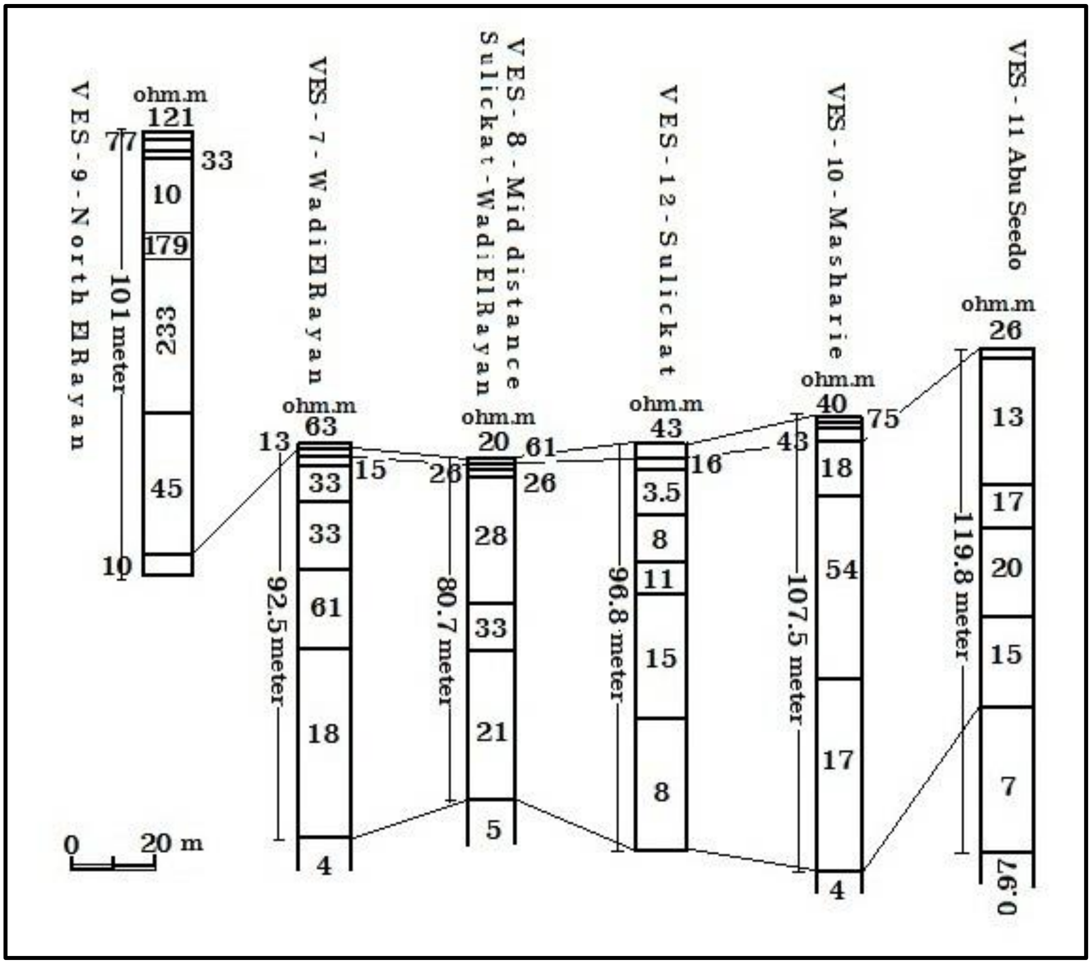

Fig (4) General correlation of resistivity interpreted data along the main road in the study area.

The general stratification model fig (4) of the alluvial fans in the area can be summarized as follows; the first strata is a coverof superficial deposits with different stone contents to pure muddy soil, which in turn cause great variationsin its resistivity value from few hundreds to few tensohm.m even less. Theformer strata is followed by mud dominated stratification with resistivity range from 8-18 ohm.m. Other frequently encountered strata is saturated sandy gravelhorizons with resistivity range from 30-60 ohm.m, and saturated gravely mud strata with resistivity range 20-30 ohm.m. These two later stratification constitute the productive aquifers in the alluvium accumulation in middle JV, which display an alternative succession with different variety of thickness.The only generalized criteria is that the alluvial fans in the area is that almost all stratification is underlay by Lisan formation, with resistivity range from 1-9 ohm.m, which is the main cause of the salinity hazard in the area.

VES (1) Suleikhat east of quarries			
Layer	P ohm.m	T m	Layer description
1	60.10	1.66	Wet mud stony soil
2	109.80	4.33	Wet gravels with sand mud
3	06.46	9.64	Saturated mud
4	34.93	29.91	Saturated gravel and sand
5	16.60	51.80	Saturated mud and marl
6	04.75	∞	Lisan Formation

VES (2) Wadi El Rayan (N 32°23.57 E 35°34.41)			
Layer	P ohm.m	T m	Layer description
1	15.50	1.78	Wet muddy soil
2	08.39	2.42	Saturated mud
3	05.36	1.99	
4	40.32	4.82	Saturated gravel and sands
5	134.95	18.42	Wet gravel with sand
6	12.29	23.56	Saturated mud
7	01.61	∞	Lisan formation

VES (3) Seel Wadi El Zerga (N 32°16.23 E 35°36.90)			
Layer	P ohm.m	T m	Layer description
1	258.29	0.5 0	Dry stony soil
2	100.45	0.95	Wet stony soil
3	18.58	2.33	Saturated sandy mud
4	08.48	9.94	
5	04.15	∞	Lisan formation

VES (4) Wadi Rajib area (N 32°14.23 E 35°36.58)			
Layer	P ohm.m	T m	Layer description
1	207.91	0.43	Dry stony soil
2	401.42	0.32	
3	727.00	0.98	
4	174.00	3.62	Wet stony with sand matrix
5	135.81	6.11	
6	151.19	37.44	
7	44.05	40.21	Saturated gravel and sand
8	03.58	∞	Lisan formation

VES (5) Wadi Kufranja (N 32°14.23 E 35°35.61)			
Layer	P ohm.m	T m	Layer description
1	61.20	3.10	Wet gravel and sand soil
2	94.50	11.71	Wet gravel
3	120.50	∞	Dry gravel and sand

VES (6) Suleikhat			
Layer	P ohm.m	T m	Layer description
1	63.15	0.5 0	Wet mud stony soil
2	15.45	0.95	Wet gravel and sand
3	13.50	2.33	Saturated gravelly sands with different clay content
4	15.56	9.94	
5	33.70	15.67	
6	04.15	∞	Lisan formation

VES (7) Wadi El Rayan (N 32°20.66 E 35°35.22)			
Layer	P ohm.m	T m	Layer description
1	63.15	0.5 0	Wet mud stony soil
2	15.45	0.95	Saturated unconsolidated sediment dominated by mud
3	13.50	2.33	
4	15.56	9.94	
5	33.70	15.67	Saturated gravelly sands
6	61.43	18.90	Saturated sandy gravels
7	18.66	44.68	Saturated mud and marls
8	04.15	∞	Lisan formation

VES (8) Mid distance between Suliekhat, and Wadi El Rayan			
Layer	P ohm.m	T m	Layer description
1	20.51	0.63	Wet muddy soil
2	61.42	1.24	Wet sandy gravels
3	26.65	2.00	Saturated gravelly sand
4	28.81	29.80	
5	33.11	11.00	
6	21.25	36.00	Saturated stony mud
7	5.00	∞	Lisan formation

Table (1) Exhibits the geoelectrical interpretation of VES (1-8)

VES (9) Suleikhat			
Layer	P ohm.m	T m	Layer description
1	121.21	1.30	Wet stony soil
2	77.75	3.10	Wet sandy gravels
3	38.68	1.50	Saturated gravelly sand
4	104.44	18.00	Wet boulders, gravels, and sand
5	179.64	6.00	
6	233.00	37.00	Carbonate rocks (aquitard)
7	45.56	34.00	Carbonate aquifer
8	10.13	∞	Lisan Formation

VES (10) West of El Masharie (N 32^{0}26.64 E 35^{0}35.42)			
Layer	P ohm.m	T m	Layer description
1	40.37	0.70	Wet sandy stony soil
2	75.13	0.50	Wet sand
3	34.92	3.70	Saturated gravelly sand
4	18.94	13.20	Saturated mud
5	45.44	43.00	Saturated sand and gravels
6	17.95	46.40	Saturated mud and marl
7	04.05	∞	Lisan formation

VES (11) West of El Suleikhat (N 32^{0}19.13 E 35^{0}35.05)			
Layer	P ohm.m	T m	Layer description
1	42.60	03.60	Wet stony soil
2	16.40	02.70	Stratified saturated mud
3	3.50	10.60	
4	08.10	10.90	
5	11.20	8.00	
6	15.80	29.60	
7	08.50	31.60	
8	05.00	∞	Lisan formation

VES (12) Wadi Hujaja (N 32^{0}20.62 E 35^{0}35.75)			
Layer	P ohm.m	T m	Layer description
1	158.25	0.70	Dry stony soil
2	293.20	1.90	Boulders and gravel
3	43.30	13.80	Saturated gravel and sand
4	21.00	6.00	Saturated gravel and mud
5	07.80	24.00	Saturated mud
6	97.60	24.10	Wet stony layer
7	23.60	30.20	Saturated gravel and mud
8	13.60	∞	Saturated mud

VES (13) Dier Alla Well NO2 (N 32^{0}11.13 E 35^{0}36.92)			
Layer	P ohm.m	T m	Layer description
1	39.70	0.80	Wet gravel and sand soil
2	10.90	3.70	Saturated mud
3	06.32	26.50	
4	40.35	06.00	Saturated gravel and sand
5	22.62	24.60	Saturated gravel and mud
6	18.30	∞	Saturated mud and marls

VES (14) North of Deir Alla (N 32^{0}11.96 E 35^{0}36.28)			
Layer	P ohm.m	T m	Layer description
1	09.05	0.40	Saturated stratified mud, and marly soil
2	17.52	1.00	
3	10.52	3.00	
4	04.42	13.40	
5	08.04	24.00	
6	12.18	33.50	
7	05.10	∞	Lisan formation

VES (15) Wadi El Rayan (N 32^{0}20.66 E 35^{0}35.22)			
Layer	P ohm.m	T m	Layer description
1	63.15	0.5 0	Dry stony soil
2	15.45	0.95	
3	13.50	2.33	
4	15.56	9.94	
5	33.70	15.67	Wet stony layer
6	61.43	18.90	
7	18.66	44.68	Saturated gravel and sand
8			Saturated gravel, sand, and mud
9	04.15	∞	Lisan formation

Table (2) Exhibits the geoelectrical interpretation of VES (9-15)

Relation between resistivity and porosity of water bearing layers

Farber e.t al (2007) elucidate therole of deep brines on the chemical composition of the regional groundwater resources in the Jordan Valley.Since resistivity of the water bearing formation is closely related to its water content, which in turn depend on the porosity and conductivity or resistivity. This relation was formulated empirically in what is well known as Archie's law

$$\boldsymbol{p} = \boldsymbol{p}_w \boldsymbol{\varphi}^{A-m}$$

$\boldsymbol{p}$ is the bulk resistivity of rock, and $\boldsymbol{p}_w$ is the resistivity of formation water.
$\boldsymbol{\varphi}$is the porosity expressed as a fraction per unit volume of the rock.
A and **m** are parameters whose values are assigned arbitrarily to make the equation fit particular group of measurements Koefoed(1979).

The value for parameter Avaries from slightly less than one for the rocks with intergranular porosity to slightly more than one for the rocks with joint porosity.

The exponent **m**is somewhat **> 2** for cemented and well sorted granular rock type and somewhat **< 2** for poorly sorted, poorly cemented granular one.

For the first approximation, value of 1 may be assumed for **A** and value of 2 for **m**. this simple inverse square relationship between resistivity and porosity will provide about the same answer as more exact equations in the normal porosity range 10-30. Practically the uncertainty in proper numerical values of **A**and **m** is less serious than the uncertainty in the resistivity of water in the formation pores.

Approximation for porosity of the alluvial fan strata could be made depending on electrical conductivity (EC) field electrode reading in (µS/ cm).The measured value could be converted to resistivity value. The Siemen(**S**) unit of electric conductance is defined as the conductance of a circuit or element that has a resistance of one ohm.

Measurement of electrical conductivity from Aian El Buwiab and Nakhiel El Buwiab in summer and winter in addition topeexisted measurementswork out an average value of 2464 µS/cm which is considered as representativefor water conductivity contained in the alluvial fans formations.This value is converted to resistivity value according to Siemen definition as follow:

$$\mathbf{2464/\ 10^{-6}\ *1000 = 2.464 \approx 2.5\ ohm.m}$$

Substituting this later value for ($\boldsymbol{p}_w$), and interpreted aquifers resistivity for ($\boldsymbol{p}$) in Archie's formula work out the following porosity estimations forbothgravellymud dominated layer, and gravelly sand layer table (3).

VES NO	Location	Layer description	Resistivity ohm.m	Porosity %
1	Suleikhat	Gravel and sand	35	27
2	Wadi El Rayan	Gravel and sand	40	25
6	Abu Obeida mosque	Gravel, sand, and mud	26	31
		Gravel and sand	35	26
7	Wadi El Rayan along main road	Gravel and sand	33	27
		Sandy gravel	61	20
14	Deir Alla	Sand and gravel	40	25
		Clays and gravel	22	33

Table (3) Exhibits the calculated porosity ofaquifers within the alluvialfans

From the table the following porosity group can be differentiated:

- **Gravel sand layer → Porosity group (20- 27).**
- **Gravel and mud layer → Porosity group (30- 35).**

Conclusion

The aquifer systems in the study area were consist of:

Ajlun and Belqa Groups formations, and/or their combinations.
The plateau gravel group and the alluvium aquifer system in JV.
The average encountered thickness of the alluvial fan deposits is 93 meters.
Layers that are considered as potential aquifers within the alluvial fan deposits are those with resistivity ranging from 30-60 ohm.m, which is dominated by sand and gravels. Their thickness vary from 80-42 meter.
The porosity of potential aquifer (gravelly sand layers) within alluvial fan is approximated to 20-27%. There are frequent muddy gravel layers, with porosity range approximated to 33%, and their thickness vary from 5 to 23 meters.
Lisan formation whichunderline most of the formation in the study area is the source of the salinity hazard.

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