Using Electromagnetic Radiation (EMR) and Continuous Vertical Electrical Sounding (CVES) to Locate Zones of Weakness for Submarine Groundwater Discharge (SGD)

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Abstract

The geophysical techniques; the electromagnetic radiation and vertical electronic sounding were used in this study for achieving our goals. The major objective of this study is to investigate and evaluate the active faults, fractured zones and the subsurface sinkholes along the Eastern shores of the Dead Sea. The faults and the fractures consider weakness zones of the submarine groundwater discharge. Then by determining the subsurface structures, features control the submarine groundwater discharge into the Dead Sea. The first EMR profile was started at coordinates 31° 410 28.1800 N and 35° 340 38.8700 E at the South Sweimah area at the northern part of the Dead Sea. Many fractured zones were found along this profile. A main highly fractured zone was observed at a distance between 790 and 1500 m to the north of the starting point. Another one was observed between 880 and 1000 m to the north of the starting point. A few sinkholes were observed between distances of about 890 m and 1265 m to the north of the starting point. The main sinkhole was recognized at a distance of 2718 to 2730 m to the north of the starting point. The second EMR profile was carried out at the coordinate of 31° 4362.700 N and 35° 35 33.400 E. The geological features were found at distances of 2455 to 2460 m from the starting point and many of the active fault and joints were found along this profile at distances intervals of about 310-315 m, 660-665 m and at 695-700 m from the starting point. The main interesting areas were found at the distance of 2440-2450, 2635-2643 m from the starting point. The main fractured zones were found between 2490 and 2505 m and from 2330 to the end of the profile at coordinates 31° 45′ 45.07″ N and 35° 34′ 33.48″ E. The vertical electrical sounding profile shows that The first shallow zone is located at offset between 0 and 40 m the second zone located at offset between 320 and 390 m and 12 m deep from the surface. The vertical distortion of resistivity values at horizontal distances 240 m represent may due to shallow fault.

Keywords: Electromagnetic Radiation, Fault, Sinkholes, Subsurface, Fractures, Dead Sea, vertical electrical sounding.

1 Introduction

The Dead Sea is a hypersaline terminal lake with a surface area in 2004 is approximately 634 km2 and its border is approximately 148 km [7]. A large parts of the Dead Sea area characterize as a highly karstic and fractured rock. The Dead Sea area has been controlled through the geological history by two factors the Tithys Ocean, which invaded the region several times, depositing the marine successions and the presence of the neighbouring Arabian Shield in the south, which displayed an important source for sediments [3]. The study area is located at the northern corner of the Dead Sea fig. (1). The study area includes the area at Sweimah and the area at the southern part of the Sweimah.

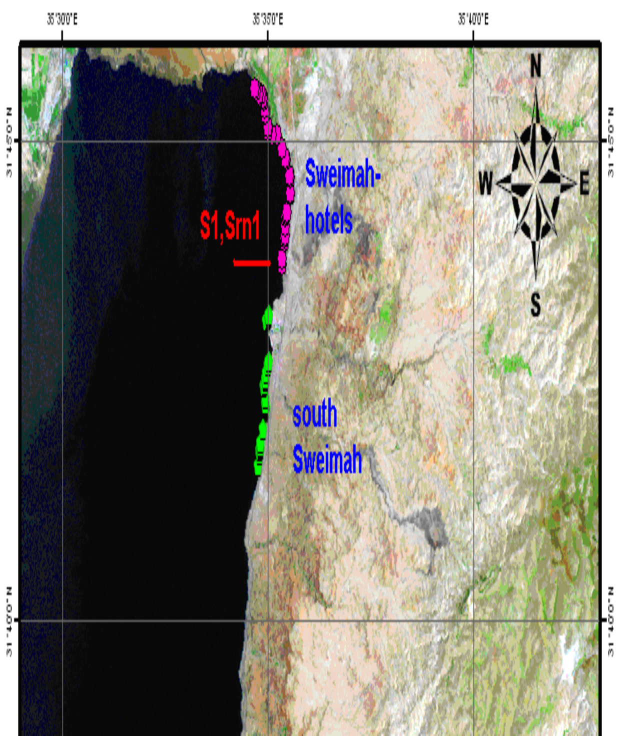


Fig. 1: The satellite image of the study area

Jordan is water stressed country and lacks for enough water resources. Therefore the deficit in the water supply was estimated at 238 MCM in 2005. This deficit is expected to rise to about 408 MCM in the year of 2020. This is because of the water demand in the country is much higher than the water supply (i.e. the water supply don't satisfy the country needs) from which emerge areal problem must be solved.

The main aim of this study is to locate the zones of weakness at the northern part of the Dead Sea and the fault hazards of the area surrounding the Dead Sea. The active faults, sinkholes and the fractured zone along the eastern shores of the Dead Sea considered as a zones of weakness for the submarine groundwater discharge (SGD). The term SGD has been used in different ways over the years. [13] defined SGD to be the net groundwater discharge to the ocean, which comes essentially from recharge. [5] defined SGD to be direct groundwater outflow across the ocean-land interface into the ocean, which would include re-circulated seawater. [6] Considered SGD to be the sum of net groundwater discharge, outflow due to wave-setup-induced groundwater circulation, and outflow due to tidal driven oscillating flow.

The drop of the Dead Sea level will have an effect on groundwater by increasing the head differences between the Dead Sea and the groundwater levels in the surrounding areas. Then the groundwater drainage is expected to increase toward the Dead Sea [9] and [12]. The decline in the Dead Sea level also accelerates the discharge of groundwater into the Dead Sea [10]. Around 423 MCM (million cubic meter per year) of the groundwater discharge to the Dead Sea for every meter drop in the level of the Dead Sea for the period between 1994 and 1998. This amount of fresh water discharging to the Dead Sea decreased to 370 MCM in 2000 as a result of exploitation mismanagement of water, which formerly fed the Dead Sea. The area underlying the coastal aquifers already occupy by the Dead Sea water. They become gradually flushed and occupied by freshwater. This freshwater become saline due to the residuals of the Dead Sea water in the aquifer matrix [11]. Submarine groundwater discharge zones were determine by [1]. They used the thermal infra - red aerial photography method. They found that there are many zones of weakness for a submarine groundwater discharge into the eastern shores of the northern part of Dead Sea.

2 Geological and Structural Aspects

The geology of the Dead Sea area is quite complicated and includes both unconsolidated superficial lithology and bedrock outcrops. The area is characterized by a highly faulted with different trends and folded with a synclines extending from southeast to northwest along the Dead Sea. The faults at the area occurred due to a compression forces during the Late Cretaceous to Tertiary. These faults reactivated in Quaternary times and new faults, fractures and discontinuities created. These considered as a weakness zones for the discharge.

The bedrock is typically highly fractured at the surface and subsurface extending greater than 10s of meter deep. The fractures are often composed of two sets of vertical fractures at approximately right angles to each other, and a third, nearly horizontal, set. They may be observed directly in exposed bedrock. These fractures are widely distributed throughout the Dead Sea area.

These fractures are the principal sources of secondary permeability in many bedrock aquifers and then the recharge occurs chiefly through these faults and fractures. Then might be serving as paths for groundwater lateral and vertical movements.

Mountains, hills and Wadies characterize the topography of the Dead Sea area; the topography of the mountains commonly having steep slopes from east to west toward the Dead Sea coast**.**

As well the Dead Sea area is characterized by high differences in the hydraulic head, which provide the impetus for groundwater movement from the high head to the low head.

Cretaceous rocks cover the eastern part of the investigated area, while westwards; the oldest formations are of middle Cambrian age. Close to the eastern shoreline of the Dead Sea, Triassic and Lower Cretaceous rock crop out. Volcanic eruptions occur in many places of the area but mostly in the western part along the Dead Sea coast. The stratigraphical lowest outcropping member is the Cambrian; Umm Ishrin formation, which consists of sandstone followed up by Triassic Zarka Ma'in group consisting of sandstones, limestone and shale that named Suwayma Sandstone limestone Shale (SSL). The upper part of the foirmation crops out in the central part of the study area. It consists of fine to coarse grained quarts arenites, silty shale and carbonates. It divided into three members only the upper two members outcrops in the study area. The Dardur and Ain Musa members. The lower part of the Dardor member consists of thinly bedded dolomitic limestone, laminated shale and marl. The middle part composed of cross-bedded white sandstone with marl and thin bands of dolomite and siltstone. The upper part consists of dark green shale, siltstone and sandstone with clay and dolomitic limestone. The Ain Musa member consists of three sub members: the lower member consists of sandstone and coarse grained sandstone separted by silty limestone and dolomitic limestone. The middle Jamala sub member is well exposed at the confluence of wadi Jamala with Wadi Ain Musa. It consists of intercalated siltstone, clay beds and sandstone. The thickness of the Suayma Sandstone Limestone Shale is about 140 m. followed up by the Lower Cretaceous Kurnub sandstone and the Upper Cretaceous Ajlun group being mainly a carbonate-dominated sequence. Belqa group Upper Cretaceous - Tertiary follows it. This group is missing in the end northern part of the study area. The youngest geological units are the Quaternary Lisan marl of Pleistocene age [4] and the basalt flows dated 0.6 Ma BP.

Topographically the study area described as a steep escarpment along the eastern shoreline of the Dead Sea controls the morphology of the Dead Sea area. The difference in the elevation between the Dead Sea Surface and the highlands surrounding the Dead Sea is between 1210 and 1600 m within of 15 Km horizontal distance to the East of the Dead Sea.

Most of the structural features in the study area are parts of and influenced by the prominent outstanding structural feature affecting the whole are along Jordan Graben. The Dead Sea Transform in Jordan is composed of three morphotectonic segments; Wadi Araba at the south, Dead Sea at the middle and Jordan Valley at the north. Zarka Main fault commences at the Dead Sea and continues eastwards. The downthrown of this fault is about 250 m near the Dead Sea. The downthrown decreases eastwards and turns over in a flexture. On the southern part of this fault basaltic eruption occurred at the downthrown block. Amman-Halabat structure is - NE-SW trending. El-Maslubiah fault. Humrat Ma'in fault is parallel to the Dead Sea coast in the southern part between Wadi Zarqa Ma'in and Wadi Manshala. It appears 2 km east of the Dead Sea coast at its southern part and 4 km distance from the Dead Sea at its northern end. It trends NE–SW and the downthrown is the NW block.

The main aquifers in the area are Amman –Al-Hissa-Wadi Essir aquifer system (B2-A7). This forms one of the most important and extensive aquifer systems in the study area. It consists of two formations: The Wadi Es-Sir (A_7) and Amman silicified limestone (B_2).
The B_2-A_7 aquifer system receives direct recharge from precipitation, which infiltrates through the soil and rock covers [8] and indirect recharge from the adjacent aquifer and from the surrounding areas. But the direct recharge is limited in some areas located farther to the east of the Dead Sea due to overlying by lower permeability strate the Muwaqqar Chalk Formation (B_3).

Lower aquifer system. This aquifer system includes the sandstone formations of different ages. The formations are Kurnub Sandstone of Lower Cretaceous age, Zarka sandstone of Triassic age, and Ram sandstone of Camprian age. These aquifers are interconnected. The aquifer system crops out along the Dead Sea Shore and in the lower reaches of Wadi Zarqa Ma'in and Wadi Waleh-Heidan, with a thickness of more than 600 m along the northern part of the Dead Sea in Wadi Zarka Ma'in and Hidan.

There are also two minor aquifers in the Dead Sea area. Na'ur aquifer (A_{1-2}) consists of limestones intercalated with thick sequences of marl. It crops out in the Dead Sea area. This aquifer becomes turns into an aquitard locally to the east of the Dead Sea. The second minor aquifer is Hummar (A_4). It consists of dolomitic limestones with a secondary permeability due to the presence of fractures and joints.

3 Methods and Materials

The instrument, which was used for performing these measurements named Cerescope as shown in fig. 2. The Cerescope is a scientific instrument for detection and registration of transient pulses of electromagnetic radiation (EMR), which produced by nanofractrures, and by piezoelectric, turboelectric or pyroelectric effects [2].

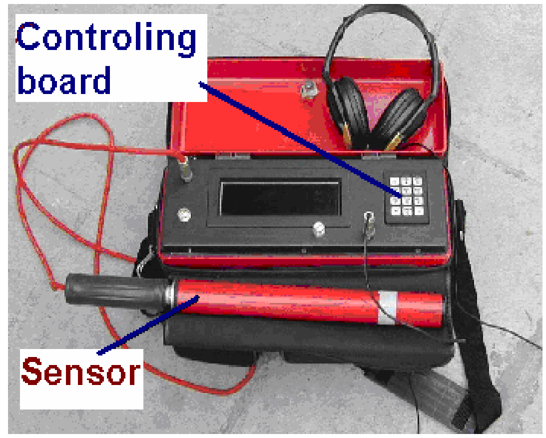


Fig. 2: the electromagnetic radiation instrument (Cerescope)

This method is depending on the measurement of natural pulsed low frequency electromagnetic radiation (EMR) signals. Generally, in geosciences the detection and analyzing of these signals can assist to conceive and understand deformation processes. The electromagnetic radiation starts during crystal deformation superior to and at the same time of the nucleation phase of nanocracks. Where the more fractures are formed the more electromagnetic Pulses are emitted. The emission and radiation direction is normal to the fracture surfaces because of the polarization (Obermeyer, Personal communication). The principle of this method is the energy release from the fault and fractured activities. These are considered as zones of weakness of the groundwater discharge.
Several different profiles were carried out in the study area. The first profile was carried out in Sweimah area. The beginning of the profile was at the coordinate 31° 43′ 62.7″ N and 35° 35′ 33.4″ E, and the end of the profile was at the coordinate 31° 45′ 45.07″ N and 35° 34′ 33.48″ E. The long of this profile was about 4 km.
One profile with a length about 3 km was carried out at south Sweimah area. This profile denoted as second profile. The starting point of this profile was located at the coordinate 31° 41′ 28.18″ N and 35° 34′ 38.87″ E, and the ending point was at the coordinate 31° 43′ 19.6″ N and 35° 35′ 08″ . Each profile subdivided into many subdivisions to make the whole profile easier for interpreted.
The second method was used in this study is the Continuous Vertical Electrical Sounding (CVES). This method was used for the determination of the different lithological units including their thickness and depth to

the water table. It also locates faults, dykes and other geological structures. Vertical electrical sounding survey of an area begins with a number of the depth sounding using the four-point method. There are done in selected locations in the field, depending on the objective, a net or profile-arrangement is used. The spacing of the sounding points may also be varied.
In each single sounding, direct current is applied to the earth through current electrodes. The equipotential surface (surface of equal voltages) runs perpendicular to the current lines. There is also a potential distribution on the surface of the ground. The surface potential reflects the resistivity (ρ) of the geological layer beneath it. The physical dimension of specific resistivity is ohm. Meter (ohm-m). Resistivity (ρ) can be determined from the current (I) flowing through the ground between the current-electrodes A and B and the voltage (V) is measured between the potential-electrodes M and M as shown in figure 3.

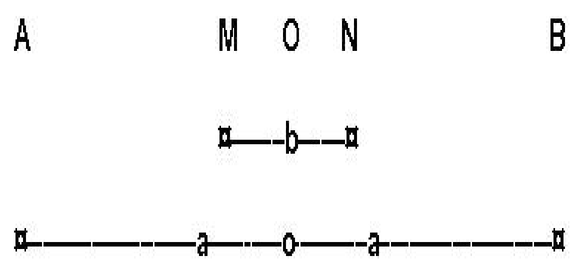


Fig. 3: The Schlumberger schematic diagram

The calculate resistivity in independent of the contact resistance's at the electrodes. If (I) is the current between the starting and ending points of the profile, and (V) is the voltage measured across the two points in the middle of the profile, then the apparent resistivity (ρ_a) is given by the following formula

$$\rho_a = K\, V/I \text{ ohm-m} \quad (1)$$

K is a constant value. It is depending on the spacing AB and MN of the current and potential-electrodes respectively.
In the case stratified material, the current preferentially travels in the highly-conductive layers. The current lines are refracted at interface between layers of different electrical resistivity. The resistivity depends quite strongly on the distance between the two current-electrodes A and B. When the values for resistivity (ρ_a) are plotted on a log-log paper against AB/2, the so-called sounding graph is obtained. In practice, at a single sounding point, measurements are taken at different electrode-spacing AB, varied by moving the current electrodes A and B to different positions.

(A and B) are the current electrodes, (M and N) are the potential electrodes, (O,o) are the mid points, (a) is the half distance between the current electrodes (A,B), (b) is the distance between the potential electrodes (M,N), where AB≥ 5 MN.
The distance the resistivity in terms of the electrical field (E) rather than the potential deference (ΔV) can be obtained from the following equation

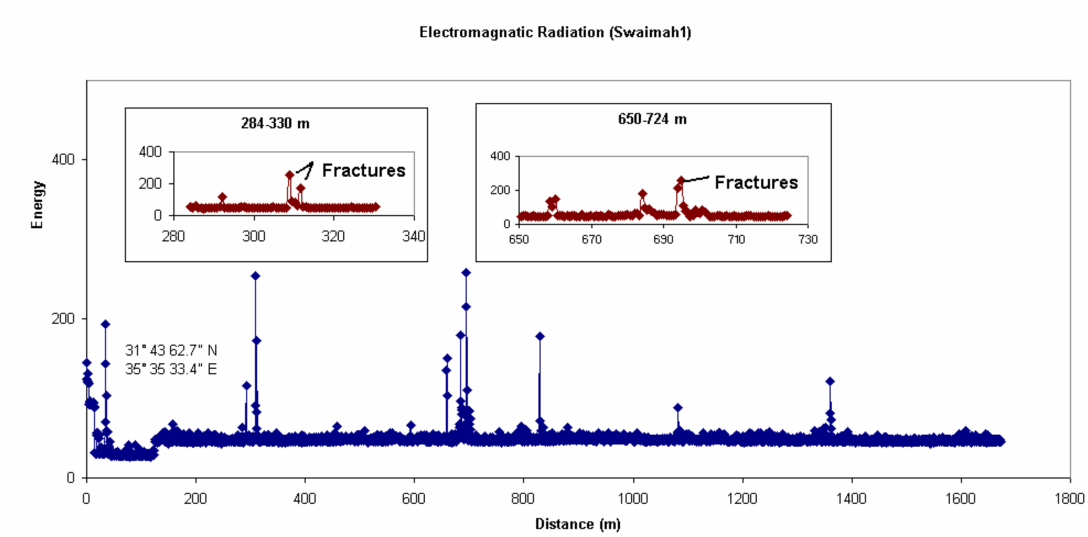
$$\rho = \pi\, (AB/2)^2 .\, E/I \quad (2)$$

Where E= lim. (ΔV/MN)/MN=electrical field
(MN) is the distance between the potential electrodes. The above equation shows that the Schlumberger apparent resistivity (ρ_a) is a function of a signal distance-variable (AB/2).
The specific electrical resistivity of rocks and the electrical conductivity of a sediment is essential electrolytic, and consequently depends on the nature amount and concentration of the electrolyte in the voids of the sediments.
High conductivities and thus low specific resistivity are typical of sedimentary layers bearing large amount of water with a high electrolyte concentration. In this case the presence of pore spaces, Joints and fractures in sediment is clearly essential. Clayey sediments are relatively good electrical conductors. Because of they consist of very fire grains having the highest porosity and the lowest permeability. So groundwater remains in the tiny pores of the clays. It is difficult to distinguish between clayey sediments and unconsolidated sediments bearing water with a high electrolyte concentration from resistivity values only. In both cases, the electrical resistivity lies approximately within the range of 1-50 ohm-m. Additional information is required in this case. However, in most sediment, the resistivity is essentially dependent on the percentages of clay and marl, so that resistivity values are indicative of grain size of the sediments. Dry rocks with no clay component show very high resistivity values (≥1000 ohm-m). One VES profile was carried out along the shores of the Dead Sea. This

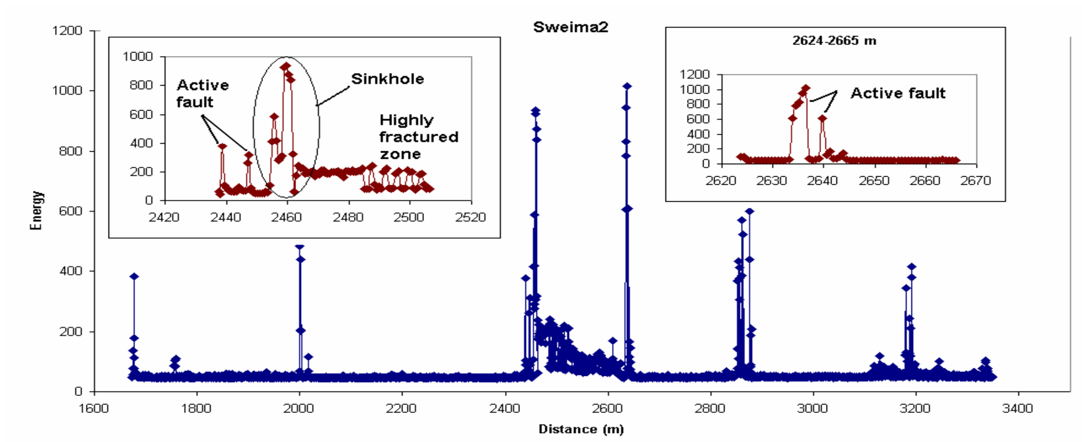
profile was carried out at the direction of north south with a length of 475 m.

4 Results and Discussion

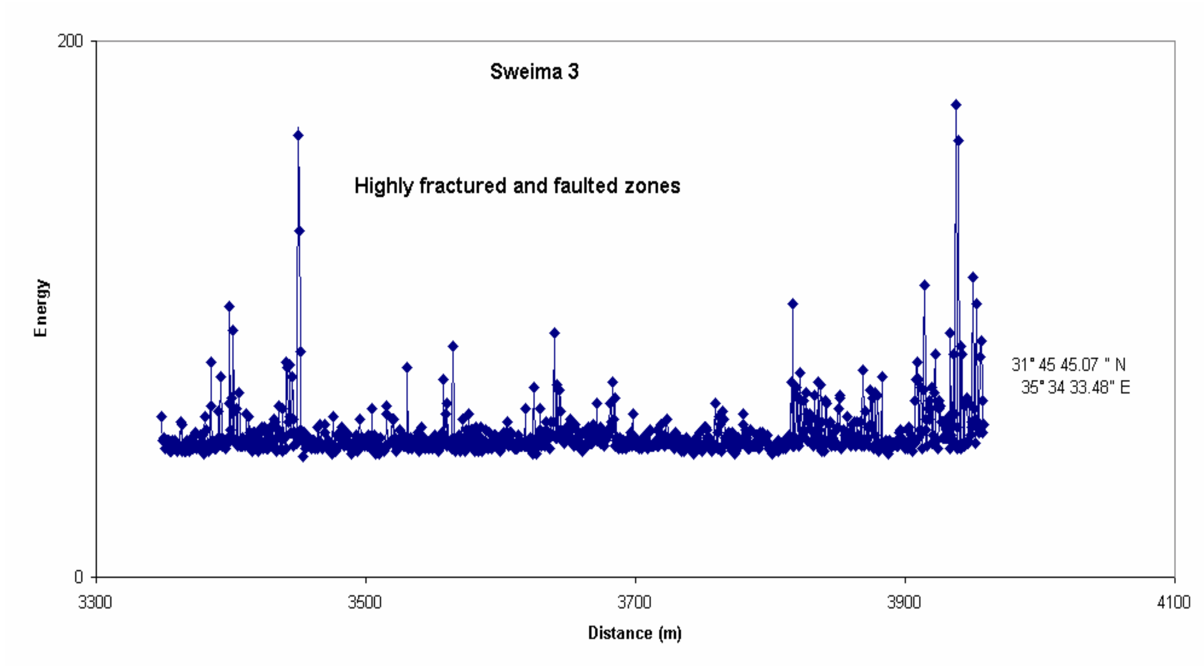
By interpretation, the profiles of EMR the following results have been obtained. High energy was observed in a distance of about 300 m from starting point. The sinkholes were found at distances of 2455 to 2460 m from the starting point and many of the active fault and joints were found along this profile at distances intervals of about 310-315 m, 660-665 m and from 695-700 m from the starting point. The main interesting areas were found at the distance of 2440-2450, 2635-2643 m from the starting point. The main fractured zones were found between 2490 and 2505 m and from 2330 to the end of the profile at coordinates 31° 45′ 45.07″ N and 35° 34′ 33.48″ E with a distance of about 650 m. Fig. (4 A, B and C) shows the results of the EMR in the Sweimah area.



A



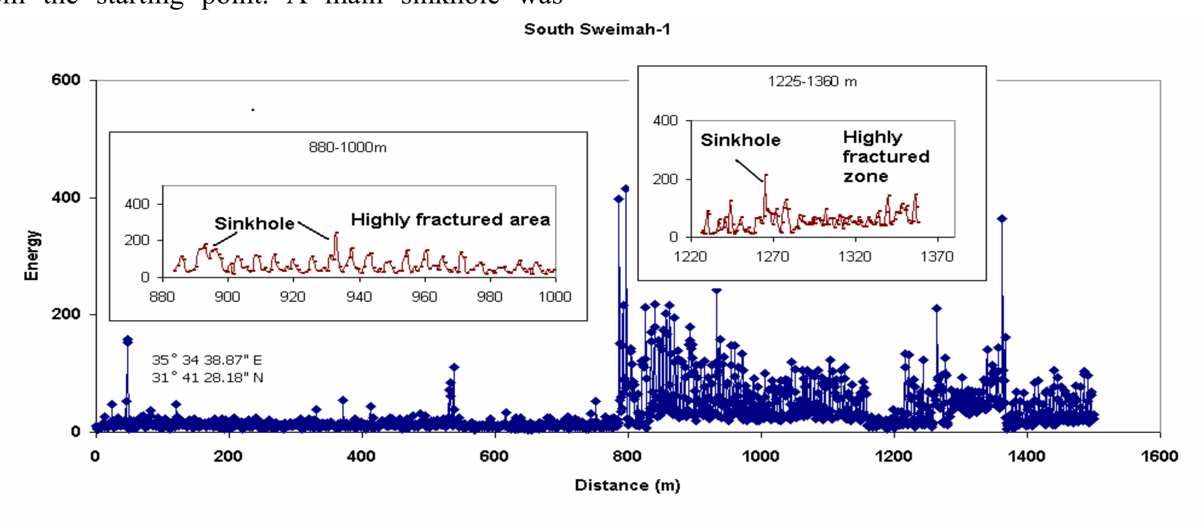
B



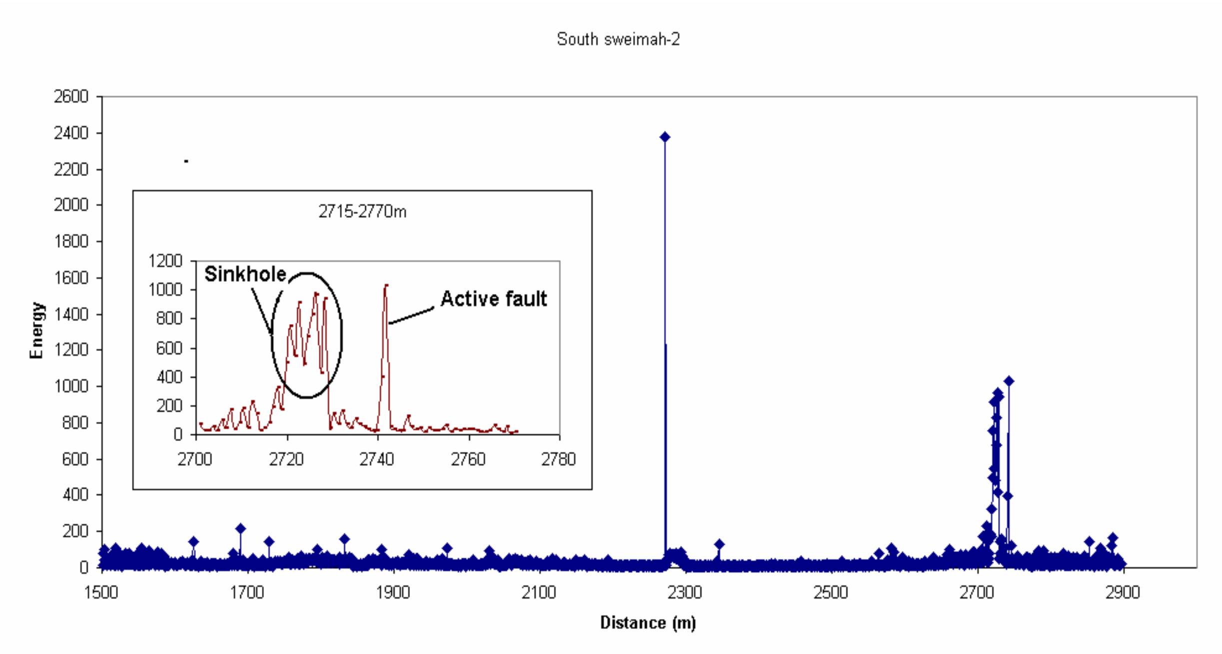
C

Fig. 4-A, B, C: Magnitudes of EMR in Sweimah area.

Many fractured zones at south Sweimah profiles were observed along the profile. A main highly fractured zone was observed at a distance between 790 and 1500 m from the starting point and another one between 880 and 1000 m. A few sinkholes were observed between distances of about 890 m and 1265 m from the starting point. A main sinkhole was recognised at a distance of 2718 to 2730 m from the starting point**.** Fig. (5 A and B) shows the EMR results in south Sweimah area.



A



B

Fig. 5 A, B: EMR results in south Sweimah area

Fig. 6 shows the cross section of the resistivity along the CVES profile which carried out for the study area. This profile shows that low resistivity dominates along the profile less than 50 Ohm-m. Two main high resistive zones with resistivity more than 250 Ohm-m were detected along this profile. The first shallow zone is located at offset between 0 and 40 m the second zone located at offset between 320 and 390 m and 12 m deep from the surface. The vertical distortion of resistivity values at horizontal distances 240 m represent may due to shallow fault.

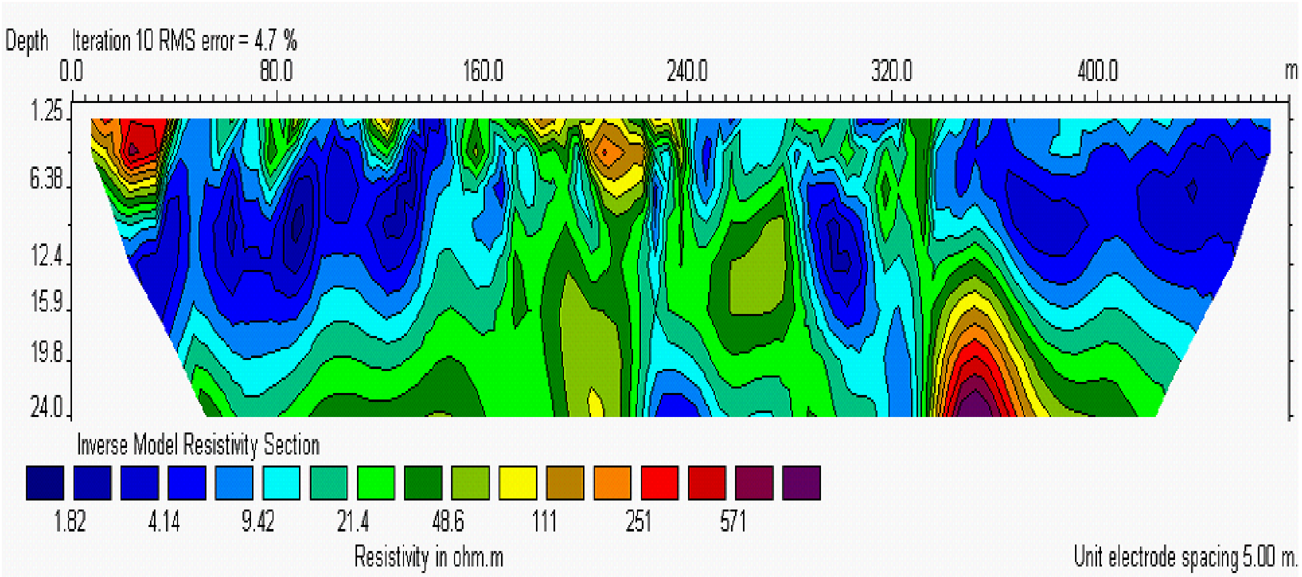


Fig. 6. Resistivity cross section along profile 1.

5 Conclusions

The geophysical techniques as the EMR and VES show a very useful for determining the shallow faults and fractures. As well the EMR is a useful technique for determine the buried (subsurface) sinkholes or underground Karst and fractures. These geological features including faults, fractures and buried sinkholes are considered as a zones of weakness for the submarine groundwater discharge along the eastern shores of the Dead Sea. The shallow faults that determining from the two techniques are coincide. By using the two geophysical techniques many faults, fractured zones and buried sinkholes were observed. These findings were coincide with the previous studies that used another technique to determining the zones of weakness of the submarine groundwater discharge into the Dead Sea.

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