Contribution of Electrical Resistivity and Ground Penetrating Radar Techniques for Tracing Sea Water Invasion and Industrial Effluents in the First Industrial Zone, Jeddah, Saudi Arabia.

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Abstract:

Vertical Electrical Soundings (VES) and Ground Penetrating Radar (GPR) were conducted in several locations within the first industrial area in Jeddah to trace the zones probably invaded with sea water and/or the zones of accumulated landfill pollutants. Five VES's were carried out within the study area; the Schlumberger array with a maximum electrode spread of 300 m was employed in all the points. The GPR survey was conducted using SIR3000 instrument with the 100 MHz antenna, 8 GPR lines with average length 150m, each GPR was measured at different localities in the study area based on the results of the VES`s results. The electric resistivity data were interpreted using the IX1D V2 software. The constructed geoelectric cross section based on the results of sounding data show that the area is generally underlain by four geoelectric layers: the first geoelectric layer has a resistivity ranging from 28 – 56 Ω.m and average thickness 1.3 m (wadi deposits of sands and gravels); the second geoelectric layer has a resistivity ranging from 2.3 – 7 Ω.m and average thickness 9.8 m (wadi deposits saturated with sea water); the third geoelectric layer shows a resistivity ranging from 0.5 – 1.2 Ω.m and average thickness 24.5 m (wadi deposits highly saturated with sea water); and the fourth geoelectric layer shows a resistivity ranging from 7.7 – 87.6 Ω.m and extends to the maximum depth of exploration (fractured basement). The significant GPR signature of the saturated layers was well characterized indicating the shallowness of ground water level in the study area. In addition, it showed trace contaminated zones in the study area caused by defects in the drainage system of heavy factories. It is also observable the compatibility of the electrical resistivity and ground penetrating of radar survey.

Keywords: *Electrical resistivity, Ground penetrating radar, sea water, ground pollutants, industrial zone.*

Introduction

As water demand and the amount of disposed waste increase with population, effective land-use planning and management is needed to protect ground-water quality.

Some Specific industries consume a large quantity of water and generate a huge amount of wastewater, which are generally discharged into a common effluent drain of industrial area. The composite effluents from these industries (textiles and food) in Jeddah city consisting high concentrations of heavy metals, and organic pollutants, which may affect the quality of ground water in/and around the study area.

In order to delineate the problems caused by saline intrusions and contamination of industrial waste water that may affect the quality of groundwater, different geophysical methods have been employed. The application of borehole surveying is intrusive, cumbersome, quite expensive, and involves a large time frame. So, this paper investigated the effectiveness of the use of non-intrusive surface geophysical techniques (Electrical Resistivity and Ground Penetrating Radar) to map and delineate the fresh/saline-water interface and zones of industrial contamination in the 1^{st} industrial zone, Jeddah, Saudi Arabia. Consequently the study of saline intrusion is crucial in order to avoid extracting saline-water for consumption and general usage in gardening, irrigation, and industrial purposes (Obikoya, and Bennell, 2013).

The investigation of seawater intrusion in freshwater aquifers has been based on geophysical techniques especially the electrical resistivity and electromagnetic methods which relies on resistivity contrasts as the seawater intruded zone is approached, (Goldman et al., 1989; Fitterman and Deszcz-Pan, 2001; Kontar and Ozorovich, 2006; Khalil, 2006; Al-sayed and El-Qady, 2007); their studies were carried out in the proximity of seas. The presence of seawater causes groundwater to be considerably saline, hence the aquifer resistivity is reduced considerably, and the resistivity method can delineate the boundaries of the body of saline water. The fact that a resistivity contrast exists at the interface between fresh and saline water is sharp, the resistivity method has proved useful.

Combining electrical resistivity (ER) and Ground Penetrating Radar (GPR) techniques partially compensates for their individual shortcomings. The electrical resistivity technique is one of the geophysical methods, which enables the determination of subsurface resistivity by introducing artificially produced electric current into the ground through a set of two electrodes, and measuring the potential field generated by the current by the aid of another set of two electrodes. Electromagnetic induction profiling is a surface geophysical technique, which is used to measure terrain conductivity, that is, the bulk electrical conductivity of subsurface materials. It employs a changing primary dielectric contrast of electromagnetic waves that penetrated through the subsurface layers.

Soomro 1993, and Rosalo-manana 2001 also described ER and GPR methods as being well suited for coastal aquifer studies because of the large contrast in resistivity between freshwater-bearing and saltwater-bearing formations. The high electrical conductivity of saline-water made the electromagnetic and electrical resistivity techniques particularly appropriate for this study.

Study area

Location:

The first Industrial Zone lies within the western province of Jeddah city, it is bounded by latitudes 21˚23'00" and 21˚27' 00" N, and longitudes 39˚ 12'00" and 39˚16' 00" E. The city is bounded from the west by the Red Sea and from the east by several mountain chains with the maximum elevation of about 500m above the sea level. Most of the drainage systems have dissected the area starting from these mountains, which lies about 30 to 40 km inland, and proceed towards the coastal plain and the Red Sea (Fig. 1).

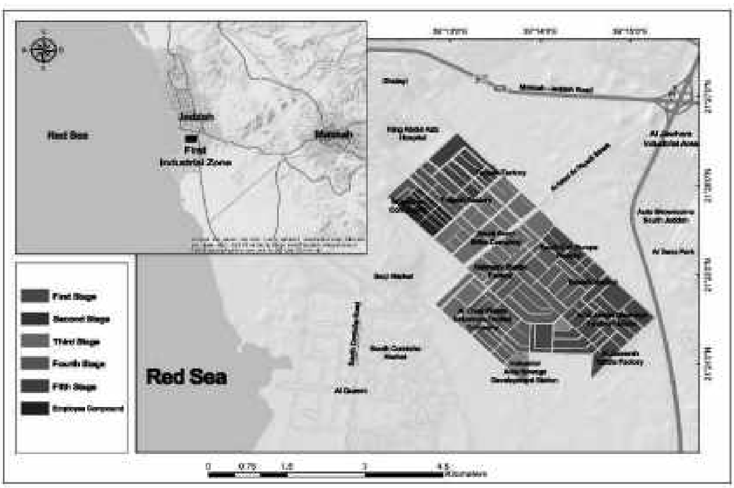


Fig. (1): Location map of the first industrial zone area, Jeddah city.

Geomorphology:

The study area comprises three distinct geomorphological zones; the Red Sea and shore features, the coastal plain and coastal hills and pediments (Fig. 2). The last zone lies east of the first industrial zone as well as the municipal Jeddah city and consists of low lying hills, and an elongated N-S oriented depression, forming a basin that lies within the coastal hills.

The Red Sea displays landforms that characterize prograde shorelines; implying that the Red Sea is recently in regression. Such features include flat lying sandy beaches, lagoons, sabkhas, sea islands, bars and spits, as well as the raised dead coral terraces and marine limestones exposed inland.

The drainage in the area consists of a large number of systems. These systems are, from north to south: Wadi Al-Muharraq, Wadi Al-Hafnah, Wadi Abu Jaffalah, Wadi Kathanah, Wadi Ushayr, Wadi Mathwab, Wadi Ghulayl, Wadi Al-Khumrah and Wadi Fatima. All of these systems drain westwards towards the Red Sea, except Wadi Fatima that abruptly diverts direction to the north at its lower course along the coastal plain and this could be attributed to active faulting.

Many researchers have investigated various aspects of geomorphology, hydrology and drainage morphometry within and around Jeddah Governorate (Abdulrazzak et al., 1988; Basmaci and Al Kabir, 1988; Basmaci and Hussein, 1988; Abu-Rizaiza et al., 1989; Sorman and Abdulrazzak, 1993; Abu-Rizaiza and Sarikaya, 1994; Gutub and Awadalla, 1994; Onder, 1994; Shehata et al., 2001).

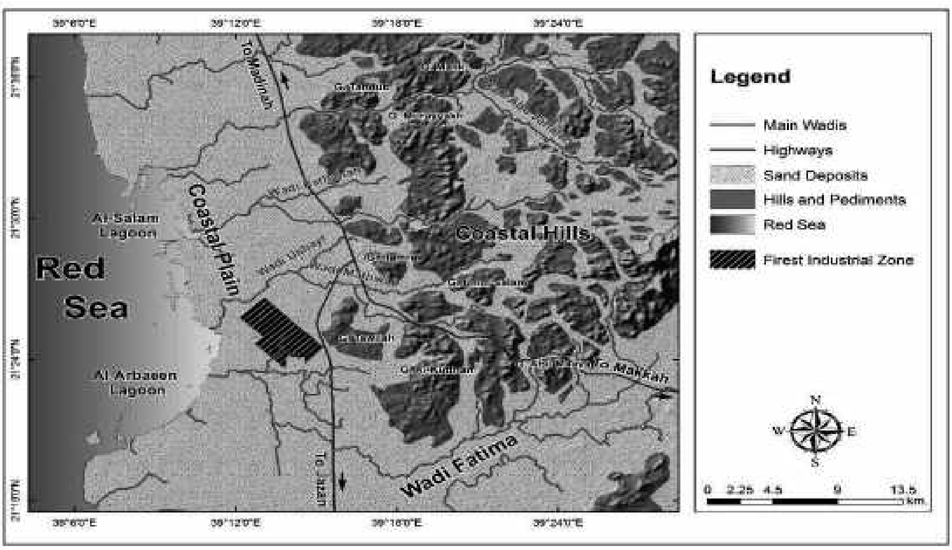


Fig. (2): Geomorphological map of first Industrial zone area, Jeddah city.

Geological setting:

Three distinct geologic units could be distinguished in the study area; these are from oldest to youngest: The Neoproterozoic basement complex, the Tertiary sediments and lavas, and the Quaternary sediments and sabkhas (Qari, 2009). The Neoproterozoic rocks lie in the eastern part of the area, which is mostly covered by the Red Sea hills and pediments. They consist of volcanic rocks (andesite and dacite), intruded by plutonic rocks (diorite and granite). The Tertiary rocks are present in the first Industrial zone that includes Shumaysi, Usfan, and Hadat Ash-Sham formations which is covered by basaltic lavas. The Quaternary unit includes the recently emerged marine deposits and corals. These rocks include the recent basaltic lava flows, the wadi alluvium, sabkha deposits, and the aeolian sands which are located along the coastal plain and pediments (Moore & Al-Rehaili, 1989), (Fig. 3).

The distribution of the geomorphologic units across the area, as well as the previously mentioned lithologic units is strongly controlled by the structures. As the area constitutes a portion of the Red Sea coast, it is implicit that it shared the history with the Red Sea rift that evolved during the Tertiary time through a series of tectonic events that resulted in the Red Sea rift. Therefore, the tectonic events that brought about the Red Sea rift had their impact on the evolution and development of the litho-stratigraphy and geomorphology of the area.

The borders of the geomorphologic zones are aligned concordant to the Red Sea shore and is generally aligned in NNW direction. This alignment is as well concordant with that of the faults that formed the Red Sea Rift as a spreading ocean (Schmidt et al., 1981).

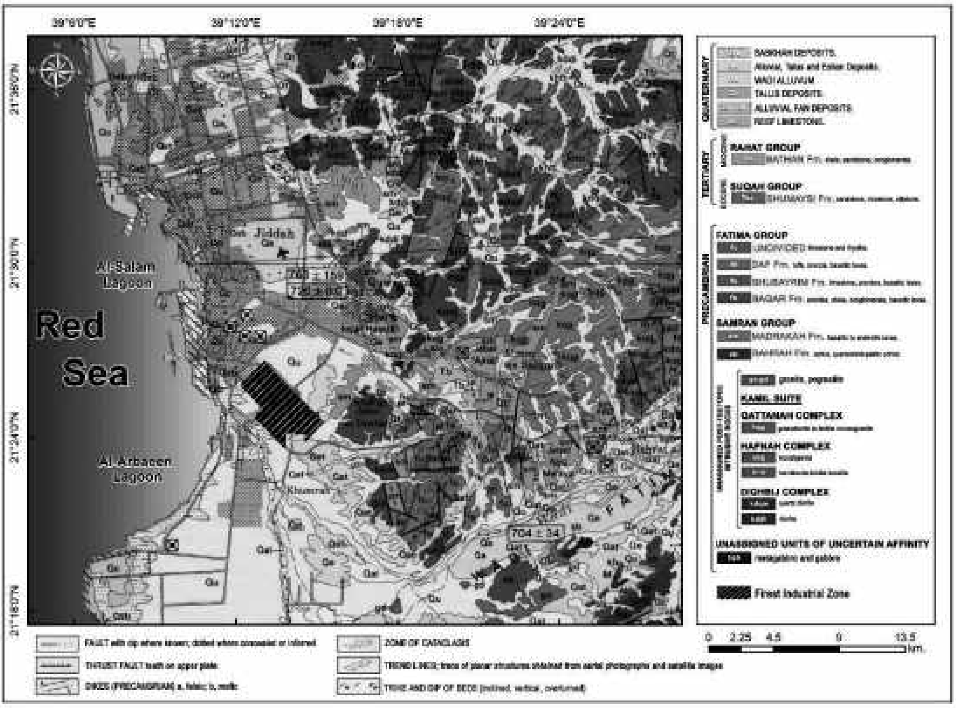


Fig. (3): Geological setting map of 1st industrial zone area, Jeddah city.

Methodology

A geophysical survey of six VES's points (Electrical Resistivity) and eight GPR profiles were conducted on the site to trace the impact of the sea water and the effluents of industries on the ground water and environment. The position of the transect lines were determined using a hand-held GPS system as shown in Fig. (4), the GPR profiles and VES's were distributed in the vicinity of the factories that can generate industrial effluents. Where, figure 5 represents some pictures of the field measurements.

Electrical Resistivity Survey (ER)

In this work, a total of six VES points were occupied along selected traverses were taken normal and parallel to the shoreline of Red Sea. The Schlumberger electrode array was utilized for the data acquisition which was done with the Syscal-R2 resistivity meter (Fig. 5). The current electrode half spacing for the survey ranged from 1 to 150m in successive steps with a maximum half spacing of potential electrodes reached 20m.

The field data were curve matched using the conventional curve matching technique and the layer parameters obtained were used as an input model for fast computer iteration and modelling software known as IX1D V2. The application of this software is a standard procedure for obtaining a fairly accurate estimate of the subsurface resistivity distribution.

Ground Penetrating Radar Survey (GPR)

Ground penetrating radar is a geophysical technique that has been extensively used to map the relatively shallow subsurface features at scales from kilometers to centimeters. The GPR technique is similar in principle to seismic, one antenna "the transmitter" radiates short pulses of high-frequency (MHz to GHz) electromagnetic waves, and the other antenna "the receiver" measures the reflected signal as a function of time.

A total of 8 GPR profiles were conducted as shown in Fig. 5, with different lengths according to the validity of the scanned area. The GPR data were acquired using an SIR 3000 system by GSSI equipped with a 100 MHz antenna. The survey done to trace the surface of groundwater, as well as any abnormal behavior due to the contamination plume from the industrial activities.

The data were acquired in continuous mode with a time sampling interval of 512 and a time window of 280 ns. The GPR data were processed using programs RADAN 6.5 and REFLEX 5.0 to remove the noise signal and to enhance the imbedded features' signals. Several processing steps were applied including;

(1) Static correction for the ground zero level,

(2) Background removal to facilitate the recognition of the imbedded infra-structure,

(3) Band-pass 2D filter to remove the noise and get clear sections, and

(4) An automatic gain control (GC).

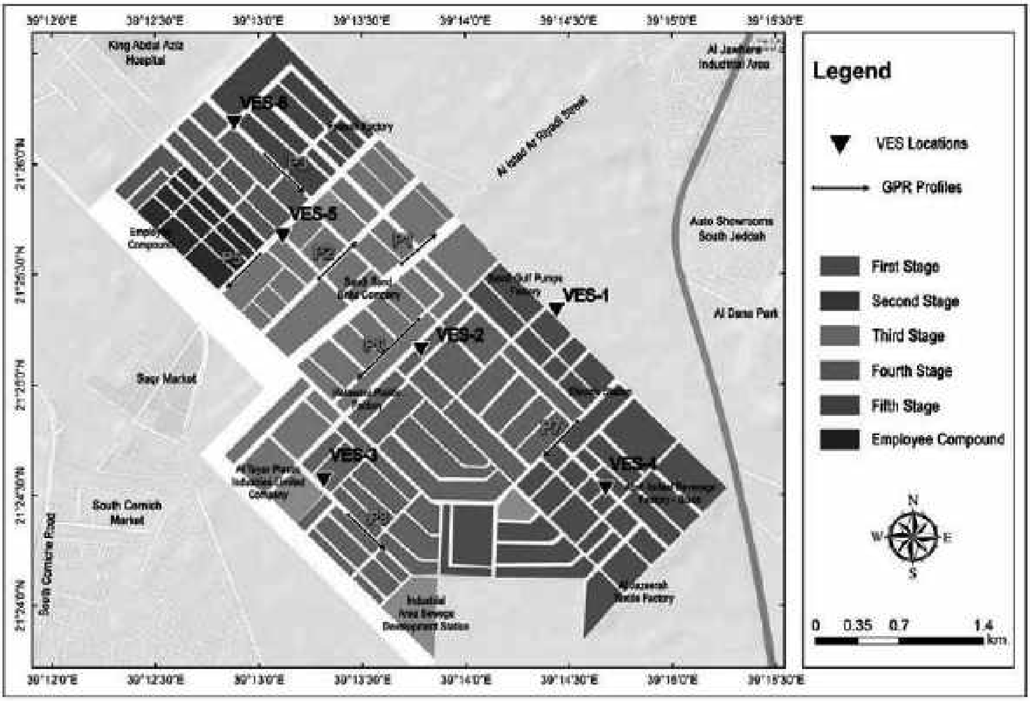


Fig. (4): Location map of the conducted VES's and GPR profiles in the 1st industrial zone, Jeddah.

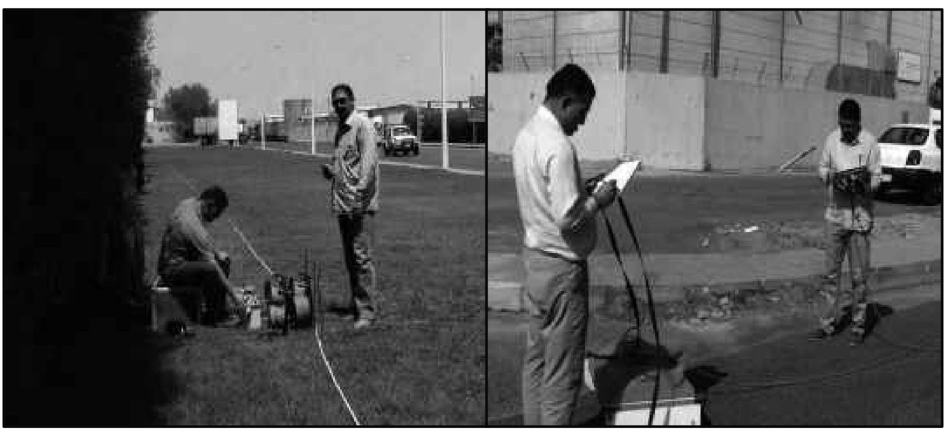
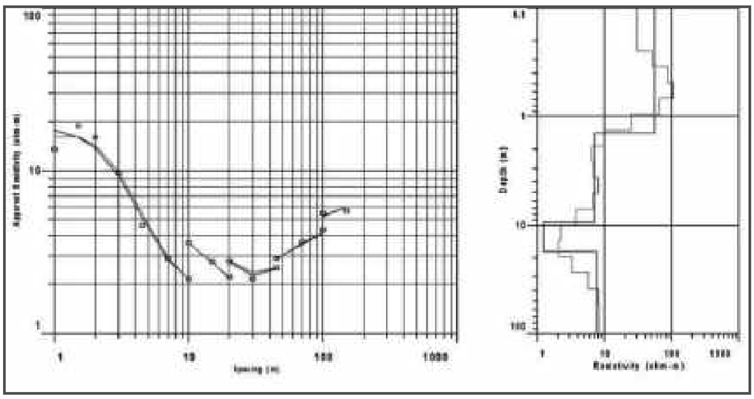


Fig. (5): Field measurements of VES's and GPR profiles in the 1st industrial zone, Jeddah.

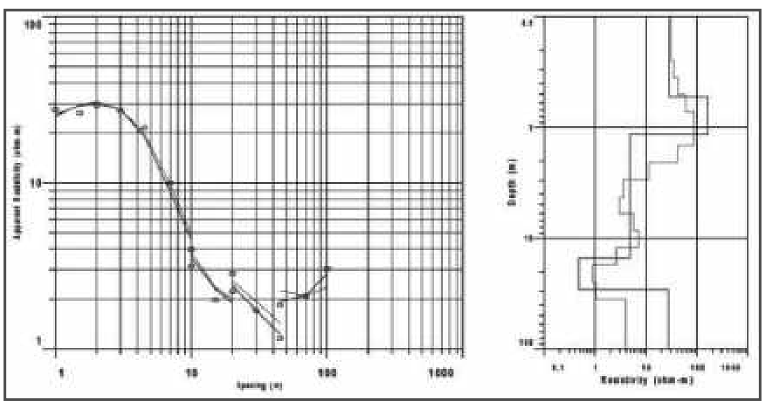
Results and Analysis

Geoelectric Resistivity

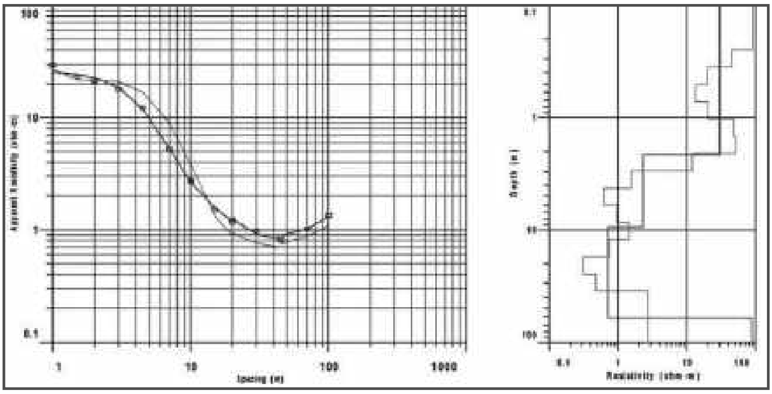
The analysis of resistivity data revealed the presence of four to five geoelectric layers. Typical curve types characteristic of saline water intruded zones were observed such as QH or QQH type. The curves were found to descend gently indicating a conductivity decrease which can be explained in terms of the seawater intrusion into subsurface formations. The descending segment of the VES curves is characterized by a steeply low resistivity zone (Fig. 6).



(a)



(b)



(c)

Fig. (6): Geoelectric resistivity models of acquired VES's (a)VES-1, (b)VES-2 and (c)VES-3.

The constructed geoelectric resistivity cross section based on the results of sounding data show that, the area is generally underlain by four geoelectric layers can be explained as following (Fig. 7):-

- First geoelectric layer has a resistivity ranging from 28 – 85 Ω.m and average thickness 1.7 m (dry wadi deposits of sands and gravels),
- Second geoelectric layer has a resistivity ranging from 2.3 – 7 Ω.m and average thickness 9.8 m (wadi deposits moisten with sea water),
- Third geoelectric layer shows a resistivity ranging from 0.5 – 1.2 Ω.m and average thickness 24.5 m (wadi deposits highly saturated with sea water) and
- Fourth geoelectric layer shows a resistivity ranging from 7.7 – 87.6 Ω.m extends to the maximum depth of exploration (fractured basement).

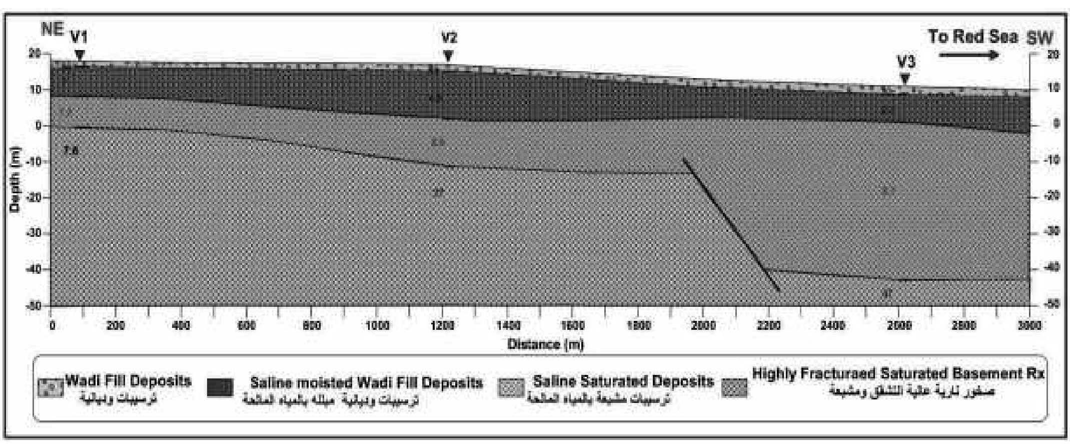


Fig. (7): Constructed geoelectric resistivity cross section (VES's 1, 2 and 3).

Ground Penetrating Radar

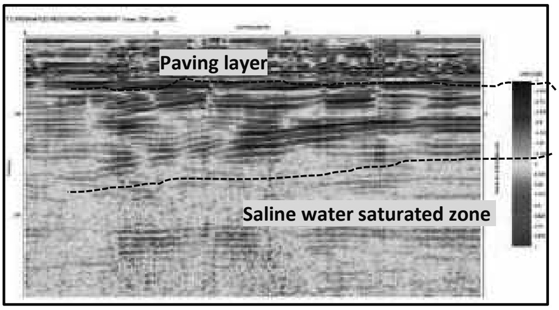
According to Olhoeft (1984), the depth of penetration is controlled by electrical conductivity, water content, scale of electrical inhomogeneity, and clay content in the soil. These controlling factors change the electromagnetic energy (GPR signal) into forms that cannot be received by the GPR system. Water saturated sediment with high electrical conductivity transforms the electromagnetic energy into thermal energy; as the wavelength of electromagnetic propagation scatters the electromagnetic energy into random directions rather than back toward the antenna (Olhoeft, 1984, 1987).

Shih and others (1986) determined that the electromagnetic contrast between dry and wet layers decreases with increasing amounts of fine-grained materials. This generalized trend was assumed to be partially responsible for the distinct water-table reflections present in coarse-grained materials.

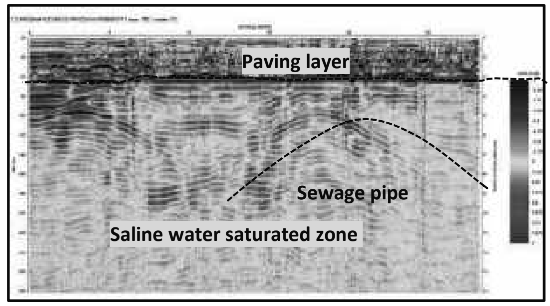
In addition to the water table, other subsurface features, such as layering and bedding of stratigraphic units, discontinuous clay layers, boulders, and buried pipelines, were observed on the GPR records. Some excellent examples of these features are given in Ulriksen (1982), Wright and others (1984), and Collins and Doolittle (1987).

The top of the saturated zone was usually the most distinct continuous reflector below the land-surface reflector on the GPR record. The strength or distinctness of the saturated zone reflector depends on the contrast between the electrical properties of the unsaturated and saturated zone, the distance over which the contrast occurs, and sharpness of that boundary compared to the wavelength of the radar signal transmitted into the ground (Fig.8).

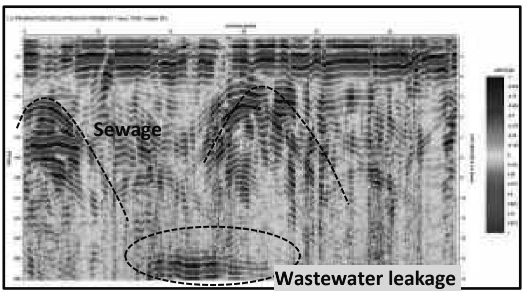
Of the 8 GPR survey profiles using 100-MHz made during the study, very distinct water-table reflectors were present in our study. The presence of fine sands, silts, and clays, were well determined beneath the paved layers of the asphaltic roads along the survey lines, causes a reduction of the distinctness of the water-table reflector on the GPR record. Also there is a group of detected utilities such as water HDPE pipelines, metallic pipelines of water and electric cables.in different localities we can determine the contaminated zones as a result of wastewater leakage from the drainage system (Fig.8.)



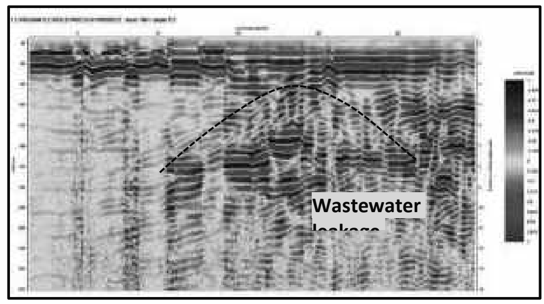
P.3 cross section



P.5 cross section



P.6 cross section



P.8 cross section

Fig. (8): Conducted GPR Profiles on the studied site.

Interpretation and Discussion

For evaluating seawater intrusion into coastal aquifers of 1st industrial zone of Jeddah, six VES's and eight GPR profiled were conducted at selected pattern to acquire both ER and GPR data to be utilized for detection of groundwater aquifer, sea water intrusion and industrial liquid contamination.

From the one dimensional interpretation of the acquired data, it was found that saline water intrusion which is characteristic of seawater penetrated the subsurface. The depth of the intrusion increased as distance from the coastline increased. In addition, typical curve types which are characteristic of coastal sedimentary basin such as QH or QQH type were observed in the study area.

The study shows that the area suffers from acute saline water intrusion, which is masking any type industrial effluents from the factories. The study however, is not a radical departure from the view that saline water found its way into the aquifers due to an upwelling of saline water, whose origin is connate. Infiltration ponds whose water are natural floodwaters can be used to recharge coastal aquifers so that the rate of withdrawal is balanced by the rate of freshwater recharge.

Seawater intrusion is a natural phenomenon in coastal aquifers. Whether we like it or not, it occurs. Ways in which this happens have been examined. However, it becomes problematic when man withdraws water close to coastal areas. So in attempting to minimize the problem, monitoring its expansion and retreat, a geophysical approach has been proposed.

Ground-penetrating radar was used to provide continuous profiles of the water table to help describe the ground-water-flow system in the vicinity of 1st industrial zone of Jeddah.

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