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Tracing Groundwater Contaminated Plumes Using TDEM and 2D ERT Data Sets at Al-Quwy'yia Area, Central Saudi Arabia

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Abstract: Groundwater contamination is one of the most significant problems in the arid countries. Al-Quwiy'yia area is an example for the groundwater contamination throughout draining away the wasted water in low land sites outside the habited area. Such operation poses a significant environmental threat in polluting groundwater. However, the main source of water supply in the whole area is the groundwater from the shallow aquifer. Therefore, transient electromagnetic techniques (TEM) and 2D electrical resistivity tomography (2D ERT) have been applied particularly close to the wasted water dumpsite for tracing the pollution plumes. Both geoelectrical methods are sensitive to electrical conductivity as well as to other physical properties, which are greatly influenced by the polluted water. Therefore, it is possible to define the contaminated groundwater plumes vertically and horizontally along the measured profiles. The ERT profiles give detailed information about the lateral distribution of contaminated groundwater, whereas the TEM stations concentrate about its vertical extensions.

Key words:

INTRODUCTION

Clean water is one of a human rights and essential requisite for economic and sustainable development in any country. Groundwater is one of the basic sources for clean water in the arid countries as it is naturally protected against the surface pollutions by the sedimentary covers. Pollution of groundwater is one of very serious problem particularly in the arid areas. Pollutions like chemicals and wasted materials in groundwater are very hard to be recognized until some illness have been reported between civilians or due to the regular sampling test from the monitoring wells.

Al-Quwiy'yia area (Fig. 1) is an example for the groundwater contamination mainly by the incomplete sanitary system in the inhabited area. The suction process and drained out the wasted water in the low land areas nearby inhabited region is the main way for throughout the wasted water. The official statistics and the surface observations confirmed that the main source of water supply in the whole area is the groundwater either from the shallow and/or deep aquifers depending on the depth of the productive wells. Illegally dumping the wasted water in the low land areas seeps down the pollutions into the shallow aquifer causing kind of severe contaminated groundwater problem. The current applicable methods of throw away the wasted water from the inhabited areas are through using sucking trucks to pump away the wasted water at low land area at eastern part of Al-Quwiy'yia area (Fig. 2). Consequently, such operation is contaminating the shallow and deep aquifers along the whole area and cumulating the contamination elements with time in the rock units.

To highlight this contamination problem and put in place low cost method for tracing the pollutions in the subsurface, geophysical survey utilizing the geoelectrical techniques has been applied [1, 2, 3]. Time domain electromagnetic and electrical resistivity methods are the most geoelectrical techniques that have a wide application in delineating the shallow subsurface properties and tracing the pollution plumes [4, 5].

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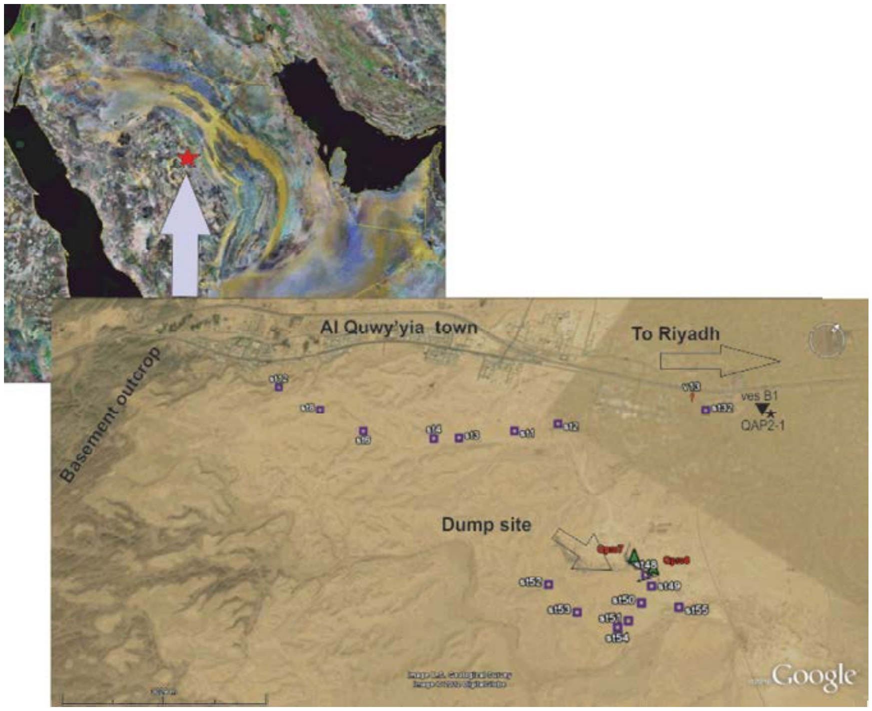

Fig. 1: Location map of the dumpsite and the different acquired data sets al AlQuwy'yia area. st # is the TEM stations, v# is the VES station, QAP2-1 is the borehole in the study area and Qpro # is the 2D ERT profiles

Fig. 2: Photographs for the surface seepage of the wasted water at the dumpsite at Al Quwy'yia area

Both methods are measuring the contrast in electrical conductivity properties of the different rock unites which are varying according to the rock types, water content and its quality and temperature [6]. In the same rock unites, the electrical conductivity is more controlled by the water contents and its quality within the matrix of the formation than by the solid granular materials itself. The increase of ions disseminations in the groundwater due to the pollution resources has direct relation with the groundwater electrical conductivity properties [7]. This fact was fully analyzed earlier using empirical relationship suggested by Waxman and Smits [8], which is demonstrated that as long as there are a free ions in the groundwater the electrical conductivity increases and the electrical resistivity decreases. The TEM and 2D electrical resistivity data sets have been utilized as a fast, low cost and effective ways for tracing the low resistivity zones in the subsurface, which is coincident with the contaminated groundwater. Moreover the location of the basement rocks, which is dipping away toward the eastern part, can be traced using the two data sets [9].

Geological and Hydrogeological Setting: Until today, few geophysical research works have been done in Al Quwy'yia area for the purpose of shallow subsurface groundwater evaluation [9]. Most of the work was dealing with the geological and mineral resources as the area is situated very close to the eastern part of Arabian shield [10]. However, there are some works have been done close to Al Quwy'yia area dealing with the groundwater recharging source along the in the shallow and deep aquifer along the eastern and central part of Saudi Arabia Hoetzel (1995). Also, Al-Amri [11] has used the geoelectrical techniques in delineating the groundwater occurrence potentiality in the central part of Saudi Arabia. Based on the previous literatures Al Quwy'yia area is located close to the Arabian Shield, which is composed of basement complex in the western side of the town (Fig. 1). To the eastern side there are the sedimentary covers (basin), which have, different lithological unites starts with the surface-weathering layer. It overlies the limestone of Kuff Formation, which is intercalated with shale units. Then close to the Arabian Shield the sedimentary unites are resting over the basement, while fare way to the north, south and eastern direction there are a Saq Formation (Sandstone) between the basement and limestone of Kuff Formation. The shallow aquifer is located in the surface and limestone layer and produced from the rare rainfall over the basement rocks. The deep aquifer is located in Saq Sandstone unit.

Methodology and Data Acquisition: The transient electromagnetic method or time-domain electromagnetic (TEDM or TEM) and 2D electrical resistivity methods (ERT) are well knownin exploration geophysics [12, 13]. The methods are using together in many ways making them ideal partners for shallow exploration. Although both methods measure the electrical conductivity or resistivity of the subsurface, they sample different volumes and have different sensitivities. TEM, an inductive technique, has an area of investigation that is a function of the descending and expanding image of the transmitted current, typically 40 by 40 meter or greater. The resistivity method is a galvanic technique that samples a more linear portion of the ground as defined by the area of current flow. The TEM method gives an absolute measurement of the subsurface resistivity while the electrical resistivity method gives a relative measure of this quantity [14].

In this work the TEM data sets have been acquired using TEM FAST 48HPC system with a single transmitter and receiver loop (coincident loop) of length 50x50m [15]. Time of measurements is ranging from 4μs to 16ms including 48 time windows with repeatability frequency changing from 3.2 kHz to 11 Hz respectively. More specification about the TEM FAST 48HPC system can be found in the operating manual (2005) and the principles of the TDEM method are described in Barsukov *et al*. [16].

On the other hand, the 2Delectrical resistivity surveys are commonly used for shallow subsurface investigations particularly environmental surveys [17]. Due to its efficiency and effectiveness in producing images of the subsurface, the 2-D geoelectrical resistivity imaging actually measures the apparent resistivity of the subsurface, which can be inverted to develop a model of the subsurface structure and stratigraphy in terms of its electrical properties [18]. The resistivity of the subsurface is affected by porosity, amount of water in the subsurface, ionic concentration of the pore fluid and composition of the subsurface materials. However, the resistivity data can be used to identify, delineate and map subsurface features such as electrically conductive contamination plumes [19]. The acquired 2D data sets in this work has been collected using SYSCAL PRO system utilizing 72 electrodes with Dipole-dipole electrode configuration and minimum electrode offset equal to 5meter. Details about the survey and 2Delectrical resistivity method can be found in some published papers as (Keller and Frischknecht, [20], Griffiths *et al*. [21], Griffiths and Barker, [22] and Loke and Barker [23]. Also one vertical electrical sounding (VES) station has been conducted close to one of the TEM station close to the borehole (QAP2-1) for getting the response of the TEM and VES data sets to the different lithological unites in the study area (Fig. 1).

Results of the TEM, VES and 2D Electrical Resistivity Surveys: During the summer of 2012,19TEM, 4VES and 2D ERT have been collected along different profiles for getting the response of the contaminated groundwater in the different data sets. The location map for these data sets is shown in Figure 1.

Comparison of VES and TDEM Models with the Borehole Logs: In order to understand the different responses of subsurface lithological unites in the resistivity model, the VES (B1) has been carried out nearby the borehole (QAP2-1), which is located close to the wasted dump site. However, there is no indication in the lithological description about the groundwater contamination in this borehole. The uppermost alluvium has at least two resistivity layers based on the moisture and lithological contents of this zone (Fig. 3). It extends to depth of about 7m from the ground surface. The limestone layer of Khuff Formation also has two resistivity layers on the VES model based of the clay contents and extends to depth of about 96m. Indeed it shows relatively low resistivity values in comparison with the alluvium layer. Most of the recorded groundwater has been defined in the Khuff limestone layer. Then the basement complex has been recorded at depth of about 96 and shows a high resistivity character in the VES model (Fig. 3).

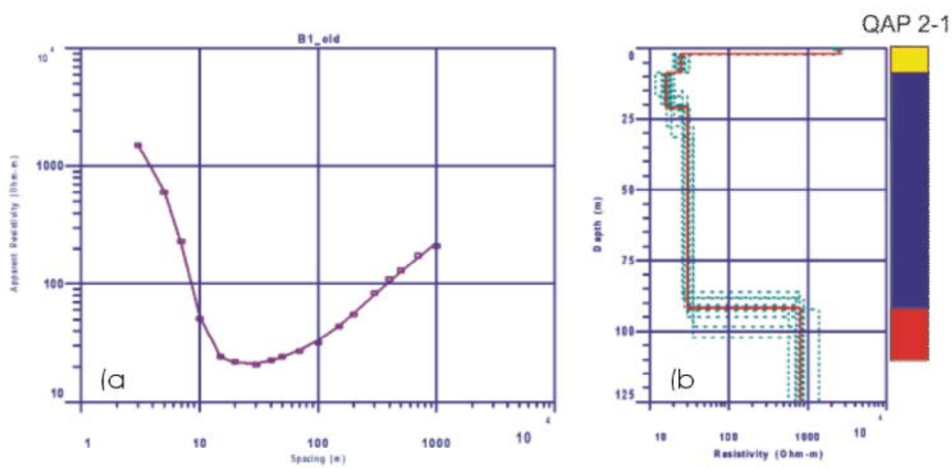

Fig. 3: The comparison of VES B1 model with the borehole (QAP2-1) lithological succession, a) the filed curve of VES B1, b) the inverted resistivity-depth model (1) shown the equivalence models (2) in comparison with the different lithological unites

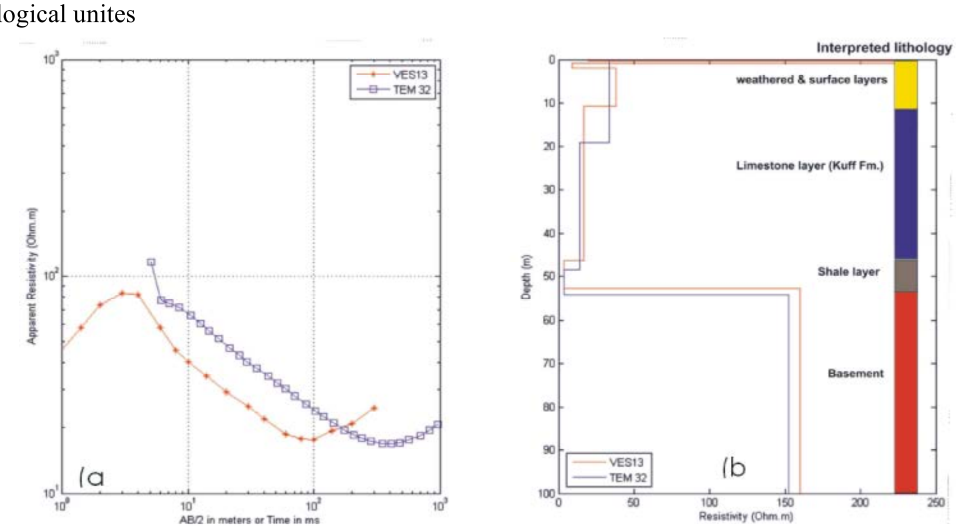

Fig. 4: The comparison of VES 13 with TEM 32 conducted at the same site, a) the filed curves of VES 13 and TEM 32, b) the inverted resistivity-depth models with the interpreted lithological unites

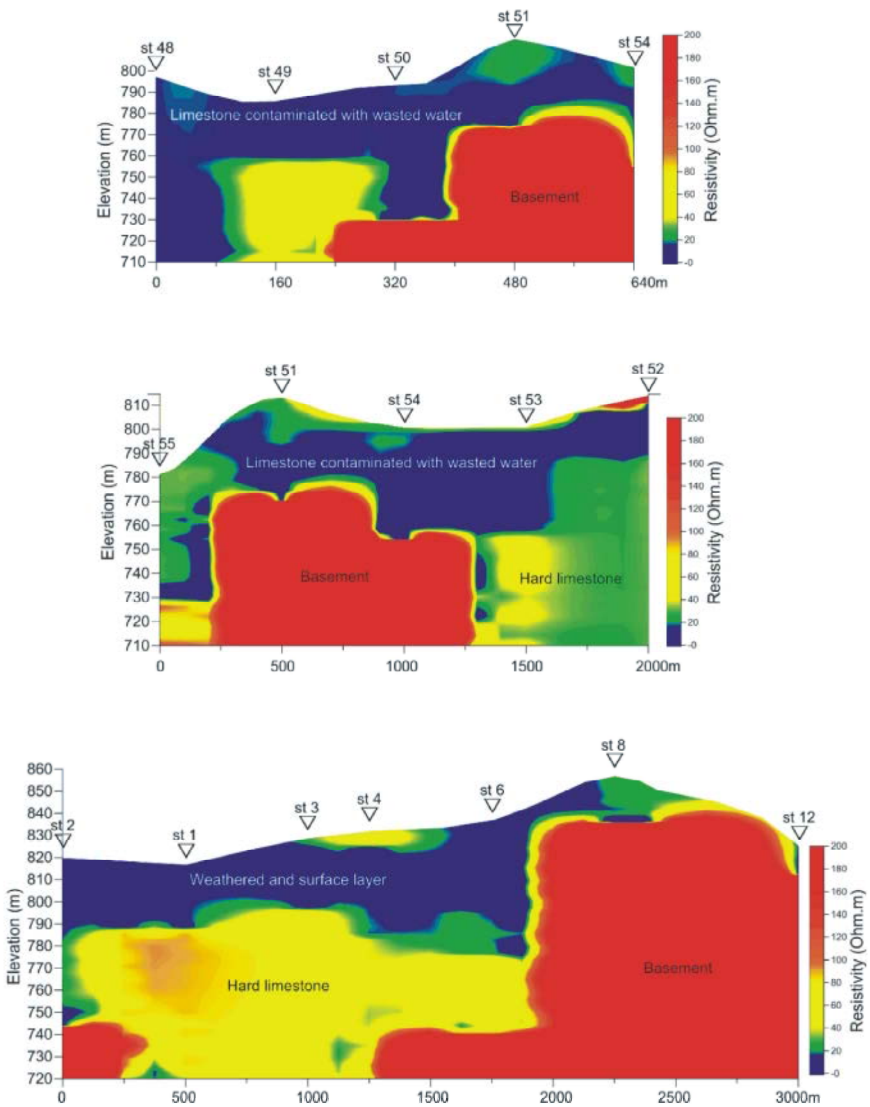

Fig. 5: Geoelecrical resistivity cross sections constructed using the lateral interpolation between the TEM stations (triangles)

Comparison of VES and TEM Data Sets: After getting the signatures of different lithological unites in the resistivity models, the VES and TEM data sets have been carried out for comparing the resultant models of the two data sets. VES 13 and TEM 32 are an example of this comparison (Fig. 4).

There is a good consistency between the two inverted models as they are representing the same subsurface lithological unites, but the measurements have been carried out in different manner. However, at shallow part of the VES model there are three layers, which are represented in TEM model with only one layer. This is referring to the dense electrode separation at the small offset in acquiring the VES data and late time of data recording the TEM measurements. Also the VES and TEM data sets has the almost same response for the shale layer at depth 45m from the ground surface and extends to depth of about 55m (Fig. 4).

Results of TEM Data Sets: Figure (5) shows the TEM profiles constructed using the lateral interpolation between the TEM stations. Two profiles were running close to the dumpsite (Fig. 5a and b) and the other one (Fig. 5c) was running relatively fare away from the dumpsite (Fig. 1). The main purpose for preparing these profiles is to emphasise the lateral movements of the wasted contaminated materials in the shallow aquifer and compares the affected profiles with no affected one.

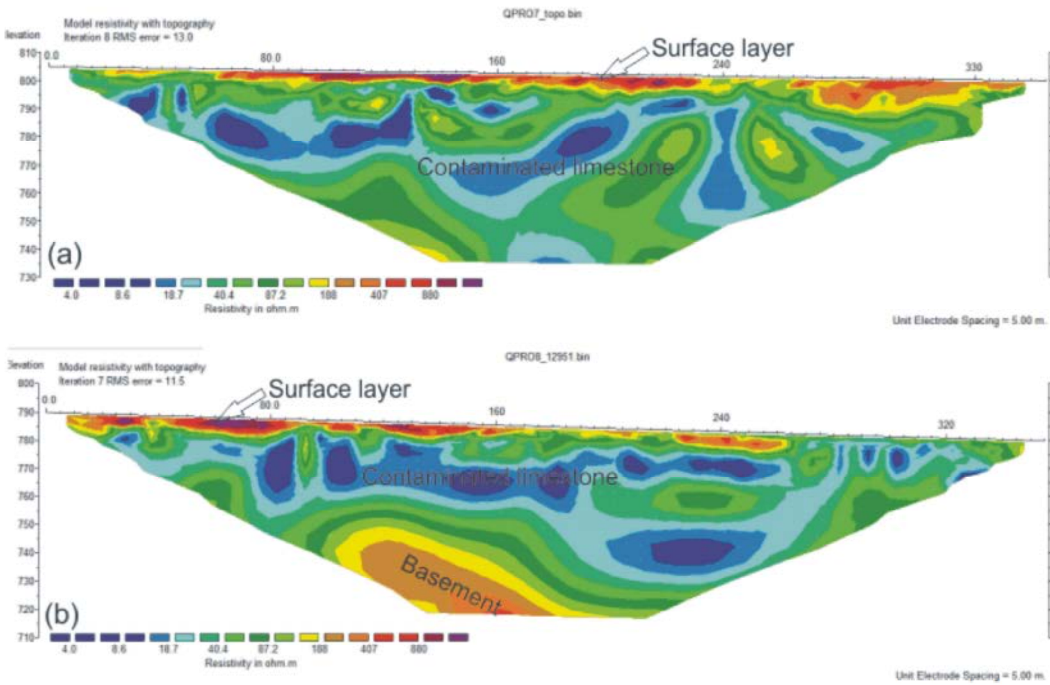

Fig. 6: 2D ERT Profiles acquired close to the dumpsite, (a) parallel to the dumpsite, (b) at the right angle to the dumpsite

After the TEM data has been downloaded in the 1D processing software and the resistivity depth models have been defined based on the previous correlation between the acquired VES and borehole, the 1D models have been arranged including stations elevation and the stations intervals in the worksheet for preparing the gridding file. The colored image for each profile has been constructed and adjusted to show the same color scale. The 1st and 2nd profiles (Fig. 5a and b) show important features regarding the subsurface contamination problem. The low resistivity (<20 Ohm.m) zones which are dominant from the ground surface to elevation of about (657m) can be interpreted as weathered and surface layer. This zone is affected with the surface dumping process of the wasted water as well as with the surface process of human activities. Underneath the surface layer the limestone layer is dominant with relatively high resistivity values (25-80 Ohm.m). However, inside this layer and close to the dump site (close to st. 48, 49 and 50 in the 1st profile and st. 55 in 2nd profile) the resistivity values decrease again due to the effect to polluted groundwater from the dumpsite. Underneath TEM stations (st. 50, 51 and 54 in the 1st profile and st. 51 and 54 in the 2nd profile) the resistivity values increase (>150 Ohm.m) due to the basement complex occurrence. On the other hand the 3rd profile (Fig. 5c) has no evidences about the subsurface contamination seepage from the dump site as indicated from the resistivity values of the limestone rock which has almost homogenous resistivity value. Also this profile is rather far away from the dumpsite location.

Results of 2D ERT: After the acquired 2D ERT data have been acquired the data is subjected to processing scheme to produce cross-sections showing the subsurface resistivity distribution in 2D manner. The RES2DINV software utilizing smoothness constraint is used. The calculated data are compared with the field data and the resistivity model is updated based on the difference between observed and calculated data. This procedure is continued until the calculated data match the actual measurements with acceptable level of error. Inspecting the inverted 2D electrical resistivity profiles acquired very close to the dumpsite (Fig. 1) reveals many important features (Fig. 6). There are two profiles one is parallel to the dumpsite, while the other is at the right angle to the dumpsite. The parallel profile is more affected by the sewage water seepage in the subsurface producing low resistivity character in the limestone layer (Fig. 6a). The thickness of the contaminated layer is more than 60m and is reducing going away from the dump site as the basement rocks starts to be traced (Fig. 6b). The 2D ERT profiles are confirming the results of the TEM data sets and show the contaminated zones with low resistivity character.

CONCLUSIONS

Groundwater contamination is very important issue particularly whereas the water is rare in the arid areas. Finding out suitable, fast, reliable and low cost method is essential in evaluating the ground water contamination. Al Quwy'yia area is an example of groundwater contamination throughout dumping the wasted water from the inhabited area into low landsite outside the town. The TEM and 2D ERT techniques have been applied in an attempt to delineate the contaminated area and compare with other clear site. The contaminated sites have a relatively low resistivity character in comparison with the clean ones. Therefore as long as there are a low resistivity zones in the measured data sets this is an indication about the contaminated areas. Such phenomena have been confirmed using the calibration process between the measured data sets and the lithological units in the study area. The TEM and 2D ERT show good indication about the contaminated area in different resolutions. It is recommended to apply both TEM and 2D ERT in dense manner around the dumpsite for clear portraying the direction of contamination plume.

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