A TDEM SURVEY TO DEFINE GROUNDWATER QUALITY IN NORTHERN KUWAIT

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ABSTRACT

As the need for secured strategic water reserves for emergencies became increasingly pressing, smaller accumulations of usable water that are spread over north Kuwait stood out as one of the most viable options. Having said that, in order to evaluate the potential of this resource, there is an obvious need for better knowledge of the spatial distribution of these waters as well as their recharge rate. Several tools and methodologies were utilized to fulfill these objectives. This paper discuss the usage of the time domain electromagnetic (TDEM) soundings method to have a better coverage of the study area. A total of 48 soundings at 24 locations were conducted. The soundings provided reasonable information on the lithology of the unsaturated zone, however, the water table was not allocated due to the presence of low resistivity layers close to the water table that resulted in weakening the signal, on one hand, and the inability to distinguish between this layer, the water table on the other hand. Nonetheless, the TDEM provided lumped salinity estimates for the top 30 m of the groundwater. However, the uncertainty of these salinities was estimated at 50%. It is recommended to conduct further studies to further investigate the potential of this reserve. Such investigations should include additional detailing of the resource and its potential through hydrological assessment.

Key Words: Sounding, Salinity, Unsaturated Zone

1 INTRODUCTION

The acute lack of natural water resources of the country has created a unique water sector in Kuwait, that is, about 90% of the potable water production is coming from the unconventional resource of seawater desalination. Although this unusual situation has been maintained for decades and probably will continue into the foreseeable future, the complete dependence on a highly industrialized source for freshwater has serious drawbacks, one of which is the lack of secured strategic water reserve. As such, the usable water accumulation in northern Kuwait stands out as a potential sizable emergency reserve. The infiltration of the rainwater/runoff from the occasional rainstorms of Kuwait is known to produce freshwater lenses in the natural depressions of northern Kuwait (Parsons, 1964). Nonetheless, freshwater accumulations are not confined to the depressions, but extend however in lesser volumes, to the formations underlying the wadis that carry the surface base flows.

During the early exploration efforts, potential usable water accumulations, i.e., total dissolved solids (TDS) <5000 mg/l, of different volumes have been reported in many parts of northern Kuwait (Parsons, 1964). While the main two depressions (Raudhatain and Umm Al-Aish) have been evaluated extensively, most of the other identified/potential usable water accumulations have been given next to no attention. This was mainly due to their irrelevance in the pursuit of freshwater bodies large enough for economical exploitation. However, in the context of securing a strategic emergency reserve for the country, these relatively smaller accumulations are significant assets.

The lack of information on the location, extent and TDS content of these accumulations as well as the recharge rates to the watershed are deficiencies that prevent preparation of emergency utilization plans for these resources.

In this context to address these deficiencies, this paper has an overall aim of exploring the potential of the shallow groundwater resources in northern Kuwait.

2 METHODOLOGY

Forward modelling was used as a means to design the survey to ensure best results possible. More specifically, it was used to test the proposed geophysical method and geophysical parameter (resistivity) and to establish the constraints of the method (i.e., power of the source) and the minimal desired contrast (layer thickness, resistivity contrast) necessary for detection. For TDEM, the field layout (transmitter and receiver moment) can also be predesigned. Synthetic TDEM curves were derived from existing borehole logs. With only two logs available, it had to be assumed that the rest of study area had similar or higher resistivity. Synthetic field curves were calculated for different groundwater depths in the same resistivity range. From this, it was concluded that decay curves generated with loop sizes of the transmitter up to 80 x 80 m with a current of 10 amps could probably reach depths over 100 m, depending on the resistivity and background noise.

Freshwater lenses can be detected, depending on its depth, relative thickness according to the depth and the resistivity contrast. Borehole logging was conducted to provide means for calibrating (e.g., lithology, water quality, and porosity) and validating (e.g., true depth of the groundwater table) the TDEM soundings. Eight boreholes were selected that represented various water qualities, water levels, and topography. TDEM soundings (40 x 40 m + 80 x 80 m) were conducted at the same location. Synthetic liners and filters were used for logging both resistivity and gamma. Resistivity was measured with a focused dual-induction probe (Robertson DIL38, Plate 5) combined with a natural gamma detector (50-mm x 25-mm NaI(Tl) scintillation crystal). A TDEM soundings survey was conducted using a system of a transmitter and receiver loop. The setup of the system was designed based on the forward modeling conducted earlier, where loop size and configuration as well as induced current were estimated. The design of the system was done using TEMIX software. In the field, the necessary corrections were made to accommodate EM noise from infrastructures (e.g., power lines). At the field, the activities were started with borehole logging and TDEM measurements at different wells at different locations. The purpose of this preliminary measurement was to design the best configuration for the TDEM measurements in between the wells and to check the applicability and desired resolution of the system in use. The borehole logs also linked the changes of the resistivity toward lithology, water content (porosity), and water quality.

The TDEM soundings were conducted by inducing EM signals in the transmitter loop, and the receiver measured the induced signal, which is a result of the primary signal coming from the earth, in time (milliseconds). This results in decay curves, where time series of the diminishing signal is produced. The loop size and induced current were adjusted frequently to ensure the needed penetration depth. Multiple soundings in line were made to produce cross sections. In the interpretation of the measurements, depths of penetration and resolution were calculated using the software TEMIX. Field curves were inverted with smooth modelling in order to see the trend in a single curve as well as the change of trends between different curves. These changes were correlated to and explained by the change of lithology, groundwater depth, and quality as obtained from borehole logs. A DEM was used to define the distribution of watersheds and stream networks, as well as geometric properties. This DEM was produced from satellite images from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER). Geologic and soil maps, available from previous studies were used for mapping the geology, soil and land use types.

3 RESULTS AND DISCUSSIONS

Eight boreholes were logged with a combined gamma ray - dual induction conductivity probe. The main purpose of these loggings was to provide calibration points for the interpretation of the TDEM soundings. The unsaturated zone showed resistivity varying between 3 and 300 Ohm. High resistivity in this zone are generally well in line with the lithological descriptions provided by the drill cuttings, which shows that low moisture sand is dominant. Low resistivity, on the other hand, were less obvious. The limited presence of clay, as indicated by high gamma count, does not run synchronic with the low resistivity zones which rules out the classical interpretation of associating the low resistivity with clay particles. Alternatively, these low resistivity layers are probably sand and gravel layers densely cemented with gypsum, as most of the core cuttings show calcareous sand and gravel layers. The resistivity of gypsum is highly dependent on its moisture content. Dry gypsum can have resistivity up to 1000 ohm, while moist and swollen gypsum can go down below 10 ohm. This layer had been reported before (Kwarteng et al., 2000) and is locally known as gatch. The presence and spatial distribution of this layer is of great hydrological significance as it allows little flush-through by percolating water in the unsaturated zone and probably indicative of conditions with little or no recharge at all. Special attention was given to mapping the spatial extent to this layer using the TDEM. The saturated zone was visible in resistivity logs in those parts where the resistivity appeared to be relatively consistent. These resistivity, combined with the salinity values within the vicinity of these wells, confirmed a poor cementation of the sediment. The logs also confirmed the relatively low contrast in resistivity just above and below the water table.

This fact, along with the large range of resistivity values and resistivity contrasts above the groundwater table, complicated the distinction of the water table using the TDEM. In total, 48 TDEM soundings at 26 different locations were carried out (Fig. 1). The allocation of the soundings was aimed at covering the areas between the borehole loggings and providing profiles/cross sections of the study area lithology.

The first soundings were performed close to the selected boreholes at the same time as the logging. At these locations, the logging results were used as a model for the data inversion. Essentially, the well-identified resistivity/lithology relation established from the well loggings was used as fitting models to interpret the resistivity measured by the TDEM. Although this application confirmed that TDEM method could be much more successful in profiling the subsurface than the previously applied geophysical methods, i.e., electrical resistivity, this survey also showed that there were significant limitations to the application of TDEM under the conditions of northern Kuwait. The TDEM clearly showed different hydrogeological conditions within and outside the depressions. Logs in old wells and TDEM soundings in the depressions showed fairly high resistivity (40 to 50 Ohm) for the upper saturated aquifer, characteristic for unconsolidated sands and gravels with fresh groundwater (TDS <1500 mg/l). Outside, the depression resistivity of the saturated aquifer were much lower (3.5 to 7 Ohm), corresponding to salinities of 3500 to 11,000 mg/l. Overall, the water table was however detected with uncertainty.

This could have been due to the low resistivity encountered above the water table, which reduce, or in some cases, eliminate any contrast between the unsaturated zone and the water table, i.e., the main signature of the water table showed significant reduction in resistivity. Also, in the areas with a deep groundwater, the penetration depth was not enough to reach the water table. This could be due to the presence of the low resistivity zones, i.e., mostly the gatch layers, above the water table that absorbed most of the signal. The high noise in some areas (mostly due to power lines, buried pipes, etc.) has also prevented the identification of water table depth. Nonetheless, five geophysical profiles (Figs. 2, 3, 4, 5 and 6), based on smooth inversion, have been constructed from the well and TDEM resistivity. The location of the profiles is shown in Fig. 1. The estimates of TDS values have enhanced the distribution of the available information on the salinity; however, it should be utilized with caution. The TDEM interpretations and their subsequent conversions to TDS values involve uncertainties that are of methodological origin and/or due to difficulties faced in the field due to the lack of resistivity contrast around the water table and the approximation of the formation resistivity and porosity. The limitations inherited in the application of the TDEM method for estimating the TDS at the specific study area under consideration suggest that uncertainties of 20 and 30% for formation factor and formation resistivity respectively, should be taken into consideration. The TDEM salinity data, which represent the entire top 30 m thickness of the aquifer, were utilized, along with the multi-probe data to map the salinity distribution over the depth of 0-30 m (Fig. 7). As one would expect, higher salinities, compared to the 0-15 m map, are seen over the entire area. Nonetheless, significant areas remain within the usable water quality range (less than 5000 mg/l). Overall, the salinities estimated by the TDEM seems higher than those measured in the wells, which suggests that, under the conditions of this current survey, the TDEM method tends to overestimate the salinity.

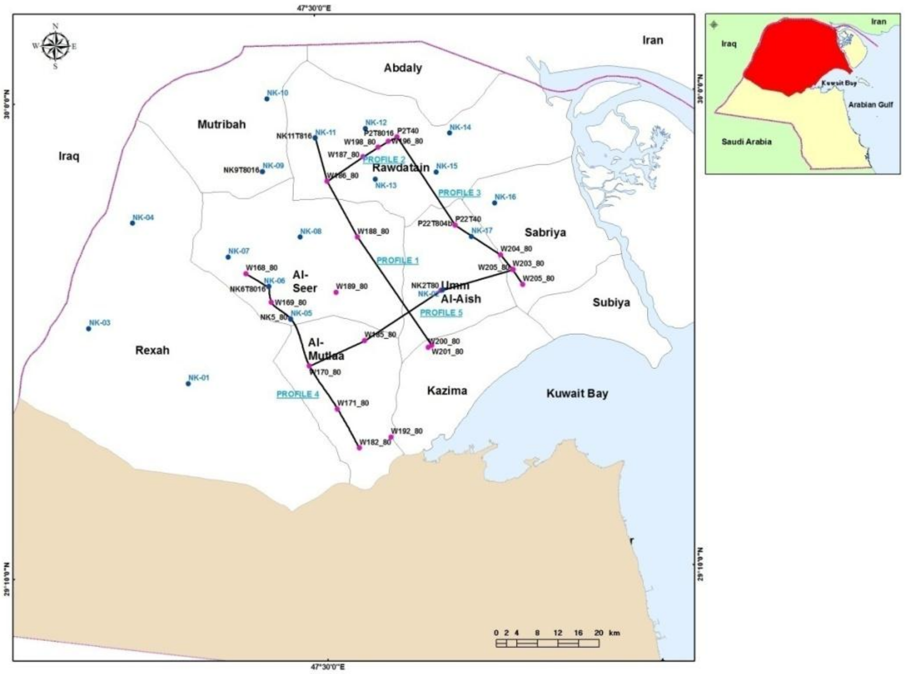

Figure 1. Locations of TDEM soundings, logged wells and geophysical profiles.

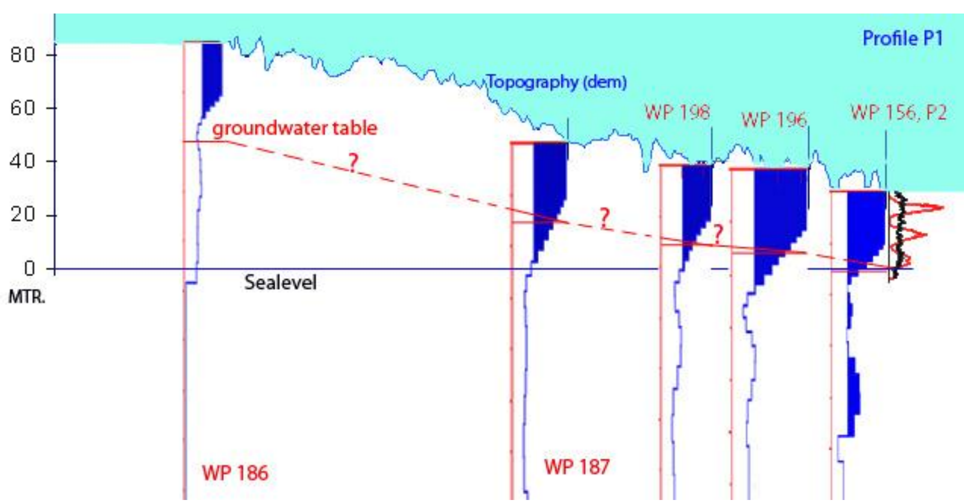

Figure 2. Profile 1 - smooth inversion.

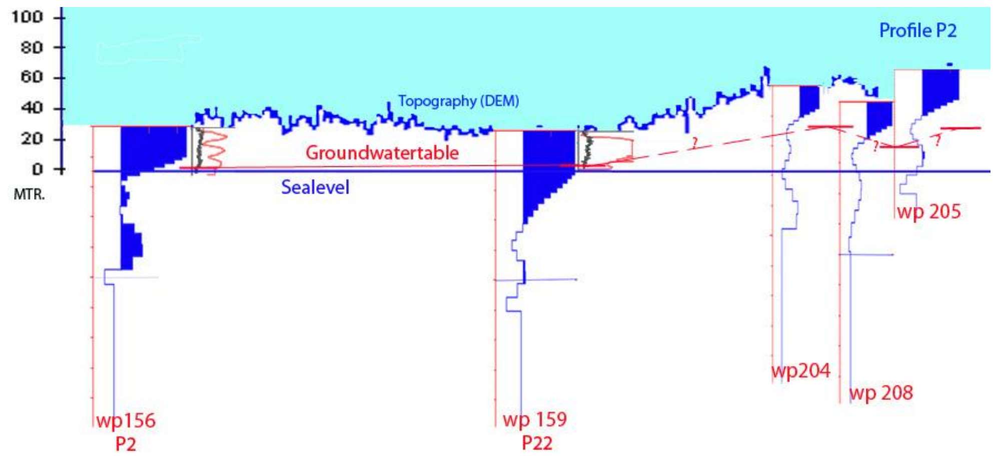

Figure 3. Geophysical profile 2 - smooth inversion.

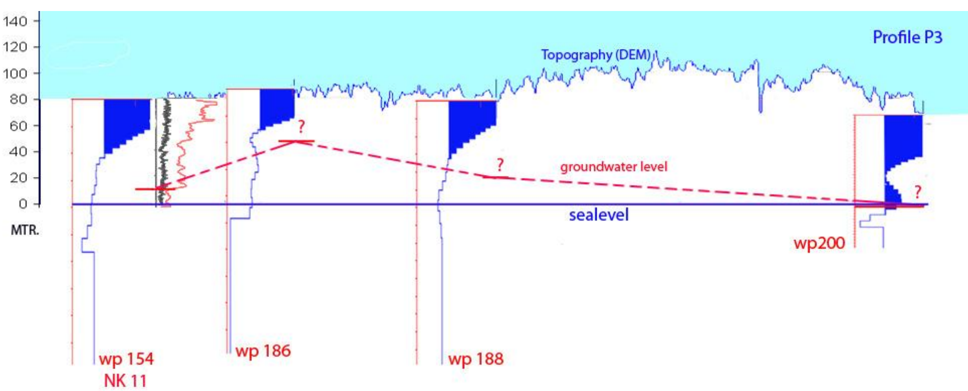

Figure 4. Geophysical profile 3 - smooth inversion.

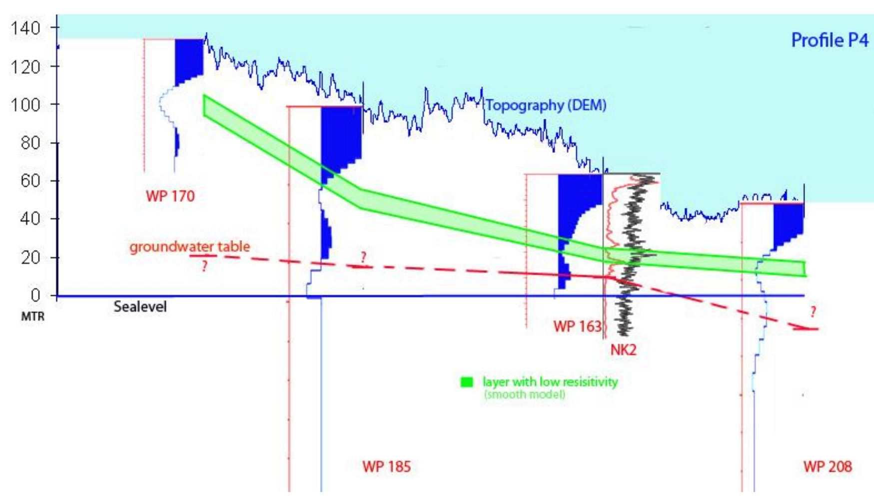

Figure 5. Geophysical profile 4 - smooth inversion.

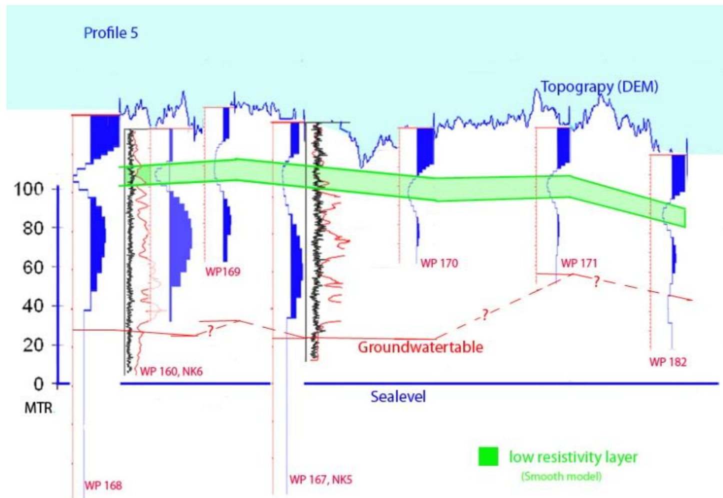

Figure 6. Geophysical profile 5 - smooth inversion.

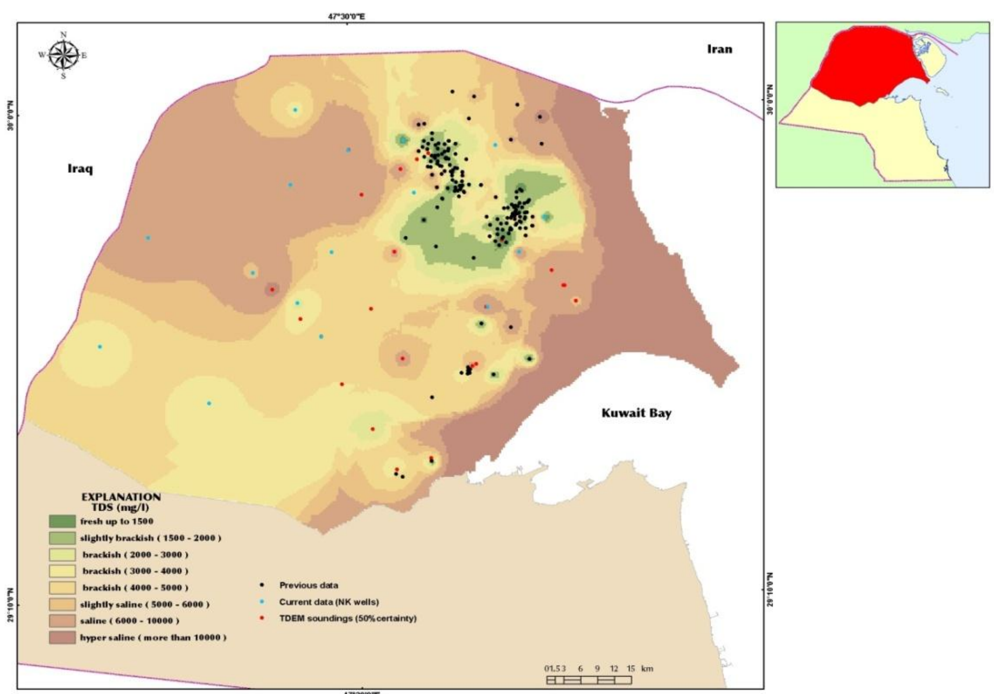

Figure 7. Spatial distribution of groundwater salinity for depth range of 0-30 m below water table. Data produced through direct measurements by multi-probe as well as interpretation of TDEM soundings.

4 CONCLUSION AND RECOMMENDATIONS

The complete dependence of Kuwait on highly industrialized water resource, i.e., desalination, for its domestic water is raising concerns about the consequences of shutdowns in the desalination plants due to technical problems, environmental pollution, or even sabotage. The fact that Kuwait has very little storage capability makes these concerns even more pressing. One potential source for increasing such a reserve is the usable groundwater (TDS<5000 mg/l) that are potentially existing under the watersheds of north Kuwait. For such waters to be considered as a reserve, much more information is needed. To cover this knowledge gap, this study was conducted to provide data on the presence of this water and its distribution. To enhance the density of the information over the study area, TDEM soundings were utilized. A total of 48 soundings at 24 locations were conducted.

The soundings provided reasonable information on the lithology of the unsaturated zone but was not able to allocate the water table due to the presence of low resistivity layers close to the water table that weakened the signal, on one hand, and the inability to distinguish between these layers of the water table. Nonetheless, the TDEM provided lumped salinity estimates for the top 30 m of the groundwater. However, the uncertainty of these salinities was estimated at 50%. It is recommended to conduct further studies to further investigate the potential of this reserve. Such investigations should include additional detailing of the resource and its potential through hydrological assessment.

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