GROUNDWATER AQUIFER CHARACTERIZATION USING GEOPHYSICAL METHODS

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Abstract

In arid regions groundwater aquifers are one of the main sources of water and they are recharged only through rain. Efficient use of aquifers for drinking or agriculture is extremely important. To utilize this water in an optimum way we need to characterize the aquifer geology, its depth, thickness, and the rate of recharge. We could also increase the recharge rate by redirecting rain waters to these aquifers and use them as natural reservoirs for future use.

In this study we characterized the geology of Wadi Qudaid, 80 Km north of Jeddah, Saudi Arabia (KSA) for use as a potential rainwater aquifer. In this work, we collected seismic, electric, and EM data to find the depth to and thickness of the aquifer and compared our results to observations in a nearby well. Seismic data are interpreted using traveltime tomography and early arrival waveform inversion, while EM data are inverted to find the true subsurface resistivity.

Seismic tomograms and EM results show the existence of 3 subsurface layers (1) a surface layer consists of sand-silt-gravel, (2) a layer of consolidated sand with some gravel, and (3) a layer of highly fractured igneous rocks.

Introduction

Geophysical methods have been used for groundwater management for a long time. Such methods are very efficiend in solving groundwater-related problems such as; find groundwater aquifers (Inverarity et al., 2011), seawater intrusions (Allen, et al., 2002), managing groundwater aquifers (Skokan and Munoz, 2010; Abraham et al., 2010), monitoring aquifers (Eigenberg and Woodbury, 2012), track flow paths (Kofoed et al., 2011), etc. Kirsch (2009) presents a good review of different geophysical methods and how we can use it in groundwater applications.

In this work we show the results of a preliminary study made at Wadi Qudaid area, 80 km north of Jeddah, KSA. The main purpose of this study is to characterize the subsurface aquifer for better groundwater management and use. The main water resource at the area of study is groundwater and desalination from Red sea. Rain is the only water source that recharge the groundwater aquifers, where the average annual precipitation rate in the area of study is around 56-78 mm and the average number of rain days per year is 14 days, which makes this area one of the arid locations in Saudi Arabia. Locals depend mainly on groundwater for drinking and agriculture activities, although they have minimal, if any, information about the aquifer size, capacity, and recharge rate. In this study we have two targets (1) determine the aquifer characteristics, such as size, thickness, depth to top, etc. and (2) study the possibility of increase the recharge rate by redirecting rain waters to the aquifer and use it as natural reservoir for future use.

Location and Geophysical Data

The area of study is known as Wadi Qudaid and is located at the western side of Saudi Arabia (Figure 1a) at the Red sea. Wadi Qudaid is located around 80 km north of Jedah, KSA, and 25 km east of Thuwal, KSA. Wadi Qudaid is one of the longest valleys in the area, hence it is an important source of groundwater at that region for both drinking and agriculture activities. There are about 200 water wells in the valley; however, the aquifer dimension and size are almost unknown. Uncontrolled groundwater pumping by locals may affect the quantity of the water stored in the aquifer since the aquifer characteristics, including size and water volume, are unknown.

In this study we collected 2D seismic, electromagnetic (EM), and self-potential (SP) profiles (Figure 1b) to investigate the subsurface geology and aquifer characteristic in the area of interest.

Seismic Data Acquistion and Interpretation

The 2D acquisition geometry of the seismic line consists of 117 vertical component receivers with a 2.0 m spacing and one shot at each receiver position, which gives a total profile length of 232 m and a total number of recorded traces = 117 x 117 = 13689 traces. In this field experiment, we used a 200 lb weight drop (Figure 1c) to generate the seismic source energy with 10 to 15 stacks at each shot location. Each common shot gather (CSG) was recorded with a sampling interval of 1.0 ms for 0.25 s (Figure 2).

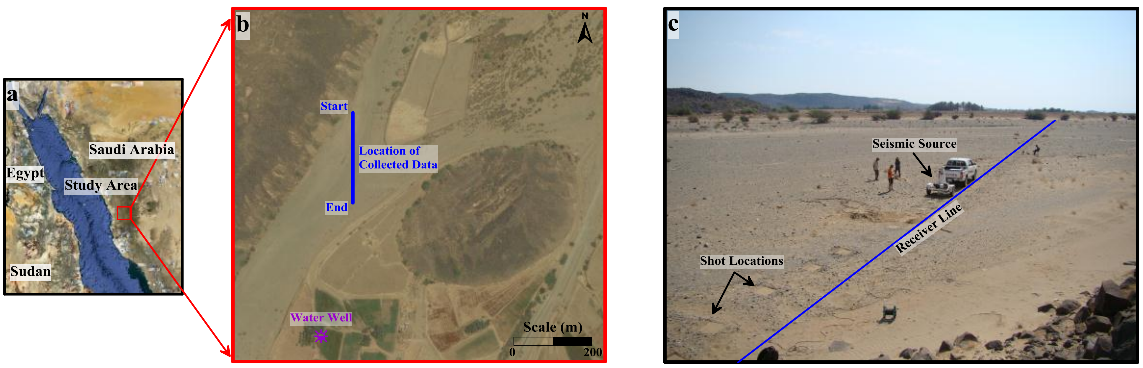

Figure 1: (a) A map shows the study area, Wadi Qudaid, (b) the location of the seismic, SP, and EM profiles, and the water well at the site, (c) A photo (looking south) taken during data acquisition.

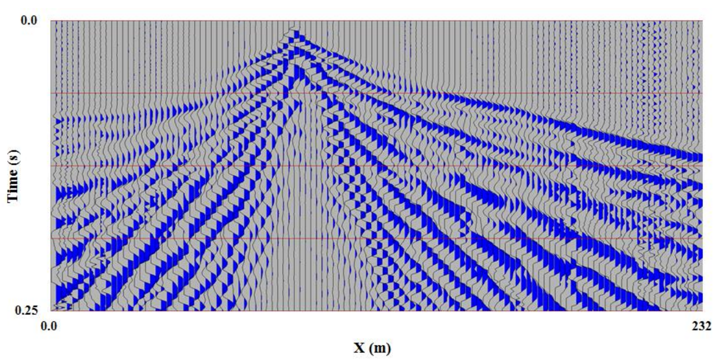

Figure 2: A sample of the collected common shot gathers, CSG#40.

The collected data are inverted using traveltime tomography, where the first arrivals of all shot gathers are picked and then inverted to generate a travel time tomogram (TTT) as shown in Figure (3a). We can recognize three layers at the tomogram, the first layer (ST-1) is a surface layer consists of sand-silt-gravel with a velocity of 400-800 m/s and thickness 4-18 m, the second layer is a consolidated sand layer with some gravel and has a velocities of 1200-1600 m/s and thickness of 5 – 10 m, the third layer is the bed rock and consists of highly fractured igneous rocks and velocities > 2000 m/s. The three layers are shown in a water well (2 m diameter) at around 1 km south of the area of interest.

The traveltime tomogram is used as the initial velocity model for early arrival waveform inversion (EWI) and the result is shown in Figure (3b). The EWI also shows 3 layers with the same velocity ranges as the traveltime tomogram; however many local velocity anomalies are shown in the EWI tomogram, especially in the second layer, which indicates a higher resolution than the traveltime tomogram. The similarities between the traveltime tomogram and the EWI tomogram increase the confidence on the seismic results.

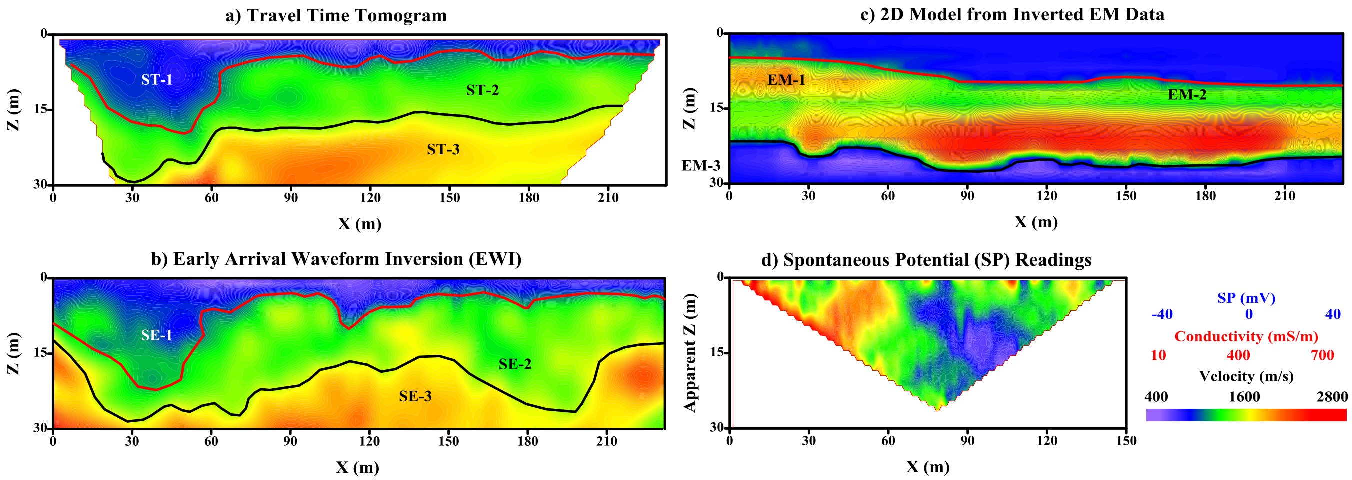

Figure 3: (a) The traveltime tomogram, (b) the EWI tomogram after 30 iterations, (c) the inverted EM data, and (d) the raw SP readings. The black lines at (a) and (b) indicate the water table with a velocity of 1500 m/s, while the red contour lines of 1000 m/s denotes the interface between the surface layer (gravel + sand) and the second layer (consolidated sand). In c), the red line is the contours for 160 mS/m.

EM Data Acquisition and Interpretation

An electromagnetic (EM) profile is recorded at the same location as the seismic profile. The data are collected using the EM34-3 (http://www.geomatrix.co.uk/em34-3.php) instrument with three different coil separations (frequencies) at each station. We used the 10 m (6400 Hz), the 20 m (1600 Hz), and the 40 m (400 Hz) coil separation in the horizontal mode. We used FreqEM software (http://www.geotomosoft.com/downloads.php) to invert the raw data, where a 1D resistivity model is generated at each station and then all 1D models are combined to create the 2D model shown in Figure (3c). The 2D EM model is roughly consistent with the traveltime tomogram and EWI tomogram (Figures 3a and 3b). The 2D EM model also shows a 3 layer model, however with different structure. The low-velocity anomaly shown on both the traveltime tomogram (ST-1) and EWI (SE-1) tomogram corresponds to the local anomaly (EM-1) shown in the EM model between x = 0 - 60 m and depths less than 13 m. This anomaly corresponds to a gravel-sand layer. The second layer (ST-2 in the traveltime tomogram, SE-2 in the EWI tomogram, and EM-2 in the EM model) corresponds to a sand-silt layer with some gravel. The seismic and EM results do not accurately matches; we believe that more data are required to accurately understand the subsurface structure in this area.

SP Data Acquisition and Interpretation

One SP profile is collected with a total length of 150 m using Syscal R2 (http://www.iris-instruments.com/index.html) instrument. At this stage we did not processed the SP data (Figure 3 d shows the collected raw SP data), in the future we will process this data set and collect a 2D resistivity profile to compare its results with the seismic and EM results.

Conclusions

In this study we collected seismic, EM, and SP to characterize the groundwater aquifer at Wadi Qudaid, western side of KSA. The seismic data are inverted using traveltime tomography, and then the final result of traveltime tomography is used as initial model for the early arrival waveform inversion.

Results show that there are 3 layers in the subsurface (1) the overburden, which consists of loose sand, silt and gravel with thicknesses of 4 - 18 m. Its seismic velocities are 400 - 800 with resistivities of 10 – 30 Ohm.m. (2) The second layer consists of consolidated sediments with thicknesses of 5 – 10 m. The seismic velocities range is 1200 - 1600 m/s and the resistivities are 30 - 60 Ohm.m. This layer is partly to fully saturate with water and considered with the third layer as the main subsurface aquifer. (3) The bedrock, which consists of a highly fractured igneous rock and can be considered as part of the aquifer. The depth to the top of this layer is around 26 – 30 m at the northern part and increase to around 40 – 45 m at the southern part from ground surface. The velocity of this layer is greater than 2000 m/s with resistivity values of 120 Ohm.m. The water table is laying at a depth of approximately 18 m from ground surface as shown in a water well next to the study area (Figure 1b). The EM does not show consistent results with the seismic, which indicates that more data are required to overcome the ambiguity in the final results.

As a future work, more seismic and EM data will be collected as well as 2D resistivity imaging.

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