Application of Ground penetrating radar (GPR) to discover water table

Saeed Parnow [1], Hamid Bizhani [2], Mahdy Zarei [3]

[1] *Ph.D. Student, Institute of Geophysics, University of Tehran, saeed.parnow@ut.ac.ir*
[2] *MSc, Faculty of Mining, Petroleum and Geophysics Engineering, hamidbizhani1992@gmail.com*
[3] *MSc, Faculty of Mining, Petroleum and Geophysics Engineering, mahdyzarei@gmail.com*

ABSTRACT

Ground penetrating radar (GPR) is one of the non-destructive and quick geophysical methods that can give high resolution and continuous sections of the subsurface by transmitting, reflecting, and recording of EM waves with high frequency. In this study, the performance of the method is investigated for displaying the water table and the transition zone. A GPR survey, composed of a few profiles with the distance more than 700 m (longer than 700 m through a few profiles) with 50 MHz unshielded antenna made by Swedish company "MALA Geoscience" was done in the North East of Nikshahr on the bed of a local dried river to determine its water table. In this paper, at first, the important parameters of the water table, the general principles of GPR for displaying of the water table and its structures were examined. Then, the necessary processing for the environmental noises of the region is described. After applying these processing, the GPR sections show strong, continuous, and sharp reflections from the water table and the transition zone. The processing used in this study was included initial processing in GPR and suitable filters for the removal of coherent and non-coherent noises.

Keywords: Ground penetrating radar (GPR), Water table, Transition zone, Nikshahr

INTRODUCTION

Today, geophysical methods are widely applied to explore groundwater and water table level. The main goal is to determine the geophysical characteristics of aquifers and hydrological conditions such as porosity, permeability, transmission, and flow (Maheswari et al., 2013). In this regard, geological maps, drilling data, and other auxiliary information will be very useful in the analysis (interpretation) of geophysical data. Various geophysical methods, such as electrical methods, seismic, magnetic, and electromagnetic methods, can be used to determine the water table level, but each of these methods has its own weaknesses so that to determine the water table level close to the ground level, these methods lack the ability to visualize high resolution of the subsurface. Ground penetration radar (GPR) is a non-destructive, high-resolution method used to study structures close to the ground level. In Iran, the GPR method has been used for purposes such as determining the location of metal and non-metallic pipes (Hosseini et al., 2016), determining the thickness and type of glacier (Parnow et al., 2016), identifying cavities and examining stratification (Kamkar-Rouhani et al., 2012), and archaeological excavations. This high-resolution geophysical method can provide important hydrological information about near-surface layers (Zhu et al., 2009). In areas, where sediments have low conductivity, the GPR method is a powerful tool in hydrological studies (Jol, H.M., Smith, D.G., and Richard A.M., 1996). In this study, GPR data on a local river in the northeastern part of Nikshahr, located in the northeast of the village of Hatk, were evaluated to assess the level of the water table. Over the years, the water level in the studied area has dropped, and eventually, no water is seen at the river surface and the river has dried up. The processed GPR sections have indicated strong, continuous, and distinct reflections of the transition zone and the water table level.

Theory and Methodology

The GPR instruments usually use two antennas to send and receive electromagnetic waves. The transmitting antenna sends a very short pulse (frequency between 10 MHz and 2 GHz) into the ground. The receiver antenna, which is located near the transmitter, also receives reflective signals. The strength of the reflective signal depends on the contrast of the electromagnetic and geometric properties of the subsurface targets. In theory, the three characteristics of magnetic permeability, electrical conductivity, and the dielectric permittivity of the subsurface materials cause reflection, refraction, and attenuation of waves and their recording in GPR receiver. In practice, however, the contrast in the dielectric permittivity reflects the electromagnetic waves sent by the GPR transmitter, and the electrical conductivity weakens these waves (Davies, J.L., and Annan, A.P., 1989).

Determining the exact depth of the water table using the GPR depends on the thickness, dielectric permittivity, and conductivity of the layers in addition to the frequency used. The penetration depth of the GPR method is influenced by various factors such as the number of subsurface layers, the amount of inhomogeneous and electrical conductivity. The amplitude of the return signal depends on the electromagnetic properties of the subsurface targets and their effective cross-section. The strength of the scattered signal and hence the scattering cross section very strongly with frequency (Annan, 2001). As the frequency increases, the cross-section of small inhomogeneity increases and prevents wave propagation to deeper regions. Therefore, lower frequencies should be used as much as possible in inhomogeneous environments (large-grained sand). It should be noted that reflections related to small inhomogeneity (compared to GPR wavelengths), like random noise, prevent the radiogram from providing a clear image of the subsurface. To eliminate these random reflections, it is possible to use appropriate processing such as mean, median, curvelet, and non-local mean filters (Oskooi *et al.*, 2018).

The Survey, Processing, and Interpretation of GPR data

In this paper, the aim was to evaluate the water table level of a river full of rubbles. Therefore, according to the discussions in the GPR principles section for detection of the water table level, an unshielded 50 MHz antenna (made by MALA Geoscience Company) with a fixed distance of 4.2 meters between the transmitter and the receiver has been selected (**Figure 1**).

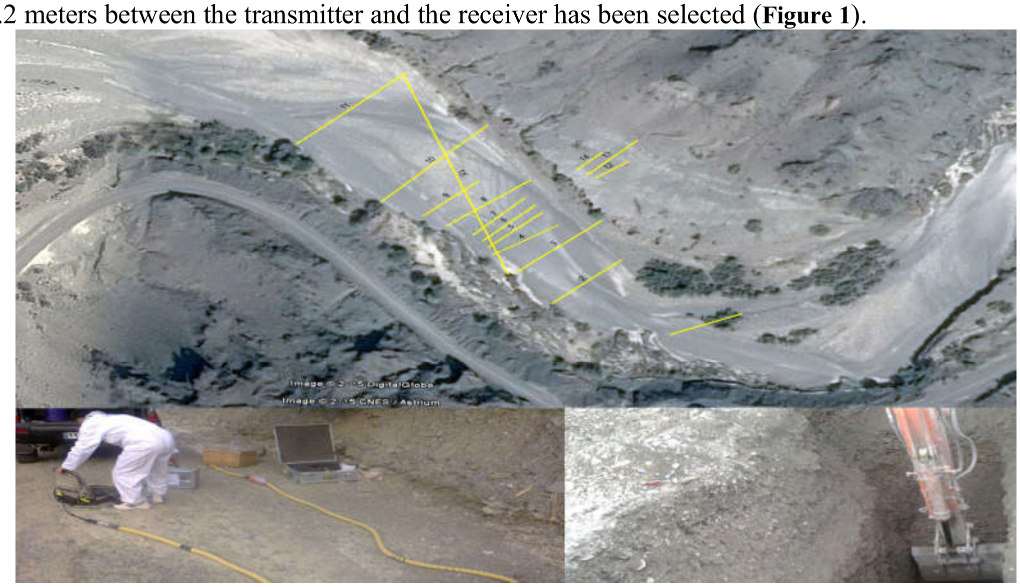

Figure 1: Study area, including location of GPR profiles and data acquisition.

Reflections of the GPR electromagnetic waves from water table level are typically continuous reflections with large amplitude. The strength and resolution of the reflections above the water table level and the transition zone, depending on the thickness of the transition zone and the electrical permittivity of the saturation region (Fetter, 2001). In general, the goal of geophysical data processing is to achieve a clear image of the sub-level goals by removing unwanted noise and amplifying signals (increasing the amount of signal compared to noise). The amplitude of processing used on GPR data is determined by the intended purpose and the amount of environmental noise. Noise can be defined as anything other than the desired data. Noise includes disturbances and parasites, caused by known or unknown devices (mobile phones,

power cables, plant roots, direct air and ground waves, etc.). In general, Noise can be divided into two main groups of coherent and non-coherent. In this paper, direct air and ground waves (coherent) and reflections from small-scale heterogeneities such as rubbles (non-coherent) have been identified. In this research, it has been tried to apply appropriate processes and display data using MATLAB software. In the following, the processes used are summarized, and the effect of using them on GPR data is displayed step by step.
More than 700 meters of the ground surface has been surveyed by the GPR along 15 profiles in the studied area (**Figure 1**). But in this paper, only the data of one of the several surveyed profiles (profile5, **Figure 2a**), 34 meters long, with a time sample 1.4 ns and 744 GPR trace, has been processed and interpreted. After applying the initial processing, including the dewow filter, static correction, and inverse amplitude decay on the desired profile is shown in **Figure 2b**. To apply inverse amplitude decay as a gain function, first, the instantaneous amplitude of all traces of the profile is calculated using the analytical signal, and then the mean and median attenuation function of the amplitude is obtained. Finally, the best fit is approximated on attenuation models. To eliminate random noise, various methods can be used, in which the mean filter (one of the most basic methods of accidental noise elimination) has been used. **Figure 3a** shows the result of applying the mean filter on **Figure 2b** with a 3*3 window to attenuate random noises.

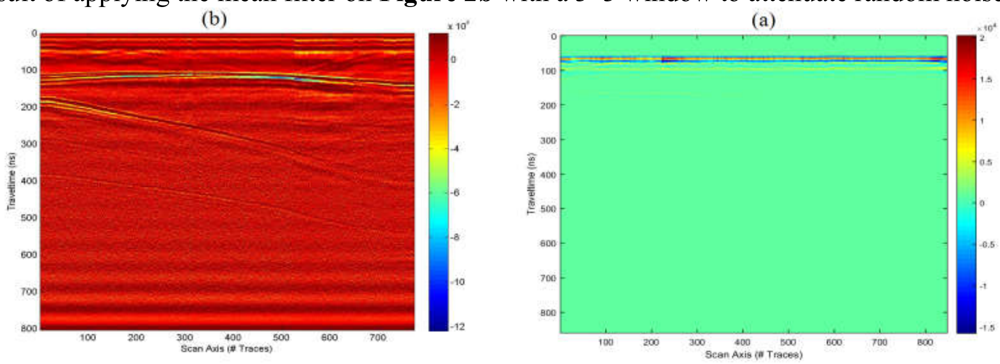

Figure 2: (a) The raw line section selected in the study area (profile5) and (b) profile5 after applying the initial processing.

Finally, in order to eliminate direct air, ground waves and low-frequency noises (linear coherent noise) in the section resulting from previous processing (**Figure 3a**), the background removal filter has been used. Other filters such as radon transform, F-K transform, and SVD can be used to eliminate such noises. The background removal filter eliminates these linear events with a slope near zero. **Figure 3b** shows the result of applying the background removal filter on **Figure 3a**. In **Figure 3b**, at a time of about 100 ns, continuous reflections with large amplitudes are observed at all sections (these reflections are indicated by the letter A in the figure). According to the excavation information from the studied area, this reflection is related to the transition zone. The fine grains of sand and the presence of clay in the studied area have been the cause of the high thickness of the transition zone at this time. The sloping phenomenon B is also related to the water table level according to the excavation information. According to this section, it can be said that the particle size has decreased from left to right, caused more transition zone thickness. The great resemblance of reflections marked with the letter C to B reflections is probably related to the raining phenomenon and reflection C cannot be attributed to an electromagnetic contrast.

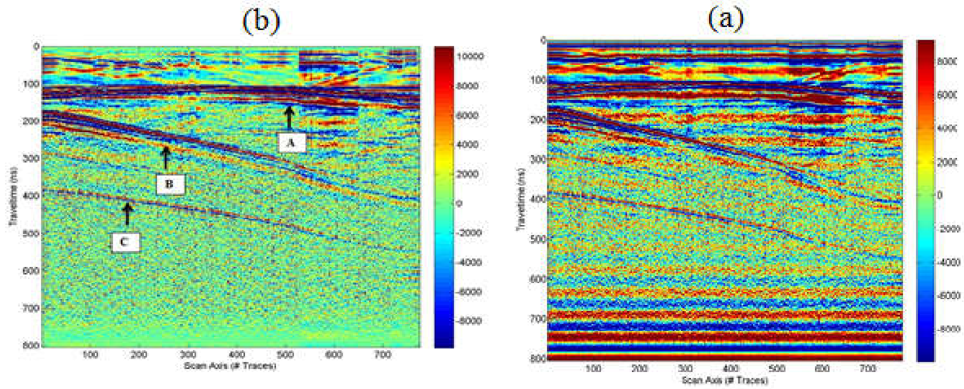

Figure 3: (a) Figure 2b section after applying the mean filter and (b) Figure 3a section after applying the background removal filter.

CONCLUSION(S)

In this paper, the GPR method was investigated to demonstrate the water table. The results have proven that the GPR method is a successful tool to detect the water table in large grain depositional environments. After the suitable Processes, the final processed sections have illustrated the water table with considerable accuracy. There are two main points to be considered when determining the water table using the GPR method. First, a frequency must be used that can pass through the transition zone and display the water table and transition zone. Second, in the large grain depositional environments, the frequency of transmitter antenna has a relation with the scattering cross-section of these sediments and with increasing the frequency, the return exponentiation of the sediments will raise. Therefore, lower frequencies should be utilized as much as possible so that less energy is returned from the radiation signal and the wave can penetrate to a greater depth.

REFERENCES

Annan, A. P., 2001, Ground Penetrating Radar Workshop Notes: Sensors and Software.

Davies, J.L., and Annan, A.P., 1989. Ground-Penetrating Radar for high resolution mapping of soil and rock stratigraphy. Geophysics Prospect, 37, 531-551.

Fetter, C.W., 2001, Applied hydrogeology, 4th, Prentice- Hall, New Jersey.

Hosseini, M., Kamkar-Rouhani, A., Mohammadi Vizheh, M., Parnow, S., 2016, Importance of three-dimensional ground penetrating radar surveys in accurate display of the images of subsurface installations, Case study: Shahrood University of Technology, Journal of Research on Applied Geophysics, 2 (2), 67-76.

Jol, H.M., Smith, D.G., and Richard A.M., 1996, Digital ground penetrating radar (GPR): A new geophysical tool for coastal barrier research (examples from the Atlantic, Gulf and Pacific coasts, USA), Journal of Coastal Research, 12 (4), 960-968.

Kamkar-Rouhani, A., Eshaghi, E., Arab-Amiri, A., 2012, Processing and interpretation of ground-penetrating radar (GPR) data for detection of cavities, investigation of bedding and grain sizes and also estimation of clay content in shallow subsurface sediments, Journal of the Earth and Space Physics, 38 (4), 155-173.

Maheswari, K., Senthil Kumar, P., Mysaiah, D., Ratnamala, K., Sri Hari Rao, M., and Seshunarayana, T., 2013, Ground Penetrating Radar for Groundwater Exploration in Granitic Terrains: A Case Study from Hyderabad, Geological Society of India, 81, 781-790.

Parnow, S., Kamkar-Rouhani, A., Arab-Amiri, A., and Karimi, N., 2016, Processing and interpretation of ground penetrating radar (GPR) data in order to determine thickness and basement topography of Alamkooh glacier, Journal of the Earth and Space Physics, 42 (1), 154-157.

Oskooi, B., Parnow, S., Smirnov, M., Varfinezhad, R. & Yari, M., 2018. Attenuation of random noise in GPR data by image processing, *Arabian Journal of Geosciences,* 11**,** 677.