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STUDY OF HYDROGEOLOGY BY USING GROUND PENETRATING RADAR TECHNIQUES

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ABSTRACT

Ground penetrating radar (GPR) is a near surface geophysical method that can give high determination image of the dielectric properties of the features from few tens of meters on the surface. GPR is a geophysical method to capture subsurface feature using electromagnetic waves with the frequency band of 10-1000MHz. This paper examine about the different uses of GPR in hydrogeological studies. The interpreted GPR image is helps to evaluate hydrogeologic properties, such as water content, porosity, and permeability. Its non-invasive abilities make GPR an attractive contrasting option to the traditional methods utilized for subsurface characterization and to study the behavior of groundwater head near pumping well. It has been widely used to map subsurface formations and to recognize fate and transport of contaminants in groundwater.

KEYWORDS: GPR, hydrogeology, geophysical method and groundwater level

I. INTRODUCTION

Ground penetrating radar (GPR) is working based on the principle of geophysical method which is used to investigate subsurface information of earth. GPR uses the electromagnetic waves with the frequency ranges from 10 MHz to 1,000 MHz. This electromagnetic energy is passes through subsurface of earth material and it is reflected back to the surface where there are electrical property contrasts. GPR is used to plot geologic conditions on map that includes depth to bedrock, groundwater table, depth and thickness of formations, sediment strata on land, location of subsurface cavities and fractures in bedrock.

Electromagnetic waves travel at a speed that is evaluated by the electrical permeability the material. The speed is differing between materials with various electrical properties, and a signal passed through two materials with various permittivities over a same distance will arrive at different times. Transit time is defined as the time interval taken by the wave to travel from the transmitting antenna to the receiving antenna. The essential unit of electromagnetic wave travel time is the nanosecond (ns), where 1 ns $=10^{-9}$ s. Since the speed of an electromagnetic wave in air is 0.3 m/ns, the movement time for an electromagnetic wave in air is around 3.3333 ns/m travelled. The speed is corresponding to the opposite square base of the permittivity of the material, and since the permittivity of earth materials is constantly more prominent than the permittivity of the air, the movement time of a wave in a material other than air is constantly more noteworthy than 3.3333 ns/m. The main constraining element inside and out of penetration of the GPR technique is constriction of the electromagnetic wave in the earth materials. The weakening overwhelmingly comes about because of the transformation of electromagnetic energy to warm energy because of high conductivities of the soil, rock, and fluids. Dispersing of electromagnetic energy may turn into a prevailing element in weakening if an expansive number of in homogeneities exist on a scale equivalent to the wavelength of the radar wave.

The depth of penetration of GPR can be in excess of 30 meters in materials having a conductivity of a couple of milliSiemens/m. In specific conditions, for example, thick polar ice or salt stores, penetration depth can be as incredible as 5,000 meters. Be that as it may, penetration is normally under 10 meters in most soil and rock. The GPR method is delicate to undesirable signs caused by different geologic and social elements. Geologic sources of noise can be caused by rocks, creature tunnels, tree roots, and different in homogeneities that reason undesirable reflections or scattering. Noise may be created due to the reflections from nearby vehicles,

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buildings, fences, power lines, and trees. Electromagnetic signals received from cell phones, two-way radios, TV, and radio and microwave transmitters may leads error on GPR records. Accuracy is a measure of the repeatability between estimations. Accuracy can be influenced by the area of the reception apparatuses, tow speed, coupling of the radio wires to the ground surface, varieties in soil conditions, and capacity and care associated with picking reflections. The significant restriction of GPR is its site particular execution. Frequently, the depth of penetration is constrained by the nearness of conductive clays or high conductivity pore liquid. Understanding of GPR information requires a very trained operator.

II. MATERIALS AND METHODS

2. 1 GPR Principle

The electromagnetic wave in subsurface material is governed by Maxwell's equation. The electromagnetic wave behaviour in subsurface material is strongly dependent on its electrical conductivity. And the electrical conductivity is normally controlled by water. When material conductive, electromagnetic filed is diffusive and cannot propagate as electromagnetic wave. When it is resistive, or dielectric, electromagnetic field can propagate as electromagnetic wave. Some electromagnetic geophysical exploration methods such as MT and EM methods use the EM diffusive filed, because the penetration depth is large. However, the interpretation is not easy in these methods. GPR use the EM wave and its interpretation is rather easy. The material characteristics vary from diffusive to dielectric, when we change the frequency. This is normally described by the tangent loss factor or tan δ. Equation 1 is the Ampere's Law in EM field

$$\nabla \times H = \sigma E + j\omega\varepsilon E$$

All the electrical characteristics of material is determined by electrical conductivity, permittivity and permeability. In GPR technology, the permittivity is the most important parameter, because in higher frequency any material behaves as dielectric. GPR measures the reflected electromagnetic wave from subsurface structure. The velocity and reflectivity of the electromagnetic wave is considered by the dielectric constant or permeability of the soil. When the dielectric constant of the soil is ε_r , the velocity in this material is given by

$$v = \frac{c}{\sqrt{\varepsilon_r}} = \frac{3 \times 10^8}{\sqrt{\varepsilon_r}} (m/s)$$

The wavelength λ (m) and the operating frequency f(Hz) and the velocity of the wave is related as:

$$\lambda = vT = \frac{v}{f} (m)$$

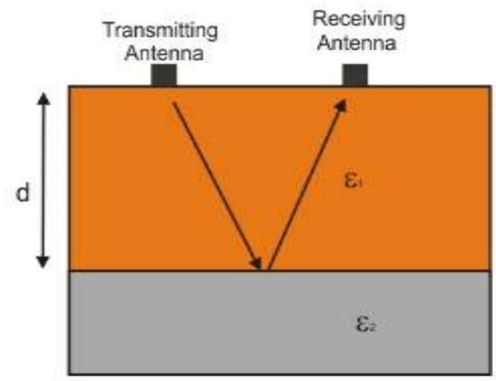

Figure 1. Electromagnetic wave reflection at a geological boundary (Source: Sato, 2001)

GPR transmits a pulsed electromagnetic wave from a transmitter located on the grounds surface and signals are received by a receiving antenna on the ground surface (Figure 1). The transmitted signal propagates through the subsurface material and reflected by objects such as geological boundary, buried objects and ground water. The received signal is recorded by a Personal Computer (PC). When the electromagnetic wave velocity v is known, measuring the travel time τ (s), we can estimate the depth of the reflecting object d(m) as follows:

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$$d = \frac{v\tau}{2}(m)$$

III. RESULTS AND DISCUSSION

According to Olhoeft (1984), the depth of penetration is controlled by electrical conductivity, water content, scale of electrical in homogeneity, 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; the rotation of the dipolar water molecule in the electromagnetic field turns electromagnetic energy into mechanical energy, and, in a viscous medium, then into thermal energy; changes in electrical properties in a material heterogenety on the same geometric scale as the wavelength of electromagnetic propagation scatters the electromagnetic energy into random directions rather than back toward the antenna; diffusion limited chemical processes around colloidal-sized particles then turn electromagnetic energy into chemical energy (Olhoeft, 1984, 1987). Kyosuke Onishi, et al., (2004) tried to use GPR to detect the behavior of interface between the fresh and saline water.

Predicting the success of GPR methods would require prior geologic knowledge of the area of interest to determine whether the subsurface conditions are favorable for the use of GPR. This investigation could be as simple as a review of existing information to determine the local lithology. A more time-consuming, but probably more informative preliminary investigation would involve performing a direct current or very low frequency resistivity survey to determine the effectiveness of the GPR method (Johnson, 1992). McGlashan et al. (2006) used borehole radar in hydrological study to identify spatial variability in aquifer porosity. The groundwater flow velocity profile derived from the GPR data is measured in agreement with flow velocities

Lin et al. (2009) investigated the feasibility of detecting underground water level by using GPR. Salih (2007) carried out a GPR survey near pumping well to measure the recovery time and movement of groundwater table. Another two GPR profiles collected from some distance far from the pumping well. The interpretations of the processed data reveal to the usefulness and high accuracy of GPR in the shallow groundwater surveys, the reflection of signals not reflect the real water table level but the top of capillary. Qi and Sato (2005) determined the water table depth and the Hydraulic Properties of the aquifer depending on the separation of residual signal between the GPR profiles before and after the stop of Pumping. Takishita et al. (2004) were conduct a field study to measurements the ground water behavior in sandy soils using surface ground penetrating radar, the GPR measurements had a similar trend to water table behavior that measured by observation well. The velocity of radar through the subsurface is dependent on the dielectric constant (ε_r) of the materials, which is the ratio of the amount of stored electrical energy when a potential is applied, relative to permittivity of a vacuum (Lowry et al. 2009). It is defined thus

$$\varepsilon_r = \varepsilon_s / \varepsilon_0$$

Where;

ε_r = Dielectric constant
ε_s = Static permittivity of the material
ε_0 = Electric constant.

The higher the dielectric constant the less velocity as shown in the Table 1. Xuan and Jin (2014) used the resistivity sounding method for detecting the condition of sea water intrusion of groundwater. Electrical prospecting method contains a lot of methods, and resistivity sounding method is one of them. Sea water intrusion is a hidden and complex phenomenon, and it occurs in the coastal areas. The cause of this problem is the water under the action of pressure difference supply infiltrates the groundwater aquifer caused by human over-exploitation of groundwater, and as a result, the sea water intrusion can make fresh groundwater to salt water. Sea water is rich in all kinds of ions, so it have low resistivity, and underground water contain less ion than sea water, so its resistivity is higher than sea water's resistivity. According to the difference of conductivity of sea water and fresh groundwater, the researchers usually adopt resistivity method in the survey of sea water intrusion. The focus of the research is the main channel of sea water intrusion, the brackish-water interface, determines the bedrock water storage structure, and monitoring the scale and scope of sea water intrusion.

Xuan and Jin (2014) used the GPR method for detecting the condition of landfill leachate pollution of groundwater. Ground penetrating radar is a kind of instrument that using broadband high frequency short pulse electromagnetic wave to detect object. The working principle of the instrument is based on the different dielectric constants of underground materials. When the electromagnetic wave propagated through one medium, if the wave encountered the interface of two different geological structures with different dielectric constants (such as the interface of polluted soil and unpolluted soil), the electromagnetic wave reflection and transmission phenomena would happen. The distribution of the energy of reflection and transmission mainly related to the electromagnetic wave reflection coefficient of the interface. Leachate pollutants can change the surrounding medium's porosity and fill the original void space, and that will prevent water's infiltration. As a result, the value of dielectric constant has changed, and then reflection coefficient has changed. So the signal can produce reflection events on the radar profile, and then it can easily identify the polluted areas' depth and scope based on the profile.

Table 1. Typical values of some radar parameters for some materials (Milson, 2003)

Material	ε_r	v
Air	1	0.3
Ice	3-4	0.16
Fresh water	80	0.033
Salt water	80	0.01
Dry sand	3-5	0.15
Wet sand	20-30	0.06
Shale and clay	5-20	0.08
Silts	5-30	0.07
Limestone	4-8	0.12
Granite	4-6	0.13
Dry salt	5-6	0.13

IV. CONCLUSION

This paper examine about the various uses of GPR for hydrogeological studies. GPR image is interpreted to help with evaluating hydrogeologic properties such as water content, porosity, and permeability. Its non-invasive abilities make GPR an attractive contrasting option to the traditional methods utilized for subsurface characterization and to study the behaviour of groundwater head near pumping well. It has been widely used to map subsurface formations and to recognize fate and transport of contaminants in groundwater. Thus, GPR plays very important role for identification and mapping of subsurface features and water bearing zones.

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