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Integrated Study of GPR, ER and GIS

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Abstract

The aim of this study is to integrate GPR and ER data sets within a GIS and analyze the integrated data sets. The study demonstrated that GIS is a sophisticated tool for analyzing data from multiple sources.

1. Introduction

Ground penetrating radar (GPR) is a geophysical method that has been developed over the past thirty years for shallow, high-resolution, subsurface investigations of the earth. This non- destructive method of subsurface analysis is becoming increasingly important for many environmental and shallow geophysical applications. GPR uses high frequency pulsed electromagnetic waves (generally 10 MHz to 1GHz) to acquire subsurface information. Energy is propagated downward into the ground and is reflected back to the surface from boundaries at which there are electrical property contrasts.

GPR is used to map geologic conditions that include depth to bedrock and water table, location of objects such as pipes, drums, tanks, cables, mapping landfill and trench boundaries mapping contaminants and conducting archeological investigations. Electrical resistivity (ER) surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock.

Due to inherent ambiguities in data interpretation that can result from using only one geophysical method, it is desirable to acquire and integrate data from two or more geophysical methods such as GPR, ER to determine the subsurface structure. The ability to image the same subsurface with more than one geophysical method reduces part of the uncertainty in the interpretation of most geophysical data. However, in most cases the scale difference of the various geophysical measurements is large; hence, the integration of more than one method is difficult. Nevertheless, it is possible to integrate different geophysical data sets if they are acquired within the same profile and combine them with other data sets stored in a GIS. In this paper, integration of GPR and ER data within a GIS environment and the related analysis have been described.

2. GPR Survey

The detectable depth range of GPR survey is depends on soil and sediment mineralogy, clay content, but the most important factor is the water content in the soil. Generally, electromagnetic wave can easily penetrate into dry soil therefore GPR can easily be applied to dry regions like Mongolia. Figure 1 shows the GPR system that consists of a PC, a control unit, and transmitting and receiving antennas. The control unit is connected to the transmitter and the receiver by optical fiber.

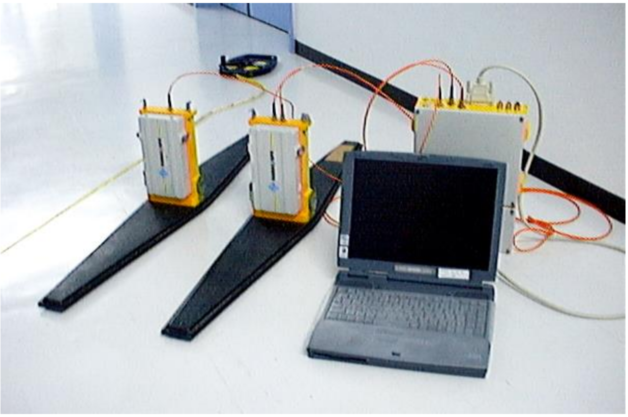


Figure 1. GPR system (RAMAC/GPR, MALA Geoscience).

GPR measures the reflected electromagnetic wave from subsurface structure. The velocity and reflectivity of the electromagnetic wave in soil is characterized by the dielectric constant of the soil. When the dielectric constant of the soil is ε_r , the velocity in this material given by

$$v = c / \sqrt{\varepsilon_r} \qquad (1)$$

where c is the velocity of light in air. Therefore, the travel time from a boundary at the depth d is given by

$$t = \frac{2d}{v} = \frac{2d\sqrt{\varepsilon_r}}{c} \qquad (2)$$

When electromagnetic wave is incident to a flat boundary of two different materials having the dielectric constant of ε_1, ε_2 the reflection coefficient of the wave is given by

$$\Gamma = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}} \qquad (3)$$

The great advantage of GPR over other geophysical methods is its ability to determine the actual depth of objects and model them in 3 dimensions.

1D and 2D GPR field experiment to monitor seasonal groundwater level change was carried out in pumping well No.10 of Central Water Source Area of Ulaanbaatar City with several times and in different seasons from 1999 until now. 2 kind datasets we obtained by GPR field survey from 1999. Here, we outline the GPR experiment of 2000. This survey design differs from normal survey design in that the GPR survey lines are parallel, perpendicular and at an angle each other.

We used a GPR system with 100MHz antennas, to obtain enough penetration depth. The experiment was carried out along 2 dimensions mesh, namely small grid survey lines by 6mx6m, large grid survey line by 18mx18m around pumping well. Common offset (CO) and common-midpoint (CMP) method were used as GPR technique. The survey lines begin from the wall of the pump house, which are about 3m from the well position.

3. Interpretation of 3D GPR Data

The GPR data was analyzed using ReflexW v. 3.01 (Sandmeier Scientific Software, Karlsruhe, Germany). Total 28 profiles were surveyed for 3D data interpretation of GPR data. We used an encoder attached to a string wheel, which measures the antenna position and GPR data was acquired every 0.1m. Also we conducted TDR (Time Domain Reflectometry, IMKO, Germany) measurement for determination of the velocity of the EM wave. The measured average water content of the ground surface is 3.6% in the experiment site. The corresponding dielectric constant is 3.55 and velocity of EM wave is derived as 0.1592m/ns. From the velocity spectrum of CMP it causes strong reflection at 120ns. We used the velocity of 0.14m/ns for interpretation, because it will be average velocity in the layer above the wet soil layer. We can see the reflection that may be caused from the water table around 80ns.

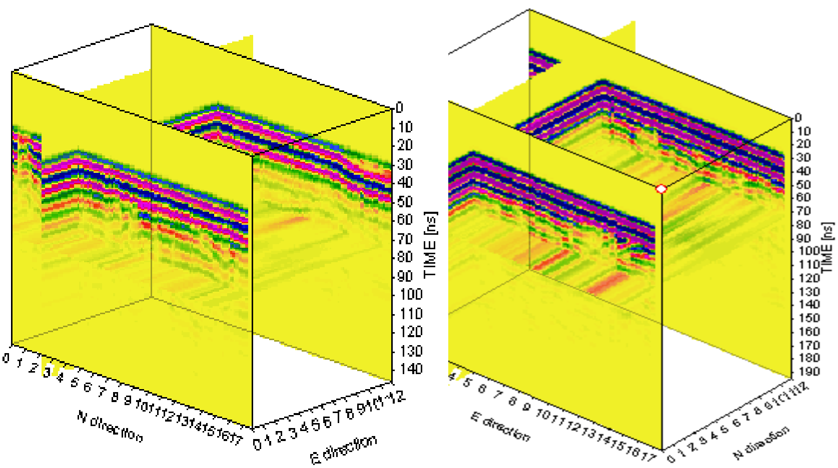
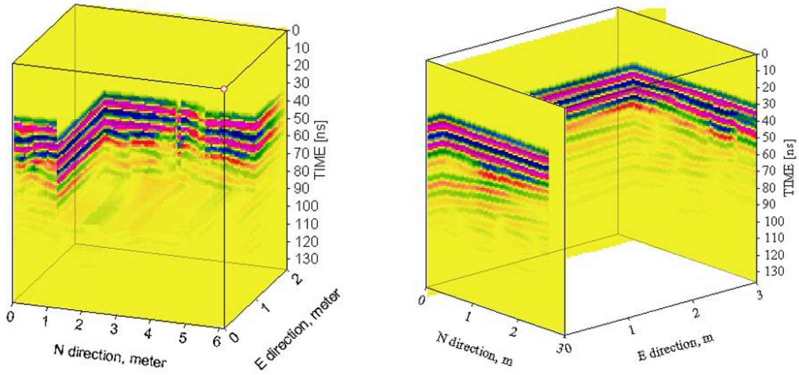


Figure 2. 3D GPR profile of 18m x 18m grid shows (a) generated by E3-E7 lines, (b) generated by N3-N7 lines.

Figure 2 (a) shows the 3D GPR data created from 2D parallel lines of E3-E7, (b) shows the 3D GPR data created from 2D parallel lines of N3-N7. To generate 3D GPR profile from parallel lines it must be in same length. For small 6mx6m grid we surveyed along 7 survey lines with 2 different lengths. Figure 3(a) shows the 3D view of GPR profile generated by parallel lines N05, N06 and N07, (b) shows 3D view of GPR profile generated by parallel lines N01, N02, N03 and N04.



(a) (b)

Figure 3. 3D GPR profile of 6m x 6m grid shows (a) generated by parallel lines N05-N07, (b) generated by parallel lines N01-N04.

4. Electrical Resistivity Survey

The electrical resistivity method is one of the most useful techniques in groundwater hydrology exploration because the resistivity of a rock is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content. In general, it is possible to map different stratigraphic units in a geologic section as long as the units have a resistivity contrast. The electrical resistivity survey involved electrical sounding, which is based on measuring the potentials between one electrode pair while transmitting direct current between another electrode pair. The depth of penetration is proportional to the separation between the electrodes, in homogeneous ground, and varying the electrode separation provides information about the stratification of the ground.

Electrical sounding is designed to provide information on the variation in subsurface conditions with depth. Sounding is typically used to help determine the depth to the water table, the thickness of sand, gravel and rock layers, and the actual value of electrical resistivity versus depth.
Using the basic equation in a homogenous medium,

$$V = \frac{\rho I}{2\pi r} \qquad (4)$$

where V -voltage
ρ -electrical resistivity
I -current
r - distance between the current electrode.

We can solve resistivity of the subsurface as

$$\rho = 2\pi \frac{\Delta V}{I} k \qquad (5)$$

here ΔV - potential difference
k- geometrical factor.

But in inhomogeneous subsurface we define an apparent resistivity, ρ_a. ρ_a is the value obtained from Eq.(5) and will only equal to the true resistivity if the subsurface is homogeneous:

$$\rho_a = 2\pi \frac{\Delta V}{I} k \qquad (6)$$

It is the resistivity of an equavalent but fictitious half space and depends on electrode geometry and spacing.

The Schlumberger array is used for profiling and sounding. The two potential electrodes MN are located at the centre of the spread and are closely spaced compared to the two current electrodes AB that are also located symmetrically about the centre point.

The current electrodes are then expanded, and the geometric factor k is defined as:

$$k = \frac{1}{2}\left[\left(\frac{AB}{2}\right)/MN - \frac{MN}{4}\right] \qquad (7)$$

We can solve for the apparent resistivity of the subsurface as:

$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a} \frac{\Delta V}{I} \qquad (8)$$

where: s-half space of current electrodes, AB/2
a-distance between potential electrodes, MN.

Electrical resistivty experiment was conducted on 17 October, and 5-7 November 2003, with the aim of determining a water containing alluvial layer as well as ground water level by Tohoku University and Geo-Ecological Instititute of Mongolian Academy of Sciences reserchers. The experiment site was selected in well No.10 and the measurement points were chosen in the same location of GPR survey line as NW, N and NE directions with 10m-25m intervals. In total 45 measurements were conducted in 2 different times. Seven electrical resistivity soundings were collected along survey lines using the Schlumberger electrode configuration with electrode spacing 0.65 to 70 m at each sounding location.

The location of electrical resistivity soundings is shown in Figure 4.8. Sounding station 1 (ES-1) was completed in the starting point of GPR experiment. Sounding ES-2, 3, 4, 5 and 6 are located with 10m intervals to each other along survey line and last ES-7 was located with 25m intervals to ES-6. The apparent resistivity values obtained from the measurements were plotted against half the current electrode spacing AB/2.

These sounding curves are correlated to theoretical model curves to determine the subsurface stratigraphy. In order to relate the electric resistivity related to the average depth between 2 points to the real situation, a transformation was performed to the difference between the depths. The interpretation was created by Geo-Ecology Institute researchers of Mongolian Academy of Sciences and we obtained the interpretated results. The interpretation was made using a differential-potential method (DPM), by applying Petrovskii transformation. It determines more than 4 layers, thus indicating more accuracies.

The resistivities determined by the Petrovskii transformation are marked by red colour on the field note and the graphics is drawn by the red colour as well. Along the NE line, on the EPS-1 the first resistivity on 0.8m is 606 Ωm and the last resistivity on 60m is 239 Ωm and total 15 measurements were made in each sounding. On the sounding curve there were determined 8 layers. The break points in which the resistivities significantly change become one of the basis for determining the layers. For example, the boundary between layers 6 and 7 is located on the break point in which the curve directly change and it was used for averaging. Also it is possible to determine that there is 1 layer which has less thickness and more resistivity in between these 2 layers. Using a DPM ρ_d has been calculated as follows:

$$\rho_d = \frac{s_i - s_{i-1}}{1} : \left(\frac{s_i}{\rho_i} - \frac{s_{i-1}}{\rho_{i-1}} \right) \qquad (9)$$

where: ρ_d - differentialized resistivity

$s_i; s_{i-1}$ - AB/2

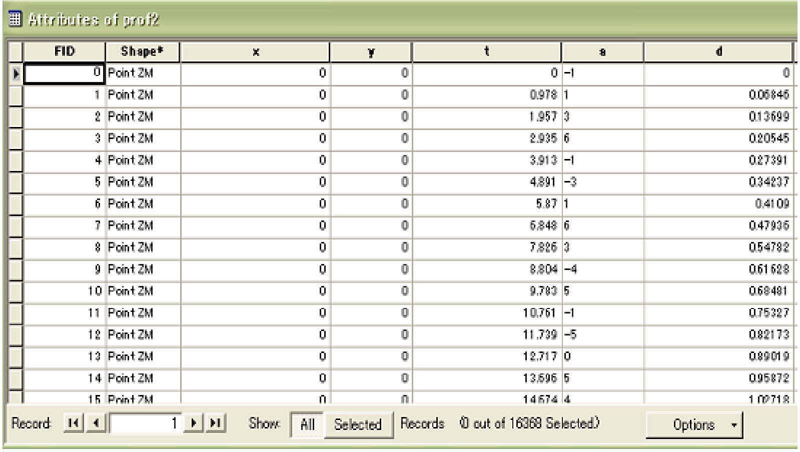
$\rho_{i;} \rho_{i-1}$ - electrical resistivity related to the electrode spacing s_i, s_{i-1} (AB/2).

To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area surveyed, is important. As a result, 3-5 layers, which are distinguished by their differentialized resistivity have been detected. From the interpretation the layer of 10m-30m depth is considered as an active groundwater zone and the upper layer of its water containing alluvial aquifer are filled by coarse gravel and sands. As it was seen from the resistivity below 10m depth was gradually decreased.

5. GIS Data Analysis

ArcView 8.2 and extension 3D Analyst (Environmental Systems Research Institute Inc., Redlands, CA) were both used in the GIS Analysis. The GPR data with topographic relief was exported in 4 columns ASCII text format using ReflexW software. At this point it is necessary to convert this file to *.dbaseIV or *.csv format; it is rather unfortunate but unless this is done, ArcView will not recognize the tabular profile data. ASCII text file was imported to the GIS software in tabular csv (*.csv, comma separated value) format.

The GPR data contains several thousands lines of data, called traces, in a linear direction; the specific number of traces depends on the length of the survey line. In this research each trace contains 1024 recorded data points in the vertical direction called samples. Essentially, the total number of points in one GPR survey line is equal to the number of traces multiplied by the number of samples. The exact number of samples is chosen in the GPR control unit before data collection. Each record was written in the format (x, y, t, a) where “x” is the distance along survey line, “y” is horizontal distance, “t” is travel time in ns, and “a” is wave amplitude. A fifth column “d” was added after exporting to indicate depth in meters. Calibration of the depth axis is a procedure to correctly depict depth within GPR profile. The depth is calculated from velocity (m/ns) value from Eq.(4.2) entered by manual. This velocity is calculated from the dielectric constant used in collecting GPR data. 2D shapefile were constructed from the roughly 50,000 points of data the tables contained as shown in Figure 4. The amplitudes of electromagnetic wave for each sample point were displayed in 3D scene for analysis in Figure 5.



Attributes of prof2

FID	Shape*	x	y	t	a	d
0	Point ZM	0	0	0	-1	0
1	Point ZM	0	0	0.978	1	0.06846
2	Point ZM	0	0	1.957	3	0.13699
3	Point ZM	0	0	2.935	6	0.20545
4	Point ZM	0	0	3.913	-1	0.27391
5	Point ZM	0	0	4.891	-3	0.34237
6	Point ZM	0	0	5.87	1	0.4109
7	Point ZM	0	0	6.848	6	0.47936
8	Point ZM	0	0	7.826	3	0.54782
9	Point ZM	0	0	8.804	-4	0.61628
10	Point ZM	0	0	9.783	5	0.68481
11	Point ZM	0	0	10.761	-1	0.75327
12	Point ZM	0	0	11.739	-5	0.82173
13	Point ZM	0	0	12.717	0	0.89019
14	Point ZM	0	0	13.696	5	0.95872
15	Point ZM	0	0	14.674	4	1.02718

Record: 1 Show: All Selected Records (0 out of 16368 Selected) Options

Figure 4. Attribute data created by ASCII file of GPR profile.

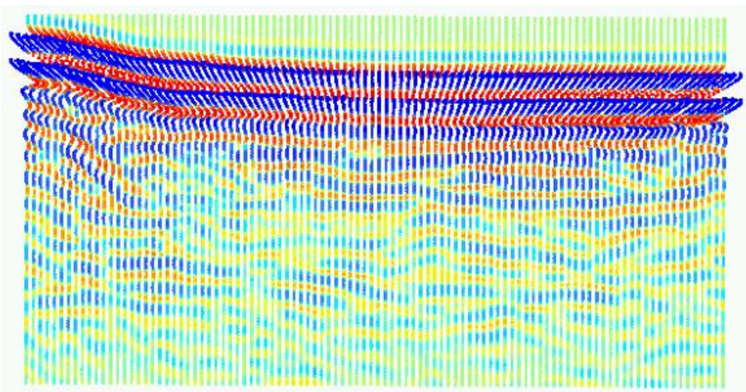


Figure 5. 3D GPR profile plotted in ArcView.

6. Discussion

The 3D representation of GPR data sets may have a good ability to estimate true distributions and forms of subsurface profiles because each layer changes continuously in relation to the changes in the depth. The data sets of GPR experiment conducted in 2000 have a special feature and this is the only data set that were acquired by 2 dimensional mesh. From these data sets, we developed 3D GPR data set. It could be seen that we could be obtain data with very high quality if we locate the antenna positions very accurately.

Figure 6 shows integrated GPR and ER data acquired in same time in November 2003 and compiled within ArcView. GPR data shows the data, which acquired along NE line with 50m and conducted in same time within resistivity survey. Electrical resistivity data was imported into the GIS as raster data. Vertical cross section obtained from resistivity survey overlaid GPR profile in GIS. Distance between 2 soundings is 10m. For NE line 5 sounding stations corresponded to GPR profile. Starting point of GPR experiment and sounding station ES-1 of ER survey was completed in 3m from the wall of pumping well. We can see from GPR profile /Prof8/ a strong reflection at 70ns. If we estimate depth of reflection object from EM velocity (0.14m/ns) it will be 5.6m from the surface. During GPR experiment we also observed water level in pumping well. It was 4.52m. The reference level of the water level is 1.15m below the level of the survey line at x=0m, it means water level is 5.57m from the ground surface.

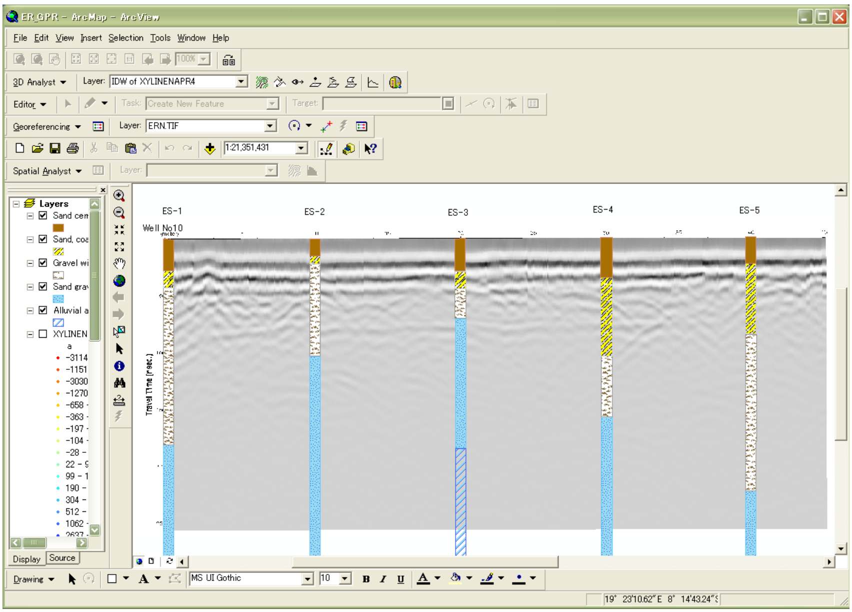


Figure 6. Geological section of NE line based on electrical resistivity survey combined with GPR profile within GIS, ArcView. Vertical cross section of resistivity survey overlaid on processed GPR profile8 along NE line (GPR experiment of Nov 2003).

As seen, clear reflection at 70ns was caused from the water table. Electrical sounding curves from the ER survey the layer of 10m-30m depth is considered as an active groundwater bed and the upper layer of its water containing alluvial aquifer are filled by coarse gravel and sands. At ES-2 around 8m, at ES-3 around 5.4 m below layer as interpreted as sand gravel aquifer. In winter and spring seasons around pumping wells down to 7-12 m cones of depression appear within a radius of 0.5-1.5 km. The distance between ES-1 and ES-3 is 20m. From the Lu's study around pumping well No.10 cone of depression appearing within a radius 23m. If pumping water table down to 7-12m cones of depression appear within 23m sand gravel aquifer as fourth layer at ES-1 might be considered as deeper to other sounding stations. From the other side, the groundwater bed of the Tuul River is contained in the sand and sandy soil with alluvium and upper layer is deepened 5-19 meters, the lower layer deepened 35-120m. However, the weakness of the ES method resistivity survey is that it might incorrectly determine shallow and thin layers, and interpretation is equivocal. It means water zone of 5-19m might be considered by ER survey not real stratigraphic unit. Integration of GPR, ER and GIS was developed successfully. From the both analysis, data sets support each other.

7. Summary

The GPR measurements conducted in September 2000 using a GPR equipment with 100 MHz antenna and further analysis were described in detail. The survey design in these measurements differs from normal survey design in that the GPR survey lines are parallel, perpendicular and at an angle to each other. Therefore, the 3D GPR profile was created and further interpretation was performed.

Electrical resistivity experiment and GPR experiment conducted in November 2003 were described. The experiments were conducted with the aim of determining a water containing alluvial layer as well as ground water level. Here, we successfully integrated GPR and ER data sets within a GIS environment and conducted the related analysis.

As it could be seen from the analysis, both data sets support each other in terms of determining the detailed information related to groundwater condition at pumping well No.10. By combination of all geophysical results we obtained a detailed image of subsurface condition around the pumping well.

8. References

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