LYSIMETER STUDY TO IDENTIFY GPR RESPONSE UNDER DIFFERENT CONTAMINANT LEVEL IN GROUNDWATER

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Abstract

Potentials of groundwater contamination due to different pollutant loads can be assessed using different technologies available through quality detection, mapping extend of the contaminant plume and migration of the plume. Real field situation is very complex and application of some techniques might be a challenging task especially with respect to data interpretation. Creating of controlled condition which represents the real field situation is very much important to understand the field situation and applicability of such techniques. Among the available geophysical methods, ground penetrating radar (GPR) technique is suitable for studying the subsurface features. A lysimeter (4.0 m x 1.0 m x 1.5 m (L x W x D)) study was conducted at the Meewathura farm of the Department of Agricultural Engineering, University of Peradeniya to verify the applicability of the GPR technique in detecting contamination level in groundwater. The lysimeter was filled with sand as a media and two iron bars (with a diameter of 5 cm) were placed at 1.0 m and 3.0 m length intervals at 0.2 m above from bottom of the lysimeter. GPR reflection surveys were carried out on lysimeter at different level of contamination. GPR wave response was studied under each situation and analyzed the reflected waves from bottom of the lysimeter and iron bars. 2D GPR wave simulations were carried out using GPRMAX2D for the same lysimeter conditions. For this purpose, a contamination plume with different EC values (to obtain different contaminant levels) in groundwater was introduced to the model domain. Both modeling result and lysimeter study were revealed that the energy of reflected wave attenuated and disappear the reflected event with increasing contaminant level (increasing EC).

Keywords: Electrical conductivity, contamination, ground penetrating radar

1. Introduction

Potentials of groundwater contamination due to different pollutant loads can be assessed using different technologies available through quality detection, mapping extend of the contaminant plume and migration of the plume. Even though, real field situation is very complex and application of some techniques might be a challenge in the data interpretation. Therefore, creating of control condition which represent to the real field situation is very good task to understand the field situation and applicability of techniques.

Among the available geophysical method GPR method is very good for studying the subsurface features. GPR is a non-invasive geophysical method (Huisman et al., 2003) designed to image the subsurface features. GPR instruments operate by radiating radar frequency EM energy reflected into the subsurface from a transmitting antenna and recording energy reflected from subsurface structures with a receiving antenna (Lane et al., 2000). Cosgrave, (1987) concluded that GPR is well suited to mapping and monitoring the movement of the upper surface of the plume and at 100 MHz, GW conductivities in excess of 125 mS/m (0.125 S/m) severely attenuate reflected energy. Electrical conductivity of the soil or rock materials along the propagation paths leads to significant absorptive losses which limits the depth of penetration. Pomposiello et al. (2004) used four GPR profiles with 150 MHz - 500 MHz antenna for determining the depth of the water table and evaluate the horizontal extension of contamination and they identified contaminated plume using absence of reflectors and existence of very weak signals. Clay soils and ionic contaminants in the groundwater will increase conductivity of the GW, which leads to greater attenuation losses and decreased GPR signal penetration. Rosqvist et al. (2003) obtained resistivity measurement of GW samples and the data were supported with EC of water samples which range from 80 – 323 mS/m. Purpose of this study to identify GPR reflected wave behavior under different contaminant level in groundwater.

2. Materials and Methodology

A Lysimeter was constructed at Meewathura farm (Figure 1), department of agriculture engineering, University of Peradeniya. Dimension of the lysimeter was 4.0 m x 1.0 m x 1.5 m (Figure 1) and it was constructed using cement and sand (Figure 1). All side walls and bottom layer were lined with cement and it will support to avoid leakage.

Figure 1: Constructed Lysimeter at Meewathura research site

2.1 Experimental design of lysimeter study

The lysimeter was filled with sand as a media up to 0.2 m height from bottom of lysimeter. Then iron bars were placed at 1.0 m (bar “A”) and 3.0 m (bar “B”) distance from South. Diameter of iron bars were 2 inch (radius = 0.0254 m). After placing iron bars, lysimeter was completely filled with sand. Then PVC pipe (0.9 m of height) was connected to outlet and it was supported to keep a constant head of water column.

2.2 GPR surveys on lysimeter

There were ten GPR surveys carried out after injecting different salt concentration to the water table in Lysimeter. GPR survey was conducted on lysimeter with antenna frequency of 200 MHz using 0.5 m of antenna separation and 0.1 m of step size. Average depth of WT was 0.25 m. After each GPR line data collection, water samples were collected from 0.1 m below the water table (WT was at 0.25 m depth and water samples were collected at 0.35 m depth).

Table 1: Experimental detail of GPR surveys

	Time	*Situation*	*Water sample number*	*Line no*
Survey -1	*09.50*	*Background 2 (before wetting)*	*1*	*Line 38*
	10.00	*Wetting for 15 min (Rate=0.17L/s)*		

Survey -2		*After wetting*	*2*	*Line 41*
	11.05	*C=50g/L of salt solution add 1 Lto WT*		
Survey -3	*11.07*	*After add 1L of salt solution*	*3*	*Line 42*
Survey -4	*11.30*	*C=50g/L of salt solution add 1 Lto WT*	*4*	*Line 53*
Survey -5	*11.41*	*C=100g/L of salt solution add 2L to WT*	*5*	*Line 54*
	12.00	*C=200g/L of salt solution add 2L to WT*		
Survey -6	*12.05*	*Add 1 L of fresh water*		*Line 55*
Survey -7		*C=400g/L of salt solution add to WT*		*Line 56*
Survey -8	*12.28*	*Add 1L of fresh water*		*Line 57*
Survey -9	*12.30*	*C=500g/L of salt solution add 2L to WT*	*6*	*Line 58*

Table 2 shows measured EC of water samples after each GPR survey under different salt concentration.

Table 2: Electrical conductivity of water samples

Water sample number	*Followed GPR Line no*	*Electrical conductivity (S/m)*
1	*After Line 38 (survey-1)*	*0.000252*
2	*After Line 41 (survey-2)*	*0.000158*
3	*After Line 42 (survey-3)*	*0.016*
4	*After Line 53 (survey-4)*	*0.062*

5	*After Line 54 (survey-5)*	*0.080*
6	*After Line 58 (survey-9)*	*0.159*

2.3 Analyzing of GPR response

2D color images were developed with using EKKO_ View Delux and EKKO-View software (sensors and software Inc.) for GPR line data. Raw GPR line data were not processed with GPR processing techniques which were available in the software package. Therefore, it will help to recover the raw amplitude variation of each trace.

Energy attenuation of GPR traces analyzed using PickerV2 software; amplitude of reflection events were picked both bar “A” which is originating at 1.0 m on x-axis (uncontaminated area) and bar “B” which is originating at 3.0 m on x-axis (contaminant area). Then peak amplitude values were plotted with respect to the EC of each corresponding water sample.

2.4 GPRMAX 2D simulation

Conceptual model domain was run with having same dimension and introducing 0.9 m of plume depth in groundwater. Three different EC levels (0.02 S/m, 0.09 S/m and 0.35 S/m) were introduced to plume. 2D images were developed for each GPR wave response.

3. Results and Discussion

3.1 Analysis of GPR response under different contaminant level

GPR raw data are used to study the GPR wave response under different salt concentrations. In each GPR survey, calculate the velocity of radar waves using curve matching (function available in EKKO_View). Theoretically reflection from the WT, iron bar (subsurface reflection) and bottom of the lysimeter should disappear due to energy attenuation (Cosgrave, 1987 and Mimrose et al, 2012). Figure 2 shows the 2D color image of survey-1. It is a result of settled lysimeter having uniformly wetted sand media. EC of the collected water sample from the saturated zone is 0.000252 S/m at survey-1. The average radar wave velocity for the survey-1 is found as 0.062 m/ns. Survey-2 (wetting for 15 min at a rate of 0.17 L/s) is having 0.060 m/ns of wave velocity and it has been reduced from 0.062 m/ns (Figure 3). In the mean time, EC of the saturated zone is reduced (0.000158 S/m) than the survey-1, potentially due to dilution effect after adding water to the lysimeter.

Energy of reflected events gradually decreased and starts to disappear with time when increasing the level of salt concentration in injecting water. Figures 4 to Figure 10 Show 2D GPR profiles obtained from increasing concentration of salt solution.

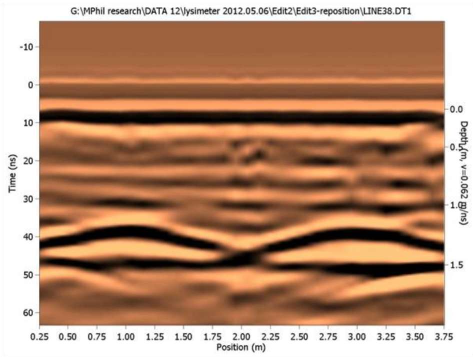


Figure 2: GPR radargram of survey-1 (EC=0.000252 S/m)

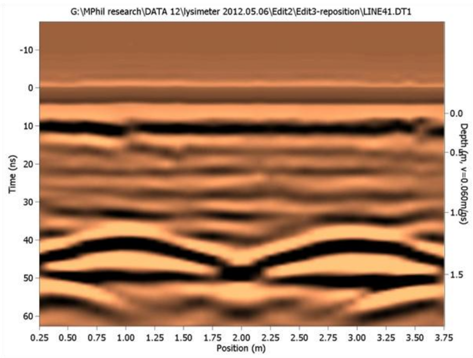


Figure 3: 2D GPR profile (survey-2) after addition 153 L of freshwater (0.000158 S/m)

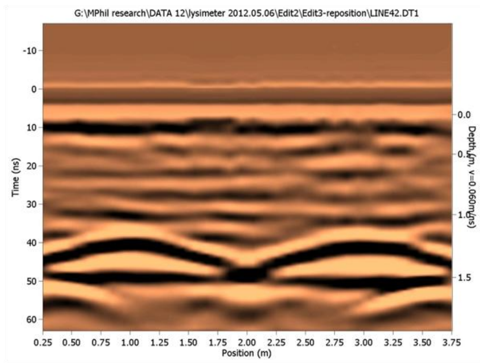
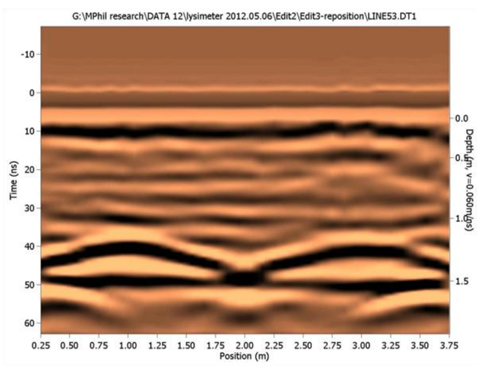


Figure 4: 2D GPR profile of survey-3 (0.0165 S/m)



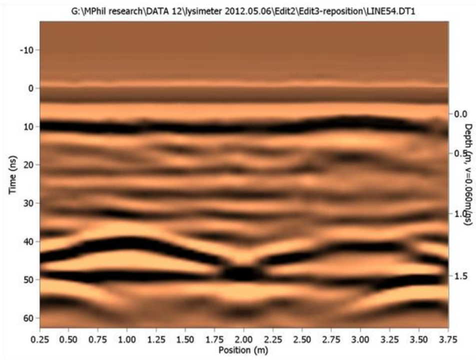


Figure 6: 2D GPR profile of survey-5(0.08 S/m)

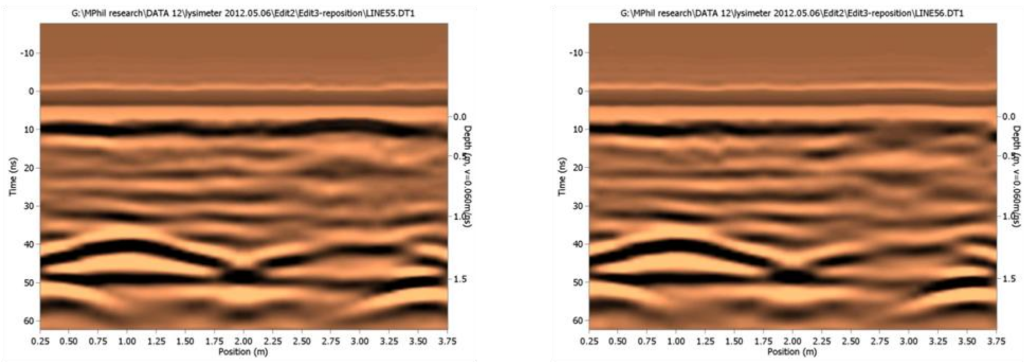


Figure 7: 2D GPR profile after applying salt solution (a) Survey-6 (b) Survey 7

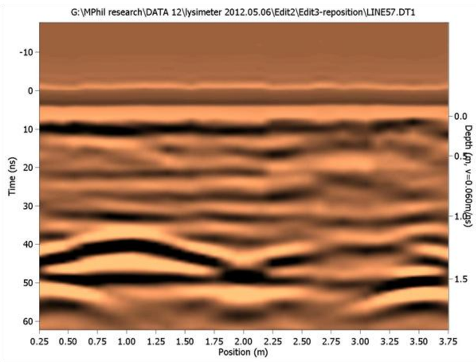


Figure 8: GPR radargram of survey-8 (after injecting 1L of fresh water)

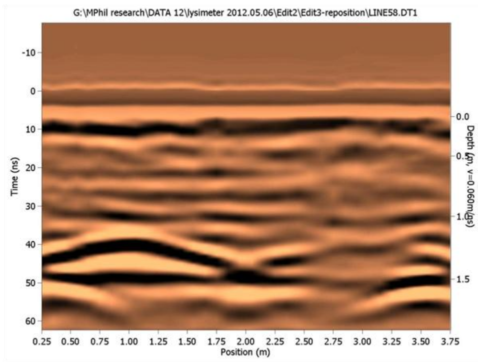


Figure 9: GPR radargram of survey-9 (after injecting 500g/L of salt solution-0.159 S/m)

It is very clear in these figures (Figure 4-Figure 9) that gradual disappearance of reflected wave energy from bar "B" and bottom of the lysimeter with increasing EC levels in groundwater. However, the reflected wave energy from bar "A" and bottom of lysimeter in non-salt water applied areas remains same throughout this experiment.

Figure 4 (concentration of 50 g/L) is resulting an EC of 0.0165 S/m which is greater than survey 2. At bar "B", the peak amplitude of the iron bar reflection was found to 9466 mV (Figure 10). The reduction of the peak amplitude from 13,032 mV to 9466 mV was observed when the EC in groundwater was increased from 0.000158 S/m to 0.0165 S/m (increased by nearly 100 times). This effect of increasing EC on the reflected wave from the bar "B" is clear in Figure 10 where as the reflection from bar "A" is not affected since the EC of groundwater was not changed in this area. After increasing 100 times of EC (from 0.000158 S/m to 0.0165 S/m) it is reducing 1/3 of peak amplitude value in bar reflection (from 13032 mV to 9466 mV).

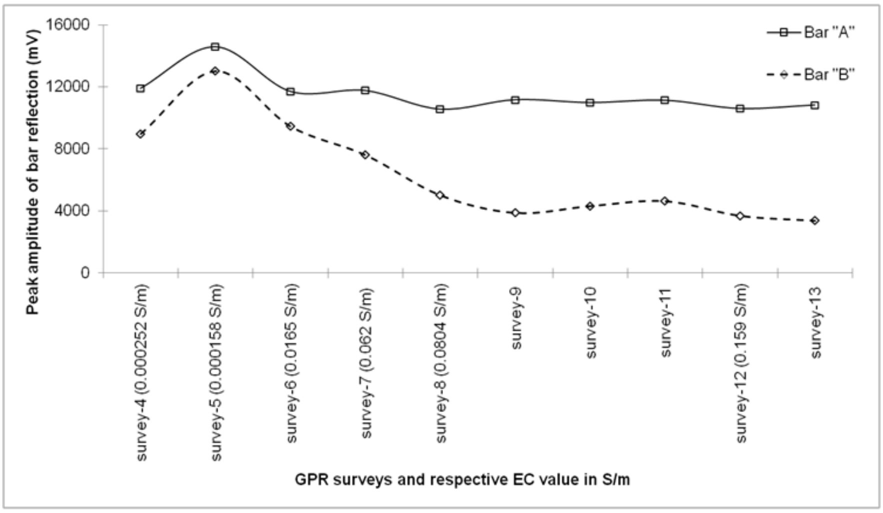
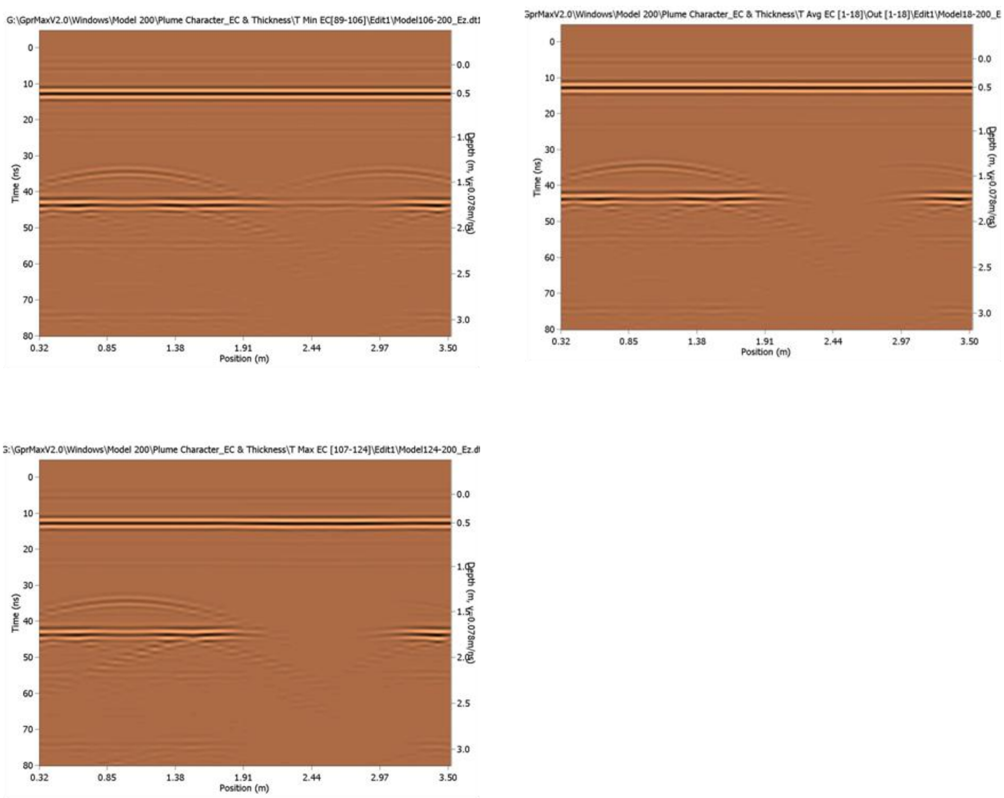


Figure 11: Variation of peak amplitude of bar reflections

Figure 10 shows the variation of peak amplitude of reflected traces from bar "A" (uncontaminated area) and bar "B" (contaminated area) with increasing concentration of injected salt water. Variation of reflected trace amplitude from bar "A" is less than that from bar "B" (Figure 11). Though, at second point of graph, amplitude increases both bar "A" and bar "B". It is due to the dilution effect after adding water (wetted uniformly) to the lysimeter and level EC in GW reduced from 0.000252 S/m (survey-1) to 0.0158 S/m (survey-2). A *t test* is performed to compare the mean differences of reflected wave amplitudes from bars A and B and results revealed that two means are significantly different at 0.05 level [P=2.12] and reduction of reflected wave amplitude is significantly decreases with increasing EC of groundwater.

3.2 Analysis of wave response in GprMax 2D simulation

Figure 11 show 2D color image of 0.02 S/m (Fig. 11(a)), 0.09 S/m (Fig. 11(b)) and 0.35 S/m (Fig. 11(c)). It is very much agreed with lysimeter data; increment of EC level in contaminant plume will disappear the any subsurface reflections. Contaminant area can be identified using GPR radargram when it pollute with inorganic contaminants.



4. Conclusions

When media has inorganic pollutant (salt solution) the GPR subsurface reflection (both bar reflection and bottom reflection) are disappearing. Both modelling result and lysimeter study were revealed that the energy of reflected wave attenuated and disappear the reflected event with increasing contaminant level (increasing EC).

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