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Application Of ERT For 2-D Imaging Of Water And Underlying Bed At Laboratory

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Abstract- Assessment of the solute transport process in surface water and its underlying bed is very important for its proper management. The objective of this study was to estimate contaminant movement from running water to underlying bed and to understand pollutants transport behavior in running waters with the application of electrical resistivity tomography (ERT). The current study was conducted in a glass tank measuring 45x45cm with a slice of 10cm from both sides for balance water level and groundwater movement. A total of 24 stainless steel electrodes were installed by floating electrode method fixed at the center of tank on surface of the water at the space of 2cm. GeoPen E60CN a multichannel electrical resistance measurement machine was used for 2-D ERT measurements. Wenner array method was used for the measurements and obtained data was used for 2D inversion by using RES2DINV software. Results demonstrate that ERT method is very efficient for the environmental studies of surface water and its underlying bed and optimization of other water quality related parameters.

Keywords: ERT, surface water, salinity, solute transport

1. INTRODUCTION

Surface water is a major source of potable water and also shelters to all living organisms which are being affected due to rapid urbanization. Proper management of water resources is therefore imperative to reduce water pollution (Allanson, 1973; Klapper, 2003; Beklioglu *et al.,* 2003). Surface waters are also important for the recharge of aquifer also and are anticipated in the increase of salinity level in groundwater. Understanding the flow and transport of contaminants from surface waters to ground is a key for its preservation and proper management (Hayashi and Rosenberry, 2002; Kalbus *et al,* 2006; Amidu and Dunbar, 2008). The boundary zone between surface water and its underlying ground requires more attention for its protection and pollution control strategies (Klapper, 2003).

The techniques used for the investigation of surface water pollution and its underlying bed are point based sampling which can not represent entire study area. Therefore, a technique which can distinguish contaminated zones in water and its underlying bed in 2-D or 3-D is so far a need of time for better understanding of solute transport and its remediation stratagem. Electrical resistivity tomography (ERT) can be a possible solution for this kind of studies, because it is capable to underline the disparity of different resistivity zones in water layer and it bed area. Historically ERT was used for the identification of abnormal area of resistivity that varies sharply with the background values (Zohdy *et al.*, 1973; Peric, 1981; Nyquist *et al.*, 2008; Ward, 1990).

The electrical resistivity surveying method has gone through impressive changes during a period of last ten years. Recently ERT is widely used in environmental studies for water-covered areas because it has high quality imaging and quantification capabilities with two and three dimensional spaces (Zhou *et al.*, 2001; Binley *et al.*, 2002; Leroux and Dahlin, 2006; Allen, 2007). ERT studies for water covered-areas can be conducted in many ways such as mixed-electrode array, under-water or bottom-laid electrode array and floating electrodes array (Loke and Lane, 2004; Goes and Meekes, 2004)

Several scientists used ERT method in many studies for example Rucker et al. (2011) used ERT for geological mapping along the Panama Canal and reported that ERT is efficient technique for detecting accurately the zones with contrasted bulk density. LaBrecque and Yang, (2001) evaluated the effectiveness of ERT for monitoring of the environmental remediation processes in field experiments. Snyder and Wightman (2002) used ERT method with continuous resistivity profiling (CRP) scheme to assess the clay sediments that create complexity in aquifer recharge. Manheim et al. (2004) conducted ERT studies for the detection of freshwater areas below the coastal areas. Kwon et al. (2005) carried ERT surveys with floating cable to investigate the fault zone underlying river. Belaval et al. (2003) used continuous resistivity profiling (CRP) to delineate the subsurface saltwater/ freshwater interface by detecting conductivity changes in the marine environment. Allen

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and Merrick (2006) and Amidu and Dunbar (2008) used the same technique for the investigation of surface and groundwater edge beneath the rivers and water-reservoir. Shaaban and Shaaban (2001) suggested that field prospecting use of electrical resistivity can be associated with laboratory studies.

This study presents the imaging of the surface water and its underlying bed at laboratory by using ERT to assess the sodium chloride movement from surface.

Water to ground. The objectives of the present work were to assess the process of solute transport from surface water to ground and to evaluate the effectiveness of ERT for the imaging at running water to understand contaminant movement behavior in rivers. The research was conducted in a tank constructed with transparent glass filled with porous medium at bottom with constant inflow and outflow conditions. NaCl solution was used as a contaminant for monitoring solute transport in water and its bed.

2. MATERIAL AND METHODS

The experiments were conducted in the hydro-geophysical laboratory of Hydrosciences Department, School of Earth Sciences and Engineering, Nanjing University, P.R. China.

2.1 Experimental setup

A transparent tank measuring 45x45cm, constructed with glass was used for this experiments, a 10cm hatchet from both sides of the tank was given to balance surface water level and groundwater movement. The tank was sealed at the bottom and kept open at the top where water is the top layer, a middle layer of clay (15cm thick), and brown sand at bottom layer (15cm thick). Then water was allowed in the tank by tap water to the height of 35 cm Thus, a simple river condition was simulated with the lower half of the tank as the porous medium (river bed where as the upper half as a river water body). Total 24 stainless steel electrodes were installed on the surface of water at the center of tank through floating electrode scheme with the space of 2cm **(figure 1).**

2.2 Solution preparation and injection

Before the experiments, NaCl solution was prepared by adding 50g NaCl in 10 liters of tap water. The NaCl solution was slowly injected at top from same direction at which water was added to the tank and solute injection was adjusted to 5ml/min by a flow meter installed whereas the water inflow and outflow was kept constant **(Figure 1).**

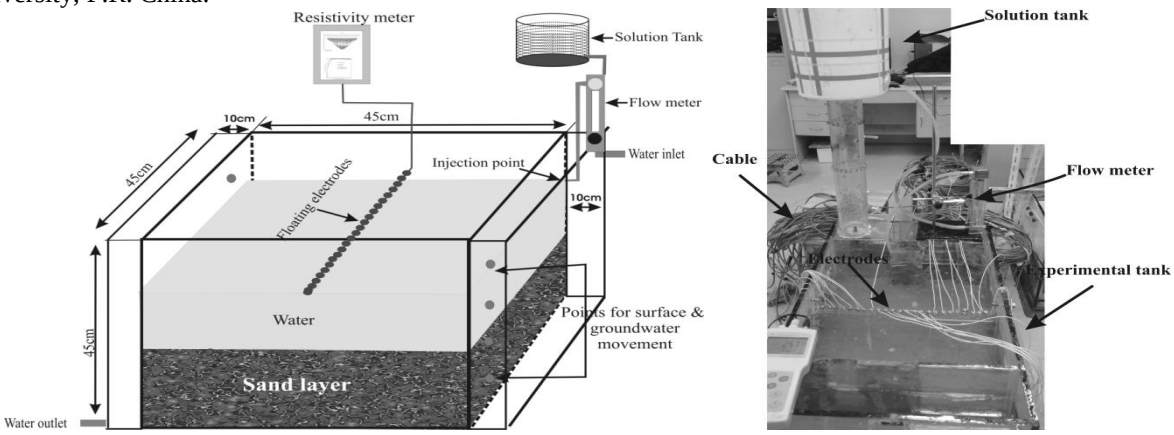


Figure 1 Schematic design and plate of experimental tank

2.3. Data acquisition

During the experiment electrical resistance was measured by floating electrodes method with interval of 360 seconds. The floating electrode cable consisted of 24 stainless steel electrodes installed with an interval of 2cm between neighboring ones. The floating electrode cable was fixed at the center of tank (Figure 1). A multichannel electrical resistance measurement machine (GeoPen E60CN) was used to conduct the 2-D ERT measurement. The Wenner array method was used for the measurements. For one measurement a total of 84 data was obtained.

2.4. Data processing and inversion

Data processing and inversion techniques used in current study are described in this section.

First, apparent resistivity ρ_s was calculated from measured resistances by using equation (1).

$$\rho_S = 2\pi \frac{\Delta U_{MN}}{I} \left(\frac{1}{R_{AM}} - \frac{1}{R_{BM}} - \frac{1}{R_{AN}} + \frac{1}{R_{BN}} \right)^{-1} \quad (1)$$

where ΔU_{MN} is the potential difference among M and N, I is current, R is the distance among the electrodes, A and B are current electrodes and M and N are potential electrodes.

Then the calculated apparent resistivity data was used for 2D inversion by using RES2DINV software after Loke et al. (2003) Loke and lane (2004). An iteratively reweighted smoothness constrained least

squares optimization technique was considered for the data inversion (equation 2).

$$\left(J_i^T R_d J_i + \lambda_i W^T R_m W\right)\Delta r_i = J_i^T R_d g_i - \lambda_i W^T R_m W r_{i-1}, \quad (2)$$

here g_i is the data misfit vector having disparity with the logarithms measured and calculated apparent resistivity values. Δr_i is the variation in the parameters of model for *I*, the iteration and $r_{i-1,}$ the model parameters (the logarithm of the model resistivity values) vector for the previous iteration. J is Jacobian matrix of partial derivatives and W is the roughness filter. λ determines the relative importance given to minimizing the model roughness. R_d and R_m are weighting matrices introduced to modify the weights given to the different elements of the data misfit and model roughness vectors.

The calculated apparent resistivity values were also used for temperature correction for its equivalence at 20°C by equation (3) recommended by Mansoor and Slater (2007) after Keller and Frischknecht (1966):

$$\rho_{20^oC} = \rho_T[1+a(T-20^oC)] \quad (3)$$

where ρ_T is apparent resistivity at the ambient temperature, *T* (temperature measured during experiment), ρ_{20^oC} is the apparent resistivity at 20°C, and a is the temperature conversion coefficient having value of 0.025per °C.

In last, temperature converted apparent resistivity data was used for the estimation and imaging of salinity distribution through equation (4), after Manheim et al. (2004).

$$S = 7.042 \times \rho^{-1.0233} \quad (4)$$

where *S* is the salinity in part per thousand (‰) and ρ is the water resistivity in ohm.m. Given equation is an empirical relationship among resistivity and salinity for seawater at 20°C, same was used by Amidu and Dunbar (2008) for the investigation of salinity in water reservoir. We also used this equation as an approximation in current study.

3. RESULTS AND DISCUSSION

3.1. Apparent resistivity and inversion model

Figure 2 A and B presents temporal distribution of apparent resistivity and inversion model. The obtained image for background data show five zones of different apparent resistivity; first zone 10 ohm.m the water layer, located between the depth of 0 to 0.02 meters, second zone of 20 ohm.m the clay layer located between the depth 0.02 to 0.04 meters, third zone of 30 ohm.m the brown sand and clay layer boundary area located at the depth of 0.04meters and fourth zone of 40 ohm.m located at the depth of 0.75 meters and the fifth zone of 70 ohm.m located at the depth of 0.15 meters. Whereas, the inversion model obtained for the same data with RMS error of 9.8% in 3 iterations clearly differentiates the interface zone between water and its underlying bed and the boundary zone between clay and brown sand. After inversion the water layer show resistivity around 10 Ohm.m, clay layer 50 to 70 Ohm.m and brown sand layer around 100 Ohm.m. After solution injection great disparity in values of resistivity can be seen with the time presented in the images **(Figure 2A and B).**

The inversion model obtained after 360 seconds of solution injection show visible changes in the temporal distribution of resistivity in water layer and its underlying bed than that of the background image. The image acquired after 720 seconds show that the resistivity has decreased than that of 100 ohm.m at underlying bed; however, few points of high resistivity are still located at the interface zone between water and underlying bed. Conversely the underneath area shows extremely low resistivity value which confirms that NaCl solution has reached at this part rapidly. This may be due to leaching of the salts near walls of the tank than that of central area of water bed. After 1080 seconds the solution injection was stopped, the resistivity during this time ranges from 50 to 80 Ohm.m at clay layer. The Image obtained after 2160 seconds demonstrate that the resistivity of whole the area has decreased and after 1440 seconds from the stopping of solution injection (2520 seconds of total experiment) the resistivity is increasing and the visible changes are observed from the bottom area of the experimental tank.

Since the start to end of the experiment the inflow and outflow of water was kept constant and it shows that when the solution injection was stopped the salts washed away from the bed by flowing water. This validate that flowing fresh water can reclaim the pollutants not only from the interface zone but also from the underlying bed. The image obtained after 4680 seconds of solution stopping (5760 seconds of the total experiment time) represents the flushing out mechanism of salts from the interface zone and underlying area. This demonstrates that ERT method is capable for the investigation of the environmental studies at running water and its underlying bed. Our results are well in agreement with those reported earlier such as Amidu and Dunbar (2008) reported that lower the resistivity values the higher the apparent salinity.

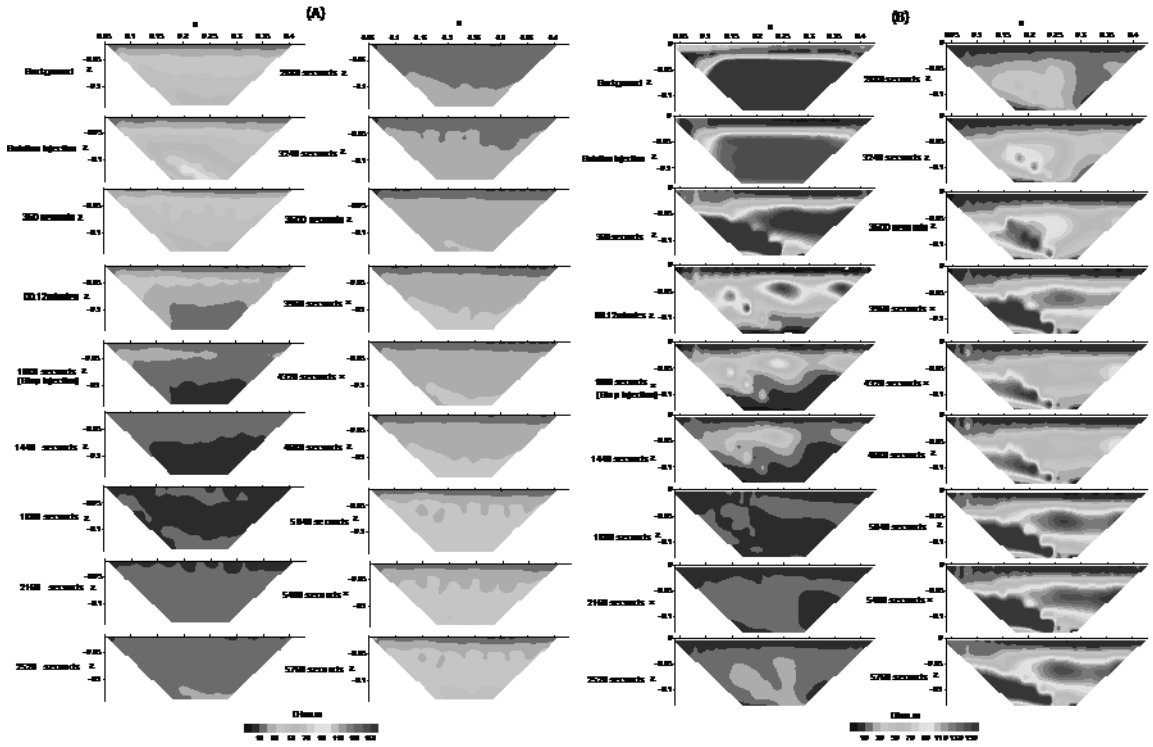


Figure 2. A comparison of apparent resistivity distributions and inversion model at different times

3.2. Apparent salinity

Figure 3 presents the image obtained for apparent salinity calculated from the apparent resistivity values subsequent to the water layer and its underlying bed. The image for background data demonstrates that the salinity level at water layer is 0.43‰ while the salinity level at its underlying bed ranges from 0.03 ‰ to 0.23‰. After solution injection the salinity of water layer and its underlying bed is increased rapidly. However, in clay layer the salinity shows slow changes than that of water and brown sand layer. The image obtained after 1440 seconds of the experiment reveals that water layer has apparent salinity between 1.03‰ to 1.23‰ while the salinity level at the underlying bed is 0.83‰. Images after this time show that the salinity level of interface zone and the bottom layer is decreasing as solution injection was stopped before that. The images obtained after 5760 second show that the salts from the bed of the water are flushed and it is reclaimed. Here low resistivity values corresponds high salinity and thus high resistivity demonstrates the flushing of salts due to freshwater flow.

Saline inflow was investigated by Barrett *et al.* (2003) and Allen (2007) at Murray River, Darling basin Australia through ERT and was successful in locating saline interception bores on groundwater below the river. Amidu and Dunbar (2008) conducted ERT studies for the assessment of salinity distribution in water reservoir and suggested that this method is viable in environmental studies for water-covered area. The findings of this study are in the agreement with those who reported well.

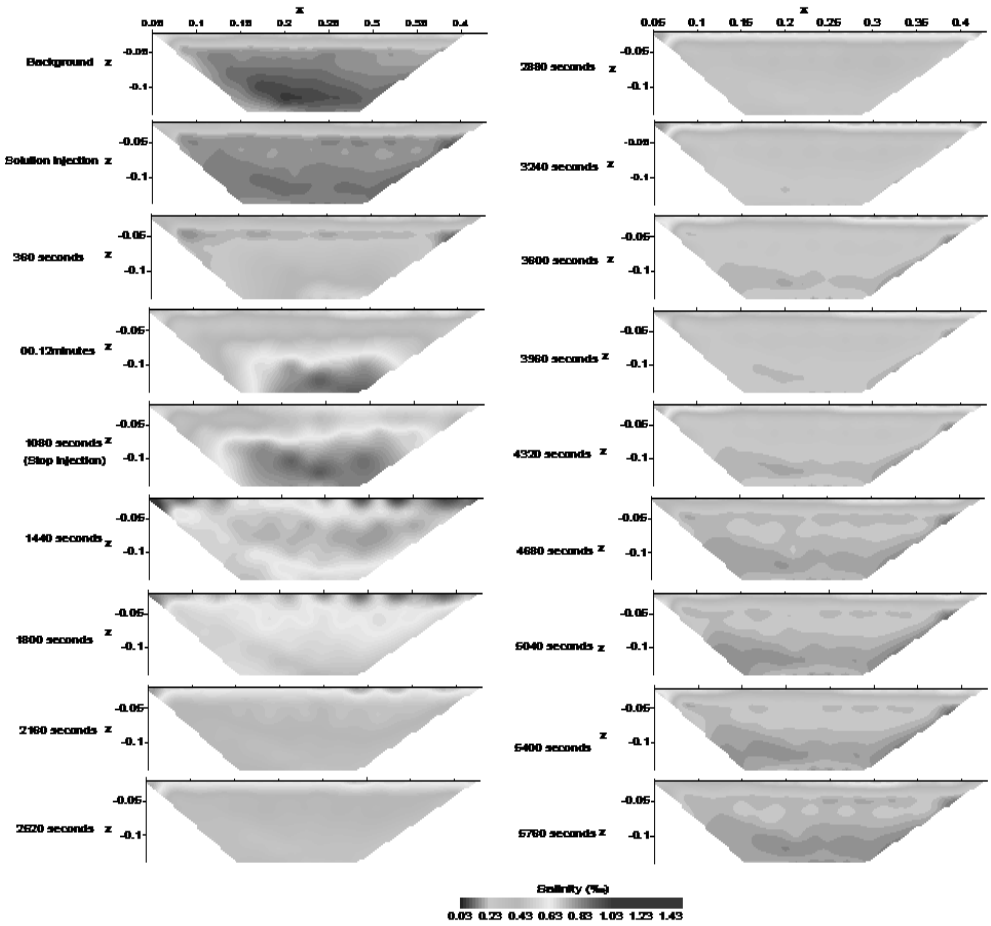


Figure 3 A comparison of apparent salinity distributions at different times

4. CONCLUSION

Electrical resistivity tomography (ERT) method is used to investigate contaminant movement from running water to underlying bed and evaluate the effectiveness of ERT for the imaging of running water to understand solute transport behavior in rivers.

The obtained data illustrates that this method is very useful for the environmental studies at water and its underlying bed evaluation for their management and conservation of factors affecting the discharge of wastewater. The perceived data for resistivity and calculated salinity demonstrates that this method is not only efficient but also cost effective for such kind of studies. When this technique is applied at field its acquired data can be a good support to other environmental studies at restoration of efforts. The present study also validates that ERT is a useful method for the evaluation of surface water quality and monitoring of the temporal distribution of salinities in the surface waters and its interface zone.

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