Time lapse ERT monitoring of Olive-oil mills' wastes (OOMW) using simulation and experimental data.

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SUMMARY

Olive oil production is one of the most important activities in the Mediterranean area and in Greece in particular. Olive oil production generates a large volume of liquid wastes which can cause severe pollution due to the high organic and in-inorganic load that they convey. In this work we assess the ability of time-lapse electrical resistivity tomography (ERT) technique to monitor Olive-oil mills' wastes (OOMW) movement into an aquifer. Test involve performing extensive synthetic modelling using computer generated models for cross-hole ERT arrangements and applying various 4D time lapse inversion processing to the monitoring data. Further, 4D time lapse inversion was performed to cross-hole ERT data obtained during a tank experiment which involved simulation of OOMW movement into a saturated aquifer. Results validate the applicability of cross-hole time lapse ERT to monitor OOMW movement and help to decide ways for optimum data processing and collection.

Introduction

Olive oil production is one of the most important activities in the Mediterranean region and in Greece in particular. Olive oil processing is associated with the production of wastewaters (OOMW) which their unsupervised disposition can have a significant impact into the environment. The OOMW are typically disposed in permeable evaporation ponds or often are disposed directly nearby streams and rivers. OOMW can affect both soil and groundwater due to the high organic and in-inorganic load which is considered toxic towards living organisms (Roig et al., 2006; Mekki et al., 2007).

Due to the highly conductive signature of OOMW the geoelectrical methods are an obvious monitoring tool for detecting the movement and the diffusion of the contaminants within soil and groundwater (Papadopoulos and Chatziathanasiou, 2013). Experimental tests conducted in a tank (Seferou et al., 2013) verified the effectiveness of cross-hole ERT to trace the movement of OOMW into the unsaturated and saturated zones.

Application of ERT in time lapse mode has gained growing popularity as a monitoring tool since it can help assess the geoelectrical changes among others those induced by pollutant movement. Typical processing of time-lapse ERT data which involved either simple image subtraction or difference inversion has been growingly replaced by more advanced approaches where time dimension is also included into inversion. Kim et al. (2009) proposed a four dimensional (4D) inversion algorithm involving regularization in both the space and time domains and this approach has been found to reduce inversion artefacts. Karaoulis at al. (2011) noted that the time regularization sometimes makes the inverted results too smooth in the time domain, and proposed an algorithm the 4D Active Time Constrained inversion. A further major development in this field has to do with the introduction of L1 norm minimization in both time and space domains (Kim et al., 2013) as an additional option to the standard L2 norm minimization. The new time lapse inversion algorithm allows the selection of any combination of the L1-L2 norm data misfits and two kinds of model roughness in the space and time domains.

The main target of this work is to assess the ability of time-lapse electrical resistivity tomography (ERT) technique to monitor Olive-oil mills' wastes (OOMW) movement into an aquifer using the state-of-art ERT time-lapse inversion approaches described above. Tests involve performing extensive synthetic modelling using computer generated models for cross-hole ERT arrangements and applying various 4D time lapse inversion processing to the monitoring. Further, 4D time lapse inversion was performed to cross-hole ERT data obtained during a tank experiment which involved simulation of OOMW movement into a saturated aquifer. These experimental data was obtained in a previous work but was only processed as a single inversion images and not as time-lapse ones.

Simulation models

The purpose of performing modelling is twofold. One is to generally evaluate the ability of time-lapse ERT approach to map pollutant movement and the other is to better evaluate the software parameters and their effect on the time-lapse inversion results under the specific measurement geometry and pollutant concentrations. The latter is very important since it can guide the experimental data processing in an efficient way.

In this framework the computer geometry simulated the existing ERT monitoring arrangement in the tank (see Seferou et al., 2013). The control experiment took place in $1m^3$ tank which was filled with fain grain sand and was saturated with water while an OOWM pollutant release took place.

The synthetic cross-hole ERT measurements were simulated using the DC2DPro program (Kim, 2013) and were initially inverted as individual data sets using both the L1 and L2 minimization norms for data misfit (D) and smoothness model (S) in order to evaluate the optimum inversion parameter setup. We concluded that the best results were obtained using either the L2 norm for both data and model (L2D_L2S) although the L1 norm for both (L1D_LIS) produced good results as well. Several synthetic models were tested using different resistivity contrasts in order to simulate different concentrations of conductive targets corresponding to the pollutant that was released in the tank. A typical simulation model is depicted in Fig. 1 (top panel). The measurement geometry involves 2 boreholes with 13 electrodes in each borehole while the measurement configuration used was bipole-

bipole (AM-BN) which is known to have good signal and reasonable resolution (Bing and Greenhalgh, 2000). Note that the same geometry and measurement protocol was used for the tank experiment, which is presented later. The inversion results for the time-steps using the L2 minimization norm are depicted in the bottom panel of Fig.1 and they manage to reconstruct the initial model quite nicely.

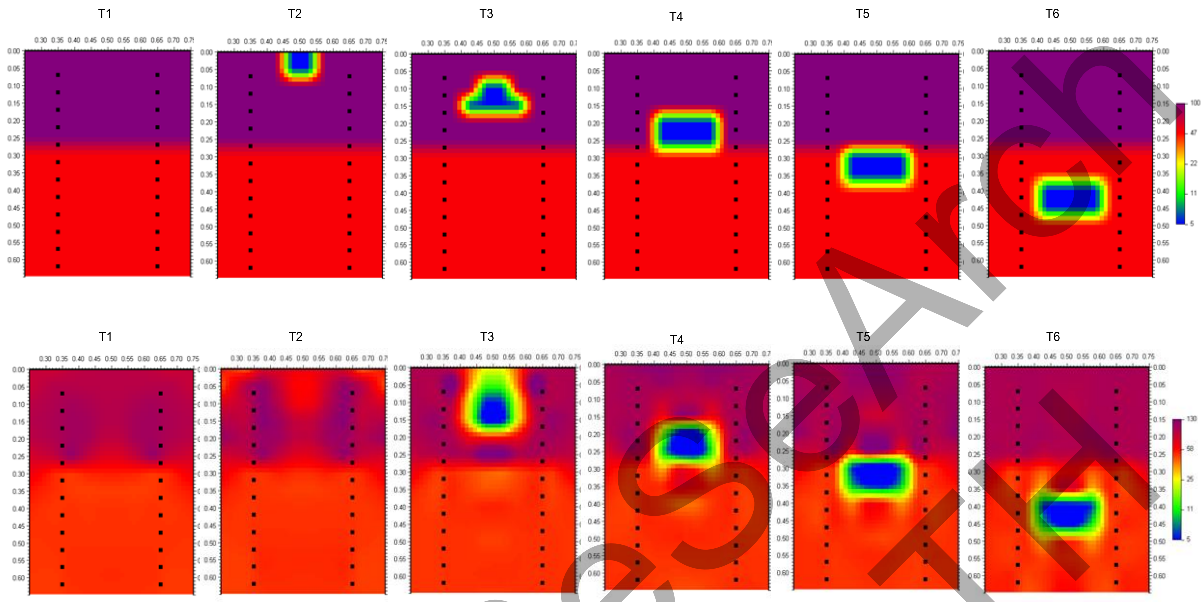

Figure 1: (Top panel) typical time-lapse ERT simulation model used in this work involving 6 time steps. (Bottom panel) inversion results using the L2 minimization norm for both data and model.

Subsequently, we used the full 4D time lapse procedure for the simulation using different combination of the L1 and L2 minimization norms for the time domain misfit (T), (Kim et al, 2013), but in the light of the individual inversion results the 4D inversions took place using the L2 norm for both data and model using the following inversion parameter settings: L2D_L2S_L2T and L2D_L2S_L1T. The result from the inverted images indicated that the smoothest images are achieved by suing the L1 norm minimization for time space (T) while the configuration L2L2_L2 produced results which were depicting the anomalous body more clearly but also the images were suffering from some artefacts. In Fig.2 the time lapse results in the form of ratio images after the 4D inversion using the L2L2_L1 configuration is depicted.

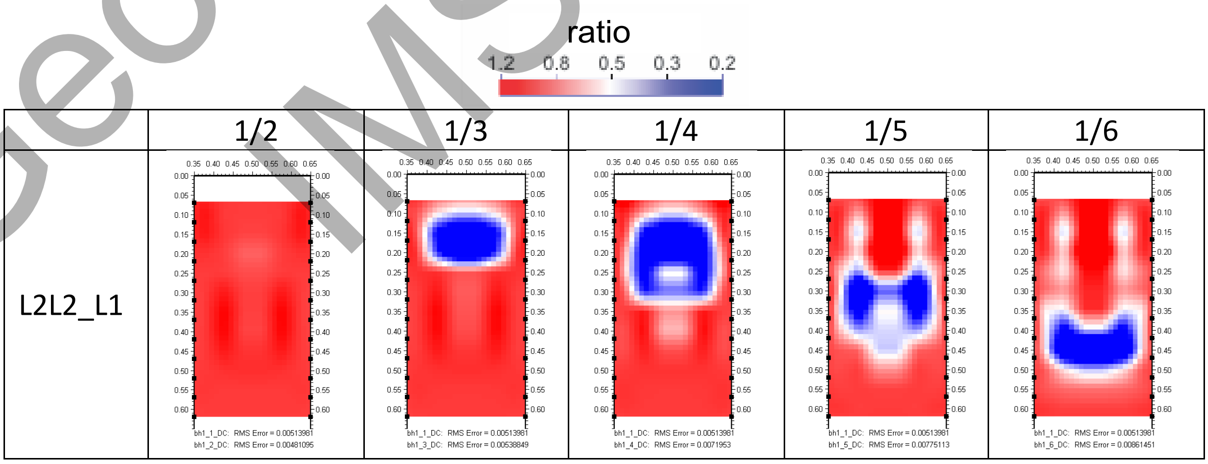

Figure 2: 4D inversion results for the model of Fig.1

Experimental data: time lapse inversion

The experimental data were obtained using a tank with dimensions: 1m x 1m x 1m made of plexiglas, in order to create a control laboratory experiment. Four boreholes were placed in the tank made by plastic pipes and twelve steel electrodes were installed at the plastic pipes at different depths to each borehole. The inter-electrode spacing was 5cm, the first electrode was placed 7cm below the top and the last electrode was 0.418m from the bottom, the distance between each borehole was 30cm and the boreholes were placed 35cm from the boundaries of the tank.

The tank was filled with fine grain sand. At the beginning of the experiment water was released from a central valve at the bottom of the tank to saturate the layers of sand. When the water table was stabilized at all layers and the separation of the unsaturated zone and the saturated zone was clear, the OOMW contaminant was released at the central area of the tank at the region between the 4 boreholes. The contaminant was released with a controlled flow rate of 250-270ml/h.

The cross hole data set was obtained using a bipole –bipole (AM-BN) configuration and a set of 77 data points was obtained at fixed time intervals (i.e. every 15minutes). A total of 40 time-lapse data sets were obtained.

The ERT time lapse data of the OOWM release experiment were inverted using the 4D inversion scheme (Kim et al., 2013). In Figure 3 some selected inverted ratio images are depicted for 2 different inversion parameter configurations. In the top panel the 4d inversion was carried out using the L2L2_L1 configuration while the results at the bottom panel correspond to the L2L2_L2 parameter selection. The results at the top panel (L1L1_L1) show more robust inversion results with less artefacts but some targets are not very clear, on the other hand the results of the bottom panel of Fig 3 with the L2L2_L2 inversion display a better resolution depicting the movement of the OOWM not only at the top layers but at the bottom as well.

Conclusions

In this work we assess the ability of time-lapse electrical resistivity tomography (ERT) technique to monitor Olive-oil mills' wastes (OOMW) movement into an aquifer via synthetic and experimental data. The aim was to apply state of art 4D time-lapse inversion algorithms to better evaluate the effectiveness of the approach and to test different inversion parameter combinations in order to decide which processing protocol is optimum for this type of targets. The results validate the applicability of cross-hole time lapse ERT to monitor OOMW movement and help to decide ways for optimum data processing and collection.

Regarding the inversion parameter selection for the 4D inversion we concluded that the L2L2_L1 parameter selection was better for the simulated data but the L2L2_L2 parameter configuration depicted much better the movement of the OOMW in the experimental data case. It is clear that extensive modelling and testing with various inversion parameters is required in order to create processing protocols which are custom build to the particular problem that is being investigated.

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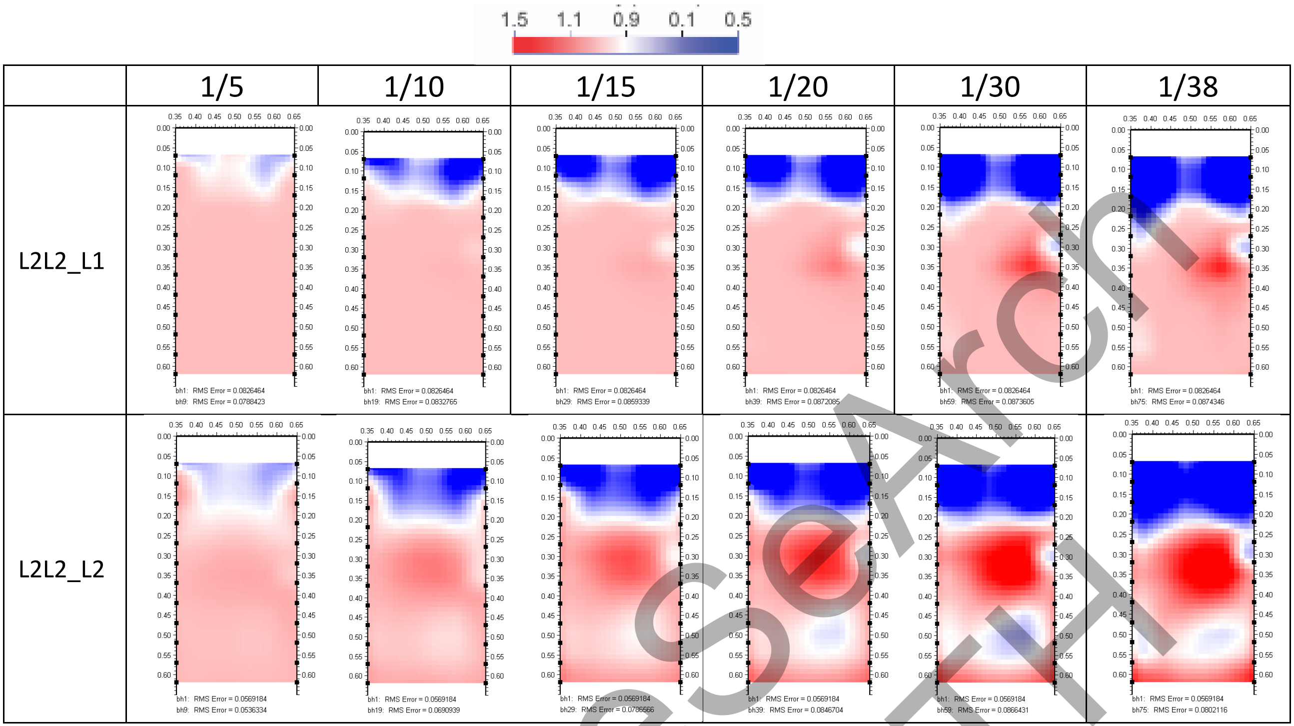

Figure 3: Time lapse inversion of the experimental data.

References

Bing, Z., & Greenhalgh, S. a. (2000). Cross-hole resistivity tomography using different electrode configurations. Geophysical Prospecting, 48(5), 887–912.

Karaoulis, M., Kim, J-H., Tsourlos, P. (2011). 4D active time constrained resistivity inversion. Journal of Applied Geophysics 73 (1), 25-34.

Kim, J.-H., Supper, R., Tsourlos, P., & Yi, M.-J. (2013). Four-dimensional inversion of resistivity monitoring data through Lp norm minimizations. Geophysical Journal International, 195(3), 1640–1656.

Kim, J.-H., Yi, M.-J., Park, S.-G., & Kim, J. G. (2009). 4-D inversion of DC resistivity monitoring data acquired over a dynamically changing earth model. Journal of Applied Geophysics, 68(4), 522–532.

LaBrecque, D. J. and Yang, X., (2001). Difference inversion of ERT data: a fast inversion method for 3-D in situ monitoring. Journal of Environmental and Engineering Geophysics, 5, 83-90.

Seferou, P., Soupios, P., Kourgialas, N. N., Dokou, Z., Karatzas, G. P., Candasayar, E., … Sauter, M. (2013). Olive-oil mill wastewater transport under unsaturated and saturated laboratory conditions using the geoelectrical resistivity tomography method and the FEFLOW model. Hydrogeology Journal, 21(6), 1219–1234.

Mekki, A., Dhouib, A., Sayadi,S., 2007. Polyphenols dynamics and phytotoxicity in a soil amended by olive mill wastewaters. J. Environ. Manag. 84: 134-140.

Roig, A., Cayuela, M.L. and Sánche-Monedero, M.A. 2006. An overview on olive mill wastes and their valorisation methods. Waste Management 26: 960-969.

Papadopoulos N., and Chatziathanasiou S., 2013. ERT pollution monitoring in areas of olive oil mills' wastes (OOMW): Preliminary results from a disposal site in Crete (Greece). Berichte Geol. B.-A., 93, 193-197.