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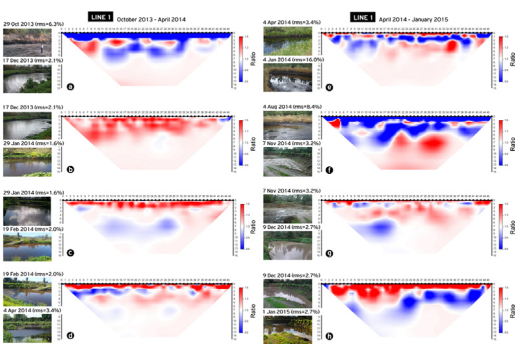
Characterization and monitoring of subsurface contamination from Olive Oil Mills' waste waters using Electrical Resistivity Tomography

Kleanthis Simyrdanis [a,*], Nikos Papadopoulos [a], Pantelis Soupios [b], Stella Kirkou [c], Panagiotis Tsourlos [c]

[a] Laboratory of Geophysical Satellite Remote Sensing and Archaeoenvironment (GeoSat ReSeArch), IMS, FORTH, Greece
[b] Department of Environmental and Natural Resources Engineering, Technological Educational Institute of Crete, Greece
[c] Laboratory of Applied Geophysics, Aristotle University of Thessaloniki, Greece

GRAPHICAL ABSTRACT



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ABSTRACT

This work describes the efficiency and ability of Electrical Resistivity Tomography (ERT) to map and monitor the subsurface contamination caused by the wastes created during the production of olive oil. The spatial distribution and temporal variation of these wastes are investigated through an integrated methodological flowchart composed of numerical modeling tests and field data collected from an active waste disposal site. An Olive Oil Mills' Wastes (OOMW) real site was chosen to monitor the subsurface flow of the wastes that are disposed of in an artificial pond for 1.5 years. Synthetic modeling was used to simulate and reconstruct the movement of the OOMW as a conductive target within a layered resistive medium. The results of the ERT data show a high degree of correlation between published ERT, geochemical, and IP geophysical results. This indicates that ERT can be a powerful tool for mapping and monitoring the byproducts of the olive oil industry, in the form of subsurface contamination, as demonstrated by the synthetic modeling. The electrical signature of the OOMW was also verified through the identification of in situ wastes within an excavation trench along the monitoring ERT line. The results show that ERT can be used as a stand-alone tool to characterize the subsurface pollution in OOMW sites.

1. Introduction

Olive oil production comprises one of the most important financial activities in the wider Mediterranean region with the annual oil product exceeding 2.600×10^3 tons. Greece is the third highest contributor worldwide after Spain and Italy and contributes approximately 15% of

* Corresponding author.
E-mail addresses: ksimirda@ims.forth.gr (K. Simyrdanis), nikos@ims.forth.gr (N. Papadopoulos), soupios@staff.teicrete.gr (P. Soupios), tsourlos@geo.auth.gr (P. Tsourlos).

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the total world olive oil production (Loumou and Giourga, 2003). Despite the well-known benefits of olive consumption in the human diet, the process of olive oil production itself, creates a large amount of solid waste and wastewater with a high organic load and inorganic constituents. The OOMW are usually disposed in artificial or natural evaporation ponds or directly in soil, torrents, rivers or lakes. These ponds are rarely the proper size for disposal and the wastewater often overflows, affecting neighbouring soil and hydraulic systems (e.g. rivers, torrents, groundwater).

These wastes exhibit specific physico-chemical characteristics depending on the production procedure, the variety and the maturity of the olives, the region of cultivation, the methods of oil extraction and the climatic conditions. The Olive Oil Mills' Wastes (OOMW) have a dark brown colour with an unpleasant smell, and consist mainly of water, high organic (mainly phenols and polyphenols), low inorganic compounds (e.g. potassium and phosphorus) and include emulsified grease (Doula et al., 2010, 2013; Arapoglou et al., 2010; Kavvadias et al., 2010). The wastes are also characterized by low resistivity (0.7–5 $\Omega \cdot m$), acid pH (4.0–5.5), as well as an increased Biochemically Oxygen Demand (40–95 g/l), and Chemically Oxygen Demand values of 50–180 g/l. Their toxicity is mainly dependent on their high concentration of phenolic compounds (Rodis et al., 2002). Thus, the disposal of these wastes without protective measures can cause changes in the physico-chemical parameters of the surrounding ecosystems, with the high risk of irreparable damage to the environment.

It is obvious that the production of olive oil cannot cease to produce wastes, and thus, emphasis must be given to the control of their pollutive effects in the environment and their mode of deposition. In this regard, high resolution geophysical techniques can provide an efficient environmental monitoring tool to study and understand the environmental degradation from the disposal of OOMW. Several geophysical methods have been applied to this effect, such as; self potential (Soupios and Karaoulis, 2015; Rani et al., 2016a), induced polarization (Ntarlagiannis et al., 2016; Rani et al., 2016b), spectral induced polarization (Kirmizakis et al., 2016).

Among the aforementioned geophysical methods, Electrical Resistivity Tomography (ERT) has been used extensively in mapping and monitoring the flow of contaminants in the subsurface since it can assess the spatial and temporal geoelectrical changes induced by this pollutant movement (e.g. Slater et al., 2000; Niaounakis and Halvadakis, 2006; Soupios et al., 2007a, 2007b, 2007c; Karaoulis et al., 2011; Power et al., 2015). Due to the highly conductive signature of the OOMW, ERT is the obvious choice for detecting the movement and diffusion of the contaminants within soil and groundwater (Papadopoulos and Chatziathanasiou, 2011; Seferou et al., 2013; Papadopoulos et al., 2014). The main objective of this work is to assess the ability of the ERT method to map and monitor OOMW movement in the subsurface through time, by applying 4D time-lapse ERT inversion and using an active disposal site in Greece (Crete).

ERT survey is a geophysical method often used for environmental prospection (particularly on land). The method works by injecting a current into the earth and measuring the potential at the same time, along a line of sensors placed on/in the ground or in a maritime environment. The purpose of the measured data is to estimate the distribution of resistivity in the subsurface and provide an estimation of the petrophysical properties of the study area, thus allowing for a geological interpretation of the area.

2. Geological and hydrogeological setting

A field site, located outside the Alikianos village (13 km SW of Chania, Crete, Greece), was selected to test the efficiency of ERT in mapping and monitoring the OOMW. The study area contained an ellipsoidal evapotranspiration pond with dimensions 75 m × 25 m within a private property, which is used to dispose the wastes produced by the nearby olive oil factory (Fig. 1). During the harvest period, the specific pond carries about 1400 tons of OOMW where more than 260 tons comprise the solid wastes that remain after the evaporation of the liquid wastes. OOMWs are removed after the end of the summer period and before the new harvesting session.

The waste site is situated inside the Keritis basin and 10 km from the Keritis River. These two features comprise the main riverine system of the Chania valley. Fig. 2 presents the geological map of the broader study area and shows two geoelectrical sections crossing the study area. The study area is composed of limestone-dolomite bedrock, overlaid with alluvial, quaternary deposits (loose sand, gravels and pebbles partly connected with clayed materials) with an average thickness of about 5–20 m. Kanta et al. (2013) suggested the presence of two (W-E and NNW-SSE) fracture systems (dashed black thick lines in geophysical sections in Fig. 2) crossing the study area (green ellipses in geological

Fig. 1. Photos with the artificial evapotranspiration pond (indicated with white dots in the lower left embedded photo) where the Olive Oil Mills' Waste is deposited during the harvest period.