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Using electrical resistivity tomography (ERT) to evaluate the infiltration in land application systems. A case study in the Carrión de los Céspedes wastewater treatment plant (Seville, Spain)

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ABSTRACT

One of the non-conventional technologies of wastewater treatment applicable to small communities is the land application system (LAS) or "filtros verdes", as this technique is called in Spanish. A correct design of LAS may imply to know the mode of occurrence and efficiency of the infiltration. Thus, the geophysical method of electric resistivity tomography (ERT) has been applied to study the infiltration in the LAS of the Carrión de los Céspedes wastewater treatment plant (Seville, Spain), where information of spatial and temporal water content changes was obtained by tracking the changes of resistivity in time-lapse ERT profiles related to an irrigation event. The ERT survey shows that there is a non regular horizontal distribution of the infiltration in the shallowest part of the soil, with distinct zones with a better infiltration. Also, the vertical infiltration efficiency is low since a large amount of the water is retained in the first shallow meter with very little infiltration at depth. This phenomenon is mainly due to soil preparation works affecting the first meter of the ground. That water retention at the shallow level may imply lateral looses of water, giving as result a lower efficiency of the LAS. Finally, the results prove that the ERT technique is a very useful method to know the structure of materials and the infiltration distribution in the ground prior the implementation of the LAS. Being a non invasive technique, ERT can be used for monitoring the efficiency of the LAS in terms of infiltration.

Keywords: Land application systems; Water reuse; Electric resistivity tomography; Infiltration

1. Introduction

One of the non-conventional technologies of wastewater treatment applicable to small communities is the land application system (LAS, in Spanish 'filtros verdes'). In LAS, the purification occurs by the interaction of soil, microorganisms and plants, through physical, chemical and biological mechanisms taking place in the vadose zone. Thus, the principal objective of the LAS is to purify the wastewater applied in the smaller possible surface to reuse the purified water for biomass production and for recharge, if the water quality allows it. This technique has broad field of application for small communities given its advantages of cost, flexibility and operability.

A correct design of a LAS may imply the knowledge of the mode of occurrence and efficiency of infiltration [1,2]. This factor is difficult to evaluate a priori without

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the use of direct techniques (e.g. lysimeters). As an alternative, the infiltration may be assessed by using indirect geophysical techniques as the electric resistivity tomography (ERT, e.g. [3]). Alternatively, ERT may be applied to evaluate the infiltration efficiency of an active LAS. The ERT method provides a 2-D image (profile) of the resistivity distribution in the vadose zone. As the resistivity is function of soil structure, water content and pore water conductivity, information of spatial and temporal water content changes for a site may be obtained by tracking the changes of resistivity in the ERT profiles through time, e.g. [4]. Thus, the infiltration may be evaluated by comparing the successive time-lapse ERT profiles related to a precipitation/irrigation event. This work presents the preliminary results of a time-lapse survey in the LAS of the Carrión de los Céspedes wastewater treatment plant (WWTP), located in Seville, Spain [5].

The LAS of the Carrión de los Céspedes WWTP is managed by the CENTA, Centro de Nuevas Tecnologías del Agua, Seville, Spain (Fig. 1). Operating since 2005, the system has a total surface of 2,000 m^2. It was designed in two stages divided in 13 parcels with 14 lines of trees: the first 5 parcels of 5×35 m with *Populus euroamericana* and the rest of parcels of 3×35 with *Eucalyptus camaldulensis*. The wastewater is distributed to each parcel by a system of tubes with 13 valves. Flood irrigation is carried out independently in each parcel by cycles of 4–10 d. The treatment is monitored by means of six lysimeters which capture effluent at depths of 30, 60 and 90 cm for sampling purposes.

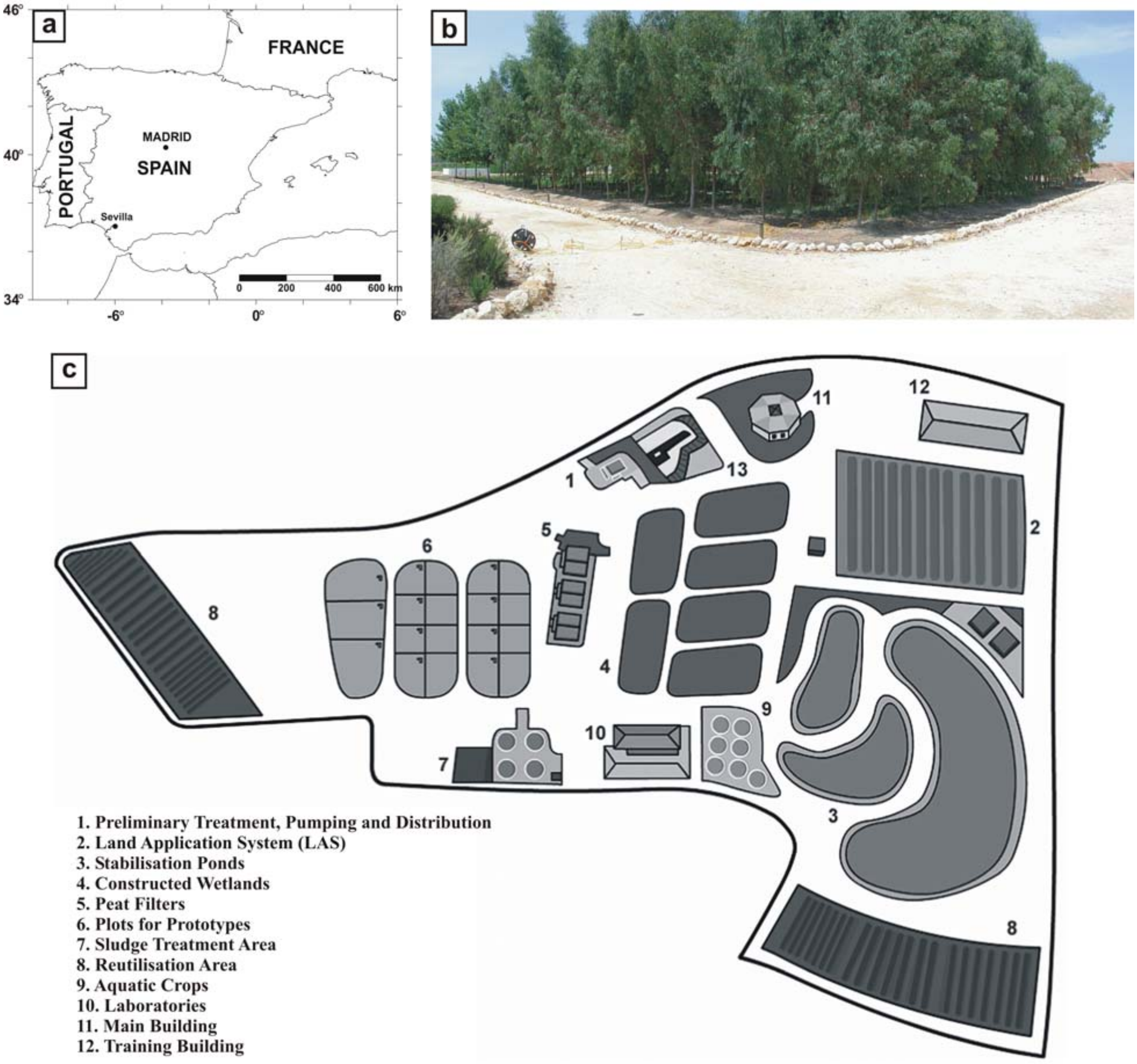

Fig. 1. a) Location of the city of Seville in Spain, b) photograph of the land application system, c) the Carrión de los Céspedes WWTP after enlargement (after [5]).

2. Methodology

In the last years, the ERT method is becoming a common technique applied to subsurface hydrology studies [6,7]. Actually, it is accepted that knowledge of the spatial distribution of the electrical properties of the subsurface media can provide valuable information for monitoring flow and water movement in the vadose zone, e.g. [4]. The ERT method is based on the measurement of electric potential differences between a series of electrodes that are generated by a current that is injected into the subsurface. This involves the emplacement of a multiple electrode string on the surface. During data acquisition, each electrode may serve both as a source as well as a receiver multiple times. A large number of unique data points may be collected during the survey, and their distribution grid and also the surveyed depth depend of the selected sequence or array of electrode pairs. A numerical inversion routine is then utilized to determine the probable electrical resistivity distribution of the subsurface.

The equipment used in this work was a Syscal Junior 48 resistivimeter. The profiles were performed with a line of 48 electrodes spaced 1 m apart. The Wenner–Schlumberger array was selected to get the best balance between lateral resolution and surveyed depth. Data analysis and modelling were carried out by using a commercial geophysical inversion program (Res2dinv).

To study the infiltration by comparing the spatial and temporal water content changes in the ERT profiles, a unique line of electrodes was installed in a parcel with no irrigation during the previous two weeks to the survey. During the study the parcel was irrigated by flooding with 6 m^3 of wastewater. Prior to irrigation, a reference 'dry' ERT profile was obtained to establish the base conditions (Fig. 2). After the irrigation, several successive time-lapse ERT profiles were acquired during 20 h with a time-lapse of one to several hours as the infiltration was progressing. Taking the initial 'dry' profile as reference, a image of the spatial and temporal resistivity changes in the ground was obtained that may be expressed as % of variation in resistivity.

3. Results and discussion

The before irrigation ERT (Fig. 3a) shows the presence of a layer of material with a mean resistivity of 12–20 Ω·m in the first meter of depth. Beneath this shallow layer, a unit with a resistivity of 3–10 Ω·m extends up to 3 m of depth. A third, lowermost unit may be distinguished up to 8 m of depth, displaying a resistivity from 10 to 20 Ω·m. The highest resistivity identified in the ERT profile corresponds to the pathways surrounding the LAS. Inside the lowermost part of the profile, a low-resistivity zone is recognized at 6–8 m of depth and between 22 m and 30 m of the horizontal length of the profile. This zone seems to correspond to the phreatic level. Taking into account lithological data from drill cores, the first shallow meter of the profile corresponds to homogeneous clayed sands with low water content, the second unit (1–3 m of depth) corresponds to the same materials with higher water content and the lowermost part of the profile (3–8 m of depth) is constituted by clays with low water content. Analyzing the variation of resistivity over the first 2.5 h (Figs. 3a and 3b) expressed as percentage of resistivity change (Fig. 3c), it can be observed that a large amount of the infiltrated water is retained in the first shallow meter. A decrease of resistivity up to 31% takes place in this unit, as a consequence of the drastic increase of water content. If the whole length of the profile is considered, the infiltration starts preferentially in two sectors, between 9 m and 18 m and between 37 m and 40 m of the profile. Over time, the identified sectors with higher infiltration expand laterally

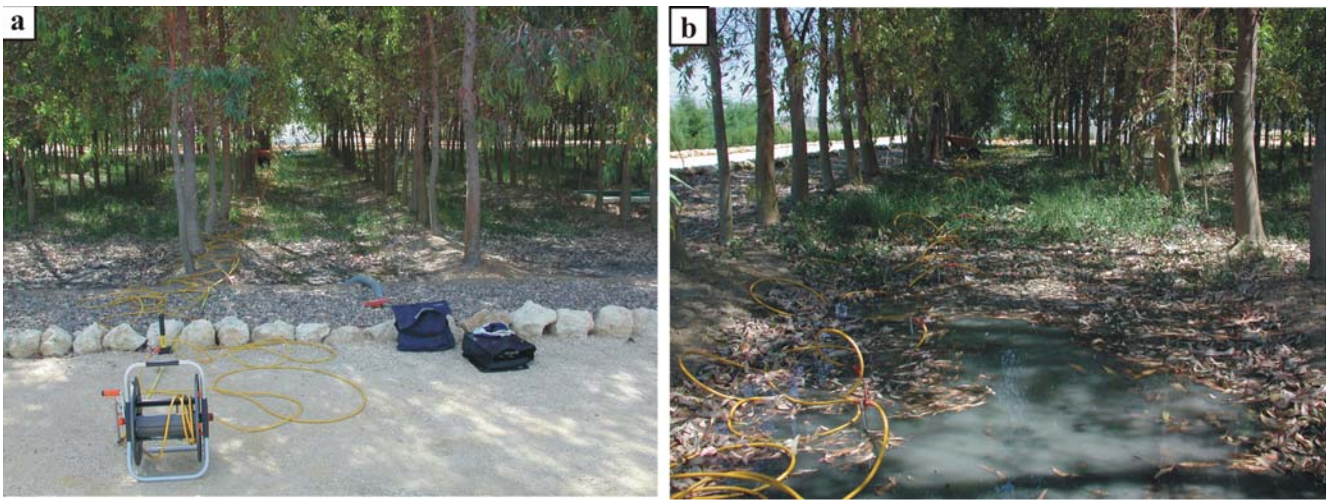

Fig. 2. Photographs of the land application system during the survey acquisition: a) before irrigation, b) after irrigation.

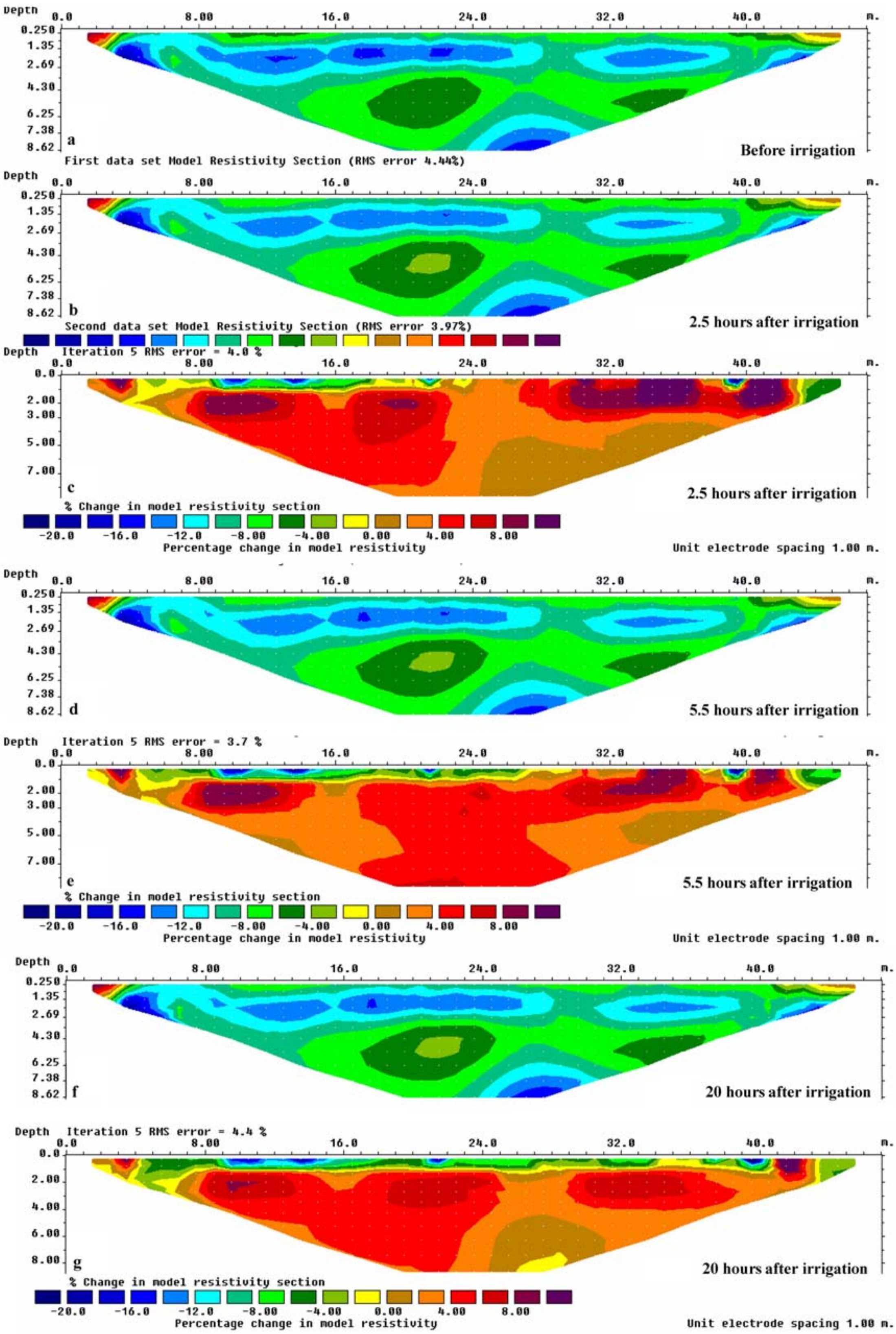

Fig. 3. Time-lapse ERT 2-D images: a) the resistivity conditions before irrigation, b), d) and f) are the resistivity profiles after 2.5, 5.5 and 20 h since the irrigation respectively, and c), e) and g) show the variation resistivity (%) for 2.5, 5.5 and 20 h profiles respectively, relative to the initial resistivity prior the irrigation.

(Figs. 3c, 3e and 3g). Thus, after 20 h since the irrigation, the overall length of the profile displays some decrease of the resistivity (between 2% and 20%) in the shallowest unit (Fig. 3g). In turn, the unit located from 1 m to 4 m of depth records just small variations of resistivity, and therefore, of water content.

The observed differences in the rate and spatial distribution of the infiltration in the upper unit must be related to the previous soil preparation works for the LAS implementation, since the unit is constituted by quite homogeneous clayed sands and no significant textural variations are identified in the original material from drill cores. This interpretation is supported by the contrast observed in the water content between this unit and that located beneath, where the materials have the same texture and composition. However, as the ERT image points out, there are some minor variations of the water content below 1 m of depth (Figs. 3c, 3e and 3g) that would be better explained by textural changes in the material. The fact that there are low variations of the water content at depth regarding those recorded in the upper unit after the irrigation implies a very low vertical infiltration efficiency. In other words, most of the infiltrated water is retained or flows laterally in the upper unit, which produces water losses from the LAS being the vertical infiltration very small.

4. Conclusions

In the studied parcel of the LAS of Carrión de los Céspedes, the infiltration is not uniform, even if the sedimentary units are relatively homogeneous in their texture and composition. The ERT survey shows a non regular horizontal distribution of the infiltration in the shallowest part of the soil, with distinct zones with a better infiltration. Also, the vertical infiltration efficiency is low since a large amount of the water is retained in the first shallow meter with very little infiltration at depth. This phenomenon is mainly due to soil preparation works affecting the first meter of the ground, as there is not a textural difference to explain that contrast in the infiltration rate. That water retention at the shallow level may imply lateral looses of water, giving as result a lower efficiency of the LAS.

Finally, the results prove that the ERT technique is a very useful method to know the structure of materials and the infiltration distribution in the ground prior the implementation of the LAS. Being a non invasive technique, ERT can be used for monitoring the efficiency of the LAS in terms of infiltration.

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