Combining geophysical, geochemical and geostatistical methods to detect contamination anomalies in a Controlled Dump in Oporto, N Portugal

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Abstract

The characterization and environmental monitoring of Municipal Solid Waste (MSW) deposits are an increasing area, in terms of the interdisciplinary studies involved. Whatever the solution adopted for the MSW treatment, its final containment on landfill is not the end of the problem. Rather, the need for continuous monitoring, tracking the evolution of the waste mass in all its surroundings, will contribute to evaluate the environmental consequences of the existence of a deposit of MSW. The assessment of contaminants dispersion in Controlled Dumps (CD) of MSW is possible through the combination of geophysical, geochemical and geostatistical methods as described in this paper. The methodology applied in this study will contribute to evaluate the environmental consequences of the Matosinhos CD (N Portugal), which is set in a granitic crystalline geological context with a permeability controlled by differential weathering associated with fracturing. The statistical methods here described (Lepeltier, 1969; Matschullat et al. 2000), more commonly applied to geochemical data, were adapted to be used with our set of 2D resistivity profiles in order to relate them and thus delineate the contamination anomalies in the CD surroundings. Groundwater samples were collected in piezometers, upstream and downstream of the CD, with the aim of directly confirming the presence of contaminants indirectly detected by the geophysical and geostatistical methods. The combination of these different approaches allows an approach towards the detection and delineation of contaminant plumes from these deposits.

Introduction

The study area corresponds to a Controlled Dump (CD) and its immediate surroundings, located in Santa Cruz do Bispo, Oporto, north of Portugal (41º13'17.95"N; 8º39'24.15"W).

In terms of the geological context, the study area belongs to Central Iberian Zone (CIZ) and is set in a granitic area, specifically two-mica granite, leucocratic, with a fine to medium grained texture (Fig. 1). The CD lies in a granitic crystalline geological context with fissure controlled type permeability, which is not common (Mota et al, 2004) in the Portuguese context. Many watercourses with dominant orientations of NS and NW-SE run through the study area. The main fracture systems are NS; ENE-WSW; NNE-SSW; NW-SE also associated with a degree of weathering.

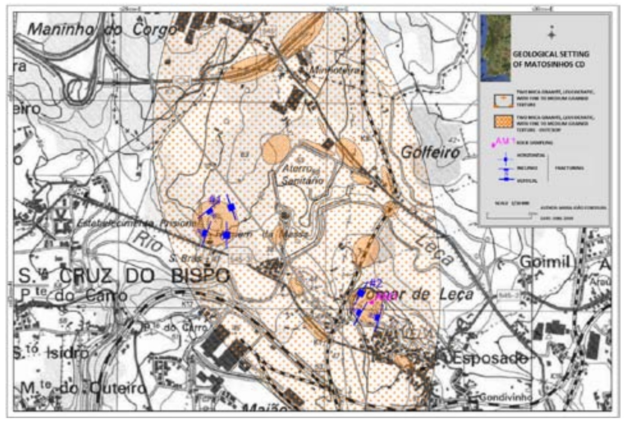

***Fig. 1** – Geological Setting of Matosinhos CD.*

The Matosinhos CD is composed by two distinct areas: the SE area without any kind of environmental control, only sealed in the top, and the NW area composed by three properly sealed cells (Fig. 2).

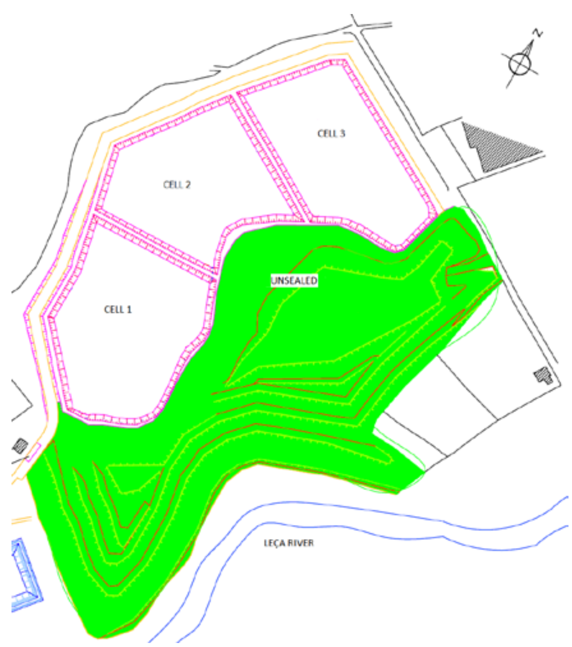

***Fig. 2** – Two distinct areas in the Matosinhos CD: sealed vs unsealed.*

There are many described examples of geophysical methods applied to contamination studies associated with MSW since the late '60s (Cartwright and McComas, 1968) and early '70s (Stollar and Roux, 1975; Kelly, 1976) and often applied to environments that have interstitial type permeability (Senos Matias, et al, 1994). Recently, the use of geophysical techniques has become more frequent and there has been a great development in recent years (Figueiras et al, 2009; Monteiro Santos et al, 2006; Mota et al, 2004).
The innovation in this study is related to the use of a statistical tool commonly applied to geochemical data (Lepeltier, 1969), which was adapted to be used in geophysical data in order to confirm the existence of contamination anomalies in CD surroundings, as well as to distinguish what level of resistivity values are anomalous and which are background.

Method

The methodology contained in this study is based on the complementarity of information that can be obtained from the use of geophysical, geochemical and geostatistical methods.
The electric fields propagate in soils and rocks due to displacement of ions dissolved in water contained in its pores and cracks, being mainly affected by the mineralogical composition, porosity, temperature, water content, quantity and composition of dissolved salts (McNeill, 1980). These conditions allow the application of electrical resistivity in the hydrogeological and environmental studies, where water and possible contaminant-rich salts are present in the pores and discontinuities of the rock (Elis, 2004).
When contaminants are present in the soil/water, changes occur in their electrical properties, for example, the contamination plumes generated by infiltration of leachate from MSW deposits cause local decrease in resistivity that can be detected with the aid of the electrical resistivity method.
The equipment used to carry out the electrical resistivity profiles is an Iris Instruments, Syscal Junior Switch 48 multielectrode resistivimeter, pre-programmed using a PC.
The electrical resistivity profiles were carried out based on the Wenner-Sclumberger array. Profiles were between 94 and 141m long and were carried out near the existing piezometers, whenever possible mutually perpendicular, in order to detect whether the spread of contaminants is done according to regional fracturing or according to another type of movement. The software used to invert the collected data was the RES2DINV (Loke, 2004).
In geochemical studies it is important to determine the geochemical background, in order to detect, in a given set of data, which values may be considered anomalous. Statistical techniques are good tools to make that kind of distinction. In statistical terms a variable has a lognormal distribution if its logarithm is normally distributed. Therefore, and assuming that the concentrations of elements have a log-normal distribution, Lepeltier described a statistical method for the determination of geochemical background and anomalies (Lepeltier, 1969). When plotting the cumulative frequency vs element concentration (in bi-logarithmic scale) a deviation from a log-normal distribution can be perceived as an inflection at the top of the curve, representing an anomaly (Lepeltier, 1969; Matschullat et al. 2000). This inflection point is numerically represented by the value: mean + 2 standard deviations (σ), of the population. Using the iterative 2σ-technique described by Matschullat et al. (2000) all values beyond the mean + 2σ are removed, until a normal distribution is obtained. Therefore, what remains in the normally distributed data is background and what is removed is anomaly (Nakic et al., 2007).
Adapting this methodology to the geophysical data obtained from the resistivity profiles performed, we can check if these two approaches show us the same anomaly. With the whole set of resistivity profiles performed so far, we tried to obtain a representative set of data from the study area in order to obtain a reliable value for background. In order to apply this methodology in geophysical data, we used conductivity values, because high conductivity values indicate the presence of positive anomalies, just like geochemical data. After data processing, they were reconverted back in order to be interpreted as resistivity values. For each depth of investigation the resistivity value was obtained from which the anomaly was considered. We then created a Boolean filter to separate the anomalous values. These data were projected and overlaid on the resistivity profiles in order to compare these two sets and thus determining the anomaly.
Groundwater samples were continuously collected in piezometers, upstream and downstream of the CD, with the aim of identifying the presence of contaminants and at the same time, seeking to establish preferential locations for pollutants, in order to establish the degree of contamination contribution from the waste mass over the time (Kabata-Pendias and Pendias, 1984; McBride, 1994; Novotny, 1995).

Results

The results of physico-chemical analysis in the water from piezometers made between the years 2005 and 2007 revealed values of conductivity in upstream piezometers (P1 and P2) between 20mS/m (50Ωm) and 65.5mS/m (15.3Ωm) and downstream piezometer (P3) between 200mS/m (5Ωm) and 800mS/m (1.3Ωm).
The values of the last analysis performed (February 2010) show conductivity values for P1, 28.6mS/m (35Ωm), and for P3 210mS/m (4.8Ωm).
These values are indicators of a clear influence of contamination from CD in the surrounding water, with the highest incidence in the downstream area of the CD (unsealed part), also seen in the resistivity profiles performed near piezometers (Fig. 3).
In resistivity profile 1 below 12m depth, resistivity values are lower than 30Ωm, on profile 3 below 3m depth, resistivity values are lower than 8Ωm, and on profile 12 below 2m depth resistivity values are lower than 30Ωm. This agrees quite well with the values obtained in the water from piezometers.

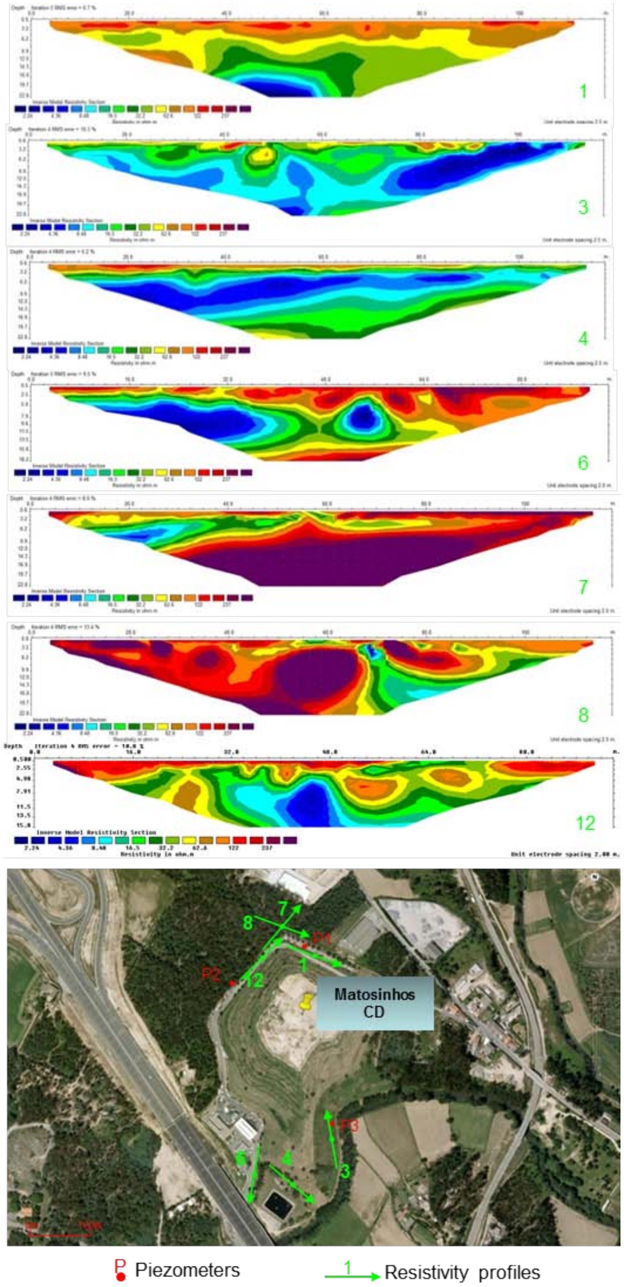

***Fig. 3** – Location of piezometers (P1, P2 and P3) and schematic layout of the electrical resistivity profiles that show anomalies (1, 3, 4, 6, 7, 8 and 12).*

According to the resistivity profiles conducted so far, it has been possible to identify two contamination anomalies from the CD. One located near P1, with resistivity values lower than 30Ωm below 12m in depth, extending to NW, and vertically limited by a more resistive material, a few meters from the northern boundary of the CD (profiles 7 and 8, in Fig. 3). The other plume, more extensive, is located in the southern part of the CD between 2m and 20m depth, with resistivity values lower than 7Ωm (profiles 3, 4 and 6 in Fig. 3).

With the profiles carried out so far it was possible to detect that both contamination anomalies were decreasing with the increasing distance of the CD. The profiles analyzed, according to the previously statistical method, show this effect of distance.

Comparing the conductivity measurements in water samples collected from upstream piezometers with the values of downstream piezometer the presence of a strong influence of contamination downstream of the CD was found and thus confirmed and correlated with the electrical resistivity data.

As we increase the number of resistivity profiles, as well as the distance from CD, we hope to achieve a more precise set of values for defining the background and the anomaly. In the future, as this case study grows, the described statistical method will be further applied in order to refine this analysis and thus confirm the presence of contaminated groundwater and to monitor and help characterize the nature of the contamination plume over time.

In essence we feel that with the application of Lepeltier method to geophysical data, it is possible to define and confirm the anomalies detected, so far, within the resistivity profiles (Fig. 4).

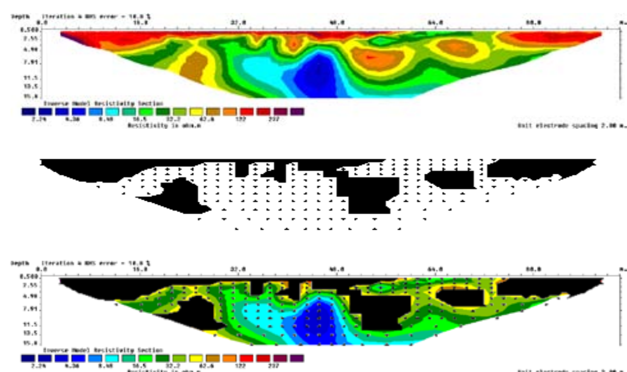

***Fig. 4** – Profile 12: Step 1 - Resistivity model (RES2DINV); Step 2 – Boolean filter (according to methodology described above); Step 3 – Resistivity profile and Boolean filter overlaid.*

Conclusions

With this study we want to underline the importance of multidisciplinarity in the environmental assessment of a CD and its immediate surroundings. We emphasize the contribution of a method usually applied to geochemical data that was adapted and used in geophysical data obtained by the electrical resistivity method.

With our set of 2D profiles was possible to detect the presence of two resistivity anomalies indicative of contamination in the Matosinhos CD surrounding, with particular emphasis in the downstream area (unsealed part). These anomalies were also confirmed with the geostatistical methodology described here. The values

obtained in water of CD piezometers agree quite well with data obtained by both other methods.
Therefore we can conclude that the combination of these three different methodologies allows an approach to the detection and delineation of contaminant plumes from this kind of MSW deposits.

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