International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 4 No. 2 Oct. 2013, pp. 254-263
© 2013 Innovative Space of Scientific Research Journals
http://www.issr-journals.org/ijias/

Geophysical Surveys for the Characterization of Landfills

H. Belghazal[1-3], C. Piga[2], F. Loddo[2], J. Stitou El Messari[3], and A. Ouazani Touhami[3]

[1]Department of Civil and Environmental Engineering and Architecture,
University of Cagliari,
Cagliari, Italy

[2]Geophysics Prospection,
GEOTECH srl,
Cagliari, Italy

[3]Department of Geology,
University of Abdelmalek Essaadi,
Tetouan, Morocco

ABSTRACT: Landfills are the classical solution for waste disposal. During the last years there has been a growing concern about the effect of landfills in public health, because leaching water can contaminate nearby aquifers. The conversion of the open dumps characteristic of many cities around the world to controlled and sanitary landfills is a critical step for protecting public health and the environment.
Landfill is not just a place where waste is disposed, but it is a technological plant designed, realized and managed to obtain a minimization of negative effects. Sanitary landfilling is a fully engineered disposal option that avoids the harmful effects of uncontrolled dumping by spreading, compacting and covering the waste on land that has been carefully engineered before use.
Geophysical surveys are increasingly filling this need, by responding to vertical and lateral variations of the fill material. The non-invasive geophysical methods which measure a different physical properties, specifically Electrical Resistance Tomography (ERT), Frequency-Domain ElectroMagnetic (FDEM) and Infrared Thermography methods (IT), could overcome a problems of the landfill in study.
The combined use of these geophysical methods therefore allows to better characterize the properties of the land and to map the subsurface in landfills and their surroundings.

KEYWORDS: Landfill, Electrical Resistance Tomography, Frequecy-Domain ElectroMagnetic, Infrared Thermography, Plan of contamination.

1 INTRODUCTION

The problem of environmental contamination is, today, one of the main concerns of earth scientists and researchers from other related fields of science around the globe. Fast industrial development and the uncontrolled growth of the urban population result in the production of toxic solid residues [1]. Urban waste materials, mainly domestic garbage, are usually disposed of in-adequately in waste disposal sites placing the underground water resources at high risk. Pollution of ground water happens mostly due to percolation of pluvial water and the infiltration of contaminants through the soil under waste disposal sites. The contaminant is a fluid that results from the decomposition of organic matter, rich in dissolved salts, containing a substantial amount of polluting substances. Contamination takes place when this liquid reaches the groundwater table, thus affecting the potability of underground water and putting the community that makes use of that resource under health risk [2]. The solution to the day-to-day problems of modern urban societies demands fast and effective geophysical methods. One of the most frequent demands in metropolitan areas includes detecting the location and extent of contamination patches in areas as small as landfill sites. In such context, the integrated use of geophysical methods provides an important tool in the evaluation and characterization of contaminants generated by urban residues (domestic and/or industrial). Among those geophysical methods, electrical, electromagnetic and infrared thermography methods have been found very suitable for such kind of environmental studies, due to the conductive nature of most contaminants [3, 4, 5, 6, and 7].

Ilbono landfill has been the disposal sites of urban solid waste for a long time. The negative environmental impacts caused by wastes deposition are manifested in the landfills, adjacent zones, namely, in the groundwater, because these structures are located above permeable and porous formations, which aid in contamination scattering.

It is well known that groundwater contamination can easily occur and carry on for a long time, because recovery is slow and difficult. The problems associated with municipal, abandoned or non-controlled landfills are of general concern, especially because of the interactions between the hazardous contents of the leachates derived from them and the groundwater [8]. Geophysical methods may be used to investigate the history of a landfill as different types of landfills have different properties.

2 METHODOLOGY

In view of the large number of poorly documented landfills, fast and inexpensive methods to investigate the shallow subsurface are becoming increasingly important. Non-invasive surface geophysical techniques are increasingly used for landfill characterization, particularly where intrusive methods are hazardous and pose significant risks to health and safety.

2.1 ERT METHOD

Geophysical methods measuring the electrical resistivity have been used to follow the leachate flows [9]. These methods essentially consist of injecting an electrical current (I) through two metallic electrodes and measuring the potential difference (ΔV) between two other electrodes. The apparent resistivity (ρa) is given by the following relationship (1)

$$\rho a = k\,(\Delta V / I) \qquad (1)$$

With K a geometrical factor which only depends on electrode position. The ρa is the ratio of the potential obtained in situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1 Ω.m resistivity [10]. The apparent resistivity measurements provide information about resistivity for a medium whose volume is proportional to the electrode spacing. The larger the electrode spacing, the higher will be the investigated volume. The data point corresponding to this investigated volume is conventionally represented on a section at a depth equals to the electrode spacing. The apparent resistivity measurements do not allow interpreting the distribution of resistivity inside the Electrical resistivity (or its inverse, the electrical conductivity) depends on several parameters: water content, temperature, ionic content, particle size, resistivity of the solid phase, permeability, porosity, tortuosity, pressure and clay content [11]. Except for the moisture content and temperature, the influence of these parameters on resistivity in waste mass is unknown [12].

2.2 FDEM METHOD

Electromagnetic energy can be applied to the ground using transient current pulses instead of the continuous waves mentioned above [13]. The collapse of a steady state primary magnetic field will induce eddy currents to flow in a conductive earth, and these will give rise to a transient secondary magnetic field, which may be detected in a receiver coil as a time-dependent decaying voltage. The characteristics of this transient decay can be related to the conductivity and geometry of the subsurface geology [14, 15].

FDEM-induction instruments measure subsurface apparent electrical conductivity without galvanic contact using alternating electromagnetic fields to induce subsurface eddy currents [16].

The electromagnetic survey has been used for various near-surface applications including Landfill mapping.

This non-intrusive approach enables rapid mapping of conductive subsurface structures and can easily locate buried waste or contaminated areas. The magnetic susceptivity is particularly suitable for the detection of metals and helps a lot in the detection of buried drums or, for example, to recognize different waste type (foundry wastes from ferrous foundries).

2.3 IT METHOD

Anybody possesses a temperature greater than absolute zero emits, in agreement with the Planck law, energy in the form of electromagnetic radiation. For ordinary temperatures the maximum of the electromagnetic radiation is concentrated in the spectrum of infrared radiation characterized by a wavelength between 0.75 µm and 100 µm in agreement with the Wien's law [17].

$$W = \frac{2hc_0^2}{\lambda^5 (e^{\frac{hc}{\lambda KT}} - 1)} \tag{2}$$

$$\lambda_{\max} = \frac{2897,7}{T} \tag{3}$$

The thermal imaging devices are conceptually similar to a camera, but with the peculiarity to be projected, not to capture the electromagnetic spectrum in the visible light range, but the spectrum of the infrared band.

The electromagnetic energy emitted from the object in the field of thermal infrared radiation is focused through a system of special lenses on an element sensitive to infrared radiation, called microbolometer. This later converts the amount of infrared energy received into an electrical signal that appropriately converted to digital allows the software of the camera to reconstruct an image in false color is representative of the surface temperatures of the object framed (thermogram) [18].

IT is a process in which heat at any temperature can be converted into a thermal image, using specialized scanning cameras.

This method is being used increasingly in the aerial survey of landfill sites, as a result of advances in the development of portable, high-sensitivity thermal imagers to detect the leakage of methane gas and leachates escaping from the sites economically. The method produces an image of temperature variations over the ground surface. Ground investigations are essential to calibrate any temperature anomalies against the presence of methane leaks or the movement of leachates. The method should not be confused with infra-red photography, which is used widely in surface vegetation studies.

3 GEOPHYSICAL SURVEY

3.1 ERT SURVEY

The area available for the geophysical surveys is small, trapezoidal in shape with dimensions of the sides equal to 70, 60, 45 and 45 m. This limits the ability to perform investigations deep. We were made 4 ERT within the landfill, and one in environment not disturbed positioned as shown in figure 1.

Fig. 1. Aerial photography of the landfill with the positioning of the ERT profiles

For the acquisition of data we used Georesistivitymeter Advanced Geoscience Inc and it has been programmed a sequence of measurement of dipole-dipole type. This configuration, as compared to others, allows us to better determine the lateral variation of resistivity.

Although substantially different between them, the ERT from 1 to 4, realized internally to the landfill, show common elements that can be analyzed simultaneously. The ERT 5 was performed downstream of the retaining wall, located east of the perimeter of the landfill. The objective of this measure was to evaluate the distribution of the average resistivity of the material below the bottom of the landfill and the possible presence of water (Figure 2).

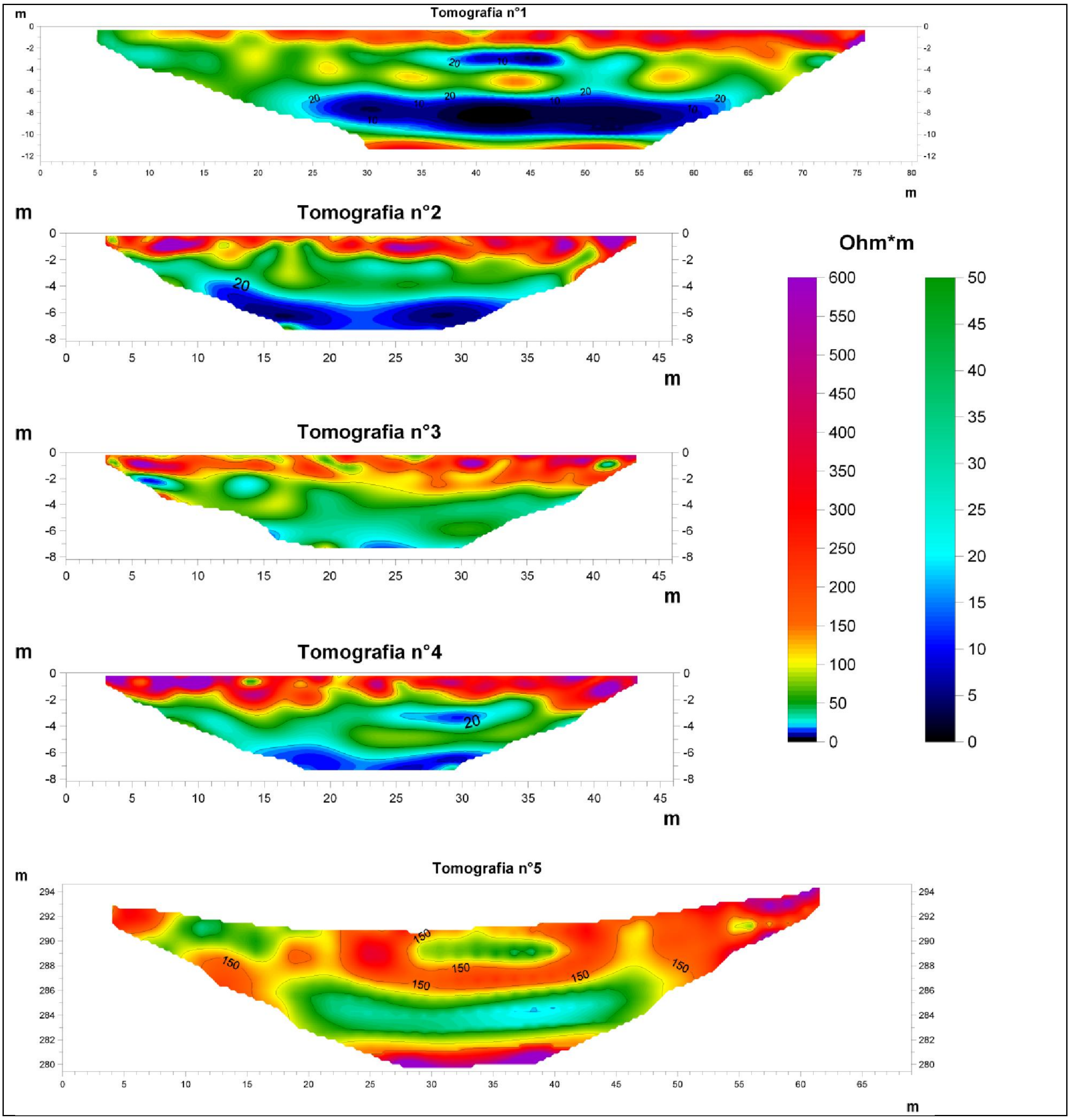

Fig. 2. Resistivity model for the Ovar landfill with contaminated areas

3.1.1 PROFILS 1-4

The spacing between the electrodes influence on the depth of investigation reached, the ERT n ° 1 shows the distribution of subsurface resistivity for about 12.00 m, while n° 2, 3 and 4 reach 7.50 meters depth

The results show the presence of three electro-main layers: resistive, characterized by values between 100 and over 600 Ohm*m, referable both to the presence of materials well draining (gravel) or similarly to compact materials and waterproof (rock), conductive, characterized by resistivity between 20 and 100 Ohm*m, related to bulk materials and wet, very conductive, with values less than 20 Ohm*m, related to organic materials wet.

3.1.2 PROFIL 5

The resistivity section shows average higher than those found within the site, with values always above 20 Ohm * m. Therefore, the very conductive layer is absent.

This profile marks the presence of the aquifer unpolluted

3.2 FDEM SURVEY

The electromagnetic data were acquired with a GF Instruments CMD electro-magnetometer with coils placed in vertical configuration. The spacing between the coils is equal to 3.77 m.

The data were acquired by running parallel profiles between them, with average spacing of approximately 1.5 m along two directions perpendicular to each other. The measurements were carried out with the use of a Differential GPS which has allowed the georeferencing of data and results. In total, we have gained 4800 data of electrical conductivity, and phase, distributed with a cover shown in figure 3.

Fig. 3. Aerial photography of the landfill with the positioning of the FDEM profiles

FDEM data do not require special processing, but are interpolated to produce maps that are then interpreted qualitatively. They do not allow the interpretation in depth, but show in detail the lateral variations of conductivity (Figure 4)

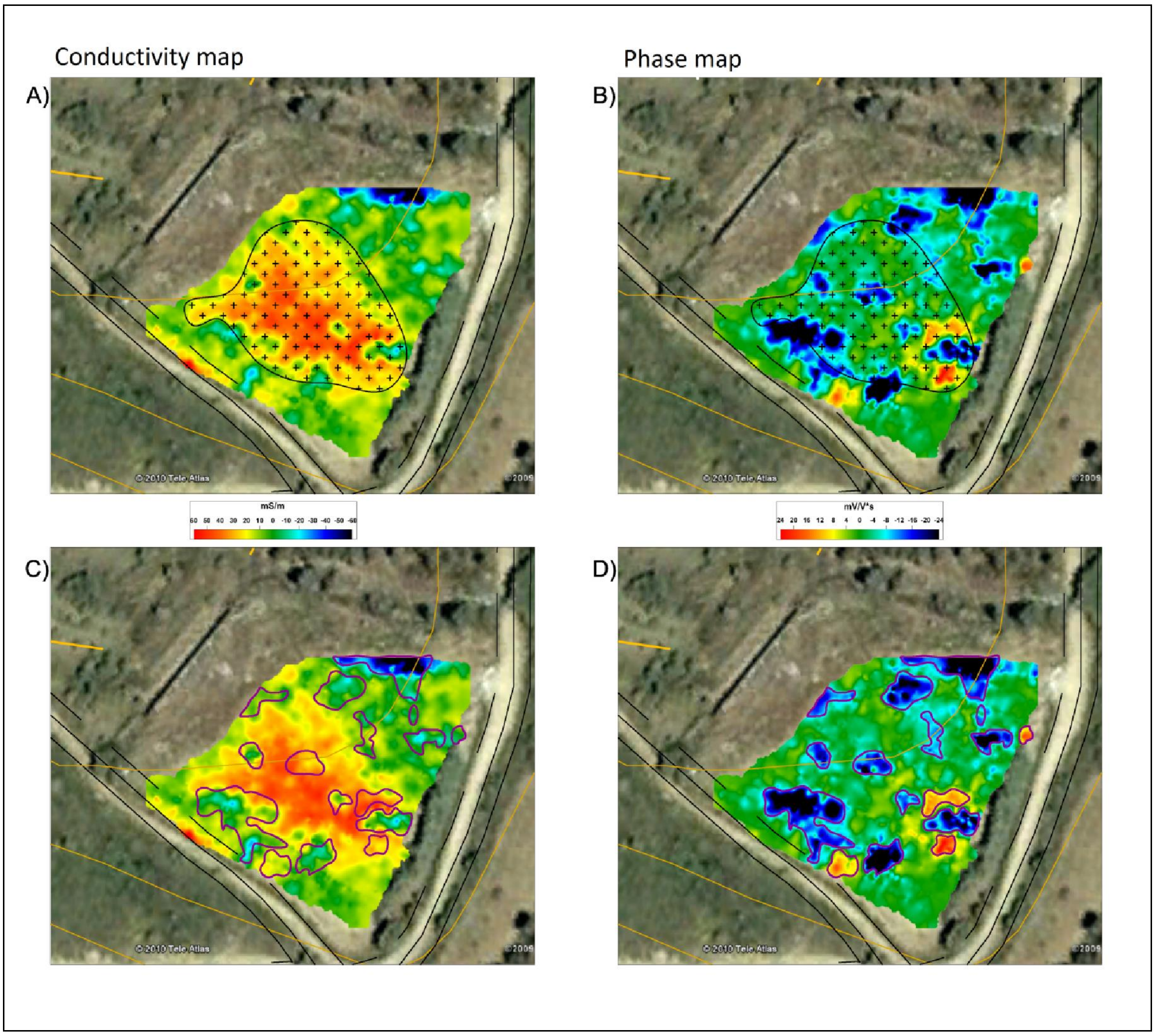

Fig. 4. FDEM results, A,C) Apparent conductivity maps, B,D) phase response maps

The results obtained show clearly apparent conductivity values and phase, positive and negative. The map of the phase is the result of the presence of metallic materials, very close to the ground surface. The map of conductivity shows the presence of a conductive area with conductivity values varying between 20 and 60 mS / m to which are associated phase values close to zero that indicates the presence of a conducting and non-ionic metal type. Inside the conductive area, we find the presence of a circumscribed areas characterized by maximum and negative values of phase, in these points, it is likely the presence of metallic surface and/or elements made by resistive materials and tires.

3.3 IT SURVEY

Management of landfill gas can be improved if leaks can be detected and rectified effectively; an infrared camera produced by Flir Model S65 has been used to detect gas leaks accurately by identifying them as anomalies.

The FLIR S65 operates in the electromagnetic band between a wavelength of 7.5 µm and 13 µm, using an uncooled microbolometer FPA sensor having a resolution of 320x240 pixels, with a spatial resolution of 1.3 mrad and an accuracy of 2°C. The visualization of the scene is done in real time on a display "LCD 4" placed on top of the camera, the thermogram can be stored on a memory card in standard Compact Flash, JPEG radiometric format. This thermocamera also has the ability to acquire color images in the visible spectrum.

The shooting in the site investigation were carried out from an elevated position along the dirt road that runs along the landfill in his south side Ovest.10 thermograms were acquired, disposed in such a manner as to cover the entire extent of the landfill (Figure 5).

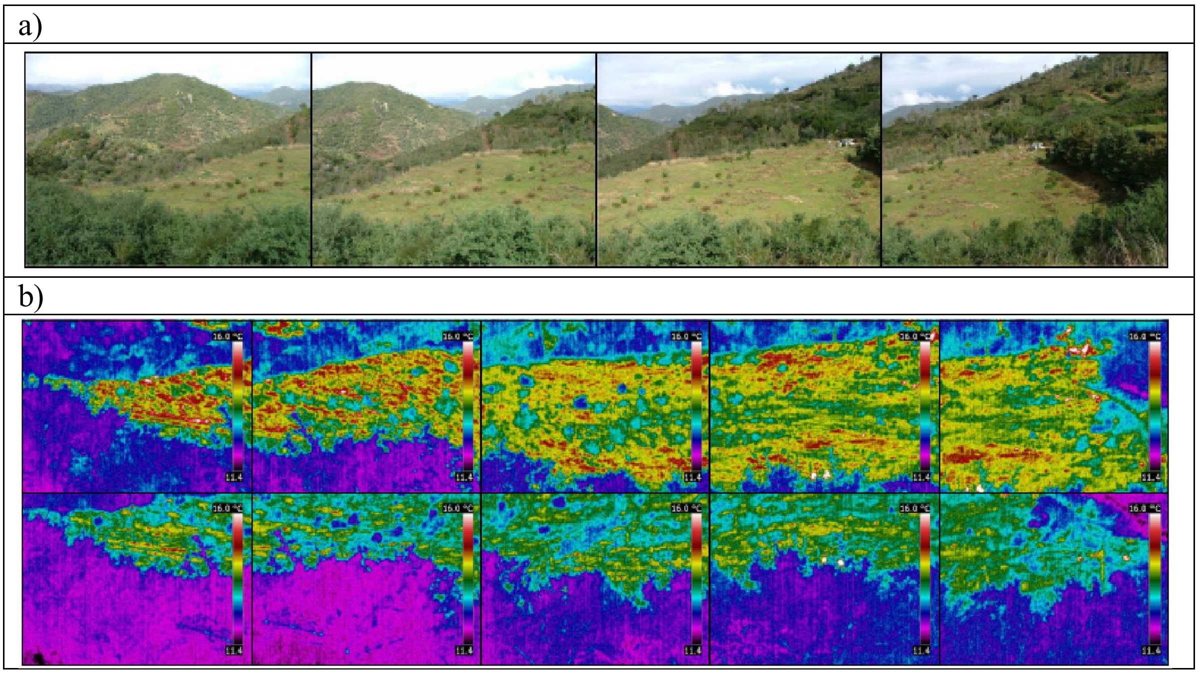

Fig. 5. IT results, a) Photography in the visible spectrum, b) Photography in the infrared spectrum

The thermography, showed a surface temperature of the soil of the landfill between 13°C and 15°C. The variability in the values of temperature is uniform over the entire area of investigation. The lift of biogas is the product of an exothermic chemical reaction that should heat the soil in correspondence of any buildup. The thermographic analysis did not detect significant temperature anomalies, and let not therefore be inferred that any biogas able to find a way to escape widespread in the superficial layers of the landfill little compacted, without giving rise to accumulation zones.

4 RESULTS ANALYSIS

The analysis of the results obtained allows to highlight important features of the landfill:

- **Geometrical characteristics of the landfill**

Based on the results obtained it is possible to assume a vertical distribution of waste in the landfill, characterized, in the surface (0 to 3.4 m), the presence of dry waste, not compacted, draining into the middle (3, 4 - 6 m), from waste more compacted, less draining, with a greater wet fraction, in the lower part (6 - 10 m), by the presence of compacted waste and liquid substances with a high saline content.

- **Volumes approximate**

Although the reconstruction of the volumes of waste requiring a higher spatial density of measurements performed, the results allow to estimate a quantity of material present in the landfill, below the surface investigated, excluding therefore the steep side, equal to about 32,000 m3.

- **Pockets of biogas**

The first meters below the surface of the landfill are characterized by abnormalities of high resistivity which does not allow to exclude the presence of biogas in the surface. As previously illustrated, the materials present in the first layers are poorly compacted and well draining, it is reasonable to infer that such a matrix in the gas would escape routes to the surface. The thermographic analysis shows a variation of the temperature, and does not highlight areas with anomalous values of temperature, compared to the surrounding context. On the basis of these considerations, it tends to exclude the presence of accumulations of biogas in bags, both in the surface layers which are absent in depth where resistivity anomalies related to these phenomena.

- **Ferrous materials / Leachate**

Are indicated in Figure 4, the areas in which it is the presence of ferrous materials. The electro-conductive layer is characterized by values attributable to the presence of leachate with depth between 4 and 6 meters.

- **Presence of aquifer water**

Tomography n° 5 (Figure 1) shows resistivity values that are compatible with the presence of clay materials, which a flow of groundwater at a depth of about 7 meters from the ground level, which is roughly about 12 meters below the base the containment wall.

5 CONCLUSION

The combined use of geophysical methods is being used for contaminant and landfill mapping with great success [19].

The geophysical characterization of industrial and urban abandoned waste disposal can allow to estimate the volumes of refuses that must be reclaimed and to know the pathways of leachate and pollutants and its connections with fresh aquifers or lagoon or salt water. The geophysical indications are volumetric and therefore the geophysical methods can give better than the direct method answers to the waste disposal site reclamation.

In particular, all the electric and electromagnetic data allowed to delineate the resistive and conductive trends of the waste disposal.

REFERENCES

[1] G. Santarato, N. Abu-Zeid, "Progetto di bonifica e recupero ambientale dei siti comunali di discarica per rifiuti urbani di Valle Isola: studi ed indagini preliminari (in Italian)", Unpublished report, Comacchio County, Italy, 68 pp, 1998.

[2] V. Iliceto, G. Santarato, R. Merola, F. Ardizzoni, F. Finotti, "La polarizzazione indotta nella localizzazione di discariche di rifiuti solidi urbani. Ingegneria sanitaria ambientale", *Genn.-Apr.j*:63–72, 1994.

[3] T.J. Ulrych, O.A.L. Lima and E.E.S. Sampaio, "Insearch of plumes: a GPR odyssey in Brazil", *64th Annual Int. Meet., Soc. Explor. Geophys. SEG, Los An-geles, USA*, pp. 569– 572, Expanded Abstracts, 1994.

[4] E. Lanz, L. Jemmi, R. Muller, A. Green, A. Pugin and P. Huggenberger, "Integrated studies of swiss waste disposal sites: results from georadar and other geo-physical surveys", *Proceedings of the fifth International Conference on Ground Penetrating Radar (GPR '94*), Kitchener, Ontario, pp. 1261– 1274, 1994

[5] W.A. Sauck, "A model for the resistivity structureof LNAPL plumes and their environs in sandy sediments", *Journal of Applied Geophysics 44*, 151–165, 2000

[6] E.A. Atekwana, W.A. Sauck and D.D. Jr. Werkema, "Investigations of geoelectrical signaturaes at ahydrocarbon contaminated site", *Journal of AppliedGeophysics 44,* 167– 180, 2000.

[7] L. Orlando and E. Marchesi, "Georadar as a tool toidentify and characterise solid waste dump deposits", *Journal of Applied Geophysics 48*, 163– 174, 2001.

[8] G. Buselli, G.B. Davis, C. Barber, M.I Height, S.H.D. Howard, "The application of electromagnetic and electric methods to groundwater problems in urban environments", *Explor Geophy* 23:543–555, 1992.

[9] T. Dahlin, "The development of DC resistivity imaging techniques", *Computers & Geosciences*, 27 (9), 1019-1029, 2001.

[10] M.H. Loke, R.D. Barker, "Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method", *Geophys Prospect 44*:131–152, 1996.

[11] Y. Guéguen and V. Palciauskas, "Introduction à la physique des roches", *Hermann, éditeurs des sciences et des arts*, 299 p, 1992.

[12] S. Grellier, "Suivi hydrologique des centres de stockage de déchet-bioréacteurs par measures géophysiques", *PhD thesis, Université Pierre et Marie Curie*, Paris, 238 p, 2005.

[13] J.D. McNeill, "Use of electromagnetic methods for groundwater studies", *In S.H.Ward (Ed.): Geotechnical and Environmental Geophysics*, Vol. 1: Review and Tutorial, SEG, Tulsa, 1990.

[14] E. Cardarelli, M. Bernabini, "Two case studies of the determination of parameters of urban waste dumps". *J Appl Geophy 36(4)*:167–174, 1997.

[15] M. Chiappini and M. Marchetti, "Analisi delle anomalie magnetiche in aree di discarica", *Comunicazione al 17° Convegno Nazionale del Gruppo Nazionale di Geofisica della Terra Solida*, Roma 10-12 Novembre 1998.

[16] S.H. Ward and G.W. Hohmann, “Electromagnetic theory for geophysical applications”, *In: Nabighian MN, Corbett JD (eds) Electromagnetic methods in applied geophysics*: theory, SEG Monograph 1:131 – 313, 1988.

[17] Marat Khairoutdinov, “Numerical Methods in Geophysical Simulation,” 2012.
[Online] Available: http://rossby.msrc.sunysb.edu/~marat/MAR542/ATM542-Chapter2.pdf (2013)

[18] A. Dillenz, G. Busse and D. Wu, “Ultrasound lockin thermography: feasibility and limitations Diagnostic Imaging Technologies and Industrial Applications”, *Proc. SPIE* 382710–5, 1999.

[19] J.M. Reynolds, *An introduction to applied and environmental geophysics*, Wiley, New York, 796 pp, 1996.