Proceedings of the

4th International Symposium on

Enhanced Landfill Mining

5 - 6 February 2018

Mechelen, Belgium

Editors

Peter Tom Jones

Lieven Machiels

ASSESSMENT OF MULTIPLE GEOPHYSICAL TECHNIQUES FOR THE CHARACTERISATION OF MUNICIPAL WASTE DEPOSIT SITES

Gaël DUMONT[1], Nicolas MARK[2], Tanguy ROBERT[1], Frédéric NGUYEN[1]

[1] University of Liege, Urban and Environmental Engineering, 4000 Liege, Belgium
[2] BOVA ENVIRO+, 5000 Namur, Belgium

gdumont@uliege.be, iisunza@uliege.be, nico_marck@hotmail.com, tanguy.robert@uliege.be, f.nguyen@uliege.be

Introduction

The characterisation of former landfills (also illegal ones) or many brownfields and polluted sites is a major issue nowadays. Environmentally speaking, these sites represent a potential risk towards pollution of groundwater. From an economic point of view, waste reuse/recycling and landfill mining are gaining attention. Likewise, reactivating the biodigestion process to enhance methane production and, therefore, energy production, is also considered. Finally, the rehabilitation of such sites represents a good method of regaining space in densely populated area where space is lacking.

In the exploration of landfill sites, parameters of importance are the thickness of waste layers and their horizontal extent. Another area of research and interest is the characterisation of the state of digestion and the degree of humidity of waste inside a landfill. Indeed, one can try to accelerate the biodegradation process to stabilise the landfill and as a consequence, gain energy when power plants treat the gas (methane) derived from a landfill. In the current research project, a large spectrum of geophysical methods was used to characterise a large landfill site situated in Wallonia, Belgium. Electrical resistivity tomography (ERT), electromagnetic induction (EMI), magnetometry (MAG) profiling and mapping, gravimetry and seismic acquisitions (MASW and HVNSR) were performed. Afterwards, water recirculation experiments (aiming at accelerating the waste biodegradation process) were conducted and monitored with Time-Lapse ERT.

Site and methods

Site description

All field tests were performed on the landfill site of Mont-Saint-Guibert in Wallonia, Belgium (Figure 1). This large engineered landfill (26 ha wide; up to 60 m deep; 5.3 million m³ of waste) has been active since 1958. The 11 million tonnes of waste disposed comprise municipal solid waste, non-hazardous and non-toxic industrial waste, and bulky waste. The cover layers, dams and roads are composed of inert waste and clinker. The site infrastructure includes a bottom leachate collection system and 200 vertical gas extraction wells. During the past 25 years, more than 1 billion m^3 of landfill gas have been produced.

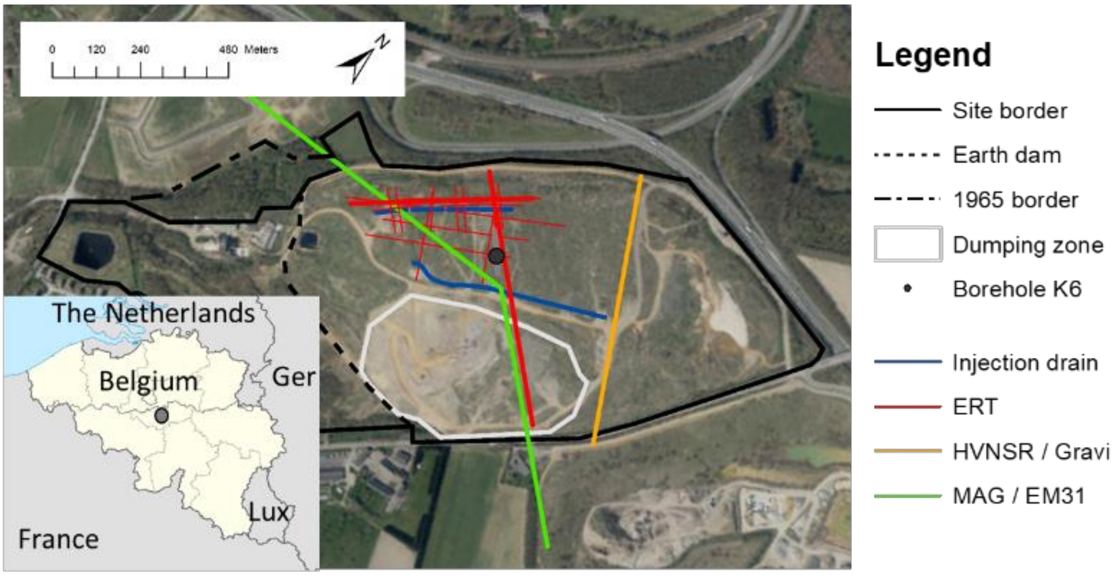

Figure 1: The Mont-Saint-Guibert technical landfill sit

Methods

The geophysical campaigns were organised between 2012 and 2015. Some of the campaigns covered the full extent of the deposit (electromagnetic and magnetic mapping). Slower methods (and therefore costlier) only provide some linear or vertical profile information (electrical resistivity tomography, seismic methods). The geophysical survey locations are found in Figure 1.

The electromagnetic mapping was conducted with an EM31 (GEONICS) in vertical dipole mode on the former and new landfill. Both the in-phase (magnetic susceptibility) and the quadrature-phase (electrical conductivity) components of the induced magnetic field were recorded. The magnetic vertical gradient data were acquired with a cesium vapour MAGMAPPER G-858 gradiometer (GEOMETRICS) and a GSM-19-GW Overhauser-effect gradiometer (GEM-Systems). Seismic data were acquired with the DacqLink2 logger, 24 4.5 Hz geophones and a 8 kg sledgehammer. As there was no ability to detect first arrivals, advantage was taken of the surface wave propagation features (these concentrate a large part of the tremor energy). The MASW allows the estimation of the vertical shear-wave velocity (*Vs*) profile inside the waste dump. The HVNSR data were recorded with a CityShark microseismic station and a Lennartz Electronic LE-3Dlite sensor (1Hz). Both MASW and HVNSR data were analysed with the GEOPSY software. Several ERT profiles were acquired on the N-W zone of the landfill with a multi-channel ABEM terrameter LS, both for characterisation and for monitoring of recirculation of the leachate experiments (Figure 1). A long transversal profile completed the ERT data set. The multigradient acquisition protocol was used with a 2.5 m to 5 m electrode spacing.

Results

Mapping

Given the metal content of the waste material (2 wt%) and the presence of clinker (28 wt%), the magnetometric and gradiometric mapping logically allows a quick and cheap delineation of the horizontal border of the site. The vertical magnetic field gradient (Figure 2c) increases the resolution of the magnetic observations by emphasising the effect of the near-surface anomalous sources. The transition between natural soil (a few 10 nT/m magnetic field vertical gradient), on the one hand, and the roads and the waste deposit, on the other hand (a few 100 nT/m), is clearly detected.

Provided that the geological target is conductive and covered by a thin layer of cover material, the EM mapping appears as an efficient and cheap method. The differentiation between the waste deposit and the host formation surrounding the landfill is very clear (Figure 2d). The resistivity inside the waste dump is only a few Ω.m. The value is smaller in the more recent part of the landfill (5 Ω.m), as compared to the older landfill zone. In the present day deposition area (no more organic materials allowed since 2010). In contrast, the host formation outside of the landfill is characterised by higher resistivities (30-100 Ω.m) (Figure 2d). The in-phase component of the EM31 signal (Figure 2b) is sensitive to the presence of magnetic materials in the upper part of the landfill. The signal is saturated in the new part of the landfill site and slightly negative over the two roads surrounding the site. The in-phase signal outside the field is close to zero.

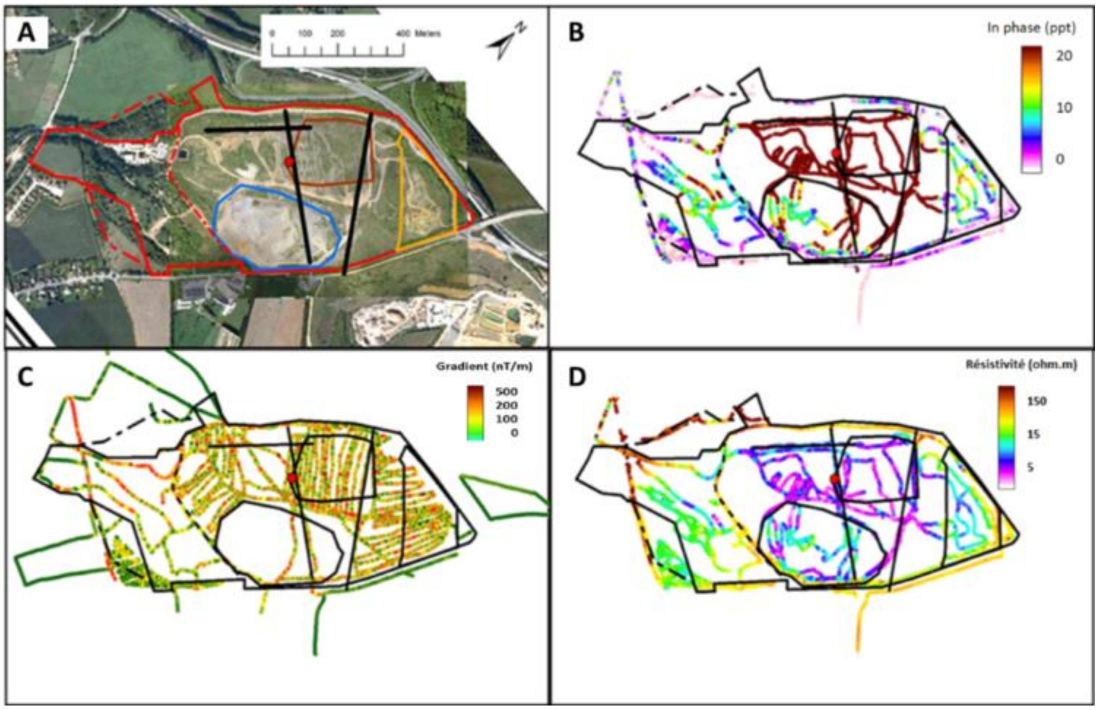

Figure 2: Electromagnetic and magnetic mapping of the landfill: a) site description; b) Electrical resistivity (EM31 in-phase); c) magnetic vertical gradient; d) EM31 out-of-phase

Thickness estimation

The thickness estimation of this particular engineered landfill was difficult with conventional geophysical methods, since surface surveys generally have a limited depth of investigation and decreasing spatial resolution and sensitivity with increasing depth. The use of combined MASW and HVNSR methods was investigated to estimate the landfill depth. Using MASW it was established that the shear-wave velocity (*Vs*) varies from 100 m/s at the surface to 180 m/s at 16 m depth. It is then assumed that the *Vs* still increases by 5 m/s/m with depth. For the landfill depth estimation, 11 HVNSR data were recorded across the landfill (Figure 1; Figure 3). The resonance peaks are clearly identified and their frequencies, ranging from 1.10 to 1.85 Hz, are correlated to the site topography (Figure 3). However, it is not clear if the resonance phenomenon results from the waste-sand interface or from the sand-bedrock interface impedance contrast.

$$f_0 = \frac{V_{s\,av\,waste}}{4 * H_{waste}} = \frac{100 + 2.5 * H_{waste}}{4 * H_{waste}}$$

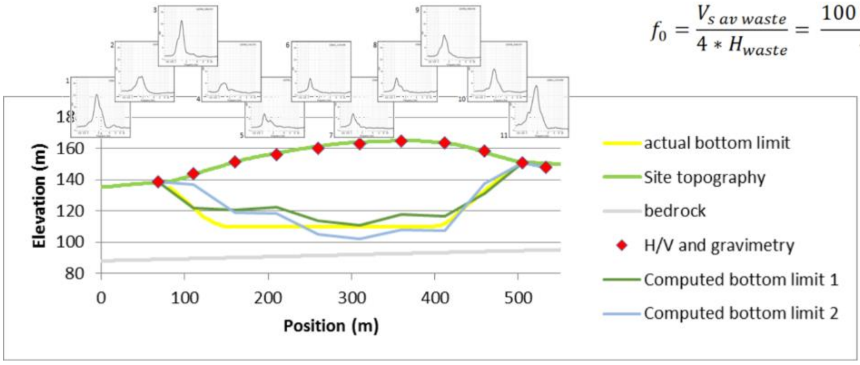

Figure 3: HVNSR resonance peaks and HVNSR transversal profile

Water content estimation

Because of the high contrasts in electric resistivity provided by borehole investigation, it is expected that geoelectrical methods might enable the accurate imaging of electrical resistivity and, related to this, the water distribution inside the waste material.

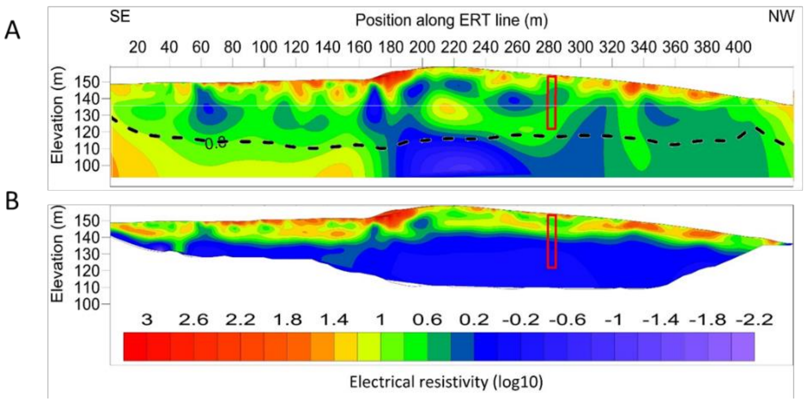

Figure 4: ERT transversal profile inverted with a basic inversion process (DOI in dotted line); b. Advanced inversion process. The borehole location is indicated by a red rectangle.

The transversal ERT profile was inverted with (1) a standard inversion procedure (robust norm on the data) and (2) a reference model to impose the depth and electrical resistivity of the saturated zone (see Dumont *et al.*[1] for more details). Hereby, the importance of incorporating prior information in the inversion to achieve a coherent result is shown. In the standard inversion (presented in Figure 4a), the depth to the water table is overestimated with respect to borehole information. The transition between the unsaturated and saturated zone appears rather smooth, while it is known to be sharp from borehole EM investigation.[1] With the reference model process (Figure 4b), the unsaturated zone was in accordance with borehole data as the depth to the water table was imposed.[1] The saturated zone appeared relatively homogeneous in the model.

Water recirculation monitoring

In this study, ERT monitoring was used and temperature measurements were performed. Hereby, large horizontal recirculation drain efficiency for superficial waste humidification in a large retrofit technical landfill was assessed. Of particular interest was the extent of the injected plume, the flow anisotropy, the existence of preferential flow paths, and the persistence of moisture increase. 60 m³ of water was injected and electrical resistivity was monitored hourly. A total of four 2D ERT profiles was acquired for each time frame. The southern tomography, along the drain, ensures that the drain is studied over its entire length. The other profiles are used to assess the recirculated liquid flow behaviour and the residence time of the added water as a function of the injected volume. Data are presented for several time periods after the injection time, *i.e.* 1, 2, 3, 12, 18 and 48 h (Figure 5). The southern profile shows that the injection drain is used on almost its entire length. The leachate plume extension changes during the 3 first hours following the injection. Initially, it has a smaller horizontal extent (Figure 5a). Afterwards, the horizontal extent increases along the field slope, while the thickness and the magnitude decrease.

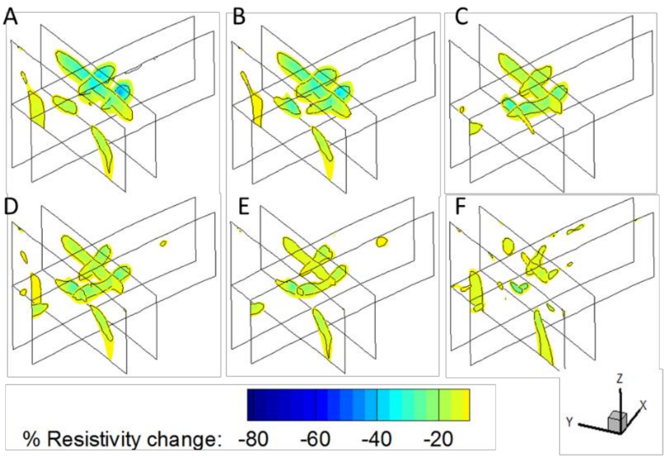

Figure 5: ERT monitoring of the 60 m³ injection after different time intervals: A. 1 h; B. 2 h; C. 3 h; D. 12 h; E. 18 h and F. 48 h after injection. The black line is the "70% of local maximum" threshold.

The observed changes are extremely high (< -40%) and focus on the injection drain (Figure 5a). As the injected liquid flows from the drain towards the North, the resistivity magnitude decreases (-25%, from 24 Ωm to 18 Ωm) close to the drain location while it increases down the slope (Figure 5c). The leachate plume extension is about 2,500 m. Three hours after the injection, water arrives at the bottom part of the field test, close to the peripheral drain (Figure 5c, profile west). During the next 2 days, the magnitude of the resistivity progressively decreases. After 48 h, only a small fraction of the waste mass has its water content increased by a few percent (Figure 5f).

Conclusions

Frequently encountered problems with former and/or illegal waste deposit sites have been addressed and several geophysical techniques have been assessed allowing to find partially and/or totally missing information of these sites. For landfills, important issues are their precise identification/localisation, the characterisation of their lateral and vertical extents, and the characterisation of their waste constituents.

Globally, the full geophysical campaign, which necessitated less than 2 weeks of surveying for a couple of technicians and one week of data treatment for an engineer, offers a good understanding of the site extension, depth, volume and water content. This information was acquired at low cost (compared to a "drilling-sampling-analyses" approach) and offers important information for site rehabilitation studies, water mitigation processes for enhanced biodegradation or landfill mining operation planning. Additionally, the recirculation experiment resulted in a better understanding of the suitability of a large horizontal drain for water recirculation on a large retrofit landfill. There was a particular interest to understand the influence of the drain horizontality, the effects of waste compaction and neighbouring gas wells on the water flow and the persistence of the water content increase through time.

Acknowledgments

This research was supported by the MINERVE project (GreenWin, Plan Marshall 2.vert) and the RAWFILL project (INTERREG and Walloon Region).

References

1. G. Dumont, T. Pilawski, P. Dzaomuho-Lenieregue, S. Hiligsmann, F. Delvigne, P. Thonart, T. Robert, F. Nguyen and T. Hermans, "Gravimetric water distribution assessment from geoelectrical methods (ERT and EMI) in municipal solid waste landfill", *Waste Manage,* **55** 129-140 (2016).