

# Geophysical Investigation of Leachate Migration and Groundwater Interaction at the Former Agoe Nyive Landfill, Southern Togo

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**Abstract:** *This research investigates the subsurface migration of landfill leachate and its interaction with shallow groundwater at the former Agoe Nyive landfill in southern Togo. Magnetic surveying and electrical resistivity tomography were applied to delineate contaminant pathways and identify zones of altered subsurface properties. Magnetic data revealed surface and intermediate depth anomalies forming a probable flow corridor, while resistivity values as low as 5 ohm.m between 15 and 23.5 meters depth indicated highly conductive zones consistent with leachate accumulation. The results suggest that the contaminant plume remains largely confined to shallow and intermediate layers, with direct contact observed between leachate and the shallow aquifer whose static level ranges from 5 to 10 meters. The study provides a geophysical basis for groundwater risk assessment in urban landfill environments.*

**Keywords:** Landfill contamination, leachate migration, groundwater vulnerability, electrical resistivity tomography, magnetic surveying.

## 1. Introduction

In African cities such as Togo, households produce several kilograms of waste per day, which is collected and transported to municipal landfills for disposal [1]. The management of this urban waste follows a classic pattern: pre-collection, collection, transport, and final disposal [2]. However, in Africa, this form of disposal often does not include the treatment and recovery of the various fractions to minimise or eliminate health and environmental impacts [3]. In a context where landfill has long been the easiest, cheapest, and most widespread solution for waste disposal, water resources (surface water and groundwater) are susceptible to various forms of pollution [4]. Indeed, the production of biogas and leachate can cause significant pollution, particularly to groundwater [5]. This can compromise the use of water resources for irrigation or human consumption [6]. In Togo, the Agoè-Nyivé landfill, one of the largest and only final disposal sites in the city of Lomé, is causing significant concern and debate because it is likely to contribute to environmental degradation. Since its closure in 2018, the area surrounding the landfill site has been affected by uncontrolled urban sprawl, with residents suffering from the resulting nuisances. The visible and dangerous nuisances caused by this landfill include smoke emissions, unpleasant odours, and the proliferation of rodents and insects. Another nuisance, although not visible, is the potential for groundwater contamination from leachate generated by the landfill, as it lacks a leachate collection, drainage, and treatment system. Some households have no sanitation facilities and obtain their water from wells and boreholes [7]. Given that the local population obtains its water from wells and boreholes, it is essential to ask the following question: How does the lack of an appropriate

waste management system (sorting, recovery, and recycling) and a system for collecting and treating the leachate produced by this landfill contribute to the deterioration of groundwater quality in AgoeNyivé? Poor management and ineffective control of the old landfill site pose a real threat of contamination to the three components of the environment (air, soil, and water resources).

Geophysical investigations play an important role in understanding leachate migration and its interaction with groundwater systems. Electrical resistivity tomography methods have proven effective in delineating contaminant plumes around landfill sites, as demonstrated by Yalo (2014), who mapped the spatial and vertical extent of groundwater contamination by leachate at the Hèvié landfill in Benin, revealing significant depth penetration and concentration variability. Also, Florent et al. (2019) demonstrated that geological formations significantly influence groundwater vulnerability to leachate pollution in the Mbé Plateau district (Congo), illustrating the importance of an integrated geological and geophysical assessment. Building upon these studies, the present research integrates Electrical Resistivity Tomography (ERT) and magnetic surveying to characterise subsurface structures and identify conductive anomalies associated with leachate infiltration in a coastal sedimentary basin of southern Togo. By applying a high-resolution, non-invasive approach in a data-scarce West African context, this study advances integrated geophysical landfill monitoring.

## 2. Geographical and Hydrogeological Context

The former Agoè-Nyivé landfill, located fifteen kilometres north of downtown Lomé (Figure 1), has been the municipality's central landfill since 2001. Its location, on the

edge of National Road No. 1, places it approximately 5 km from the northern boundary of the 5th arrondissement. It is bordered to the north by the Agoè-Nyivé-Dikamé road and the motocross training centre, to the south by the Grand Contournement, and to the west and east by the Bernard Kopé neighbourhood. Initially, the area was a 39-hectare former sand quarry that was illegally used as a dump in the early 1990s. Since its official designation as a municipal landfill in early 2001, the household waste collection rate has risen from 30% in 1995 to 70% in 2015, with estimates indicating that the site received up to 3 million tonnes of waste during this period[8]. The region has a bimodal equatorial climate, characterised by two rainy seasons (April

to July, with the maximum in June, and September to October) and two dry seasons (November to March and a short one-month dry season in August), with rainfall of around 900 mm per year. Temperatures average 25° to 26° C, reaching a maximum of 32° C in February and a minimum of 21° C in June and July. The study area is part of a geological complex consisting of the coastal sedimentary basin. This geological substratum consists mainly of Maastrichtian, Palaeocene-Eocene, and Continental Terminal formations. The static level of this shallow aquifer varies between 5 and 10 metres deep around the site, with its general flow directed towards the south-south-west.

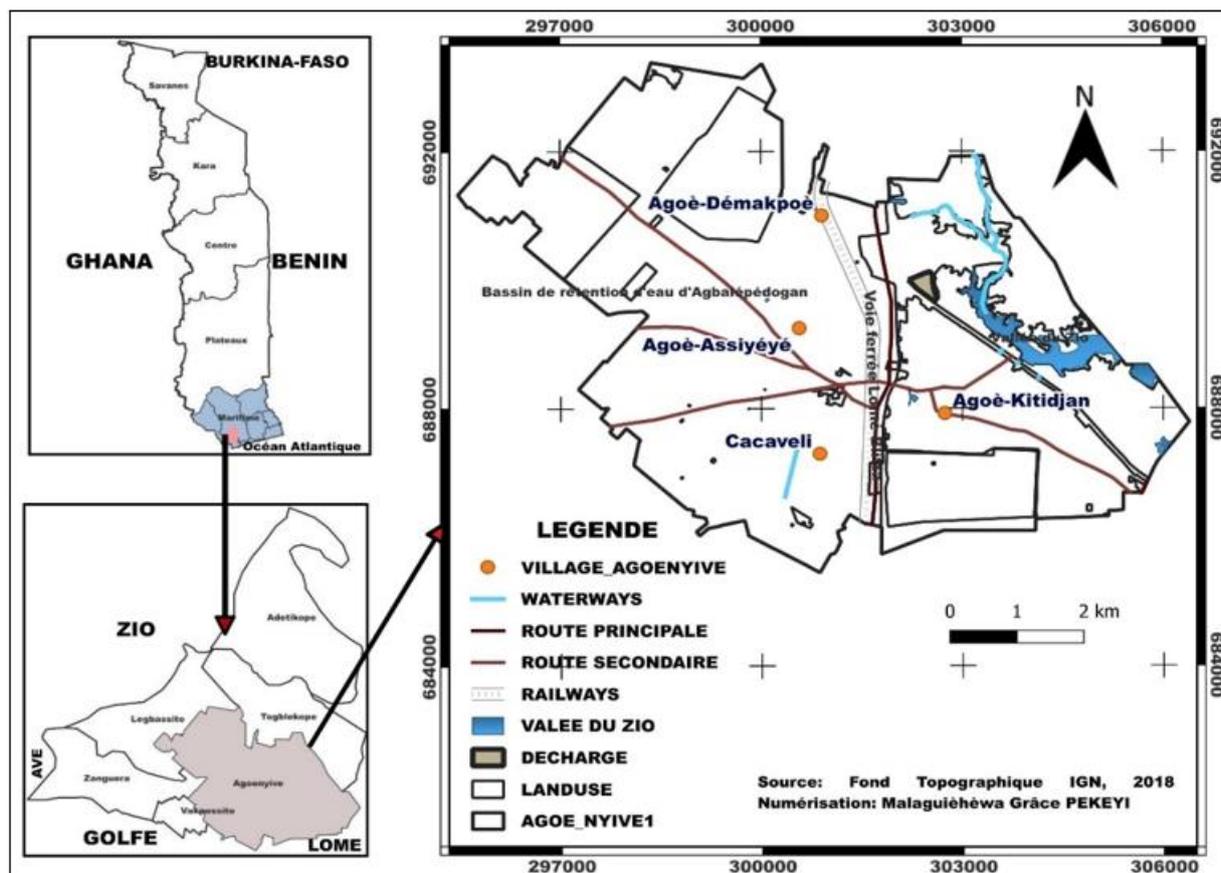


Figure 1: Geographical and administrative map of the study area

### 3. Materials and Methods

#### 3.1 Magnetic acquisition

The primary objective of this study is to detect and characterise magnetic anomalies associated with leachate-contaminated areas. The presence of leachate can locally alter the magnetic properties of underground materials due to variations in metal concentrations or changes in soil composition. This survey, therefore, aims to map potentially contaminated areas and guide future hydrogeological studies. Our study area spans 32 hectares, and the landfill itself stands at 15 metres high. Magnetic field data were collected using a mini magnetometer and accessories with a Garmin GPS, following a roughly regular square grid of 50 m x 50 m. At each station, the magnetic field was measured while the point's geographic coordinates were recorded via GPS. The collected data was transferred to a computer for processing

and interpretation to produce magnetic maps. Various maps were created using Geosoft software extensions (Oasis Montage). This enabled visualisation of the anomalies' behaviours at different depths. Four profiles were produced. They are oriented southwest-northeast (SW-NE) and cross the entire landfill site under study.

#### 3.2 Acquisition of Electrical Resistivity Tomography (ERT) data

The Wenner array has been widely used due to the foundational research conducted by the University of Birmingham group [9]. The sensitivity curve associated with this array has quasi-horizontal contours below the centre, making it particularly sensitive to vertical variations in underground resistivity [10]. This characteristic makes it an effective tool for detecting vertical changes, particularly the flow of contaminants from the soil to underlying layers. The Wenner- $\alpha$  ( $W\alpha$ ) device is distinguished by its configuration,

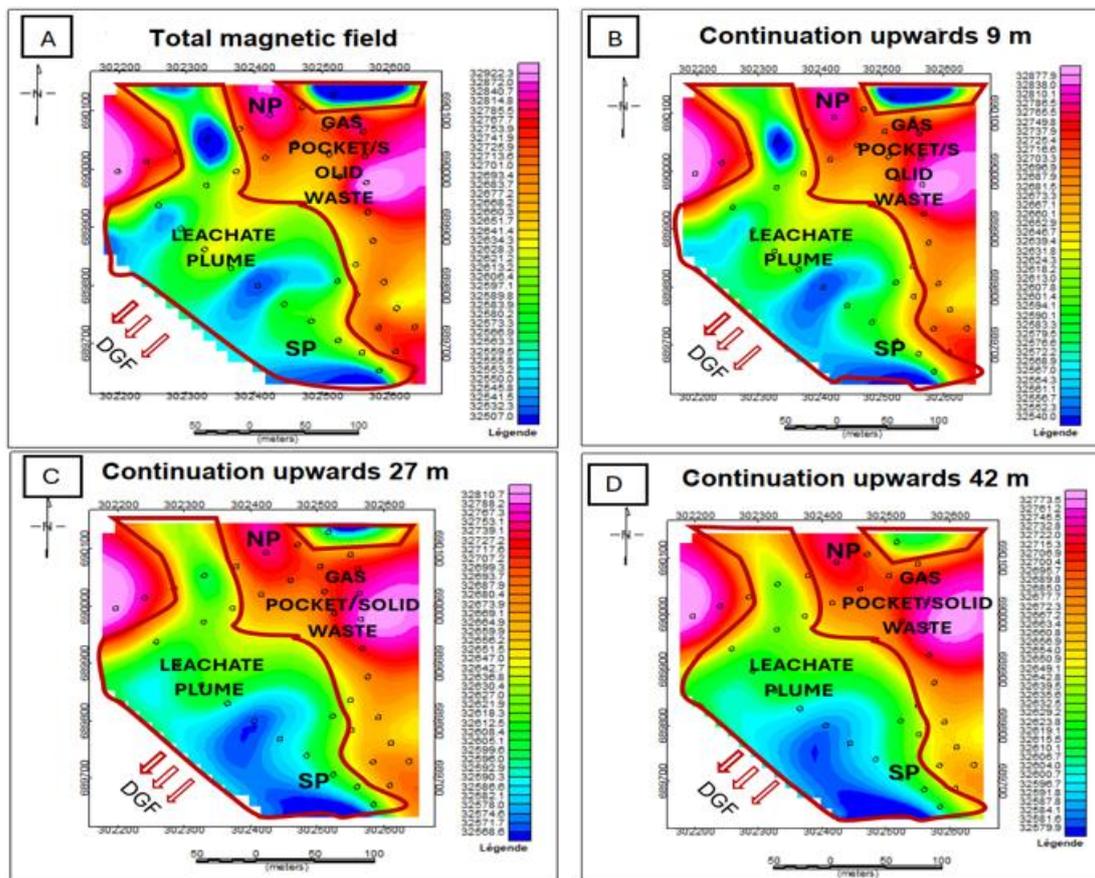
in which four electrodes are arranged at equal distances, allowing for accurate measurement using a measuring dipole between the injection electrodes, with a spacing of 10 m;  $AB = 3$  MN for this study. At the Agoè Nyivé landfill site, an ERT profile was deployed over 225 m using the Wenner-Alpha configuration. This device used four 100 m long cables with an inter-electrode spacing of 10 m, bringing the total to 23 electrodes, and a maximum spacing of 220 m between the current electrodes. A Syscal Kid resistivity meter with accessories and a GPS were used for data acquisition. The galvanic contact conditions between the electrodes and ground were excellent, thanks to the site rehabilitation work. Finally, the data were interpreted using the RES2DINV geoelectric modelling software [11], applying L1- and L2-normalised constraint methods. This integrated approach ensures an accurate, in-depth analysis of the site's geophysical characteristics. Before proceeding with data inversion, the information collected was carefully "cleaned". This cleaning process eliminates outliers that could skew the results, such as those where the measured potential difference is too small to be significant. Similarly, values with a Quality Coefficient that reflects the stability of the measurement during stacks and is too high are also

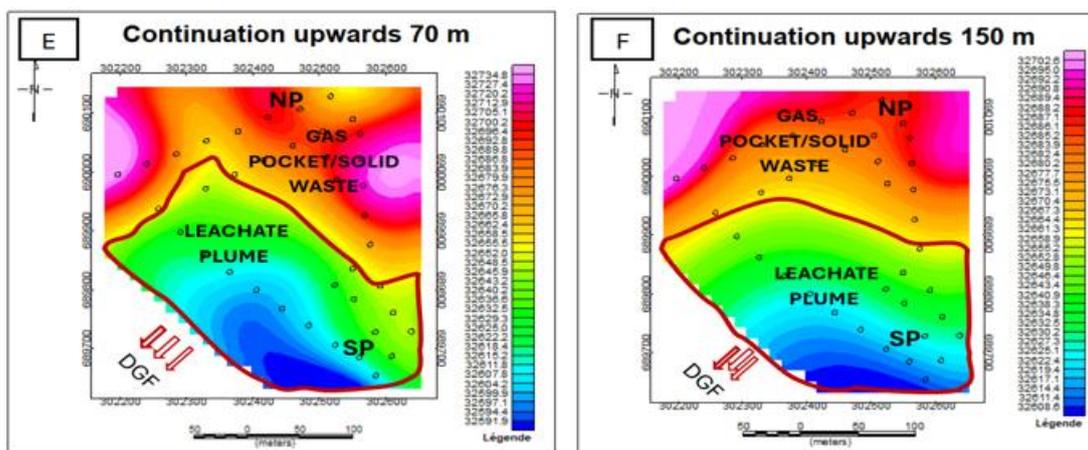
discarded. This rigorous data cleaning is a crucial step in ensuring the reliability of subsequent interpretations. This process ensures that the results are reliable and representative of the site under study.

## 4. Results and Interpretation

### 4.1 Magnetic mapping

These structures could be areas of accumulation or plumes of leachate trapped inside the landfill or drained into the water table located 5 m below the landfill, as can be seen on the 27 m elevation map. The variations measured, ranging from 32,267 nT (low) to 32,372 nT (high), reveal crucial information about the nature of the underlying materials and their distribution. The values of 32,267 nT indicate areas of leachate accumulation, shown in blue, tending towards green on the magnetic map. In contrast, values of 32,372 nT indicate probable areas of accumulation of ferrous or ferralitic materials, or of gas generated by the landfill, as shown in red and purple on the various magnetic maps (Figure 2).





**Figure 2:** Magnetic maps of the Agoè Nyivé site

(NP: Northern part; SP: Southern part) / (DGF: Direction of flow of the aquifer); A (Total magnetic field), B (9 m depth), C (27 m depth), D (42 m depth), E (70 m depth), F (150 m depth).



: The flow corridor

At the surface, the total magnetic field map reveals a marked dichotomy between the northern (NP) and southern (SP) parts of the study area. The northern part is characterised by high magnetic intensity, with values ranging from 32,360 nT (red area) to 32,372 nT (pink). This persistent anomaly, although diminishing with depth, suggests the presence of highly magnetic materials, probably of anthropogenic origin, linked to the former landfill site. Conversely, the southern part has lower magnetic values, around 32,300 nT (blue and green areas), indicating a lower concentration of magnetic materials. A notable feature is the identification of a flow corridor, evident in the surface layers. This flow corridor may be attributed to vertical leachate migration. This observation corroborates the hypothesis of leachate infiltration into the underlying layers.

Analysis of the upward continuations reveals a gradual decrease in the intensity of the magnetic anomalies with depth. At 9 metres, the northern zone retains a marked anomaly (32350-32372 nT), while the southern zone shows a decrease (32300 nT). At 27 metres, the intensity in the NP decreases slightly (32340-32360 nT), and the SP decreases more significantly (32290-32310 nT). The flow corridor becomes less pronounced. At 42 metres, the anomalies are significantly reduced, with the NP between 32,320 and 32,340 nT and the SP becoming more homogeneous (32,280-32,300 nT, yellow and green colours). The flow corridor is

significantly reduced. At 70 metres, the NP anomaly decreases further (32,300 and 32,320 nT), and the SP drops to 32,270-32,290 nT, with an almost invisible flow corridor. Finally, at 150 metres, the decrease in magnetic intensity is marked. The NP, although still present (32290-32310 nT), is greatly attenuated, while the SP shows total homogeneity (32267-32280 nT). The flow corridor is no longer detectable. This vertical distribution of magnetic anomalies allows essential conclusions to be drawn about leachate propagation and the potential for aquifer contamination. The pollution plumes are mainly confined to the soil's surface and intermediate layers. At 150 metres, the anomalies are virtually absent, indicating that the leachate plumes and probable gas accumulation pockets mentioned above are confined near the surface. At this stage, deep aquifers are unaffected by contaminant migration, which may be due to a natural geological barrier or the low permeability of the deep layers.

#### 4.2 Results of electrical resistivity tomography (ERT)

The choice of the electrical tomography profile was based on the magnetic map of the lateral distribution of the leachate (Figure 3) to cross the corridor or area of subsurface leaching. The dotted black line on the maps represents the ERT profile and its orientation on the dump. It is oriented west-southwest and east-northeast (WSW-ENE).

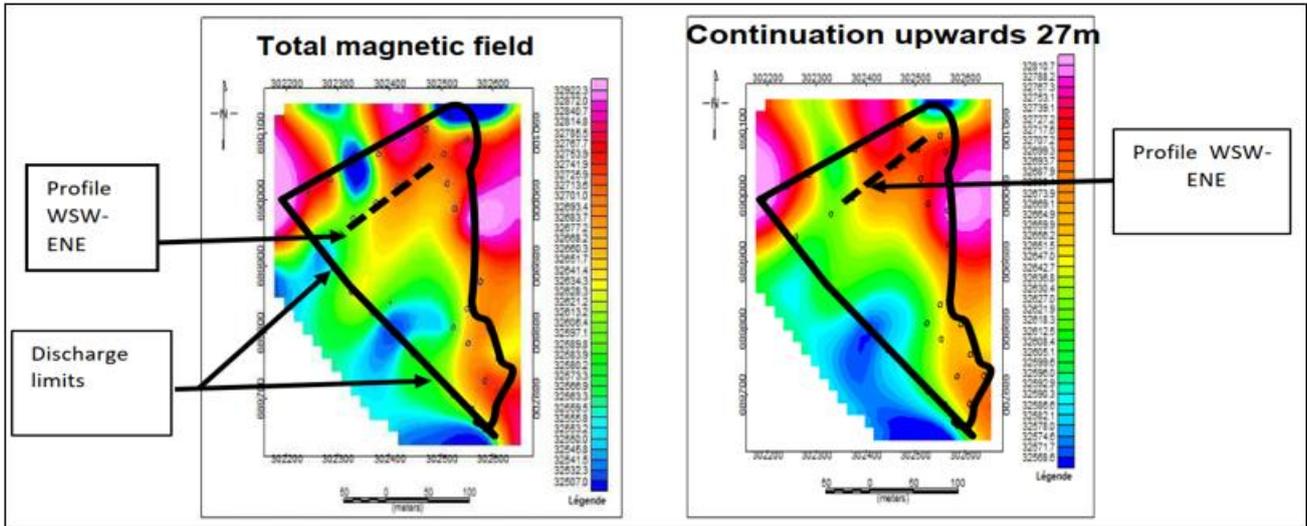


Figure 3: Magnetic maps of the Agoè Nyivé site showing the location of the ERT profiles

Data from electrical resistivity tomography (ERT) analysis at the former Agoe Nyivé landfill site in southern Togo provide essential information for understanding contaminant dynamics.

The low-resistivity areas identified on the pseudo-sections can be interpreted as accumulations of low-resistivity fluids [12], mainly leachate from the landfill.

Using Archie's law, the calculated resistivity of the unpolluted Continental Terminal aquifer is 340 Ohms.m.

Given that the average resistivity of the leachate is 2 Ohms.m [13], the low resistivity layers (below 340 Ohms.m) are assumed to be contaminated by the leachate and represent the deep leachate plume. Layers with actual resistivities greater than 340 Ohms·m are not expected to be contaminated by the leachate plume. The boundary of this plume marks the contact between the area contaminated by the leachate plume and the uncontaminated area. The electrical tomography section shows the 2D variation in the true resistivity of the layers contaminated by leachate with depth (Figure 4).

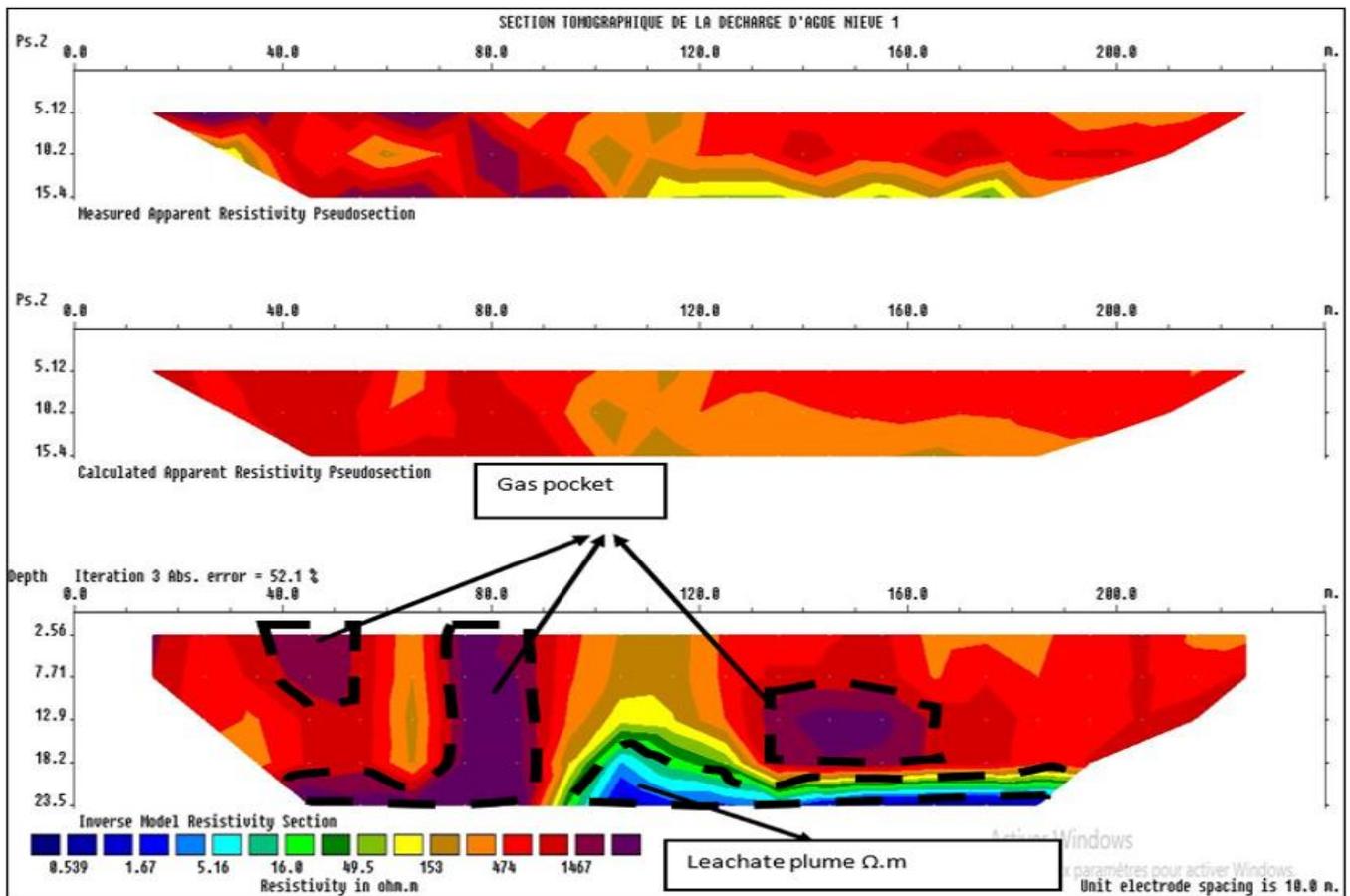


Figure 4: TRE section interpreted according to the WSW-ENE profile.

The low-resistivity zones ( $< 5.16 \Omega \cdot m$ ; from 0.539 to 5.16  $\Omega \cdot m$ ), shown in blue and green on the inverted section, are particularly significant. Located mainly between 15 and 23 metres deep, they strongly suggest the presence of a leachate plume. This interpretation is corroborated by the correlation between these values and the typical leachate resistivity (2 Ohms  $\cdot$  m). The high-resistivity zones ( $>100 \Omega \cdot m$ ), shown in red, are likely associated with more resistant materials, such as unsaturated fill, slightly altered rock formations, or gas pockets, which we noted on the magnetic maps. This observation is consistent with the landfill's reality.

In addition, the geometry of the leachate plume has a notable characteristic marked by its accumulation between 11 and 23.5 metres depth.

## 5. Conclusion

The integrated magnetic and electrical resistivity investigations delineate a shallow to intermediate depth leachate plume beneath the former Agoe Nyive landfill. Conductive zones identified between 15 and 23.5 meters depth correspond to probable leachate accumulation, while magnetic contrasts highlight areas of buried waste or gas generation. Although deep aquifers appear unaffected within the investigation depth, the shallow groundwater table remains in proximity to the contaminant plume. These findings underscore the need for continued hydrochemical monitoring to confirm groundwater quality and guide remediation planning.

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