

Geophysical contribution for the mapping the contaminant plume of leachate from rubbish dumpsite of Hevie, Benin

ABSTRACT

In the majority of the Countries in the process of development like the Benin, the presence of dumpsite of rubbish can cause pollution of the groundwater. Indeed, the leachate resulting from the scrubbing of rubbish by the rain can infiltrate and pollute the water table. The evaluation of the infiltration of the leachate was carried out by the geophysical methods of frequential electromagnetism in EM34 and Electrical Resistivity Tomography (ERT). The electromagnetic map circumscribed the lateral limits of the leachate diffusion and the electromagnetic surveys showed that it infiltrated with a depth of 20m. The two cross sections of electrical resistivity tomography of NS and SW-NE direction made it possible to map the plume of leachate. These results show that the contact water table - leachate is rather irregular, the depths of the feather of leachate varying from few meters to 22m for an average static level of 18m. This irregularity of contact between the leachate and the water table can thus explain the heterogeneity of its heavy metal pollution as the analysis of water samples of the wells shows it.

Keywords: Leachate, Frequential Electromagnetism, Electrical Resistivity Tomography (ERT), dumpsite of rubbish.

1. INTRODUCTION

In African towns, a few kilograms of municipal and domestic waste is produced per day, per family. This waste is collected and transported from the town to municipal landfills where it is deposited. In the last decade, the increasing public concern with groundwater management problems due to waste disposal has generated significant hydrogeological and geochemical research activity (V. Naudet & al 2004). This research activity concerns, for instance, the mapping of contaminant plume associated with the migration of leachate. The groundwater conductivity indicates its degree of mineralization (V. Naudet & al 2004) e.g. elevated concentrations of heavy metals due to the migration of leachate. Mapping the migration of leachate in the field by classical geochemical methods is often difficult because of the cost and time consuming. In addition, the borehole measurements are invasive and can perturb local equilibria. Establishment of steady state conditions in a borehole can then

take from a few hours to a few weeks (Christensen et al, 2000; Schulte-Ebbert and Hofmann, 2000).

Driven by the need for a cost-effective and a more continuous characterization of contaminated groundwater, growing interest has emerged very recently in the use of non-intrusive geophysical methods (Aristodemou and Thomas-Betts, 2001; Yaramanci, 2000; Buselli and Lu, 2001; Kemna et al., 2002 ; Nimmer and Osiensky, 2002). Usually the landfill site investigation is aimed at detecting and determining the extension of the polluted area and for that purpose, several researchers have used resistivity and/or electromagnetic geophysical methods (F.A. Monteiro Santos, António Mateus, Jorge Figueiras and Mário A. Gonçalves 2006). These studies are possible because both organic and inorganic chemicals can cause a large variation (usually a decrease) in the electrical resistivity of the earth material (Palacky, 1988; Aristodemou and Thomas-Betts, 2000). The geophysical methods in electrical prospection are adequate for the cartography of the mineralization of the groundwater (Yalo & al, 2012). The Electrical Resistivity Tomography (ERT) and Electromagnetic Methods (EM) are active methods used to image the Direct Current or the frequency-dependent electrical resistivity distribution inside the ground. (A. Revil, V. Naudet and J. D. Meunier, 2004). Electrical and electromagnetic methods have been successfully used in the detection of groundwater contamination and seepage in many case studies, e.g. Benson et al. (1997), Buselli et al. (1990, 1998), Campbell et al. (1998), Frangos (1997), Park (1998), and White (1994). Moreover, the uncertainty of geophysical interpretation can be notably reduced when several methods are jointly used (Albouy et al., 2001; Goldman et al., 1994).

In the present study, geophysical methods of Electrical Resistivity Tomography (ERT) and frequential electromagnetism (FEM) have been combined for mapping the contaminant plume associated with the migration of leachate from the dumpsite of rubbish of Hevie in south of Benin.

2. MATERIALS AND METHODS

2.1. Location and hydrogeology of study site

The study zone is located at the dumpsite of rubbish of Hevie on the Allada plate of coastal sedimentary basin of Benin (Fig. 1). The dumpsite of rubbish extends on a surface of

approximately 7ha. From January to October 2001, the site received 270m³ not sorted domestic wastes per day (Mama, 2010). Between 1995 and 2004, the dumpsite received more than 3000m³ of wastes.

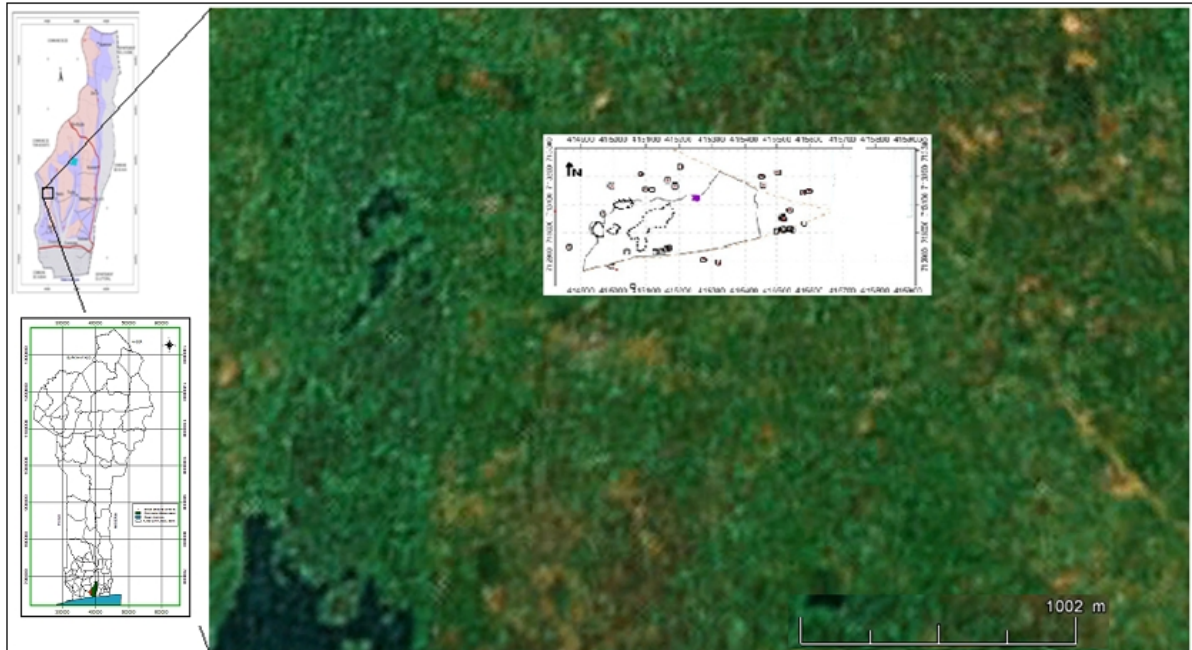


Fig. 1: Location map of dumpsite at Hevie in south Benin

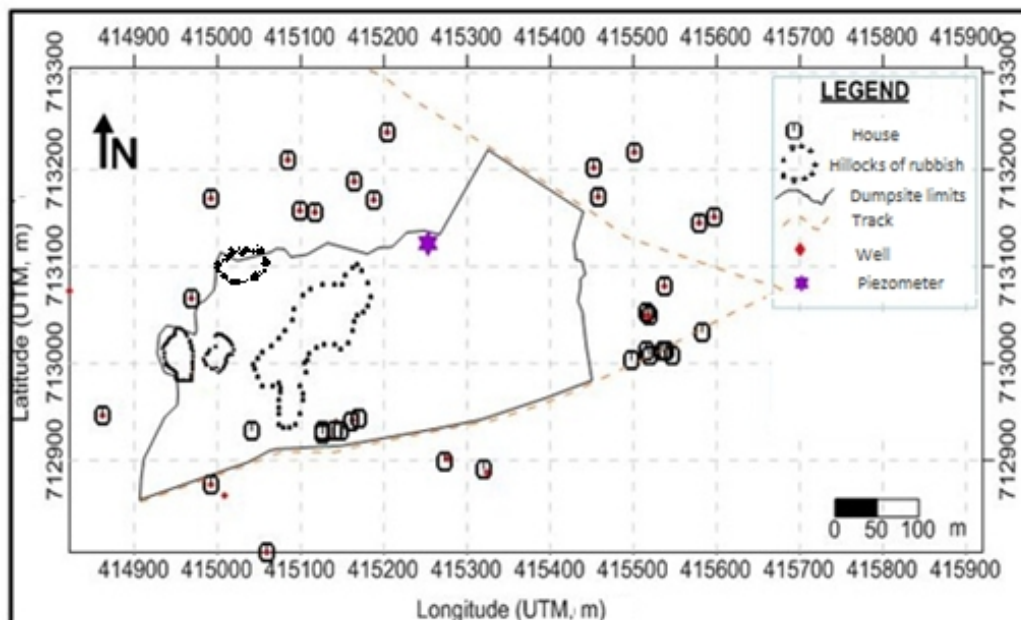


Fig. 2: Localization of the three hillocks on the rubbish dump of Hevie among the houses and exploited wells.

In the district of Hevie, the annual average temperature is 25°C with an annual cumulated pluviometry of 1100mm. The groundwater feeds directly by rainwater with fluctuations of the static level according to the seasons. The evapotranspiration is rather high and the relative humidity of about 90 %. These climatic conditions cause the deterioration, degradation and corrosion within waste which produces leachate. The zone of study located at approximately 15 km of the shore, exploits an aquiferous horizon located under a lateritic formation named "terre de barre". The shallow aquifer collected on the Allada plate is dated of Miocene - Pliocene (Terminal Continental). This aquifer consists of fine sands to coarse, gravels by places and clayey sand. The total porosity calculated starting from the granulometric study of the sandy levels of the plate in the area of Agankomey, lies between 39 and 42%, that is to say an average of 40% (Boukari, 1998). The total porosity of the surface levels of the lateritic formation in this area lies between 34 and 36% (Boukari, 1998). Fig.3 presents a simplified hydrogeologic section of the Western part of the coastal sedimentary basin of the Benin where is located the site of Hevie. The dumpsite of Hevie is directly on the lateritic formation which is above the aquifer of Terminal Continental.

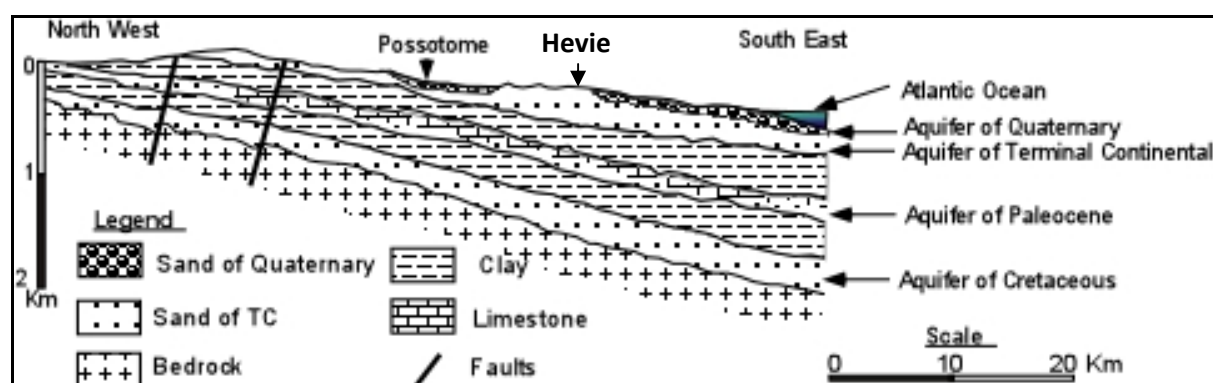


Fig. 3: Hydrogeological section of coastal sedimentary basin of Benin

The geometry of this aquifer is irregular. In the zone of study, the power of the aquifer varies between 25 and 33m. The static level varies between 15 and 20m.

2.2. EM and ERT principles of measurement

96 To implement the study method, we used the Geonics EM 34 of firm GEONICS LIMITED
 97 and SYSCAL KID Switch (IRIS INSTRUMENTS) with 24 electrodes equipments. There is a huge
 98 scientific literature on near-surface electromagnetic geophysics [Mark, E. Everett 2012]. The
 99 equipment used is an EM34 of GEONICS Ltd, Canada (Photo 1) with a choice of spacing of
 100 20m between the coils for the profiling and successively 10, 20 and 40m with respective



Photo 1: EM 34 Instrument

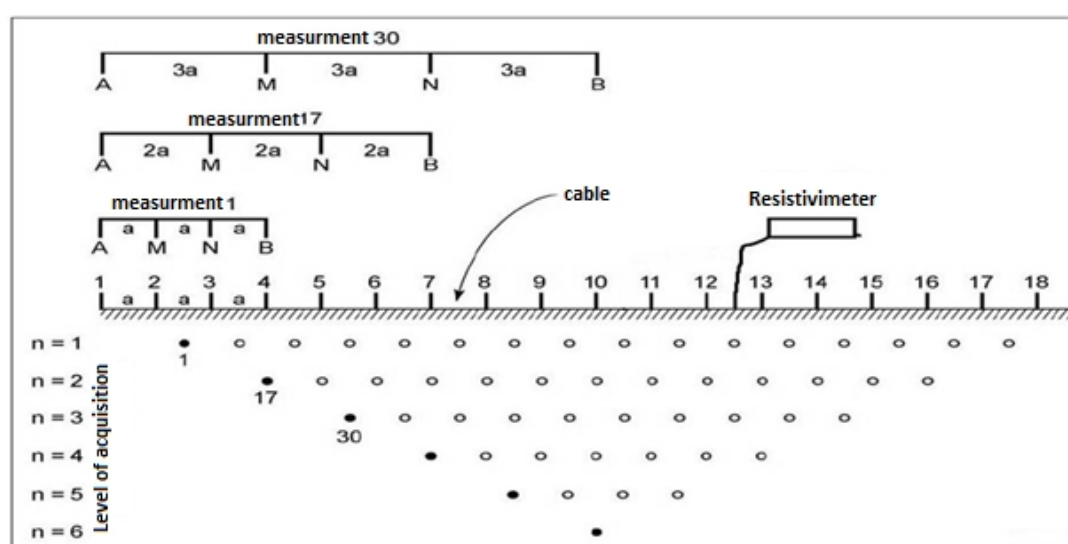
101 frequencies of 6400, 1600 and 400 Hz. Measurements were carried out in mode "vertical
 102 dipole" (horizontal coplanar coils). The mode "vertical dipole" was selected for the faster
 103 insurance of its coplanarity and its greater depth of investigation (Yalo et al., 2012). The
 104 EM34 provides information to a few tens of meters of depth for the profiling and 20m for
 105 the soundings.

106 For the resistivimeter, Marescot (2008) presents a description of the procedure of
 107 commutation of the multi electrode devices. It is about the procedure for obtaining an
 108 electric panel of tomography. The first measurement of the file of acquisition for Wenner
 109 alpha will be done using the electrodes 1, 2, 3 and 4 (Fig. 4). Electrodes 1 and 4 will be used
 110 for the injection of current (A and B), the 2 and 3 with the measurement of the potential (M
 111 and N). All the device then automatically will be connected to the following position on the
 112 line of electrode, at a distance "a" of the first measurement. Electrodes 2 and 5 will then be
 113 used as injection from the current and the 3 and 4 for the measurement of the potential.
 114 The process is repeated to the electrode 24. One thus has, for the first level of acquisition
 115 21 possibilities (24-3).

116

117 As the characteristic of the Wenner device is to keep a constant distance between all the
 118 electrodes, acquisition will thus take, for the following level, a distance equal to $2 \times "a"$
 119 making it possible to make circulate the current a little more deeply. The first measurement
 120 of the 2nd level will thus imply electrodes 1 and 7 for the injection of the current and 3 and 5
 121 for the measurement of the potential. The process is repeated again to the electrode 24.
 122 The second level will include then 18 possibilities ($24 (2 \times 3)$). One thus takes measurements
 123 of each level of acquisition with $3 \times "a"$, $4 \times "a"$, etc... It is obvious that more the distance
 124 between electrodes increases, more the number of possibilities decreases.

125



126

127 **Fig. 4: Arrangement of the electrodes for an 2D acquisition and a sequence of**
 128 **measurement for a Wenner alpha device.**

129 2.3. Study methods

130 16 profiles corresponding to 348 measurements were carried out in horizontal configuration
 131 according to a North-South direction. This azimuth was selected perpendicularly to recut
 132 the hillocks of waste, which was directed according to a East-West direction, in particular the
 133 large hillock located at the center of the site (fig. 2). The steps of measurements are 10 m
 134 and the distance from a profile to another is 25m (fig. 5).

135 Four (04) surveys, were carried out site on the whole of the site; one in the center of the
 136 largest hillock, one between two hillocks, one at the end of the side extension of the

leachate and the last one in not polluted zone to be used as outlier (fig. 5). The data of the surveys were inversed in the FreqEM software.

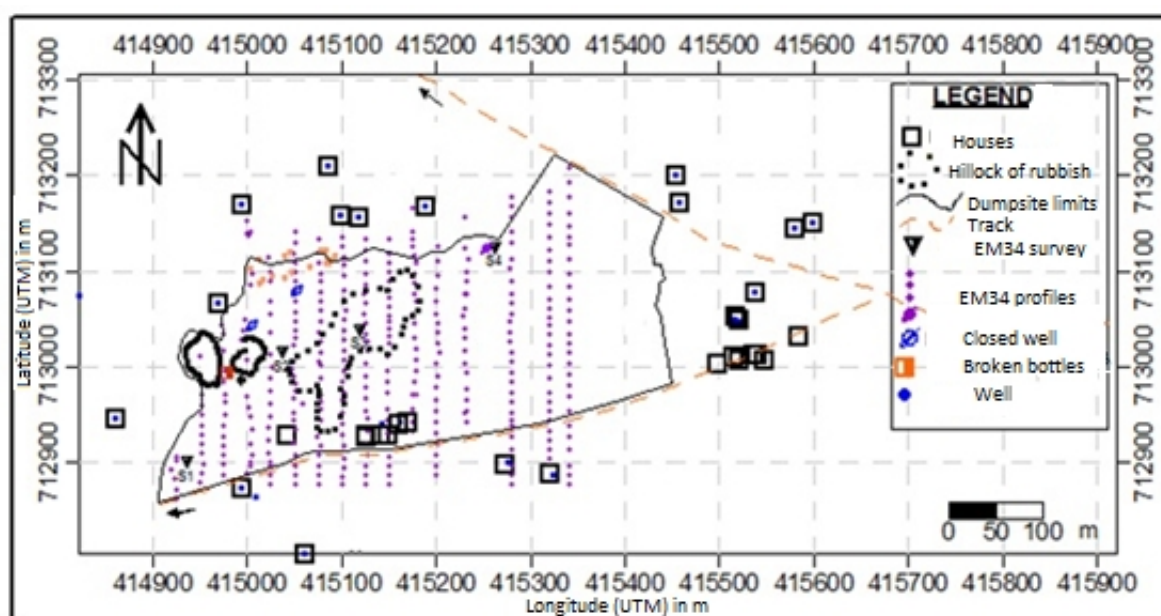


Fig. 5: Chart of the EM34 profiles and electromagnetic surveys distribution on the dumpsite of Hevie

Electrical resistivity tomography (ERT) is the measurement of the electrical field associated with the injection of current at the ground surface (Binley et al., 2002). The method of electrical resistivity tomography was employed in order to obtain a 2D model of the subsoil where the distribution of the resistivity varies vertically and horizontally along the profile. It is a quantitative method making it possible to carry out an imagery 2D or 3D variations of electrical resistivity, and to obtain information making it possible to build a conceptual model of subsoil (Descloitres et al., 2009). In the present study, the ERT aims to chart the plume of pollution associated with the leachate in order to evaluate his contact with the water table. 5m spacing between electrodes has been chosen.

In contaminant plumes, the concentrations of organic contaminants and ions increase the conductivity of the groundwater (Naudet et al., 2004). Therefore, the bulk resistivity of the aquifer polluted by the leachate is expected to be reduced. The value of Terminal Continental aquifer resistivity (340 Ohm.m) was obtained by applying the Archie law and the coefficients of Keller:

156 $\rho_r = \rho_w a \phi^{-n}$ (1)

157 with $\phi = 40\%$; $a=0,8$; $n=2$

158 and $\rho_w = 110$ Ohm.m. which was been measured in the piezometer.

159 On the electrical resistivity tomography sections, the electrical resistivities lower than
160 340 ohm.m correspond to those of grounds polluted by the leachate.

161 3. RESULTS AND DISCUSSIONS

162 3.1. Results

163 3.1.1. Lateral delimitation of the leachate zone

164 The electromagnetic map charted the resistivity (opposite of conductivity) of the grounds
165 with approximately 10m of depth.

166 The rubbish zone, characterized by the presence of 4 hillocks, presents a distribution of
167 resistivity varying between 1 and 250 ohm.m. The lowest resistivities (1 to 100 ohm.m) are
168 observed on the level of the central hillock which extends on a greater surface. The values
169 from 150 to 250 ohm.m characterize rubbish of the two hillocks located at the west and the
170 last one located at north.

171 Basically, the central hillock consists of two clusters. A very conducting central cluster (1 to
172 50 ohm.m) and a less conducting second (50 to 100 ohm.m) surrounding the first one.
173 Contours of these clusters are very well delimited on the chart of the fig. 6.

174 A third zone having an intermediate resistivity (250-340 ohm.m) is highlighted on the chart
175 between the hillocks at the west and the hillocks of rubbish. It is the zone of extension in
176 subsurface of the leachate all around the hillocks of rubbish. The entire zone with a
177 resistivity under 340 ohm.m delimitates the lateral extension of leachate at a 10m depth.

178 The electromagnetic map highlighted a resistant zone (400 to 900 ohm.m) which is being the
179 zone where the leachate is missed. This zone forms an external belt around the leachate
180 zone.

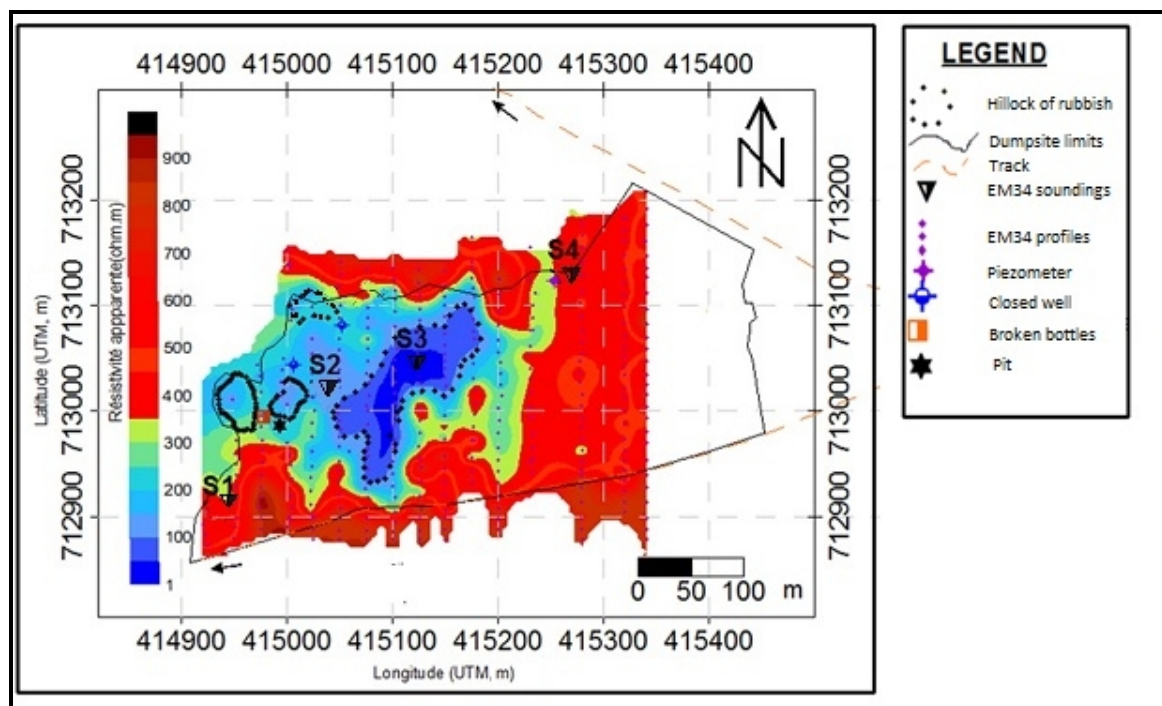


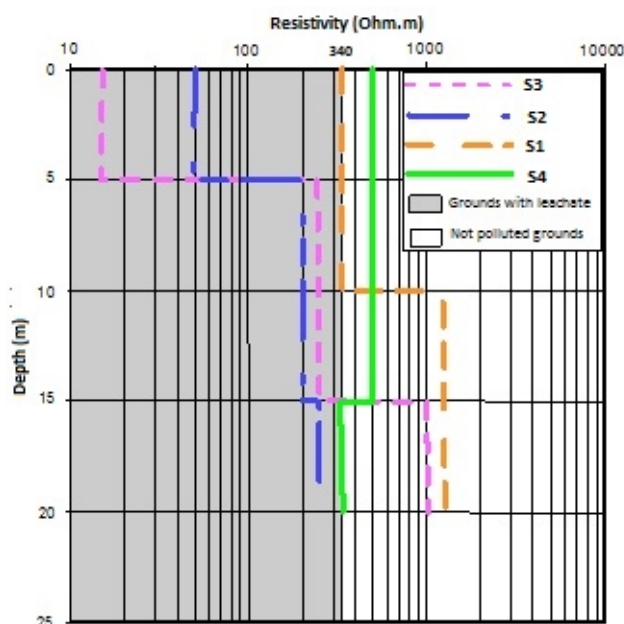
Fig. 6: Map of lateral extension of the leachate at 10m of depth using EM34

3.1.2. Estimate of the leachate depth infiltration

With an aim of estimating the infiltration depth of the leachate, a series of four surveys was realized in various points of the study zone. The positioning of the surveys has been done on the basis of conductivity chart showing the lateral expansion of the leachate in subsurface. Thus, a first survey (S3) was established at the center of the largest hillock of rubbish. A second survey (S2) was carried out between two hillocks of rubbish, inside the leachate zone. A third survey (S1) was carried out at the end of the leachate zone, to approximately 60m from the nearest hillock of rubbish. It is the zone between the polluted subsurface and that not contaminated. Lastly, a fourth survey (S4) was located the zone not contaminated in subsurface by the leachate. This survey is at 90m from the nearest hillock (Fig. 6).

The logs of survey in frequential electromagnetism show 1D variation of the resistivity (opposite of conductivity) of the grounds with the depth. In general, the qualitative inversion of the logs of surveys presents two grounds outside and at the limit of the leachate zone and three grounds inside the leachate zone.

200



201

202 **Fig. 7: Logs of surveys EM showing the grounds of various resistivities**

203

204 The log of survey S4 presents a first ground of resistivity 500 Ohm.m corresponding to the
 205 unsaturated zone with 15m thickness then a second ground of 340 Ohm.m corresponding to
 206 the resistivity of the saturated aquifer not polluted by the leachate. It is the pilot log of
 207 survey with resistant grounds because not polluted by the leachate. Thus, the figure 7
 208 shows three grounds in polluted zone (S2 and S3) and two grounds in not polluted zone (S1
 209 and S4).

210 The log of survey S1 presents a first ground of resistivity 320 Ohm.m of 10m thickness more
 211 conducting than the second ground of 1300 Ohm.m. The high resistivity of this second
 212 ground shows that it is not polluted by the leachate. On the other hand the first ground
 213 more conducting than the first ground of the pilot survey is very slightly polluted by the
 214 leachate which penetrates until 10m of depth. At the end of the leachate zone, the
 215 infiltration of this leachate is only about 10m depth with a very weak concentration.

216 The log of survey S2 presents a first ground of resistivity 50 Ohm.m on 5m thickness, second
 217 ground of 200 Ohm.m. of 10m depth, then a third ground of 260 ohm.m up to 20 m of
 218 depth. These three grounds of resistivities lower than 340 ohm.m are more conductive than
 219 the first pilot ground. These resistivities show that the leachate infiltrated until 20m depth

at least and that its concentration decreases with the depth. Between the hillocks of waste inside the leachate zone, his infiltration exceeds the 20m depth.

The log of survey S3 presents a first ground of resistivity 15 Ohm.m on 5m thickness, second ground of 150 Ohm.m, 15m of depth, then a third ground of 1000 ohm.m. The first two grounds of resistivities lower than 340 ohm.m are conductive than the first pilot ground. These very low resistivities show a high concentration of the lixiviat whose infiltration limits to 15m depth. Under the hillocks of rubbish, the infiltration of the leachate is limited by the presence of rubbish on the surface which plays a role of retention of rainwater vector of its propagation.

3.1.3. Definition of water table – leachate contact

The choice of the electric tomography profiles was also based on the electromagnetic map of the lateral distribution of the leachate (fig. 8) in order to cross not only the hillock of rubbish but also the leachate zone in subsurface.

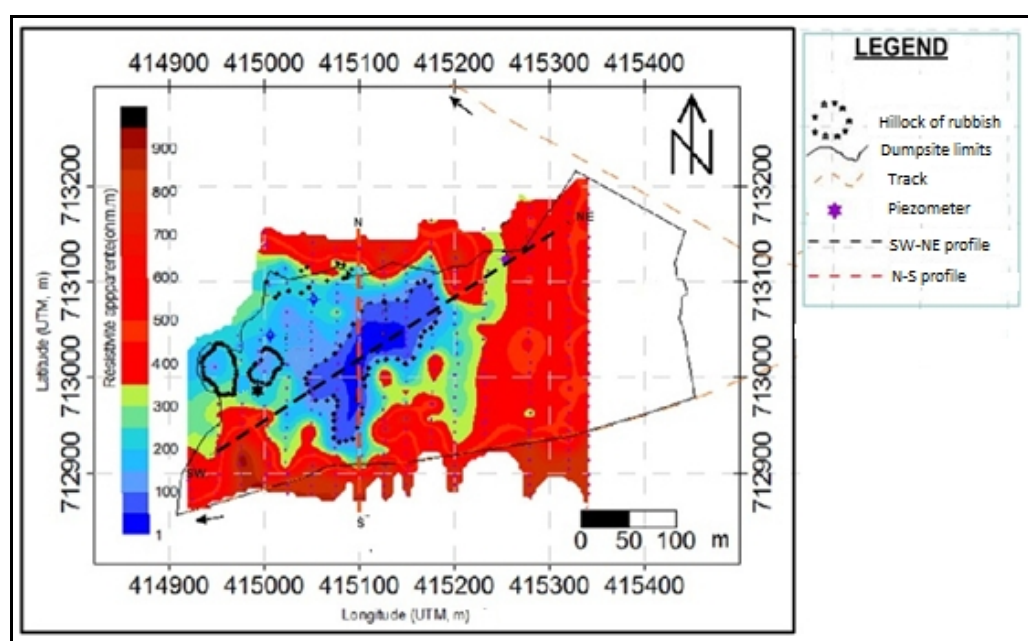


Fig. 8: Localization of the ERT profiles on the electromagnetic map

The pseudo-sections of electric tomography show the 2D variation of the true resistivity of the grounds according to the depth. The lowest values of resistivity are concentrated on the level of the hillocks of rubbish and also below these but until an

average depth of 5m. Rubbish not having been buried, these low values of resistivity is due to the infiltration of leachate of rubbish.

The layers with values of resistivity lower than 400 Ohm.m, are polluted by the leachate and represent the in-depth plume of leachate. The layers with true resistivities higher than 400 Ohm.m are not polluted by the plume of leachate. The limit of this plume marks the contact between the zone polluted by the leachate and the not polluted zone.

The two cross profiles in general present the same variations of resistivity at the difference that the conducting zone is broader on the pseudo-section of South West-North East (SW-NE) profile than on that of the North South (NS) profile. That is also illustrated by the electromagnetic chart where it is noted that SW-NE profile crosses a conducting zone over all its length while the second profile crosses this same zone at a more reduced distance (Fig. 8). The bottom marking the lower limit of the plume of leachate is not linear. Under the hillocks of rubbish it oscillates between 11 and 14m, around the hillocks of rubbish it deepens by places until 18m on the NS section and 22m on SW-NE section. In general the plume of leachate goes down more deeply around hillocks of rubbish than under the hillocks of rubbish. The deeper interface of the plume of leachate presents undulations. Considering that the average static level of the Terminal Continental aquifer is around 18m, one can conclude that the water table is not in any point of its surface in contact with the plume of leachate. Only the zones of the plume with a depth higher than 18m are in contact with the water table (Fig. 9a and 9b).

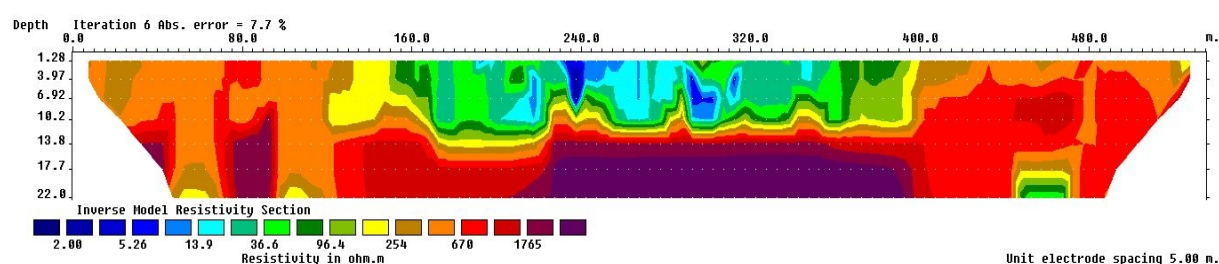


Fig. 9(a): Electric tomography pseudo-section according to the SW-NE profile

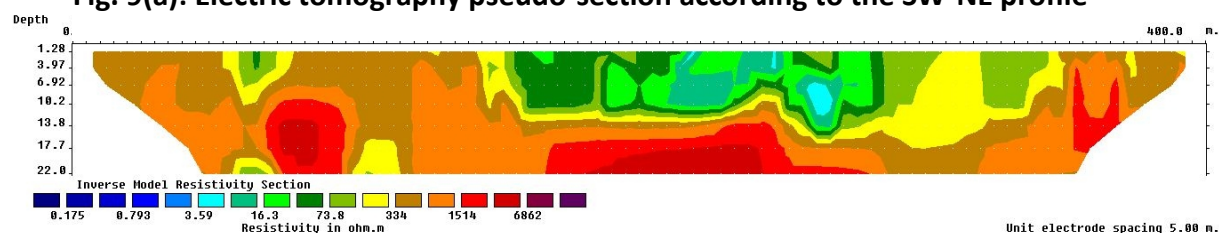


Fig. 9(b): Electric tomography pseudo-section according to the N-S profile

3.2. Discussion

The 1D logs of survey in frequential electromagnetism showed that the leachate has polluted the aquifer until 20m under and around the hillocks of rubbish. The 2D pseudo-sections in electric resistivity tomography respectively showed that the infiltration of the leachate varies from one point to another. In rainy season, period of the realization of the study, the level of the ground water of the Terminal Continental is on its higher oscillating level between 15 and 18m from the surface of the ground. The depths of infiltration of the plume of leachate being from a few meters to 22m in all the zone of study, the water table is found by places in contact with the leachate (Fig. 10). Thus, the degree of pollution of the water table is not the same one on its entire surface. Wells relatively close to each other will not inevitably have the same degree of pollution. This abrupt variation of the degree of pollution of the water table is highlighted by the physicochemical analysis of the water samples of the wells present in the zone of study. Fig.11 presents a chart of recording of water electric conductivities in the wells of the study zone, obtained following the measurements taken in wells present on the dumpsite of rubbish.

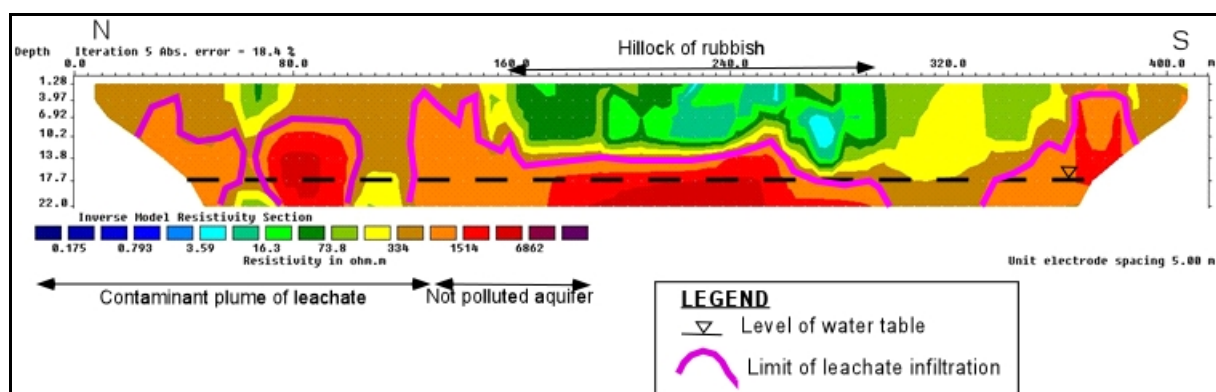


Fig. 10: ERT section showing the water table – leachate contact

Moreover, work of Mama et al., (2010) revealed that the impact of the leachate of rubbish at dumpsite of Hevie on the environment is primarily related to a pollution of the water table by the organic matter and heavy metals like lead and cadmium. The lead concentration in certain wells of Hevie reached 0,18 mg/l (Dovonou, 2012). Thus, the chemical nature of the plume of leachate on the dumpsite of rubbish of Hevie can explain

the variation of the degree of pollution in the water table according to its contact with the leachate.

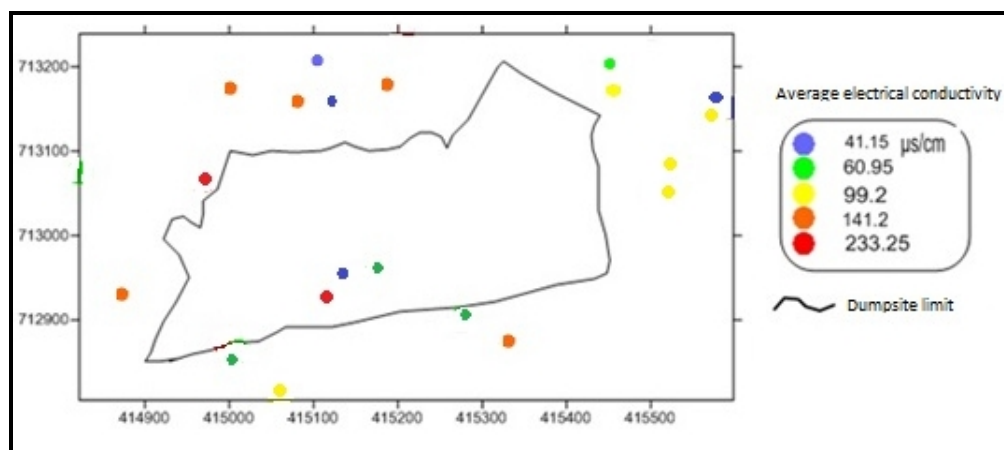


Fig. 11: Map of Electrical conductivity of well water samples on the Hevie dumpsite

4. CONCLUSION

The evaluation of the Terminal Continental groundwater contamination was carried out by frequential electromagnetic profiling, the log of electromagnetic surveys and the panels of electric resistivity tomography. The electromagnetic map showed that the leachate is laterally extended in subsurface around the hillocks of rubbish. The electromagnetic logs of surveys made it possible to estimate in the 1D depth infiltration of the leachate. This infiltration is more significant around the hillocks of rubbish than under the hillocks of rubbish. The 2D electric resistivity tomography sections showed the in-depth plume of leachate what made it possible to deduce that the contact between the plume of leachate and the top of the water table is rather discontinuous. Because of the strong lead concentration of the leachate, this discontinuity implies heterogeneity of the degree of pollution on the surface of the water table like showed it the analysis of well water samples. The use of the geophysical methods in frequential electromagnetism and electric tomography contributed for the mapping the contaminant plume of leachate from rubbish dumpsite of Hevie.

ACKNOWLEDGMENTS

The authors thank, on one hand, the African Union, financial partners of the GRIBA project and, on the other hand, the Institute of Research and Development (IRD) and his Agency (AIRD) of France for the provision of the geophysical material for prospection.

Acknowledgments through the JEA1 project. We also thank Jean-Michel Vouillamoz and Marc Descloitres for their support during this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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