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Study of the Akouedo Landfill (Abidjan) Using the Electrical Resistivity Method: Implications for the Risk of Contamination of the Continental Terminal Water Table

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Abstract

An electrical resistivity survey was carried out on the household and industrial waste disposal site (landfill) of Akouédo (Central Abidjan) with a view to searching for a possible layer of clay in the stratification which could constitute a protective screen of the aquifer of the Continental Terminal of Abidjan against the migration of leachate. Electrical surveys (SE) carried out according to the Schlumberger configuration showed that the stratigraphy of the area is composed of three to four geoelectric layers depending on the SE positions. The correlation with the lithology of two piezometric boreholes carried out indicates that the lithology of the study area is dominated by clayey sand, sand, sandy clay and clay. The average thickness of accumulated waste varies between 30 and 40 m. The virtual absence of a continuous layer of clay under the waste exposes the Continental Terminal aquifer to contamination by leachate from waste accumulated over several decades in the Akouedo area.

Keywords

Landfill, Continental Terminal Aquifer, Electrical Sounding, Akouédo, Abidjan

1. Introduction

In the autonomous district of Abidjan, groundwater from the Continental Terminal (CT) constitutes one of the main sources of drinking water supply for the populations (Soro et al., 2006; Ahoussi et al., 2011). Like large African cities, these groundwaters are threatened by pollution problems linked to anthropogenic activities such as the production of household and industrial waste. In sub-Saharan Africa, the method of disposal par excellence for this household and similar waste is the landfill method because of its simplicity, but also its lower cost than other methods such as incineration (Meres, 2009; Adjiri et al., 2018). Opened in 1965 for the management of domestic waste in the city of Abidjan (Southern Côte d'Ivoire), the Akouédo landfill has ceased activity since the commissioning of the Recovery and Landfill Center Technique (CVET) from Kossihouen in 2018 (ANAGED, 2020). Although currently unusable, the Akouédo landfill contains a large quantity of waste whose chemical and biological decomposition of organic matter generates, in addition to leachate, biogas composed mainly of carbon dioxide (~30%) and methane (~55%) (Adjiri et al., 2014; Obé & Brou, 2019; Lagobo et al., 2022) which would constitute a risk for groundwater.

The objective of this work is to know the level of vulnerability of the aquifer of the Continental Terminal of Abidjan in order to identify, using electrical surveys, the stratification of the different formations of the subsoil and the depth of burial of the waste from the Akouédo landfill.

2. Presentation of the Study Area

2.1. Geographical Location

The study area concerns the Akouédo landfill built over an area approximately of 153 hectares. It is located south of the autonomous district of Abidjan (Southern Côte d'Ivoire) and located between latitudes 5˚12' and 5˚45' North and longitudes 3˚42' and 4˚24' West (Figure 1). The Abidjan district includes ten (10)

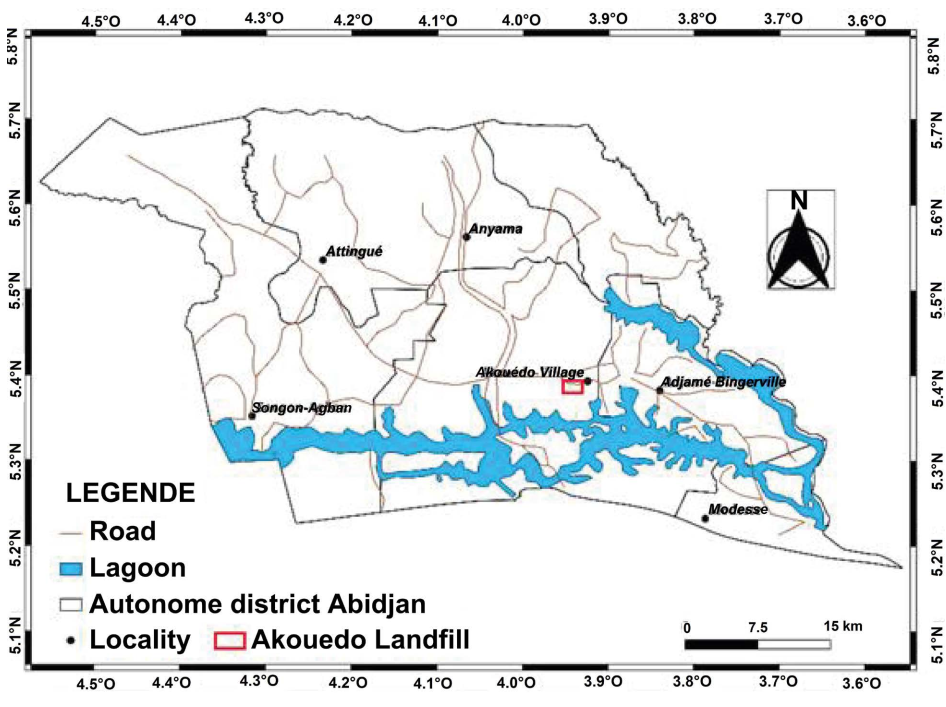


Figure 1. Geographical location of the study area.

municipalities to which are added three (3) sub-prefectures: Bingerville, Songon and Anyama. It extends over a total area of 57,735 ha including 8981 ha of lagoon, or 16% of the total area, and 48,754 ha of dry land, or 84% of the total area. According to INS (2021), this district has a large population estimated at 6,321,017 inhabitants.

2.2. Geological and Hydrogeological Context

The geological context of the city of Abidjan is that of the sedimentary basin of Côte d'Ivoire, 350 km long from East to West and very narrow in width, between 10 and 40 km from North to South. It is affected by a major accident in an E-W direction presenting a route which corresponds substantially to that of the "Ebrié" lagoon. This fault, called the "lagoons fault", divides the onshore basin into two parts; one slightly thick (around 100 meters) in the North, and the other, very thick (3000 m) in the South. The sedimentary formations are of great variety (Aghui & Biémi, 1984). We distinguish:

- Quaternary formations which outcrop to the south of the lagoon fault and in the fluvio-lagoon depressions. They are essentially made up of sand, gravelly sand, mud or clay, muddy sand and sandy or silty mud;
- Continental Tertiary formations, which are made up of coarse sands, variegated clays, ferruginous sandstones and iron ores. All these formations are of Mio-Pliocene age and result from the disintegration of the base;
- Formations of the Secondary, Upper Jurassic to Upper Cretaceous and marine Tertiary, are mainly made up of sands, conglomerates, versicolor clays, leafy clays with intercalations of marls and sandstones, sandstones, fluvial sands and sandy limestones sometimes dolomitic. The Paleocene and Eocene are, on the other hand, formed of glauconious clays, sands and small limestone banks.

As for the geology of the Akouédo landfill site, the formations are of Continental Terminal age (**Figure 2**). They are essentially made up of discontinuous lateritic armor locally covering sandy clays and clayey sands (0 to 70 m); coarse fluvial sands (0 to 90 m), black clays and clayey sands (0 to 10 m). In addition, they are also made up of gravelly sands with variegated clays (0 to 20 m) (Adiaffi, 2008).

From a hydrogeological point of view, the autonomous district of Abidjan contains continuous type aquifers located in the geological formations of the coastal sedimentary basin (Aghui & Biémi, 1984; Oga, 1998). These aquifers are composed of aquifers of Quaternary, Tertiary (Mio-Pliocene or Continental Terminal) and Upper Cretaceous (Maestrichtian) age. The depths of the water tables vary from 10 m to 60 m in the South, and 200 m in the North (Blé et al., 2020).

3. Materials and Methods

3.1. Materials

The study of the Akouédo landfill was possible thanks to equipment consisting of:

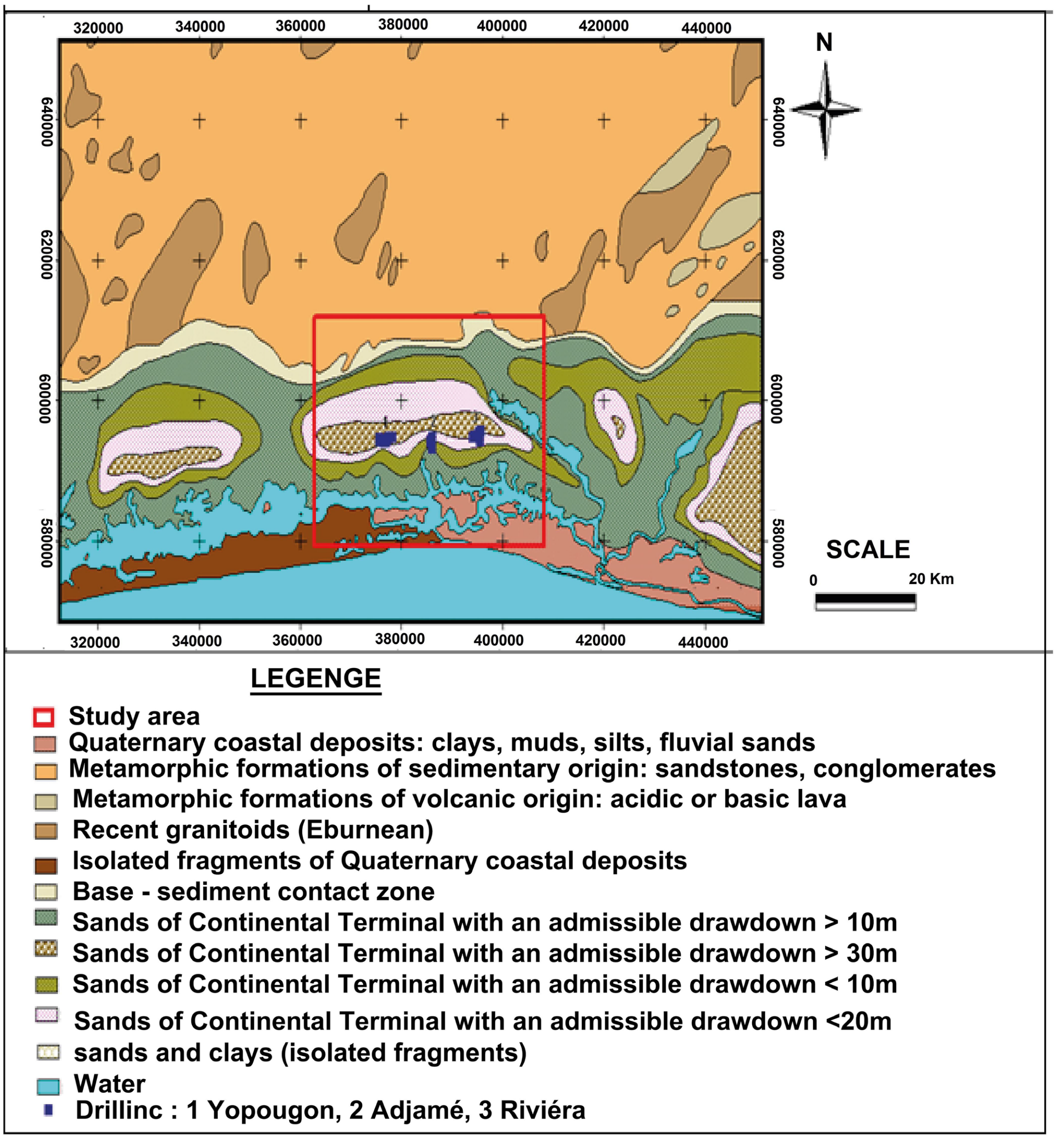


Figure 2. Geology of the study area.

- one (01) "SYSCAL JUNIOR" resistivity meter for acquiring electrical data;
- one (01) 12 Volt battery used as power supply;
- electrodes for injecting electric current into the ground and measuring the potential difference;
- four (04) reels of electrical cable for the connections between the resistivity meter and the different electrodes;
- four (04) hammers for installing the electrodes in the ground;
- one (01) compass for identifying the direction of the measurement lines;
- one (01) GPS for recording the coordinates of the electrical sounding points (SE).

Data processing was possible using the following software:

- Ix1D for the interpretation of electrical sounding curves (SE);
- Ipi2win for carrying out geo-electrical sections (2D).

3.2. Methods

3.2.1. Principle of Acquisition

With a view to studying the stratigraphy of Akouedo landfill site, the geophysical method used is exclusively focused on electrical sounding. Its principle consists of injecting a direct current of intensity (I) using a pair of electrodes A and B placed at the outer limits of a device then measuring the potential difference between another pair of electrodes M and N placed on either side of the center of the device (O).

The measuring device used is that of Schlumberger with a half-length (AB/2) between the current electrodes gradually evolving from 1 m to 250 m.

For this work, twelve (12) electrical soundings (SE) are carried out according to the positioning plan (**Figure 3**).

3.2.2. Interpretation

The interpretation of the sounding curves is carried out according to Hummel's graphical method consisting of reducing all electrical sounding curves to two layers by the principle of equivalence (Hummel, 1929 in (Youcef, 2006)). Using the IX1D and IPi2win software, modeling and inversion are carried out by matching the survey curve obtained to a theoretical curve (**Figure 4**). Furthermore, by playing on the parameters of the model which are the resistivity and the thickness of the different layers to be interpreted, we get as close as possible to the reality on the ground (Kouakou et al., 2012). Data validation is carried out after existing activity reports (**Figure 5**) and scientific work.

3.2.3. 2D Modeling

The geoelectrical sections to evaluate the lateral continuity of the strata are carried

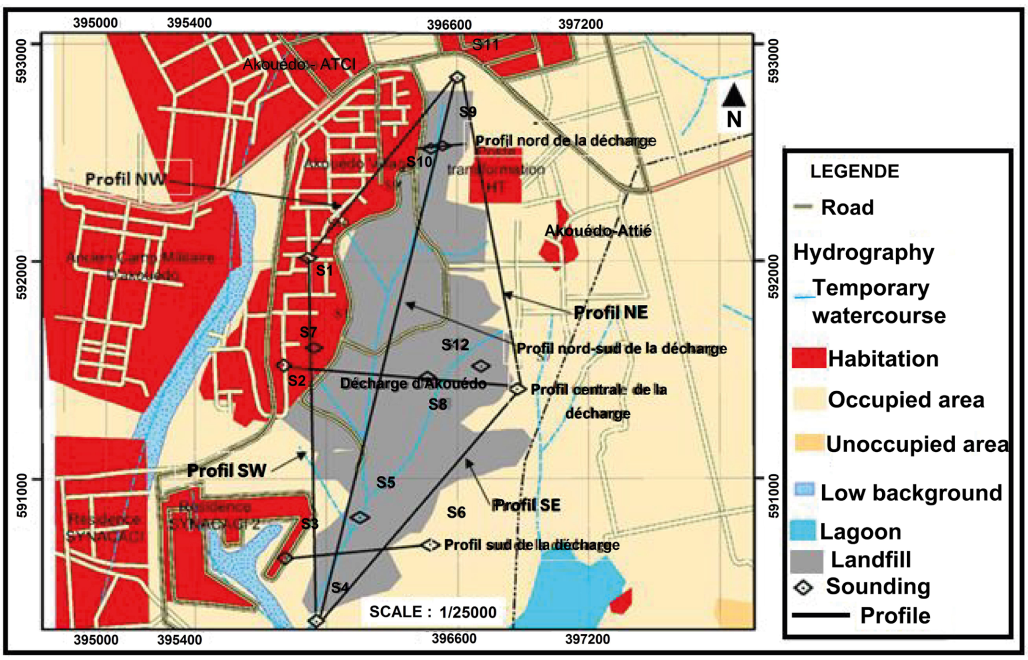


Figure 3. Positioning plan for electrical sounding waypoints.

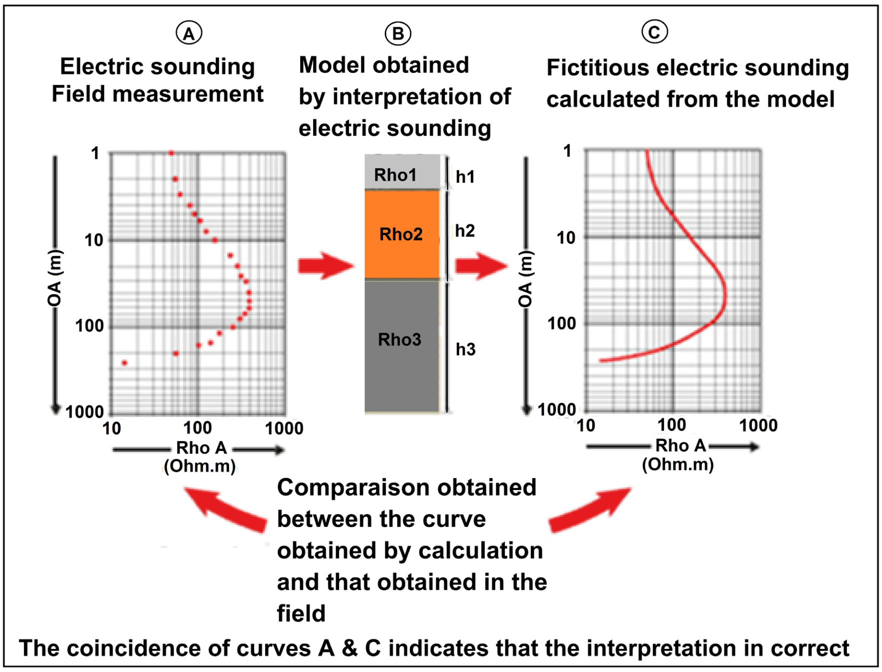


Figure 4. Model for modeling and inversion of electrical sounding curves (Kouakou et al., 2012).

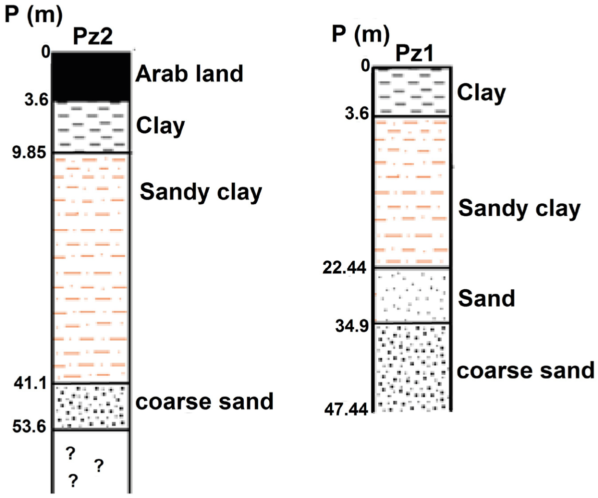


Figure 5. Stratigraphic log (Anonymous, 2014).

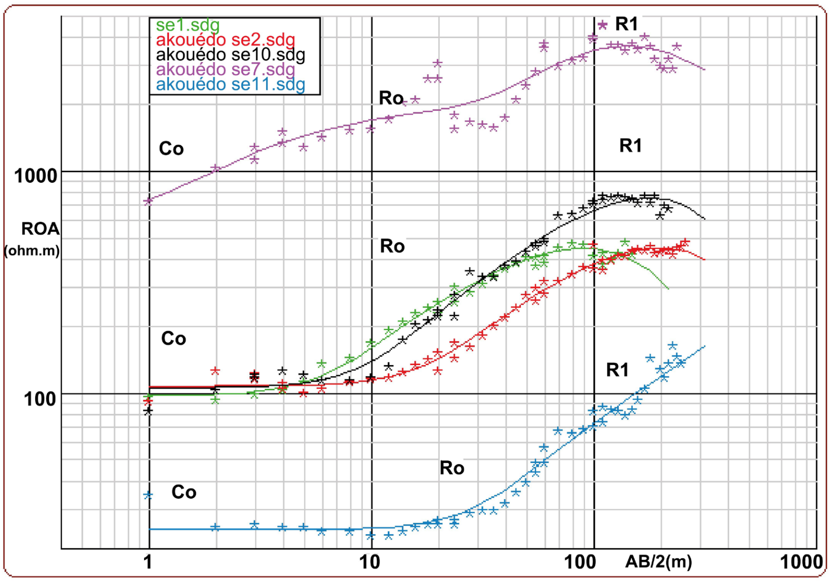
out using a function of the IPi2win software using aligned electrical sounding (SE) points. The distribution of resistivities in the subsoil is obtained by correlating the true resistivities and the true thicknesses resulting from the interpretation of electrical sounding curves.

4. Results

4.1. Stratigraphic Study

4.1.1. Family 1: Dragging Curves

Family 1 brings together all the dragging survey curves (**Figure 6**). The surveys



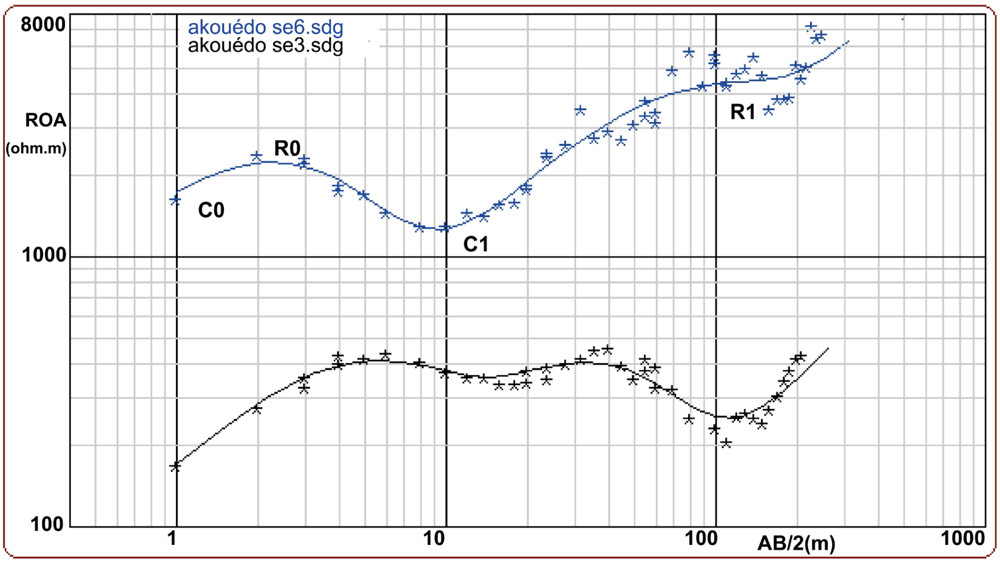
	GROUND 1		GROUND 2		GROUND 3	
	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)
SE1	92.25	3.94	267.6	21.7	318.2	-
SE2	111.3	1.8	105.7	10.87	539.3	-
SE7	613.4	2.6	1794.2	9.51	3432.1	-
SE10	80.67	2.86	211	16.7	165.1	-
SE11	23.62	4.6	21.86	25.53	284.2	-

Figure 6. Family sampling curves 1. -: Indefinite thickness.

are carried out near Akouedo landfill (SE1, SE2 and SE10 to the West; SE7 to the East; SE11 to the North). Their interpretation describes a set of three terrains (**Figure 5**). The first ground is a surface conductor (Co) with a thickness ranging from 1.8 to 4.6 m. The second ground, relatively resistant (Ro), has a significant thickness varying from 9.57 to 25.53 m. The third ground of indefinite thickness is a more resistant medium (C1) than the previous one. The stratigraphy described around the landfill would be successively composed of sandy clay, clayey sand and sand.

4.1.2. Family 2: Creeping Curves

This family presents survey curves at a relatively constant rate (**Figure 7**). Just like the previous ones, the characteristic surveys are also carried out in the surroundings of Akouedo landfill, precisely in the South-West (SE3) and South-East (see **Figure 3**). These two surveys describe four (04) grounds with alternating conductive (C0, C1) and resistant (R0, R1) levels. The first ground, relatively conductive (Co), has a thickness varying between 2.9 and 3.94 m. It would be sandy clay soil. At the level of the three other grounds, the principle of lateral continuity of the facies is not respected since the geoelectric properties described by the SE3 and SE6 surveys are different. This implies that the geological formations described by the SE3 survey contain a large proportion of clayey sediments



	GROUND 1		GROUND 2		GROUND 3		GROUND 4	
	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)
SE3	211.7	2.9	489.2	6.06	289	27.67	462.6	-
SE6	200	3.94	3247.5	2.65	900.4	7.02	5637.5	-

Figure 7. Sampling curves of family 2. -: Indefinite thickness.

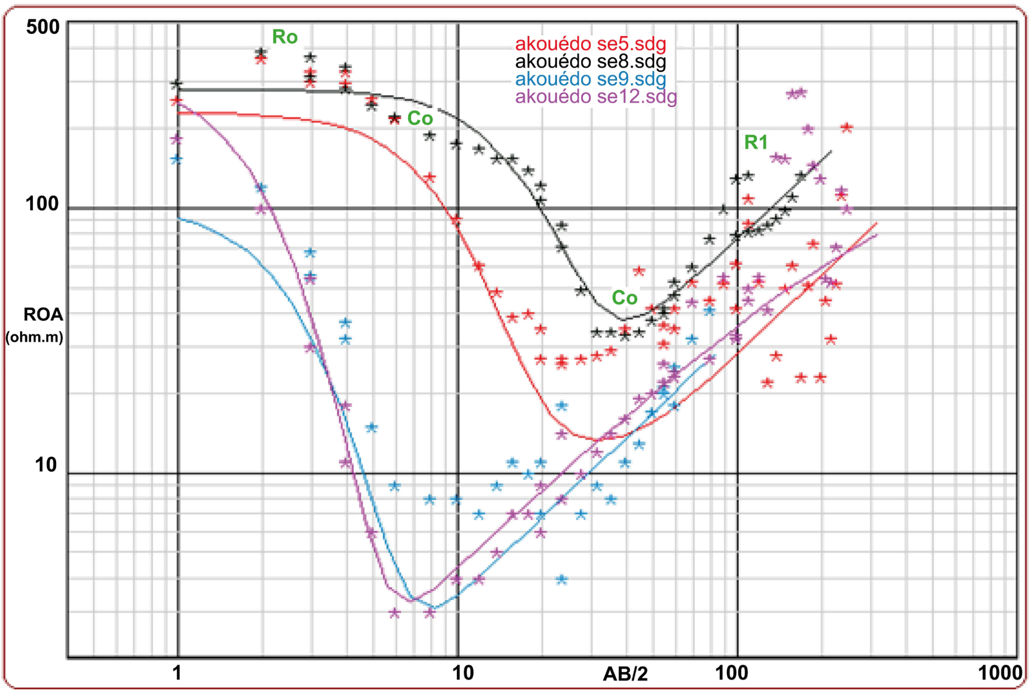
compared to those studied by the SE6 survey dominated by coarse sediments (sand). The high resistivity (ρ) of the last ground described by SE6 suggests that the bedrock is in places reached by the current lines.

4.1.3. Family 3: Boat Bottom Curves

Unlike the surveys already studied, the latter (SE 5 in the South, SE8 in the Center, SE9 in the North and SE12 in the West) were carried out inside the landfill (see **Figure 3**). Grouped within family 3, they describe a stratification composed of three different grounds (**Figure 8**). The first ground and the second ground are strata of waste, the first of which, more recent, is less conductive (R0) than the second (C0) which appears to be more decomposed. The total thickness of waste from Akouedo landfill varies between 25.50 and 35.80 m. The nature of the last underlying ground serving as a bedrock of indefinite thickness varies according to the values of electrical resistivity (187.3 Ω·m < ρ < 567 Ω·m) from clay to clayey sand. This indicates that the vulnerability of groundwater at the landfill site is considerable.

4.2. Geoelectric Sections (2D)

Figure 9 shows a longitudinal section passing through the survey points SE4, SE5, SE8, SE9 and SE10 (see **Figure 3**). The distribution of subsoil's resistivities noted the existence of a very conductive body (ρ < 30 Ω·m) enveloped by another relatively conductive ground whose resistivity is between 30 and 60 Ω·m. This conductive body is clearly visible on the cross section passing the boreholes S3, S5 and S6 observed in **Figure 10**.



	GROUND 1		GROUND 2		GROUND 3	
	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)	ρ (Ωm)	Tickness (m)
SE5	360	3.5	18	22	480	-
SE8	358.4	2.61	24.1	26.94	187.3	-
SE9	160.6	2.7	15.6	29	68.4	-
SE12	647	3.2	1784.2	32.6	567	-

Figure 8. Sampling curves of family 3. -: Indefinite thickness.

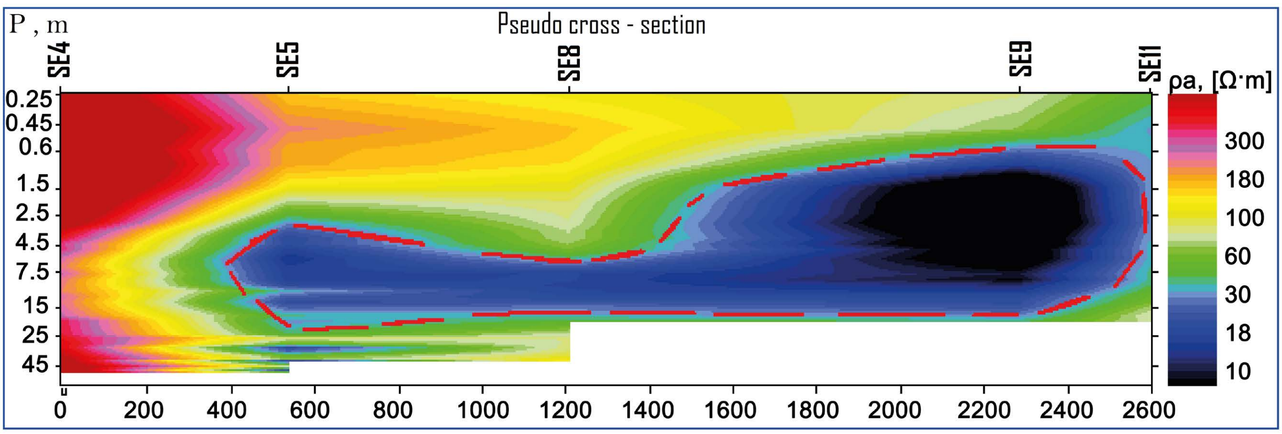


Figure 9. Geoelectrical longitudinal section of the Akouédo landfill.

The nature of the conductive body corresponds to waste buried at depths ranging from 30 to 40 m. This waste seems to be isolated from the surrounding environment by a ground of variable nature ranging from sandy clay to clayey sand as visible on the model presented in **Figure 11**. Referring to the drilling data from the installation of piezometers (pz1 and pz2) (see **Figure 8**), solid waste

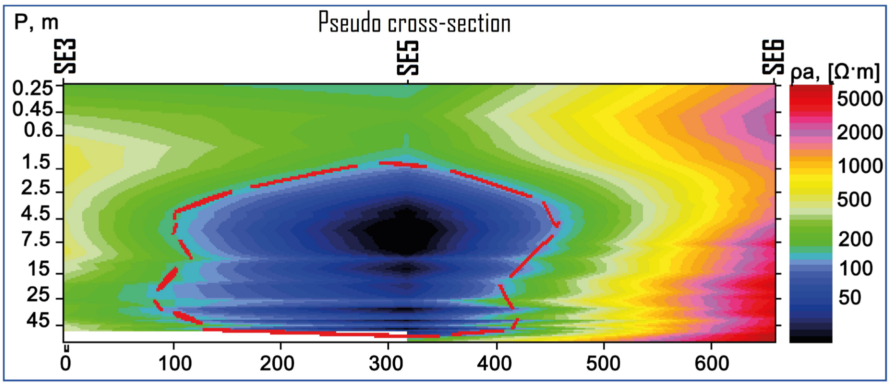


Figure 10. Geoelectrical cross section of the Akouédo landfill.

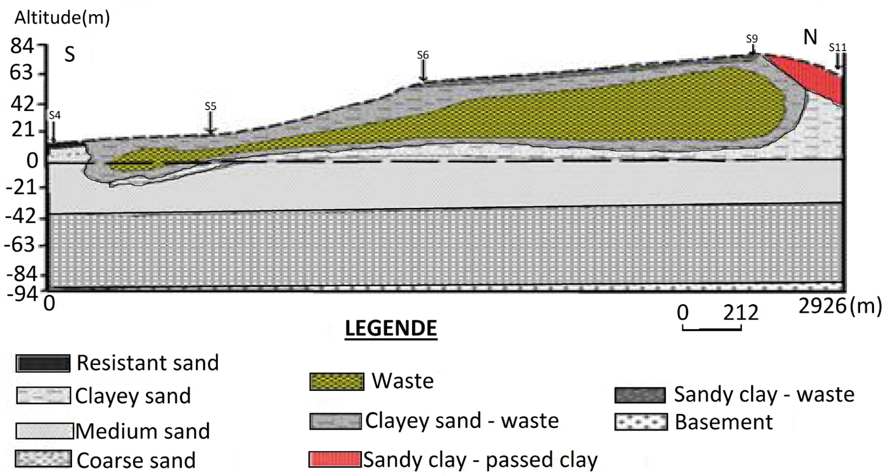


Figure 11. N-S stratigraphic section of the discharge.

would be isolated from groundwater by a small layer of sandy clay. This would not constitute a significant safety barrier against groundwater pollution given that the decomposition of organic waste produces fluid waste (leachate, biogas).

4.3. Discussion

The stratigraphic description of the Akouédo discharge using the electrical resistivity method coupled with that from piezometers (see Figure 5) made it possible to note that around the discharge site, the lithology is as follows:

- Thin clay level, or even non-existent, this discontinuity would highlight the great vulnerability of the aquifer;
- Almost superficial layer made up of sandy clay (or Arab earth sometimes) with a thickness estimated at 3 meters;
- Sandy-clay layer having a thickness of 40 to 50 m. In the field, it is sometimes outcropping in the surroundings of the landfill. In the northern part of the study area, this layer contains shreds of sandy clay indicating lateral variations in lithological facies;
- Land made up of relatively humid sand with an average thickness of 20 m. In certain places, its reduced thickness is probably due to a phenomenon of ero-

sion. This level could reveal the presence of the roof of the underlying crystalline bedrock encountered at approximately 80 m, constituting the bedrock of the area studied (Kouamé et al., 2006; Adiaffi, 2008, Aka, 2013).

Within the landfill, studies have shown that the waste has an average thickness of 30 m which rests on a thin layer of sandy clay deposited in turn on terrain varying from clayey sand to fine to coarse sand. According to the work of Blé et al. (2020), the range of water table depths less than 40 m in the southern zone of the Ebrié lagoon is more exposed to rapid contamination if there was pollution on the surface. Thus, the virtual absence of clay soil observed would indicate a high level of vulnerability of the aquifer due to discharge (Soro et al., 2010; Deh et al., 2012). However, the presence of clay-sand and sand-clay levels, relatively permeable to infiltration of pollutants, would constitute, in addition to sandy levels, an excellent filtering device for leachate in the soil. Likewise, the work of Blé et al. (2020) showed that the waters of the Akouédo area and those of the Nord Riviera well field closer to the discharge are therefore of good quality, because the different physicochemical parameters analyzed respect WHO standards. Thus, the conservation of water quality is linked to the importance of the clay-sand surface layer which behaves like a real filtering layer for this water (Vilomet, 2000).

5. Conclusion

The geophysical studies carried out as part of this environmental study showed that the lithology of Akouédo landfill is composed of clay (discontinuous and thin), sandy clay, clayey sand and sand. The mapped waste is placed on a thin layer of sandy clay that is discontinuous in places. On an environmental level, the virtual absence of clay soil would indicate a high level of vulnerability of the water table due to the discharge.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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