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The Contribution of Electrical Tomography to the Study of Water Erosion in the Nioro du Rip Catchment (Central-Western Senegal)

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Abstract—*This work focuses on the contribution of electrical tomography to the study of water erosion in the Nioro du Rip catchment area (west-central Senegal). In this area, water erosion and especially gullying cause losses of habitable and/or arable land every winter and are a source of concern for local people whose property is directly threatened. ERT (Electrical Resistivity Tomography) methods have enabled us to show that the upper part of the plateau is protected by a slab of lateritic armour and can therefore resist gullying. On the other hand, the slopes and low-lying areas are the receptacles of gullies, except in the western part of the outlet, which is protected by lateritic armourstone hardened at depth*.

Keywords— *Water erosion; Soils; Nioro du Rip; Electric tomography*.

I. Introduction

Soil erosion is a complex phenomenon that results from various processes ranging from detachment to the transport and sedimentation of particles under the combined action of rain and runoff (Morel and Koffi, 1995). On a global scale, annual soil losses due to water erosion are estimated at 25 billion tonnes (Cerdan *et al.*, 2006). The harmful effects of water erosion have been highlighted by numerous authors (Auzet, 1987; Boardman, 1998; De Ploey *et al*. 1991; Le Bissonnais *et al.*, 2002). Water erosion affectsevery region of the world and is one of the most crucial development problems facing developing countries, especially in arid and semi-arid zones where vegetation cover offers little protection (Griffithsand Barker, 1993).

In Senegal, 77% of degraded land is due to water erosion, 59.6% of which occurs in the groundnut basinwhere Nioro du Rip is located (Diop, 2008; IRD, 1999). In this locality, water erosion and especially gullying causes losses of habitable and/or arable land every winter, creating landslides, damaging riverbanks and digging gullies.

The objective of this work is to use electrical resistivity tomography to determine the spatial extent of major soil types. It will enable both horizontal and vertical structures to be observed, providing a better geological interpretation of the region, and thus a tool to aid urban development and the design ofdrainage plans.

II. Materials and methods

A. Presentation of the study area

Located 65 km south-east of Kaolack and 27 km from the Gambia, the study area is in the department of Nioro du Rip in the Kaolack region. The department of Nioro du Rip covers an area of 2,296.5 km². It is bordered to the north by the departments of Kaolack and Kaffrine, to the west by the department of Foundiougne (Fatick region), and to the south and south-east by the Republic of the Gambia (Figure 1**)**. In Nioro du Rip, water erosion has increased over the years (IUCN, 2016). The area of bare soil has increased considerably. Gullying is a blow to Nioro's agricultural and tourist vocation. Water erosion has major consequences for the soil, water quality, loss of homes, infrastructure and agriculture (Figure2 (a, b, c and d)).

Gullies caused by water erosion considerably hamper the use of farm machinery, expose drainage infrastructure, and can cut through roads or cause buildings and bridges to collapse (Ndoye, 2006).

B. The electrical resistivity tomography method

1) The principle

ERT (Electrical Resistivity Tomography) methods involve injecting an electrical current into the soil using two current electrodes and measuring the potential difference induced between two other electrodes, known as potential electrodes. Since the intensity of the current is known and the potential difference is measured, the apparent resistivity of the soil studied can be determined. This depends on the configuration of the current and potential electrodes (Ward, 1990). In mathematical terms, it is the ohmic resistance (R in ohm) of a cylinder of section S (in m²) and unit length L (in m) (Cousin *et al.*, 2012).

$$\rho = R \times S/L$$

It is expressed in Ohm.m and represents the inverse of the conductivity σ (capacity of the medium to letan electric current through) expressed in Siemens.

There are several types of electrodes used. The most used are: Wenner-Schlumberger, Wenner, pole pole and dipole-dipole (Figure 3).

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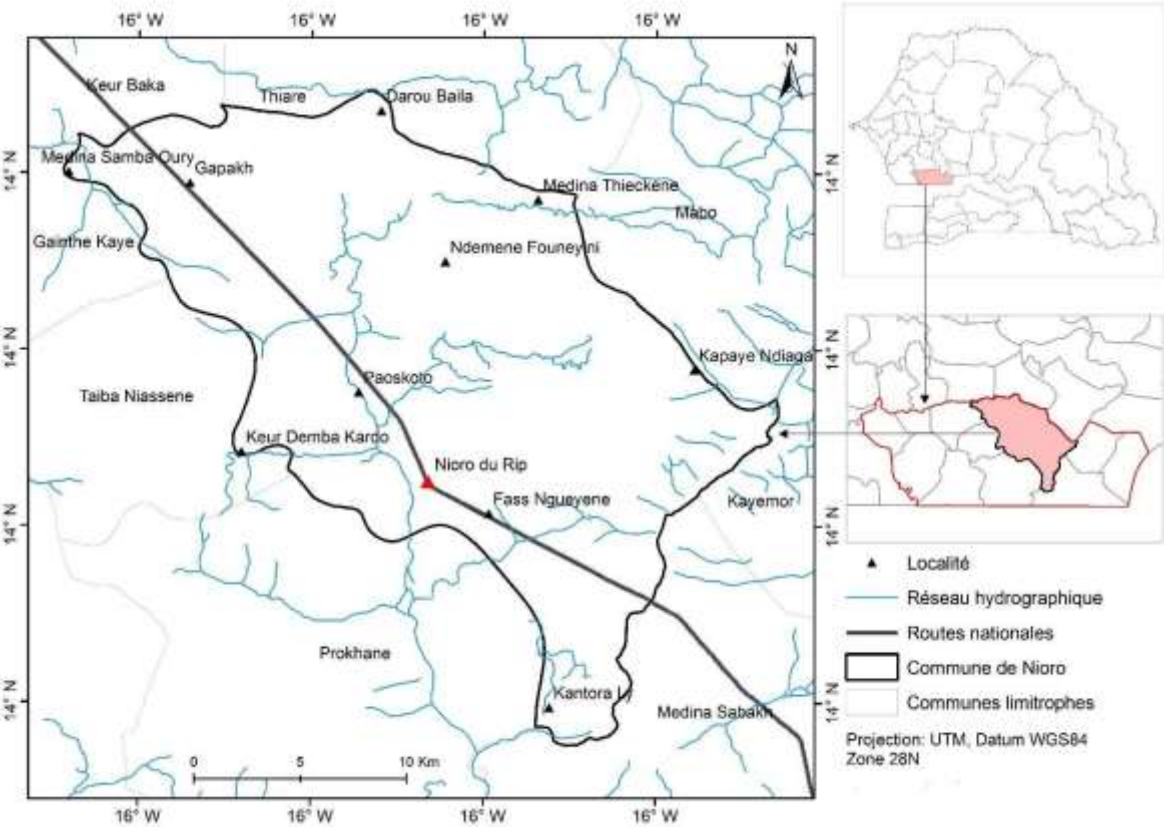
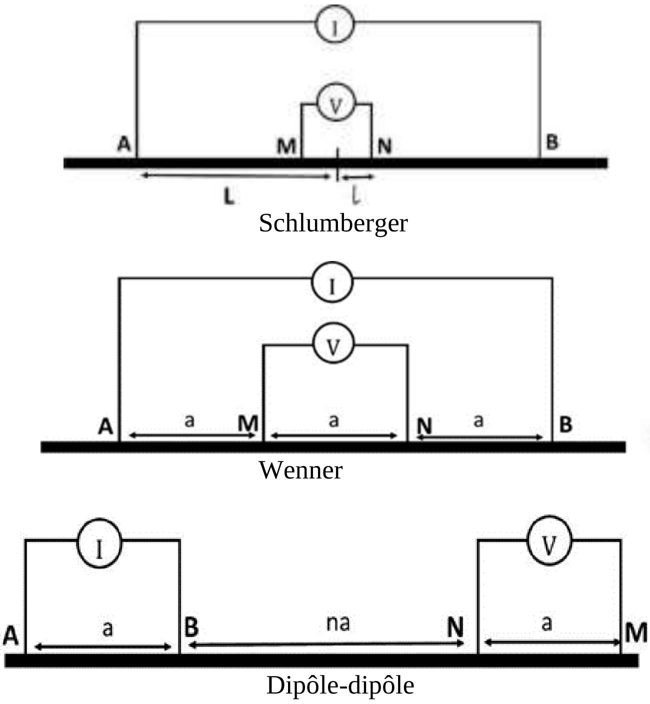


Figure 1: Geographical location of the department of Nioro du Rip

Figure 2 (a-d). Environmental damage caused by water erosion in the commune of Nioro du Rip



$$L = \frac{\overline{AB}}{2} \text{ et } l = \frac{\overline{MN}}{2}$$

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$$a = \overline{AB} = \overline{MN} \text{ et } \overline{AB} = \frac{a}{2}$$

Figure 3. The different measurement devices

The choice of the appropriate device depends on the structure to be imaged (Loke, 1994), the background noise and the sensitivity of the measuring device. The characteristics of each device should also be taken into account: for example, the sensitivity of the device to vertical and horizontal changes, the effective depth of investigation, horizontal coverage and signal strength.

The first step in interpreting electrical tomography data is to construct a pseudo-section. This is obtained by plotting the value of the apparent resistivity measured at the centre of the device and at a depth depending on the spacing between the electrodes. This representation leads to an image for which the resistivity and depth values are not correct (**Figure 4**).

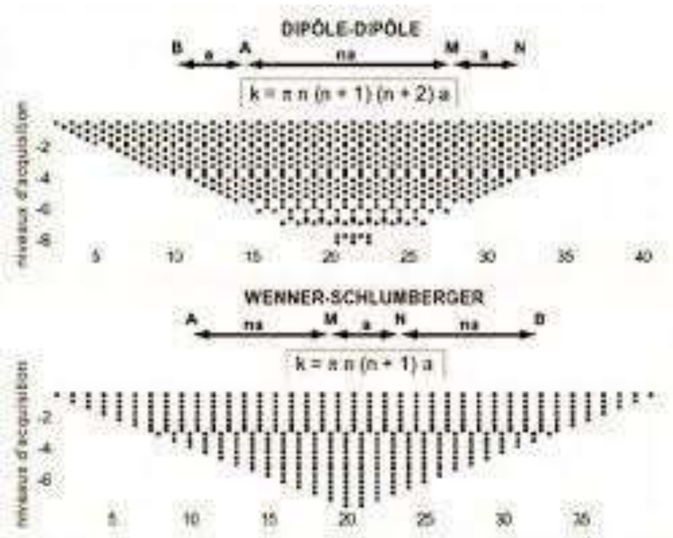

Figure 4: Example of pseudo-sections produced with a dipole-dipole and Wenner-Schlumberger device

In order to obtain a quantitative image representing variations in real (and not apparent) resistivity as a function of true depth, it is necessary to invert the pseudo-section. This inversion of the data is carried out using an iterative process that attempts to minimize the difference between the measured pseudo- section and the pseudo-section recalculated from an electrical resistivity model. This model is modified at each iteration until the measured and calculated data reach an acceptable agreement or until no further improvement is possible (Travelletti, 2011).

2) Devices and data acquisition

A geophysical campaign was organized from 15 to 18 May 2024. It was carried out as part of the variousphases of the soil studies, from site characterization to monitoring the spatial and temporal evolution ofthe soil over the course of the study. Electrical measurements were taken at the soil surface, along wells dug on the plateau, the slope and the lowland along 5 transects (Figure 5). A Schlumberger profile is used to visualize horizontal and vertical structures. Measurements were taken over 100 meters around each dug well in each soil pit.

For 2D acquisition, 42 electrodes were used with a spacing (a) of 2.5 m for an investigation of 200 m ata depth of 40 m at the level of each profile. A total of 15 profiles were carried out, 3 per transect. The electrodes were placed along a profile and connected to a multiconductor cable (Figure 6). Each electrode has a unique numerical address in the device, enabling it to be identified by the computer.

A measurement sequence or acquisition protocol is programmed on the computer. The protocol defines the quartets of electrodes to be used successively as injection and measurement electrodes (Figure 7).

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The protocol is transmitted sequentially to an electrode selector, which executes it by selecting the electrodes concerned in order to obtain apparent resistivity values corresponding to different positions and depths. The measurement is automatically stored in memory (Figure 8).

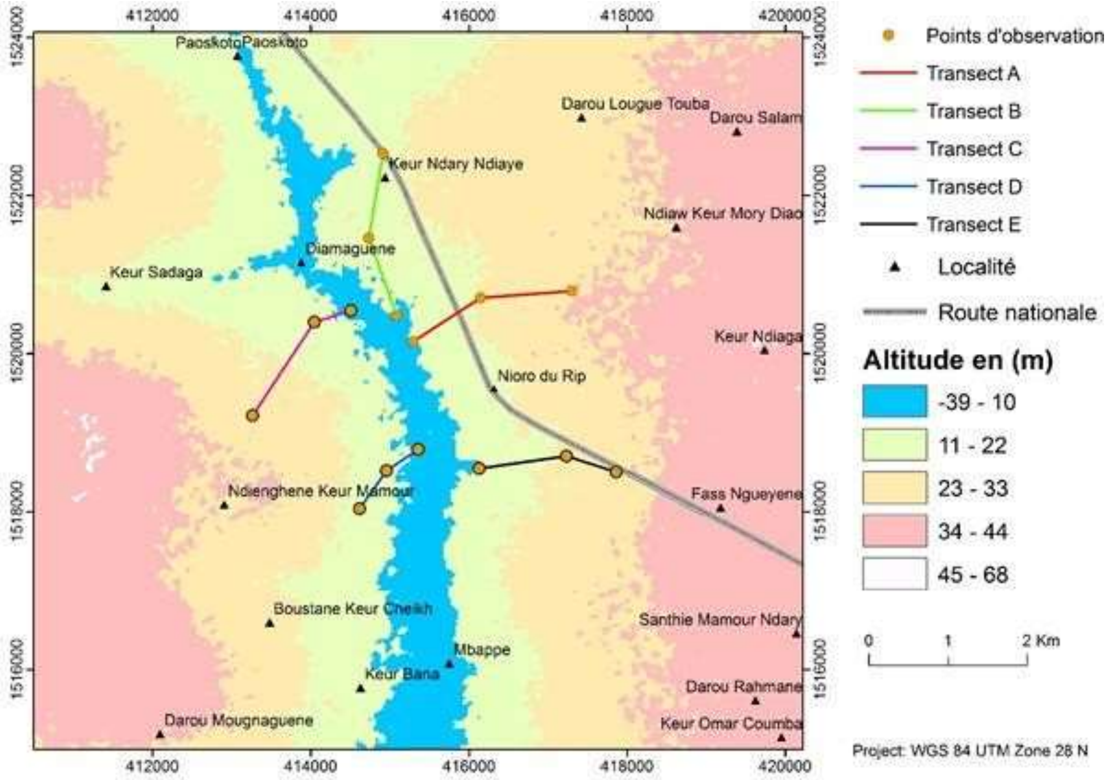

Figure 5: Map of tomographic profile transects in Nioro du Rip

Figure 6. Geoelectric measurement equipment

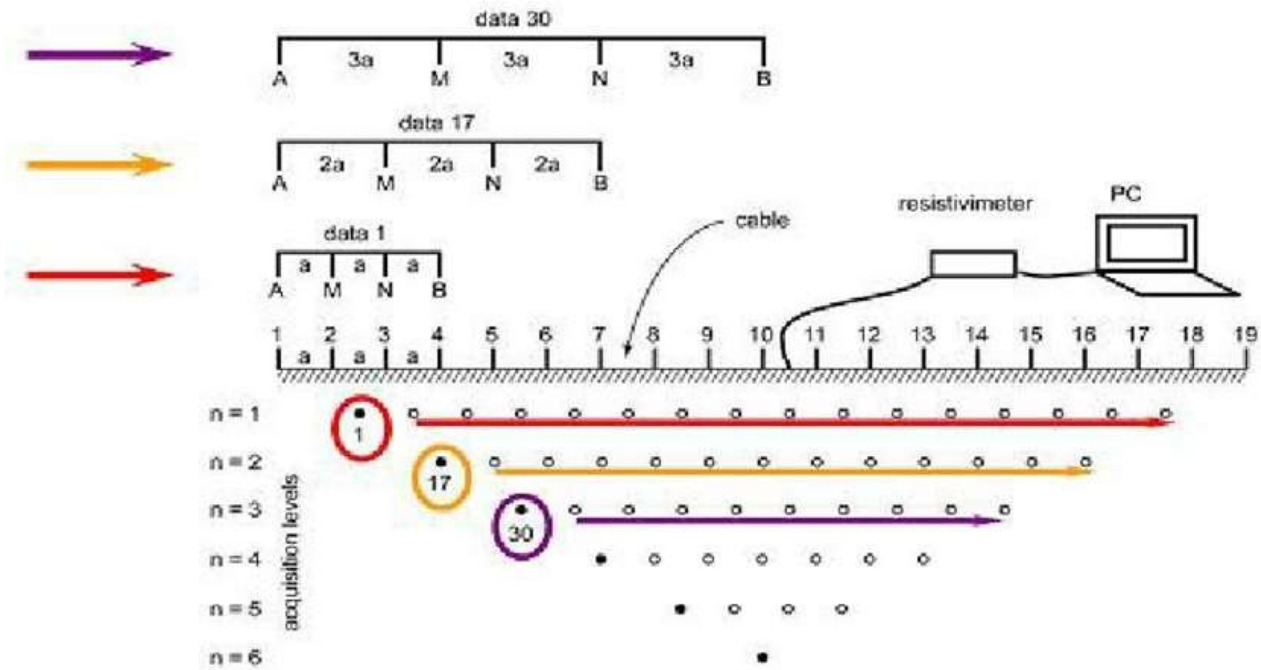

Figure 7. 2D tomography acquisition protocol (Cousin *et al*., 2012)

Figure 8. Example of a 2D tomography acquisition system

3) Data processing

The data was processed using RES2DINV inversion software, which was used to obtain geoelectric images of the prospected area. RES2DINV is a software package that automatically determines the true resistivity model from the apparent resistivity data obtained during a subsurface electrical imaging survey (Griffith and Barker, 1993). Topography must be considered in the inversion, as its influence is not negligible. The program inverts the data by correcting for the effect of topography. To produce a true resistivity model, the software needs a certain number of iterations. Generally, it oscillates between 4 and 6. The profile with the largest number of repeats is not necessarily the most geologically accurate. From the pseudo-section of measured apparent resistivities, RES2DINV determines a pseudo-section of "calculated" apparent resistivities, from whichit associates a true resistivity value with each block of the model.

III. RESULTS

We have given two examples of electrical prospecting processing. Figure 9 shows the results of electrical tomography profiles on the plateau, the slope and the lowland of transects A and E located respectively to the east and west of the outlet. It is immediately apparent that the image of resistivity as a function of depth does not show clear-cut contours: the inversion process favours weak gradients andthe interpolation creates a sort of halo of intermediate resistivities around a body whose resistivity contrasts sharply with that of its surroundings (Besson, 2007).

On the plateau, high resistivities (ρ >1000 Ohm.m) were measured for the first few meters; these correspond to a crust of lateritic layer. In the middle part of the transect, the slope formations are muchmore conductive (100 <ρ <1000 Ohm.m). However, electrical resistivity remains high due to pockets of lateritic layers and very dry soils. The resistivity is a function of the clay matrix of the layer and sand,which is more resistant or

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more conductive. The shallows are characterized by a few resistant levels noted on the surface. The resistivity is lower than the previous levels. It is often less than 150 Ohm.m at depth, except for lateritic layers and sands below the water table.

Resistivity decreases with depth along the toposequence, from the plateau through the slopes to the shallows. They range from 2,500 to 37 Ohm.m. Note the presence of laterite layers at all levels, which gives higher resistivities that are difficult to distinguish.

The ERTs carried out reveal 3 types of material from an electrical point of view according to Millot's naming model (1964; *in* Anand & Paine, 2002):

1. A first level of resistivity often greater than 1000 Ohm.m in the upper part of the profile, corresponding to the ferruginous layers. This is a very indurated level, continuous and well marked on the plateau, whose position varies throughout the sounding profile.
2. A second level beneath the layers, with a resistivity of 35 to 800 Ohm.m, corresponds to saprolite. This is a loose, highly porous material that retains the structure of sound rock.
3. A third level beneath the saprolite, with a resistivity greater than 1000 Ohm.m, corresponds to soundrock.

Resistivity levels can vary from profile to profile. These three materials appear in this order from surface to depth. The presence in the second material of small levels of low resistivity (conductors) and variable position in the profile can be noted.

This conductive material is often trapped in layers of higher resistivity. This is water contained in pores or cracks in the rock, saturated by infiltrating rainwater, or artifacts that can lead to misinterpretation.

The weathering profile is more advanced on the plateau, with a continuous layer's stone that may be bevelled, as shown in the profiles in Figure 9.

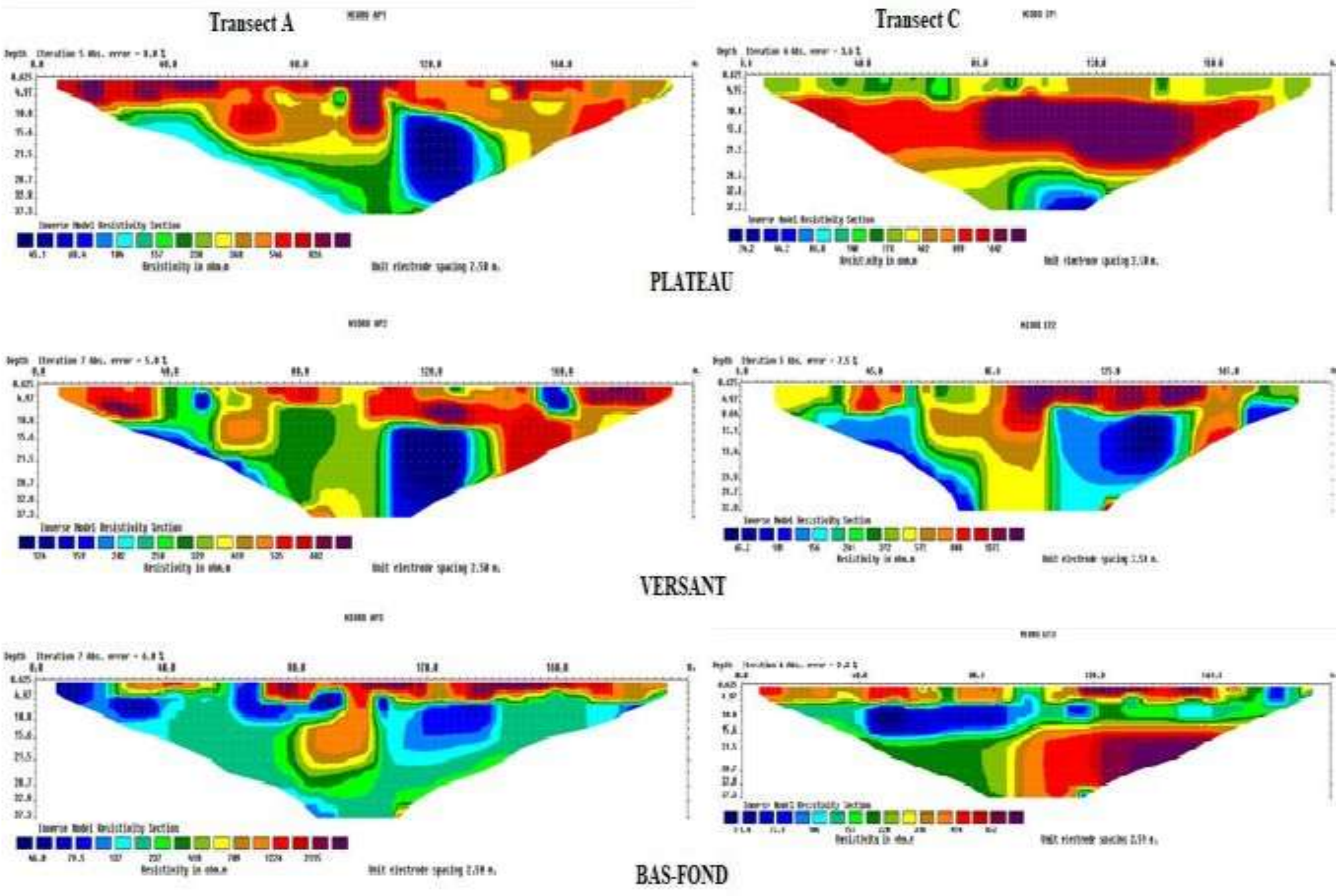

Figure 9. Electrical tomography profiles at transect level

IV. Discussion

The electrical profiles show a remarkable coincidence between the lower limits of the lateritic layers indurated when the shafts were sunk and the upper limits of the medium and low resistivity material. The electrical profiles only allow us to distinguish a low-resistance material from the saprolitic zone, whereas it is easy to distinguish the different horizons and underlying materials by observation.

On a catchment scale, the typical profile is characterized by:

A first superficial level generally corresponds to loosely coherent sands which are associated with high resistivities (Evans *et al*., 1996; Lamotte, 1993) and lateritic breastworks

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which are bevelled in places and of variable resistivity (ρ >1000 Ohm.m). This variation depends on the depth at which the substrate appears (Friedman 2005; Samouëlian et al. 2005);

A second level corresponding to saprolite is characterized by an irregular degree of weathering (ρ

±<1000 Ohm.m) which is generally influenced by numerous soil variables such as texture, water content and soil structure (Richard *et al.*, 2001). This level can be divided into sandy-loam to silty-sandy and silty-clay textured levels depending on the depth at which it appears and the texture. There is a relationship between resistivity and the main particle size classes of the samples (sand, silt and clay) (McCarter, 1984). This result is consistent with those of Dabas *et al* (1995) and Moeys *et al* (2006);

The third level corresponds to sound rock that remains resistant. It could correspond to the clayey sandstones of the Saloum Formation (ρ >1000 Ohm.m) (Roger *et al.*, 2009).

The more clayey the soil, the more water it retains, which has the effect of reducing electrical resistivity (Zanolin 2003). The presence of hydromorphic patches on the sands in the soil profile shows that the overlying conductive level towards the lowland corresponds to the sandy aquifer. Resistivity is therefore an indicator of the pedogenetic evolution of soils (Auerswald *et al.*, 2001).

V. CONCLUSION

The ERT profiles showed an alteration mantle 40 meters thick and structured into 3 levels: indurated (ρ >1000 Ohm.m); loose more or less altered (saprolite) (ρ <1000 Ohm.m); and sound rock (ρ >1000 Ohm.m). Aquifers (ρ <130 Ohm.m) exist in the saprolite in the form of pockets of varying size that are present all year round. The results of the survey are consistent with the main formations observed. The superficial part of the plateau is protected by a slab of lateritic cuirass that is resistant to gullying. However, the slopes and low-lying areas are the receptacles for gullying, except to the west of the outlet, which remains protected by lateritic cuirasses that are indurated at depth. These results show that the increase in clay content at depth means that resistivities are low at depth.

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