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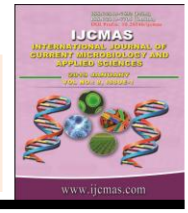

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Geophysical Characterization of an Alluvial Plain: Case of Karfiguela in Burkina Faso

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A B S T R A C T

This study was conducted on the alluvial plain of Karfiguela in the extreme southwest part of Burkina Faso as part of the Support Program for Irrigation Development (PADI). The main objectives of this study are: (1) the identification and delineation of the alluvial plain (2) identification and characterization of the geological nature of the of the lithology of the plain (3) identification and characterization of the average power of the plain and (4) the determination of the hydrodynamic properties and directions and flow direction of groundwater in the alluvial plain of Karfiguela. Concerning the characterization of materials, two investigative techniques were used for this study: (i) the electrical resistivity tomography (ERT), and (ii) the auger surveys (micro-drilling). The first technique allowed us to obtain resistivity distribution and to deduct from the nature of geological formations in place as well as their thicknesses. The second technique leads to a direct observation of the tabulations and the granulometry of the different layers that constitute the plain on a given depth. All methods lead to the same results overall, with the only difference that the second is much more accurate compared to the stratigraphy, and to the real nature of the geological layers. The results of these studies will enable to identify areas where accessibility to shallow aquifers is readily available to mobilize groundwater resources to carry out dry season cropping.

Introduction

The management of water resources is one of the fundamental issues of the world water problem. Indeed, the increasing complexity of the mobilization systems, the use of water resources linked to the increase of the levies and the rejections due to the demographic growth, the economic development, threaten more and more the quantity and the quality of this vital resource (Dezetter, 1998) (1). In Burkina Faso, the assessment of renewable water resources is estimated at 852 m3 / year / inhabitant while the scarcity threshold is estimated at 1000 m3 / year / inhabitant (DGH, 2001) (2). Burkina is therefore in a deficit situation with regards to management of water resources. Of all water-consuming activities, agriculture accounts for 64% of Burkina Faso's total water demand, and much of this demand is met from surface water, which is threatened by the fast drying up in the dry season (DGH, 2001) (2).

Our study is part of the activities carried out by the PADI Project BF101 "Sustainable Management of Groundwater for Irrigated Agriculture".

This is indeed a quantitative assessment of the groundwater resources of the alluvial plain of Karfiguelathanks to the assessment of the aquifer through the characterization of materials and the estimate of its flowpower.

Study area

The study area is the alluvial plain of Karfiguela. It is located in the extreme south-west of Burkina Faso in the province of Comoe whose administrative center is Banfora and in the Cascades region (Figure 1). This plain is located approximately between 4 ° 36'34 "and 4 ° 49'19" west longitude and between 10 ° 28'36 "and 10 ° 43'20" north latitude (NESTOR, 2017) (3). The plain has an area of about 4580.

The Karfiguela plain is characterized by five (5) geological formations (Figure 2): Kawara-Sindou Formation, Lower Sandstone Formation, Shale and Volcano-Sediment Formation, Granodiorite Formation, and Tonalitic group.

The sandstones of Kawara-Sindou (60 to 350 m thick) rest on the lower sandstone or directly on the basement. It is a formation consisting of very fine quartzite sandstone at the base and coarse sandstone above (Figure 6). It is characterized by an oblique stratigraphy and the presence of abundant wave wrinkles (Hugot, 2002) (4) (Fig. 3).

The lower sandstones (50 to 300 m thick) lie with discrepencies on the base. The formation consists successively from the base to the summit of fine red sandstone, fine quartzite sandstone and red sandstone with schist flow (Hugot, 2002)(4).

Shales and volcano-sediments These rocks present a certain complexity. Indeed, at the weathering, they can be difficult to differentiate with schistosed and weathered andesitic rocks. Globally, they are pelites, sandstone shales, gray-black gloss schists, tuffaceousschists and rare quartzitic horizons (Ouédraogo, 2006) (5).

The granodiorites are granular rocks, mesocratic relatively rich in mafic minerals and feldspars (Hugot, 2002). (5) They constitute the major part of the pedestal at the level of our study site.

The group of Tonalites includes a number of facies ranging from granodiorite to tonalite and quartz diorite. These rocks are globally very close. They are of medium to coarse grain, presenting a planar mill or a clear gneissic foliation. Locally, a ribbon is associated with foliation and gives the rock an aspect of migmatite. They are usually intersected by veins of aplite or pegmatite. In these rocks plagioclase predominates; Potassium feldspar, quartz, amphibole and biotite are less abundant (Ouédraogo, 2006) (5).

The order of magnitude of the total groundwater resources in the Comoé watershed where our study area is located is summarized in Table 1 (Diagnosis of Water Resources in the Commune Watershed, P12, RESO, 1998). The distribution of aquifer reserves is very uneven. In fact, the sedimentary zone that covers 20% of the basin contains more than half of the aquifer reserves. Renewable infiltration water is estimated at 2530 million m3, or 13.3% of annual precipitation (GOMBERT, 1998) (6).

Materials and Methods

The collection of the study data required the use of the material indicated below:

Realization of micro-piezometers

An auger 100 mm in diameter for drilling;
PVC pipes with a thickness of 2 mm and a diameter of 90 mm for the casing.

Piezometric surveys

A Leica CS10 Differential GPS for the determination of TN coordinates and altitudes;

A piezometric sensor and various probes, respectively for the manual and automatic measurement of the piezometric level of the structures.

Geophysical campaign

An acquisition system: the ABEM which contains measurement protocols;
An ABEM resistivity meter that measures the apparent resistivity of the medium;
Two (2) 12V batteries;
64 copper electrodes;
4 cables (yellow) to connect the electrodes to the acquisition system, with their coils (take care to tidy the cables so that they are easy to run on the ground and take care not to let the tips drag);
Two cable connectors;
A black cable to connect the resistivity meter to the data logger.

Granulometric analysis by sieving

An AFNOR standardized sieve column comprising sieves of a dimension between 0.08 and 100 millimeters;
Taresto remove the material;
A precision scale

In addition to the field equipment, we used several technical software. Those are:

SAS4000 Utilities which allowed us to create measurement protocols,
Res2Dinv, to invert the geophysical data,
Diver office, for the programming of Divers probes,
Sedlog, which allowed to build lithological sections,
Arc Gis and Surfer for mapping

Méthods used

There are several methods that can be used on the characterization of alluvial plains (gravimetry, the H / V method, tomography). In the case of our study the characterization was done by the tomography technique of the electrical resistivities (ERT) (Maescot, 2008)(8) supported by a series of granulometric analysis and tactile diagnosis on several samples coming from the drilling of the micropiezometers of the plain. The ERT measurement sites were chosen according to the distribution density of the structures (micropiezometers) as shown in the map of Figure 4.

The aim of this survey is to inject into the ground an electric current of intensity I between two electrodes A and B and to measure the potential difference V induced between another pair of electrodes M and N (Figure 5).

The apparent electrical resistivity of the subsoil on the basis of Ohm's law is:

$$\rho_a = K \frac{\Delta V}{I}$$

Where K is a factor dependent on the geometry of the measuring device

There are several electrode devices used in practice, but the one we chose is the most frequently used measuring device in electrical tomography (GOMBERT, 2008) (8), referred to as the Wenner device (Figure 5).

With this device, apparent resistivities are less affected by superficial lateral variations and give a good vertical resolution for detecting horizontal layers.

In addition it is well suited to sites where noise is important enough like most of our sites (Figure 6).

The width between electrodes is constant (distance a) and the current electrodes surround the potential electrodes (measurement) as shown in Figure 7.

The preceding equation then becomes:

$$\rho app = 2\pi a \frac{\Delta V}{I}$$

It is necessary, to give a good image of the basement, a sufficient density of points. The electrodes, allowing the injection of the current and the measurement of the potential, are placed along a profile (Figure 7).

Figure 7 shows how data is acquired through a Wenner device with 28 electrodes. The principle is the same, regardless of the number of electrodes.

Results and Discussion

Geological nature of the plain materials

Geophysical data collected in the field has been inverted to generate geo-electric models. The results of the inversion show that the resistivities on our study site are quite varied (Haladou (2013)) (8), SYMBORO (2016) (9).This verifies the vertical variation of the formations in place.

Indeed, for each range of resistivities corresponds a type of geological formation.

North-west side of the plain

Site N°1 (Karfiguéla)

The following observations on the inverted model can be noted: an upper layer of low resistivity (<90 ohm.m) is observed from the topographic surface to a depth of about 20 m. This geological formation is attributed to heavily clayey alluviums soaked in water. When going deeper, there is a fairly thin layer of about 4m thick with a resistivity <150 ohm.m attributed to a sandy arena. This layer rests on two other cumulative thickness formations of about 6 m, and resistivity of between 200 and 400 ohm.m. These layers could be gravel or gravelly sand. A relatively resistant zone (800 to 1000 ohm.m) is observed following the layers mentioned above

The resistivity values of this zone reflect an altered rock, probably the cracked horizon; the base in this zone being granodiorite, there is then at this point cracked granodiorite and the whole resting on a healthy granodiorite resistivity greater than 1000 ohm.m.

From the variations of the resistivities obtained by inversion of geophysical data and relying on the lithological cuttings of our surrounding boreholes, we have established a lithological cutting profile of all the power of the plain in the indicated zone (Figure 10). This scutting shows three types of formations:

A first layer formed of heavily clayed alluvium, more precisely we have a succession of pure clay, sandy clay, silty clay, gritty clay on 20 meters thick.

A second layer of sand and a third layer of gravel. All based on a fractured granodioritic base that becomes healthy deeper.The following figure 10 represents the results of the micro-drilling near the profile on site N° 1. These results confirm our conclusions drawn from geophysics in the first meters (Figure 11). Indeed, the stratigraphic logs of PZRG21 and PZRG22 micro-holes located in the vicinity of profile LR00093 show a succession of alluvial layers starting from pure clays to very clayey alluviums as it has been observed by geophysics. These alluviums are generally sands, gravel and silts.

West side of the plain

Site N°4 et N°5 (Diarabakoko)

The LR106 model of Figure 11 shows a fairly clear tabulation of the different strata encountered in the area. Indeed on the first 20 meters we have a low resistivity layer (<80ohm.m).

This layer consists of clays. From 20 to 27 m we obtain resistivities characteristic of a sandy arena and below which is a layer of gravel (500 to 700 ohm.m) of 11 m thick.Par la suite nous observons des résistivités caractéristiques de rochetrèsdure: soclefissuré (1000 à 1500 ohm.m) et soclesain (> 1500ohm.m).

When analyzing the LR107 model, three distinct zones appear: a top layer of medium resistivity, a low resistivity intermediate layer and a lower layer of high resistivity.

The first layer is a mixture of clay sand with pockets of sand or clay in some places. It is surmounted by a thin layer of lateritic cuirass to the southwest. From a depth of 10 m, a clay formation up to about 22 m deep is observed.

The depth of investigation of the profile does not allow to see clearly the basement but we still see that after the clay layer we have a possible deposition of gravelly sand on the cracked base.

A lithological cutting taking into account all the power of the plain in this zone was made from the resistivity map. This is to obtain the nature and structure of the different materials from the topographic surface to the bedrock.

These sections (Figure 12) show a typical stratification of the plains: at first a deposit of the densest materials such as gravel, followed by a deposit of less dense materials such as sand, to finish with deposits of sand and clay much less dense.

When analyzing the micropiezometer sections made in the vicinity of the profiles used to draw these logs, we see that the results are almost identical except that the drilling cuts are much more precise because these sections show the heterogeneities that often go unnoticed with geophysics (Figure 13).

Assessment and characterization of the power

Furthermore, in addition to help us determining the nature of materials, geophysical models allow us to determine the power of the plain. Indeed these models are built in a reference (X, Z). This allows to see the depth investigated by the profile. Also, from these models we have built lithological sections that show the thickness of each of the layers encountered up to the bedrock. Thus we can directly estimate the total power of the plain. This power varies according to the sites as shown in Figure 14; 15; 16 and 17.

In the North-West zone the power of the plain varies between 30; 25 and 23 meters (Figure 14; 15). Towards the south and towards the west the power is also estimated at about twenty meters but it reaches 38 meters in some places (Figure 16; 17). Table 2 gives the thickness of each of the main geological layers as well as the power of the plain per measurement site.

The following diagrams (Figure 18) allow us to better appreciate the distribution of materials at each level of the plain; but it should be noted that these diagrams have been plotted with the results of the profiles which gave better images of the basement respectively the LR00093, the LR106 and the LR102 for the North West, West and South zones; knowing that the other profiles in the same zones give more or less the same proportions.

The northwestern and western zones show dominance in clay alluvium compared to the southern zone where gravel and sandy arena take up a considerable proportion.

Saturated and unsaturated thicknesses in the plain

Knowing the piezometry on the different studied sites, we can obtain the saturated and unsaturated zones knowing that the piezometric level constitutes the veil between the two.

However, the piezometry as well as the thickness of the plain varies from one place to another; which will also bring to vary the desired thicknesses. Table 3 shows this variation for a sample of seven (7) piezometers chosen in the vicinity of our ERT profiles.

Plain's conceptual model

As shown in the conceptual model (Figure 19), the greatest thicknesses are in the southern part of the plain towards Diarabakoko and Tangrela probably due to a basement depression in this area.

Nature of the plain's limits

The nature of the slopes of the Karfiguela plain has been determined by the combination of geophysical investigations and field observations of rocky outcrops.

The interpretation of the electrical resistivity models that will follow will allow us to determine the nature of the materials at the embankment level, in order to directly deduce the geological nature of the boundaries. We will use rectangular models for interpretation because these types of models are extended on the sides and therefore provide much more information about the boundaries.

At both sites represented by the above models, the slope of the valley is located at the electrodes No. 64.

For the LR98 model, the limit is made of materials with resistivities greater than 1000 ohm.m. These materials are in accordance with the geology in place, subsurface limestone and deep crystalline rock (granodiorite).

The LR102 model also represents the limit of the plain by materials with a resistivity higher than 1000 ohm.m but the field observations show that these materials are of the consolidated lateritic grave. This limit formed thereof becomes in depth the basement.

Inverted models of the other profiles gave similar results. Thus, in the same logic, we have been able to determine on all sites the geological nature of the materials that constitute the limit of the plain. The results are shown in Table 3.

The results in Table 4 show that on the studied sites, the limits of the plain are generally zero flow limits except in the case of LR00096 where we have a limit with variable potential.

But from our studies, we cannot determine the extension of each of the limits encountered, this would be possible if we had done photo-interpretation to ensure a certain correlation between formations. So the results we have at this level are only relatively punctual.

Table.1 Total groundwater resources in the Comoé basin in million m3 (GOMBERT, 1998)

Sub-basin	Sedimentary area	Basement zone	Alluvium	Alterites	Total
Upper Comoé	25635	12370	90	96945	47740
Leraba	19985	5295	40	6910	32230
Koudoun	0	1560	10	0	1570
Baoué	0	2000	10	1480	3490
Iroungou	0	1170	10	1870	3050
Total	45620	22395	160	19905	88080

Table.2 Thicknesses of the main geological layers and power of the plain per site

zone	profile designation (site))	Nature of the main geological layers	Thickness of the layers (m)	Plain 's power (site)
North-west	LR00093	Clay materials	20	30
		Sand	4	
		Gravel	6	
		Cracked and weathered granodiorite	21	
	LR00094	Clay materials	23	25
		Sand	2	
		Gravel	-	
		Craked and weathered granodiorite	-	
	LR00096	Clay materials	22	23
		Sand	-	
		Gravel	1	
		Craked and weathered granodiorite	-	
West	LR106	Clay materials	20	38
		Sand	7	
		Gravel	11	
		Cracked and weathered granodiorite	20	
	LR107	Clay materials	22	23
		Sand	-	
		Gravel	1	
		Cracked and weathered granodiorite	-	
South	LR00098	Clay materials	20	22
		Sand	2	
		Gravel	-	
		Cracked and weathered granodiorite	-	
	LR102	Clay materials	12	38
		Sand	15	
		Gravel	11	
		Cracked and weathered granodiorite	13	

Table.3 Saturated and unsaturated thicknesses of the plain

Désignation profils	Piézomètres immédiats des sites	Puissances plaine/site(m)	Epaisseurs Non-saturées/site (m)	Epaisseurs saturées/site (m)
LR00093	PZRG13	30	2.08	27.92
LR00094	PZRD6	25	1.63	23.37
LR00096	PZRG6	23	1.6	21.4
LR00098	PZRG2	22	3	19
LR102	PZRD7	38	0.63	37.37
LR106	PZRD15	38	1.08	36.92
LR107	PZRG7	23	0.8	22.2

Table.4 Geological nature of the limits of the plain

Profil	Geological nature of the plain
LR00093	Deep lateritic consolidated in subsurface, deep granodiorite
LR00094	Poorly consolidated sandstone
LR00096	Deep lateritic consolidated in subsurface
LR00098	Limestone
LR00102	Consolidated sandstone
LR00106	Limestone

Fig.1 Map of the geographical location of the study area (SIG VREO, 2008, NESTOR 2017)

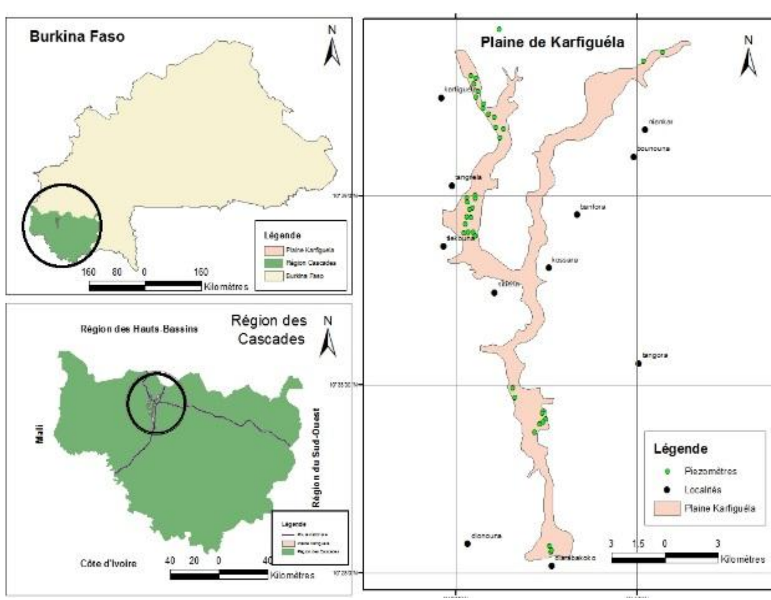


Fig.2 Geology of the study site (NESTOR 2017

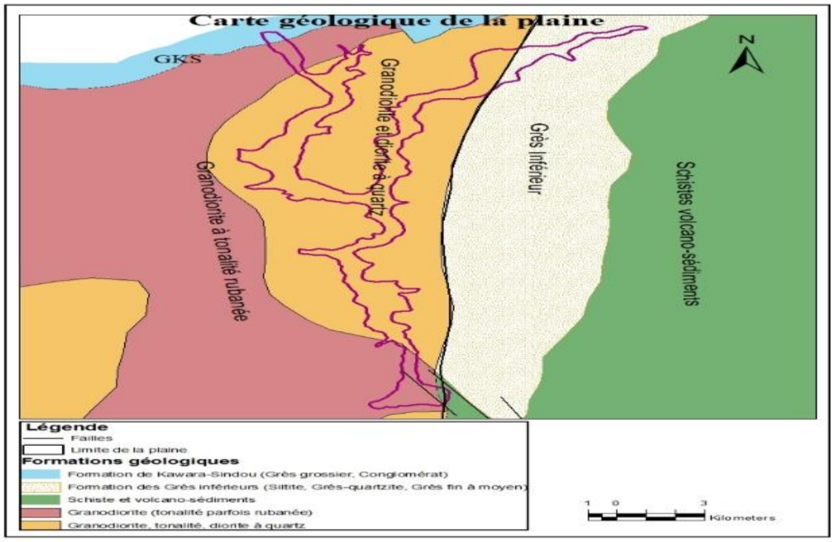


Figure.3 Kawara sandstone Sindou foliated (A), Kawara sandstone Sindou healthy (B)

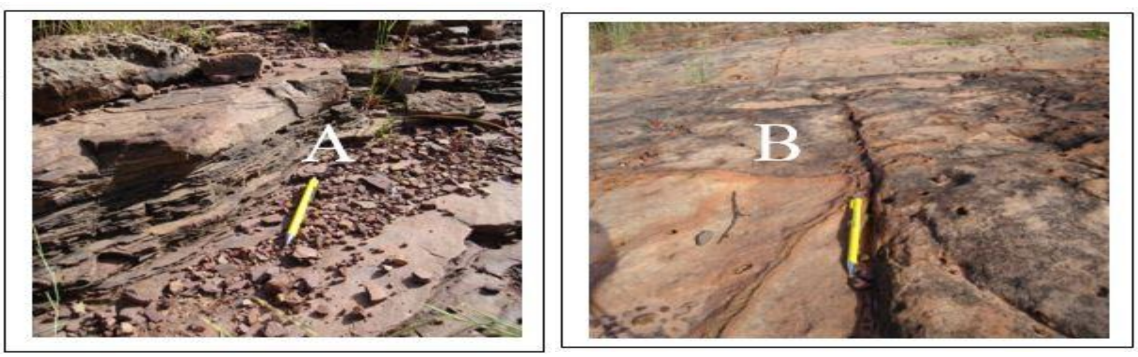


Figure.4 Distribution map of ERT profiles

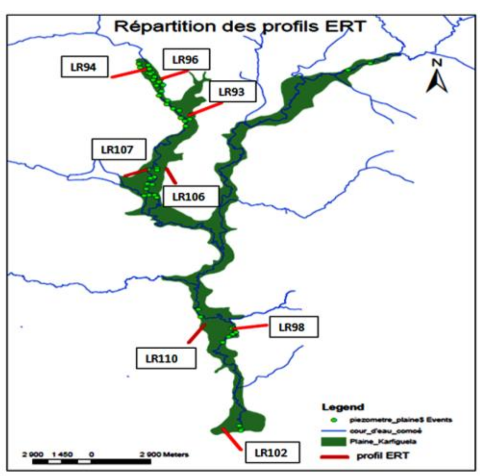
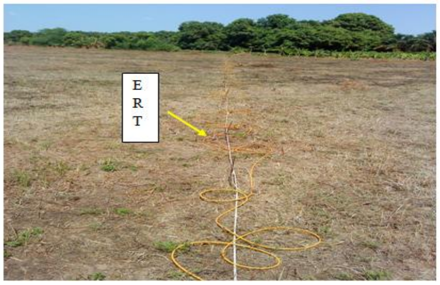


Figure.5 Measuring site n ° 7 in Tengrela (A); measurement site n ° 2 located at the level of the cascades (B), presence of high voltage pound (noise)



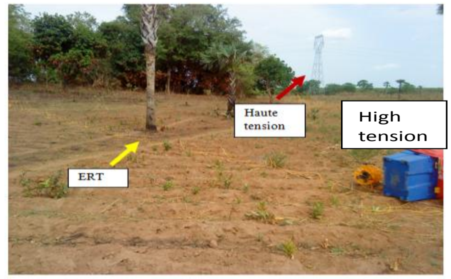


Fig.1 Wenner Configuration

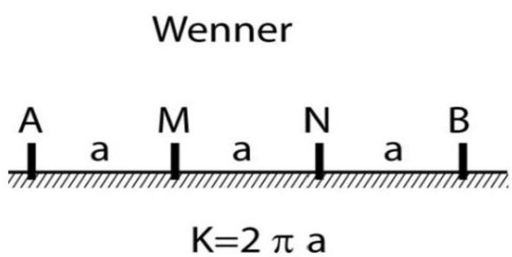


Fig.7 Representation of the electrode arrangement for a Wenner device acquisition with different acquisition levels

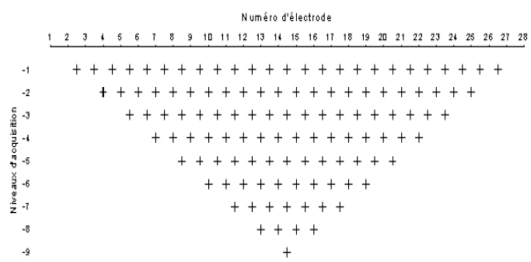


Fig.2 Inverted model of electrical resistivity of LR00093 profile

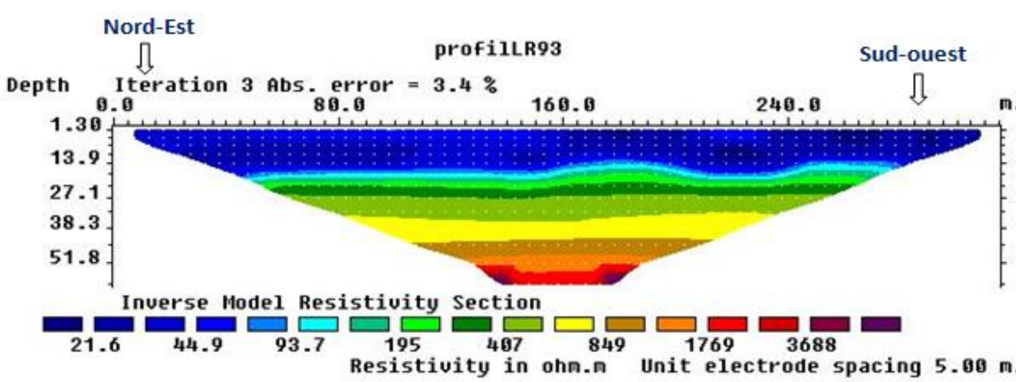


Fig.3 Lithological cutting of profile LR00093

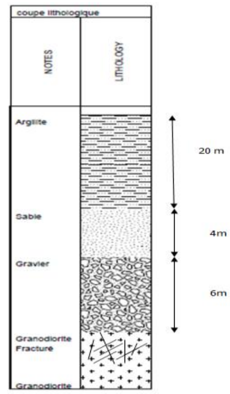


Fig.4 Stratigraphic section of PZRG21 and PZRG22 boreholes

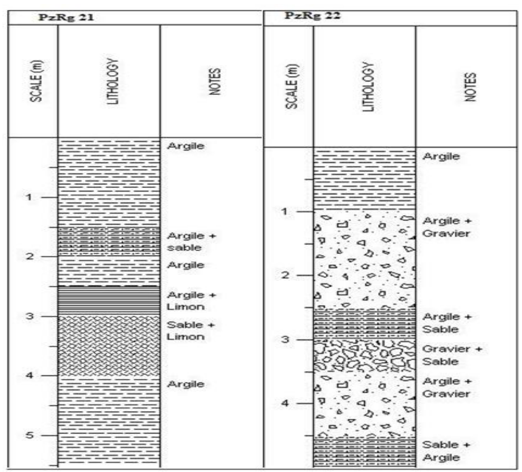


Fig.5 Electrical resistivity model of the LR106 and LR107 profiles

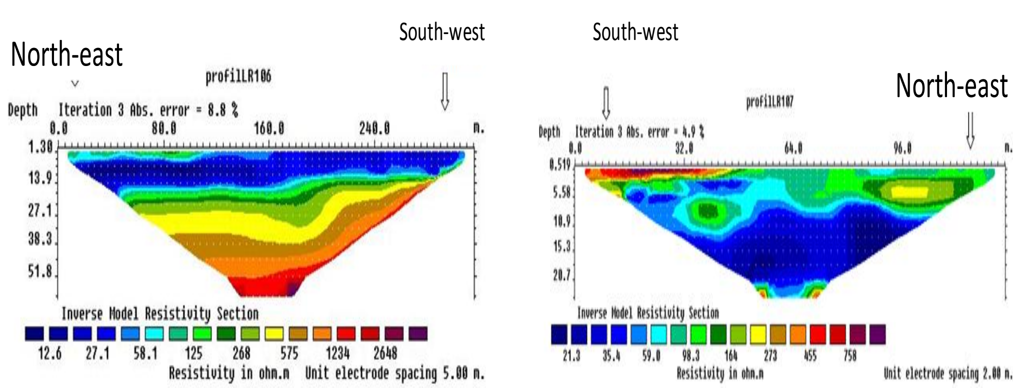


Fig.6 Lithological sections of the LR106 and LR107 models

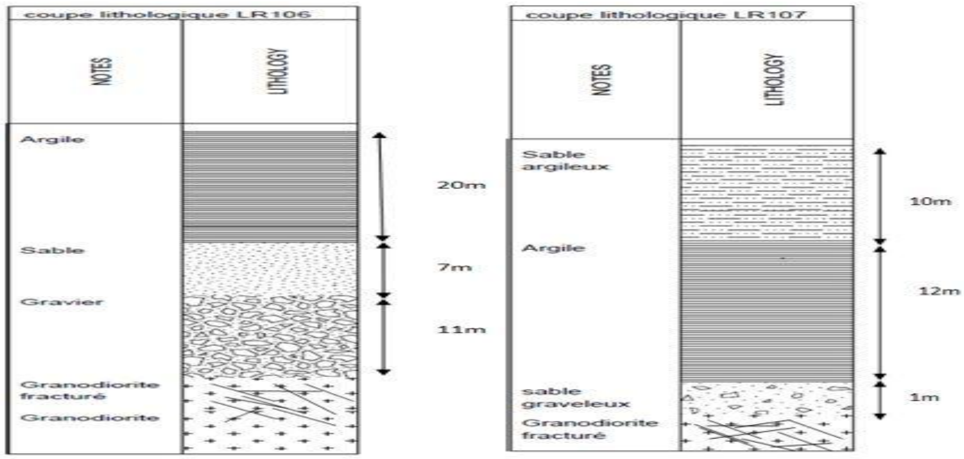


Fig.7 Stratigraphic cut of PZRDG and PZRDF boreholes

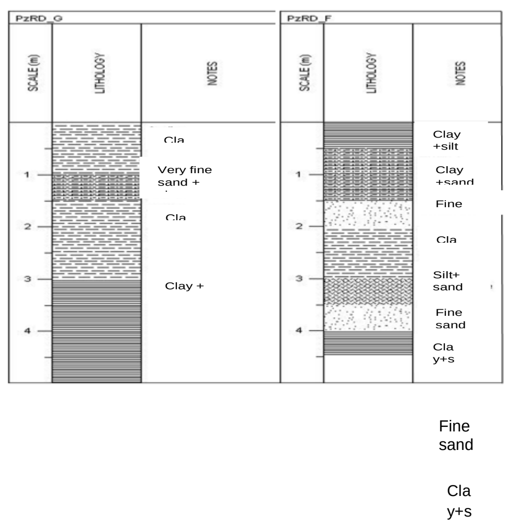


Fig.8 Lithological section of profile LR00093

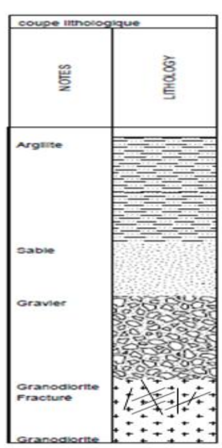


Fig.9 Lithological sections of models LR00094 and LR00096

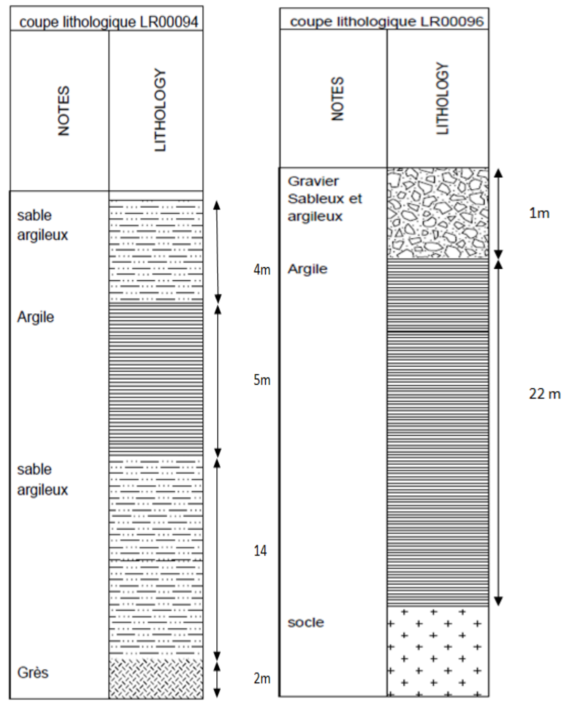


Fig.10 Lithological cut of models LR106 and 107

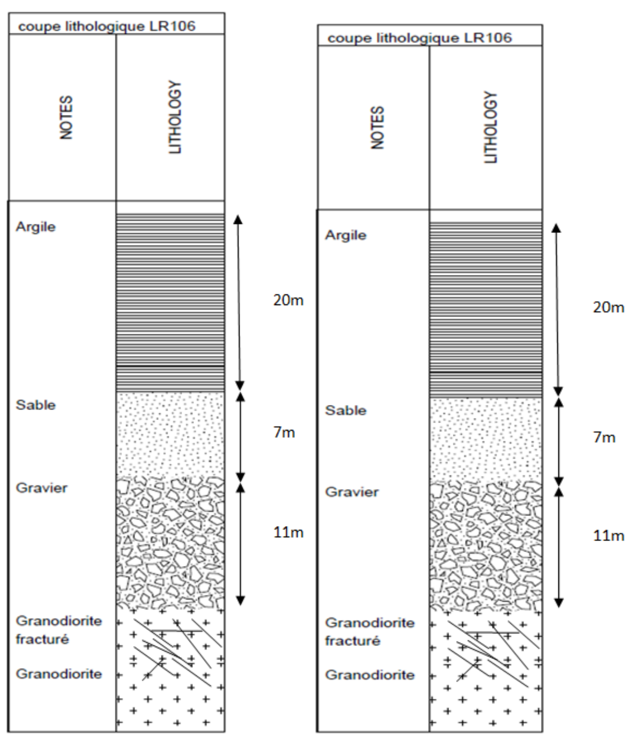


Fig.11 Lithological sections of models LR00098 and LR102

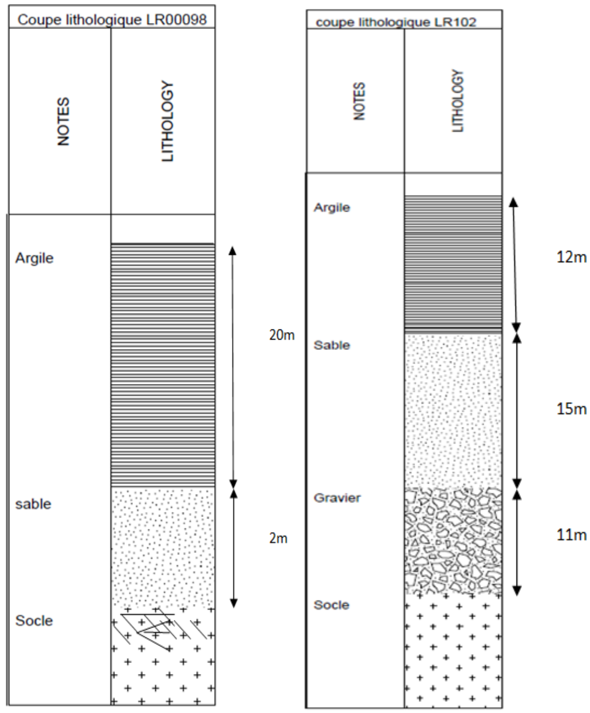


Fig.12 Vertical distribution of materials in the plain

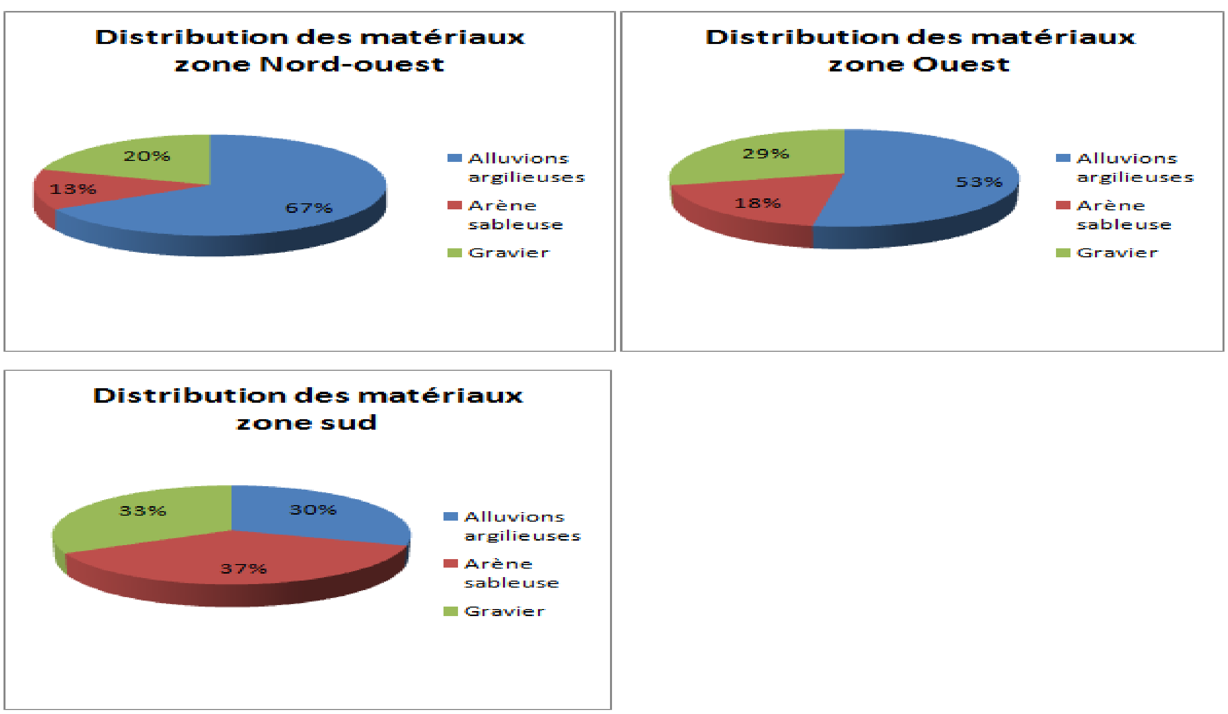


Fig.13 3D Conceptual model of the plain

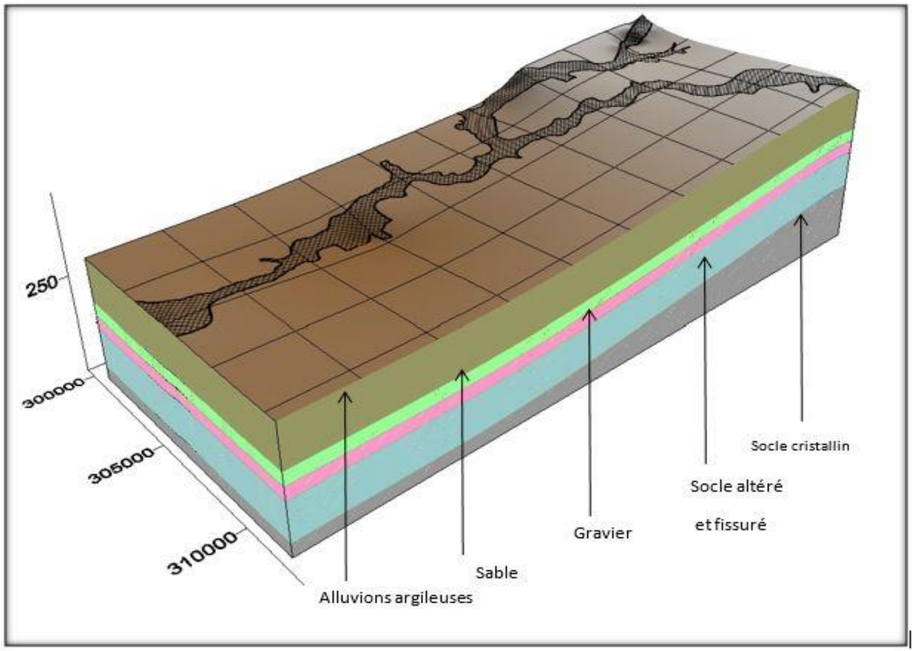
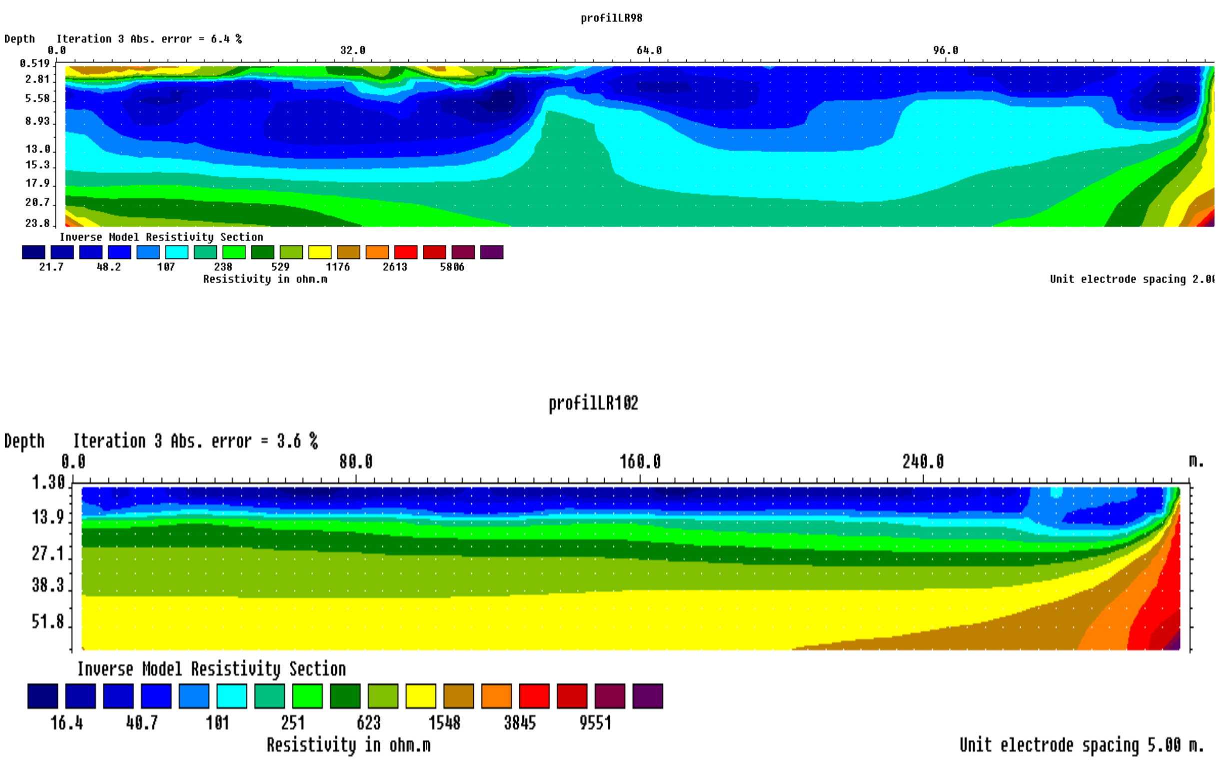


Fig.14 Extended models of LR102 profiles at the top and LR98 at the bottom



In conclusion the soils of the alluvial plain of Karfiguela are generally very suitable for agriculture. However, the considerable decrease of the flow of the river in the dry season that has spread to the large plain is problematic. To overcome this, a solution has been found.

Indeed, the solution adopted was to study the alluvial aquifer so that it could be a source of water complementary to the peasants, thus enabling them to carry out agro-pastoral activities in the wet season as well as in the dry season.

The aim of the study was to know not only the nature of the constituent materials of the alluvial aquifer but also to know its power knowing that these two parameters play an important role in quantifying the underground water resource.

The tomography of electrical resistivity associated with the wenner protocol was the geophysical technique that we used for this study. It is well suited for the characterization and vertical highlighting of horizontal layers. To support and confirm our geophysical results, we carried out forty nine (49) destructive probes (micro piezometers) auger, 6 meters deep, each with its stratigraphic log designed by tactile diagnosis from a one-step sampling. 0.5 meters. These samples were also subjected to a granulometric analysis in order to support the tactile diagnosis and to have an idea on the weight distribution of the grains of different diameters.

At the end of this analysis the overall picture that could be drawn was that particle size curves spread with grain diameter between 16 mm and less than 0.08 mm. All the methods led to the same results, which testify to the reliability of these studies. Geophysical measurements allowed us to detect ranges of resistivities ranging from the weakest (<100 ohm.m) for the highly conductive materials, through the averages (100 to 1000 ohm.m) to finish at the strongest (> 1000 ohm.m).

These resistivity values show a heterogeneity of the materials at the level of the studied plain and can be classified in three main groups according to the geology: The very clayey alluvium constituting the majority of the plain with proportions up to 67% according to the sites; sand and gravel occupying relatively small proportions. The power of the plain varies considerably according to the sites, it reaches 38 meters in the west and south zones, with saturated thicknesses varying between 19 and 37 meters

Today, we know the tabulation, the nature and the granulometry of the different materials of the plain from the topographic surface to the bedrock. We know what any potential reservoirs, their powers, their saturated and unsaturated thicknesses and their localization depths. This could therefore be a solid database for future implementation of productive works. Among the objectives, it was also a question of knowing the geological nature of the limits of the plain. This was determined by geophysics and field observations. Overall on the studied sites we have impermeable limits because constituted of crystalline rocks and / or compact sedimentary rocks. But this information is only punctual, to define the extent of these limits, a photo-interpretation study is necessary because it will make some geological correlation.

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