SIMPÒSIUM INTERNACIONAL QUALITAT AMBIENTAL DE LES AIGÜES LITORALS
12 novembre 2010

Geophysical Surveys for Delineating Salt Water Intrusion and Fresh Water Resources in the Oued Laou Coastal Aquifer, Morocco.

M. Himi [a], J. Stitou [b], L. Rivero [a], A. Salhi [b], J.C. Tapias [c] & A. Casas [a]

a) Department of Geochemistry, Petrology and Geological Prospecting. Faculty of Geology. University of Barcelona. c/. Martí i Franquès s/n. 08028-Barcelona. Spain, E-mail: himi@ub.edu
b) Department of Geology, Science Faculty, University of Abdelmalek Essadi, Tétouan. BP. 2121 M'Hanch II , 93030 Tétouan Morocco .
c) Department of Natural Products, Vegetal Biology and Soil Science. Faculty of Pharmacy. University of Barcelona. Avda. Joan XXIII s/n. 08028-Barcelona. Spain,

1. INTRODUCTION

Hydrogeological studies are very important to investigate and remedy this contamination problems but an integrated use of both geophysical and hydrological methods can be even more effective in a large class of environmental phenomena as will be the saltwater intrusion in coastal aquifer. The large resistivity contrast between the salt water-saturated formation and the fresh water-saturated ones have been used by many investigators for studying the salt water intrusion in coastal areas.

In this survey we have used in combination with hydrogeochemical study, the electrical and the electromagnetic prospecting. The area of application has been the Oued Laou aquifers situated at the north of Morocco.

2. METHODOLOGY

Electromagnetic geophysical methods make use of electromagnetic induction to measure the electrical resistivity of the ground. Systems typically consist of a transmitter loop or coil through which a time-varying current is passed. This current produces a time-varying magnetic field which induces current flow in nearby electrical conductors, such as water saturated geologic materials in the subsurface. The induced currents, in turn, produce a secondary magnetic field which is detected as a voltage in the receiver coil (Figure 1). The strength of this voltage is influenced by the electrical resistivity of the subsurface material. In this case, we have used as instruments Geonics EM34. (McNeill 1980).

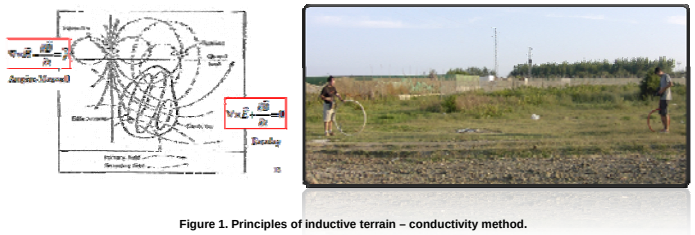

Figure 1. Principles of inductive terrain – conductivity method.

A recent technological breakthrough has been related to the appearance of multi-electrode imaging systems. The simultaneous use of a large number of in-line electrodes allows the imaging systems to combine electrical sounding and profiling in one field set-up without the need for redeploying the electrodes, providing nearly instant depth coverage. The line of electrodes is quickly scanned from one end to the other by an automated communication system, which collects readings from all possible four-electrode combinations (Figure 2). The combined apparent-resistivity data set can then be directly imported into a computer-inversion program that generates a detailed two-dimensional (2D) true resistivity section. The multi-electrode systems expand the capabilities of the traditional electrical method, combining speedy data collection with the possibility of achieving 2D images of the subsurface. (Loke and Barker, 1996).

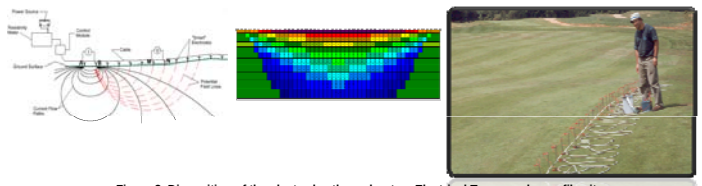

Figure 2. Disposition of the electrodes throughout an Electrical Tomography profile site

3. GEOGRAPHYCAL AND GEOLOGICAL CONTEXT

The basin of Oued Laou is situated at the north of Morocco belongs the provinces of Tétouan and Chefchaouen, and spreads on a surface of approximately 930 km^2. The extension of the aquifers object of this study is of approximately 18 km^2 (Figure 3).

Geologically, the materials that constitute the formations are essentially the Neogene and Quaternary deposits (Durand-Delga et al., 1962). The Quaternary is formed by gravels, sands, silt terraces and clays.

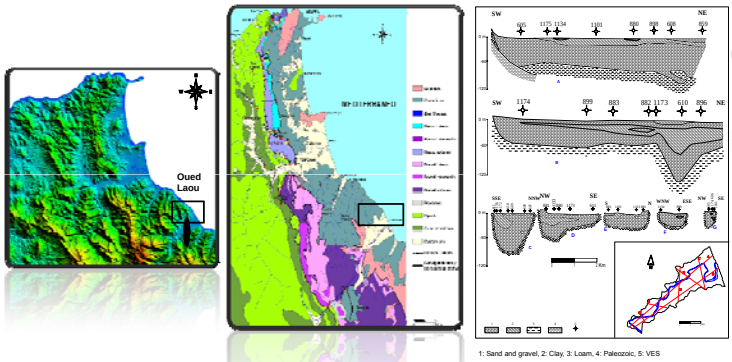

Figure. 3 Geological map and hydrogeological cross-section .

4. RESULTS

The hydrodynamic behaviour of the aquifer shows a lateral flow modality, from recharge area up to the drainage area; it is an unconfined aquifers flow system imposed by the topography, the disposition of the materials, the presence of the Laou River as well as the gravitational irrigation network. (Stitou, 1995).

The curvature and trend of piezometric level identifies a radial converging water table, characterizing the area drained by the Laou River; and a radial diverging water table, especially near the mouth of the river. (Figure 4).

The electrical conductivity and temperature recorded in the water well 894/4 located about 880 m from the coastline indicate a low variation of temperature (ranging from 20.8º C to 21.2 ºC). in the opposite, the electrical conductivity log indicate a values of about 636 µS/cm at toping of the record and stays constant until a depth of 55 meters where increases in a very quickly to reach the 30100 µS /cm at the bottom of the well (Figure 5).

Figure 4 . Piezometric map of the Oued Laou aquifer

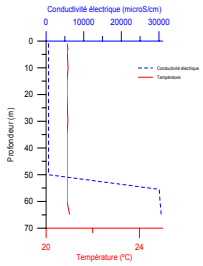

Figure 5. Temperature and electrical conductivity logs of groundwater.

The electromagnetic method was used with the objective to obtain qualitative maps of electrical conductivity variation as much laterally as with depth. For that reason we have used the two dipole configurations and the three separations between coils. A total of 67 soundings have been carried out. The Figure 6. shows the contoured apparent conductivities as measured with the EM34-3 with 10 HD (a), 20 HD (b), 40 HD (c) and 40 VD (d).

The apparent electrical conductivity values are below 50 mS/m except in two zones stuck to the coastline: The first one at the NE of the basin and second one at the environs of the mouth of the river and where the maximums values were registered (over than 300 mS/m). At the same time we observed that the electrical conductivity values increases with depth.

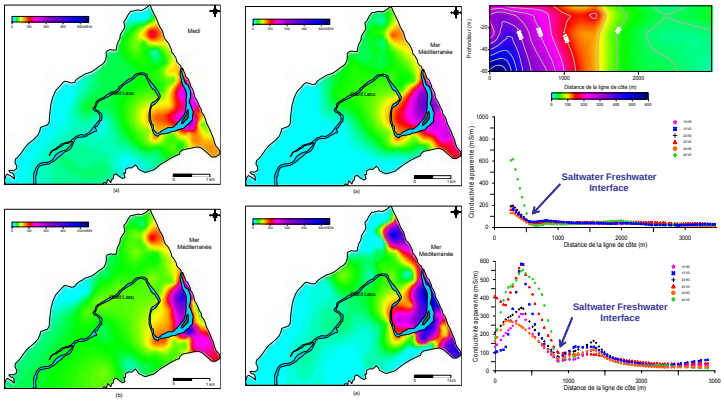

Figure 6. Apparent conductivity maps obtained from EM with 10 HD, 20 HD, 40 HD and 40 VD.

The electrical resistivity tomography data were collected along 5 profiles using the Wenner-Schlumberger array. The electrode spacing along each profile was 10 m and with a total of 48 electrodes.

For the profile 1, situated at the North-East of the area of survey, we differentiate 3 levels, the first superficial layer with a resistivity of about 30 Ωm, and a variable thickness (2 to 15 m). The second layer with a horizontal and continuous aspect and a resistivity values more than 100 Ωm and a thickness of 40 m. finally the deeper layer with values less than 10 Ωm (Figure 7).

The correlation of the electrical resistivity values with the geological information offered in the lithological column (F-608/4) allow as to attribute the superficial conductive level to the clays and sandy clays. The second resistive level corresponds to gravel and finally the deep conductive level to clays and sands saturated with saltwater.

For the profile 2, situated near the coastline, in the inverse model, the low-resistivity value of about 5 Ωm (Figure 7), which is located at the bottom of the section, corresponds to the saline water. The fresh-water layer floats on top of the saline water, since fresh water has a lower density than saline water. In this case, the origin of the salinity is directly related to the intrusion of the saltwater.

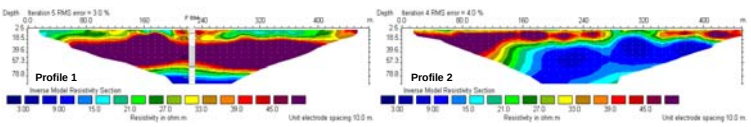

Figure 7. D resistivity cross-sections

5. CONCLUSIONS

The application of the electrical tomography has allowed us to characterize the geometry and composition of the geological formations in the Oued Laou valley. The existence of documented geological logs in the boreholes has made easy the interpretation of the vertical electrical soundings and frequency domain electromagnetic data.

At the same time, electrical tomography sections have detected very low resistivity values related to geological formations saturated salty water. The electromagnetic prospecting in domain frequency allowed delimiting in turn the areas with major or minor value of conductivity. In this case, the zones with high values of conductivity are very limited in the surrounding areas of the line of coast, and to the southeast of the Laou River.

6. REFERENCES

Durand-Delga, M., Hottinger, L., Marcais, J., Mattawer, M., Milliard, Y. and Suter, G. [1960] Données actuelles sur la structure du Rif. M. h. Sér. Soc. Géol. Fr. (Livre, Mém. P. Fallot), 1, 399-1057.
McNeill, J. D. [1980] Electrical conductivity of soil and rocks. Geonics Ltd. Technical Note TN-5.
Loke M. H. and Barker R. D., 1996. Rapid least-squares inversion of apparent resistivity pseudosections by a quasiNewton method. Geophysical Prospecting, 44, 131-152.
Stitou, J. [1995] Contribution à la connaissance hydrogéochimique des aquifères côtiers Martil-Alila, Oued Laou et Smir. Thèse de 3° cycle, Université Abdelmaleh Essadi. Tétouan. 155 pp.