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METHODOLOGICAL CONTRIBUTIONS RELATING TO GEOPHYSICAL DATA ACQUISITION AND PROCESSING METHOD OF ELECTRICAL RESISTIVITY AND TOMOGRAPHY
CASE STUDY

BY

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Abstract. In this paper, the electrical resistivity tomography with Schlumberger configuration is used in the detection of the contaminated soils by hydrocarbon in several places situated nearby an oil terminal. The obtained results were compared to the results obtained in 2001–2003 and to 2015 data taken in the same places in order to establish the evolution of the contaminants.

Key words: methodological contributions; hydrocarbon pollution; Vertical Electrical Sounding; monitoring.

1. Introduction

In recent years, Vertical Electrical Sounding (VES) techniques have become useful in the characterization of contaminated soils by hydrocarbons. These contaminants may be present in the subsurface as chemicals dissolved at

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low concentration in the interstitial water and in the groundwater (Arrubarrena-Moreno & Arango-Galván, 2013; D'Antona & Rocca, 2002; EPA 542-R-00-008, 2000). One of the most perturbed properties in the presence of hydrocarbons is the electrical resistivity of the ground materials.

In this paper the characteristics of the subsoil in some places nearby an oil terminal was determined in order to establish a relationship between the variation of the soil property and the evolution of the contaminants.

2. Fundamentals of VES Method

In the VES method artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured (Palacky, 1987). Deviations from the pattern of potential differences expected from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneity.

Most rock-forming minerals are insulators, and electrical current is carried through a rock mainly by the passage of ions in pore waters. Thus, most rocks conduct electricity by electrolytic processes (Pozdnyakova *et al.*, 2001).

Let us to consider an elementary orthogonal cylinder, of the length dl and of the section area dA, of homogeneous material with resistivity ρ. The electric resistance of this cylinder is given by the equality:

$$\mathrm{d}R = \rho \frac{\mathrm{d}l}{\mathrm{d}A}. \tag{1}$$

If a current I is passed through the cylinder, causing a potential drop – dV between the ends of the cylinder, such that – dV = dRI, from the equation (1) one can obtain:

$$\frac{\mathrm{d}V}{\mathrm{d}l} = -\rho \frac{I}{\mathrm{d}A} = -\rho j\,, \tag{2}$$

where: dV/dl represents the potential gradient through the elementary cylinder and j is the current density. The current density in any direction within a material is given, in general, by the negative partial derivative of the potential in that direction divided by the resistivity. The circuit is completed by a current sink at a large distance from the electrode. Current flows radially away from the electrode so that the current distribution is uniform over hemispherical shells centered on the source. At a distance r from the electrode the shell has a surface area of $2\pi r^2$, so the current density j is given by:

$$j = \frac{I}{2\pi r^2}. \tag{3}$$

From eq. (2), the potential gradient associated with this current density is:

$$\frac{\mathrm{d}V}{\mathrm{d}r} = -\rho j = -\frac{\rho I}{2\pi r^2}. \tag{4}$$

The potential V_r at distance r is then obtained by integration:

$$V_r = \int \mathrm{d}V = -\int \frac{\rho I \mathrm{d}r}{2\pi r^2} = \frac{\rho I}{2\pi r}. \tag{5}$$

The constant of integration is zero since $V_r = 0$ when $r = \infty$.

Eq. (5) allows the calculation of the potential at any point on or below the surface of a homogeneous half-space. The hemispherical shells in Fig. 1 mark surfaces of constant voltage and are termed constant potential surfaces.

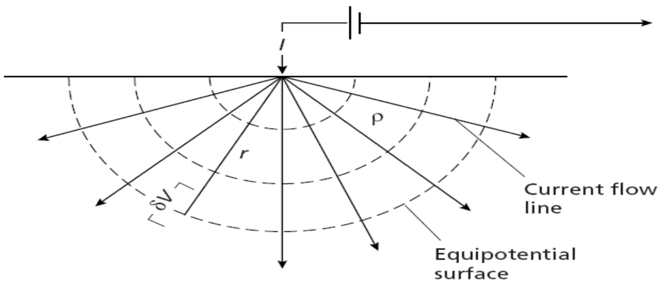


Fig. 1 – Current flow from a single surface electrode in an homogeneous soil.

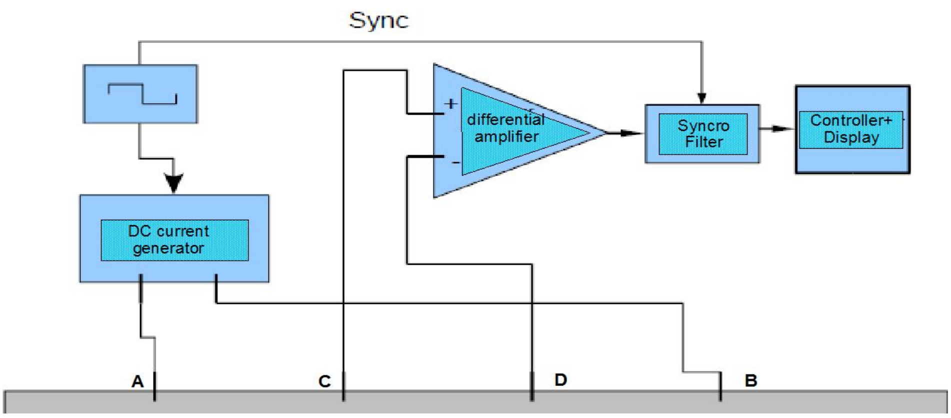


Fig. 2 – Block diagram of resistivity measurements (Călin Dan & Paul, 2011).

In Fig. 2 (Călin Dan & Paul, 2011) is a block diagram of the resistivity measurement tool. Calibration was performed following a data set of resistivities recorded and compared against the actual data measured on the ground. The measurable potential between electrodes C and D is:

$$\Delta V = V_C - V_D = \frac{\rho I}{2\pi}\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right], \tag{8}$$

hence,

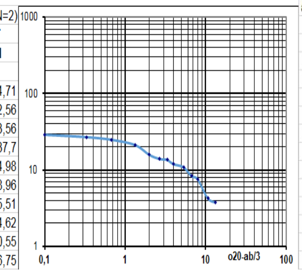
$$\rho = \frac{2\pi \Delta V}{I\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right]} = K\frac{\Delta V}{I}, \tag{9}$$

where: K is a coefficient that depends on the geometric arrangement of the four electrodes A, B, C and D (Samouëlian *et al*., 2005).

The acquisition data tool is a SuperSting R1/IP device. This is a tool for data recording, using single channel automatic surveys.

When the ground is uniform, the resistivity calculated from eq. (9) should be constant and independent of both electrode spacing and surface location. When subsurface inhomogeneity exists, however, the resistivity will vary with the relative positions of the electrodes. Any computed value is then known as the *apparent resistivity* ρ_a and will be a function of the form of the inhomogeneity. In homogeneous ground the depth of current penetration increases as the separation of the current electrodes is increased. The measured apparent resistivity values were plotted on a log-log graph paper.

ab/3	roa20	dv/I	k(MN=2)
0,1	29,00	**OILTERMEST**	
0,33	27,00	**SEPT-22-2001**	
0,67	25,00		
1,33	21,29	4,52	4,71
2	15,83	1,26	12,56
2,67	13,97	0,593	23,56
3,33	13,57	0,36	37,7
4	11,93	0,217	54,98
5,33	10,89	0,11	98,96
6,67	8,37	0,0538	155,51
8	7,55	0,0336	224,62
10,67	4,25	0,0106	400,55
13,33	3,76	0,006	626,75



ab/3	roa6/15	dv/i	k
0,1	36	**OILTERMEST**	
0,33	33	**FEB-12-2015**	
0,67	26,02	11,0262	2,36
1,33	12,21	1,03615	11,78
2	4,74	0,1725	27,48
2,67	4,10	0,0828	49,46
3,33	3,04	0,0391	77,72
4	2,58	0,023	112,3
5,33	2,99	0,01495	200,28
6,67	3,06	0,00977	313,4
8	3,09	0,00684	451,6
10,67	3,45	0,00489	706,1
13,33	3,98	0,00288	1384,7

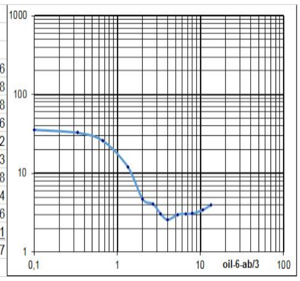


Fig. 3 – Apparent resistivity *vs*. depth of investigation diagrams (20/FC2-2001 *vs*. 6/15-2015).

A one-dimensional model of the subsurface was used to interpret the measurements. The processing of all data obtained from the ground geoelectrical measurements was done on the computer, using special programs. In a first stage, processing of the data obtained at each point of measurement led to the obtaining of apparent resistivity curves that represent the physical parameter of geological mass, tied to the strength of electric current into the ground. These curves can be seen on the right side of every one of the diagrams presented in the following pages (Fig. 3).

Resistivity survey instruments are designed to measure the resistance of the ground, that is, the ratio ($\Delta V/I$) (EPA 542-R-00-008, 2000) in eqs. (10) and (11), to a very high accuracy. They must be capable of reading the very low levels of resistance commonly encountered in resistivity surveying.

$$\rho_a = k \Delta v/I , \tag{10}$$

where:

$$k = \pi(AC \times AD/CD) , \tag{11}$$

and K is a coefficient that depends on the geometry of the ACDB array at a time.

This simplified formula is used in the practice of land measurement. Interpreting the data in the table 1 below is based on the general evolution of the phenomena of aquifers anthropogenic pollution.

Table 1**,** Section Oil Terminal railway profile SCFR. Along the railways on the East side of the North-1 depot up to Unirea Depot. Here is an evolution of the chemistry face of the profile near the railway (East storage limit). The pollution phenomenon is still rising, reaching a resistivity value in 2015 with 46% lower than in 2001–2003. Columns 2 shows resistivity statistics on 2015 measured data and column 3 shows resistivity statistics on 2001–2003 measured data. The 4 and 5 columns show the statistic balance.

Table 1

SCFR 2015 SCFR 2001-2003

	ρ_a (Ωm)	ρ_a (Ωm)	2015vs2001-03	2001-03 vs. 2015
Date number	65	78		
Sum	1010.44	2210.99	-54.30	118.81
Minimum	2.58	4.81	-46.26	86.09
Maximum	63	99	-36.36	57.14
Mean	15.55	28.35	-45.16	82.35
Stand. Dev.	17.32	27.52 casting	-37.09	58.93

3. Case Study. Pollution with Hydrocarbons

The character and quality of these geophysical results, have a great influence also in other application domains, the results are influenced by the type and number of geophysical methods used and of the adequacy of their structural context under investigation.

The existence of oil deposits in urban infiltration may occur in the foundation of the buildings as a result of accidents, by damaging the tanks or the transfer of products at loading ramps. Research by the vertical electrical sounding (VES) with Schlumberger array could delineate up pollution plume produced in both space and drainage direction. Measurements taken after several years highlighted a progress of pollution in street basement (Georgescu *et al*., 2004; Kearey *et al*., 2002).

The study zone is located at the east of an oil terminal. Because of confidentiality issues, the precise location of the area cannot be given (Fig. 4). Many hydrocarbon spills are exposed on the surface and also in the subsoil and groundwater. Some preliminary studies (*i.e.* smell tests, chemical sampling) allowed identification of some contaminated spots showing a concentration above the allowed standard limit. Thus, we have used the vertical electrical sounding VES technique in order to assess the contaminated industrial zone and establish a relationship between electrical resistivity and the presence of pollutants.

Fig. 4 – Location of study area. The oil reservoirs are situated in the left part of the map.

4. The Interpretation of Electrical Resistivity

Vertical electric survey or vertical electro sounding (VES) is to be carried out in a certain point of view, several apparent resistivity measurements with continuously increasing lengths of emission line AB. In this way is obtained a curve variation of apparent resistivity according to AB/2, which is considered to represent the average depth of investigation of the device. Layered environments use AB = 1/3 as depth of investigation (Georgescu *et al.*, 2004).

This curve (curve VES) indicates the variation of the actual vertical resistivity of observation point. Making vertical electric soundings by conducting several observation points, located along a profile, you can get a section of apparent resistivity and called in the works specialized pseudo sections surveys. This image which also appears in the quantitative/qualitative interpretation leads to the achievement of geoelectrical interpretive sections, as a reflection of geological structure on the sought profile (Figs. 5 and 6).

Electrical resistance is sensitive to water content and ionic concentrations. Electrical resistivity tomography ERT is a very attractive method for geologic medium characterization. This method is non-destructive and can provide continuous measurements over a large range of scales. In this way, temporal variables such as water and plant nutriment, depending on the internal soil structure, are monitored and quantified without altering the soil structure.

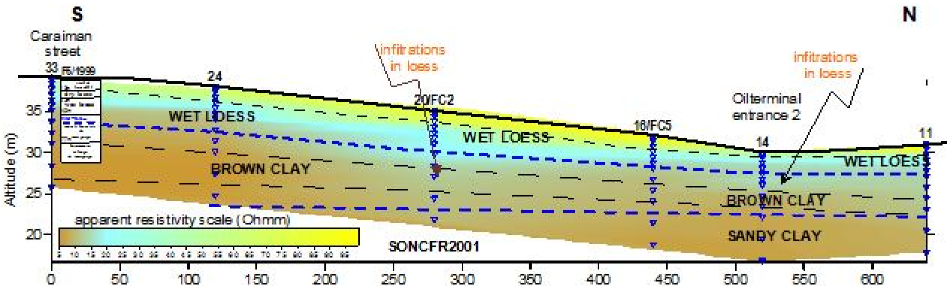


Fig. 5 – Resistivity cross section along railway in 2001.

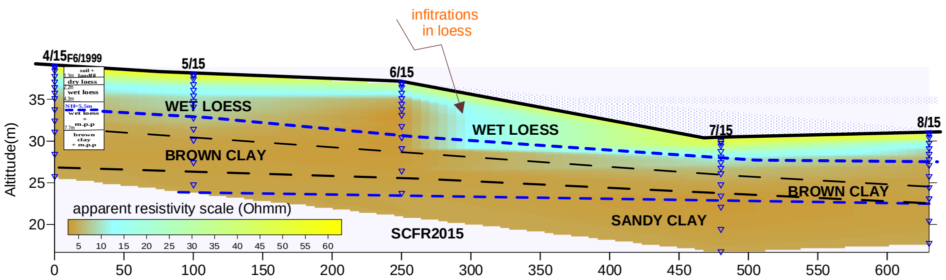


Fig. 6 – Resistivity cross section along railway in 2015.

5. Conclusions

The apparent resistivity of clay, normally, takes value between 30 and 60 Ωm but in our case, it takes values between 10 and 20 Ωm determined by petroleum fluids solved in groundwater.

The two images are remarkable for the evolution of geophysical phenomena of subsoil pollution in the living area. By linking urban and drilling information inside the Oil terminal North it was concluded that the fixes made from cracked tanks in parallel to the network of domestic sewage in the surveyed area resulted in the growth of the phenomenon of visible pollutants. Damage to the loesoid level (land sensitive to wetting (LSW)) through the intake of fluids with oil products was overlapped and it emphasized the contribution of sewage from urban network.

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REFERENCES

Arrubarrena-Moreno M., Arango-Galván C., *Use of Electrical Resistivity Tomography in the Study of Soil Pollution Caused by Hydrocarbons: Case Study in Puebla (México),* Boletín de la Sociedad Geológica Mexicana, **65**, *2*, 419-426 (2013).

Călin Dan S., Paul G., *Contributii la dezvoltarea tehnicilor de achizitie, prelucrare si interpretare a datelor geofizice utilizate in arheologie.* Fac. de Geol. şi Geof., Bucureşti, 2011.

D'Antona G., Rocca L., *Electrical Impedance Tomography for Underground Pollutant Detection and Polluted Lands Reclaiming Monitoring*. IEEE Instrumentation a. Measur. Technol. Conf., Anchorage, AK, USA, 21-23 May 2002, 1035-1038.

Engineered Approaches to In Situ Bioremediation of Chlorinated Solvents: Fundamentals and Field Applications. EPA 542-R-00-008, U.S. Environmental Rotdon Agency, Office of Solid Waste and Emergency Response Technology Innovation Office, Washington, DC 20460, July 2000.

Georgescu P., Niculescu V., Mafteiu M., *Cercetări geoelectrice pentru ape potabile minerale în zona Zizin, Borsec, Racu.* Arhiva Biroului de Expertiză şi Consulting, Fac. de Geol. şi Geof., Bucureşti, 2004.

Kearey P., Brooks M., Hill I.. *An Introduction to Geophysical Exploration.* Blackwell Science, 2002.

Niculescu V., Mafteiu M., *Studiu hidrogeofizic privind captarea de ape subterane Breaza – Bădeni, jud. Vrancea.* Arhiva Biroului de Expertiză şi Consulting, Fac. de Geol. şi Geof., Bucureşti, 2001.

Palacky G.J., *Resistivity Characteristics of Geologic Targets.* Electromagnetic Methods in Applied Geophysics, *1*, 53-129 (1987).

Pozdnyakova L., Pozdnyakov A., Zhang R., *Application of Geophysical Methods to Evaluate Hydrology and Soil Properties in Urban Areas*. Urban Water, *3*, 205-216 (2001).

Samouëlian, A., Cousin, I., Tabbagh, A., Bruand A., Richard G., *Electrical Resistivity Survey in Soil Science: a Review.* Soil and Tillage. Res., *83,* 173-193 (2005).

CONTRIBUȚII METODOLOGICE PRIVIND ACHIZIȚIA ȘI PRELUCRAREA DATELOR GEOFIZICE PRIN METODA REZISTIVITĂȚII ELECTRICE ȘI TOMOGRAFICE
Studiu de caz

(Rezumat)

Datorită transmisivității specifice a rocilor loesoide, considerăm că, fenomenul poluant continuă multă vreme după posibila eliminare a cauzei (reabilitarea rezervoarelor şi rețelei de conducte, port-oil terminal şi interior-oil terminal). Verificarea evoluției fenomenului presupune o monitorizare, cel putin semestrială, printr-un complex de metode geochimice şi geoelectrice pe locații bine stabilite. Articolul prezintă pe scurt aparatul matematic şi tehnica de achiziție şi prelucrare a datelor de măsură electrometrice folosind un studiu de caz – poluarea terenurilor cu produse petroliere. Există totuşi unele informații de foraj şi urban-edilitare care certifică eficiența metodei clasice a sondajului electric vertical (SEV) efectuat pe profile reprezentative în jurul sursei de anomalii (depozit de produse petroliere cu pierderi în mediul geologic). Interpretarea integrată a informațiilor geofizice şi geotehnice este o corelație sinergică cu orice informație din zona cercetată.