Larhyss Journal, ISSN 1112-3680, n°19, Septembre 2014, pp. 7-17

GEOPHYSICS AND PHYSICO-CHEMICAL COUPLED APPROACH OF THE GROUNDWATER CONTAMINATION. APPLICATION IN A POLLUTION BY THE LANDFILL LEACHAT OF OUJDA CITY (EASTERN MOROCCO)

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ABSTRACT

The urban waste produced by Oujda city, mixed with solid waste of industrial and hospital origin, was disposed since 1990 until 2005 on an open-air landfill situated approximately 7 km southeast of the city center. The groundwater circulates deeply (25-30 m) in grounds post-Miocene on an impermeable substratum formed by the marls of Miocene. The ground is calcimagnesic not very deep, with a more or less important layer of silts and clays.

To evaluate the impact of the leachate resulting from this landfill on groundwater quality, samples of leachate and groundwater were taken during the year 2005 (five samples of leachate inside the landfill) (three groundwater samples were taken from three wells located near the landfill) and two profiles of recognition by electric imaging were realized according to the device pole–pole two dimensional (2D) inside the landfill. The analyses of the sample leachate revealed strong content of Chemical oxygen demand (COD max = 30760 mg/l), biodegradable organic matter (DBO_5 max = 653.3 mg/l) and of mineral matter (conductivity: max = 63.73 mS/cm). The analysis of groundwater revealed that NO_3^- presents an average concentration higher than 50 mg/l (Standard suggested by WHO). The concentration of chloride exceeds 1450mg/l (Standard suggested by WHO is 600 mg/l for fresh waters). Concerning heavy metals, the concentrations of Iron, Zn and Ni largely exceed the French values standards fixed for groundwater, while the Cd contents are lower than this standard.

The results of the geo-electric prospecting showed that the very low electric resistivities (5 ohm.m), were observed in the inside and in the direct approval of the landfill site. These results highlight zones electrically very conductive, they indicate the progress of the pollution plume in the under ground. The central part of the landfill site is the place under which the contamination affected depths of 20m. These data plead in favour of a strong mineralization of waters circulating in the trainings approached the site, whose potential source is bound to a contamination by leachate very mineralized and charged in organic matter.

Keywords: Landfill; Geophysics; Electric resistivity; COD; Leachate; Groundwater.

INTRODUCTION

The demographic growth, the consumption without proper judgment and the intensification of the economic activity are on the base of the production of the solid and liquid waste. Since a few years, the domestic garbage landfills became one the main sources of pollution, contamination and nuisance. According to Abdelli (2005), the landfills were traditionally built supposing that the neighbouring ground and the groundwater were capable of diluting leachates and of limiting their effect. However, several authors showed that in Morocco, the great majority of the public landfill has a fatal effect on the components of the receiving environment, in particular the groundwater (Elkharmouz et al., 2005; Chtioui et al., 2008; Chofqi et al., 2004; Rassam et al., 2012).

In Oujda city (Eastern Morocco), the old rehabilitated landfill is situated approximately 7 km far from the city center. The site of landfill is a basin which the geologic substratum is calcareous with a calcimagnésic shallow ground and a more or less important layer of clay and silt, it is situated in the meander of a temporary river. The level of the groundwater was measured in 30 m of depth under the surface of the ground (Sbaa, 2001). Since its opening in 1990 until its closure in 2006, this landfill received daily 304 tons of mixed solid waste (urban, industrial and hospital).

The degradation of waste deposited on the site and their interaction with the precipitation engenders enormous quantities of leachate containing bacteriological, organic and mineral pollutants. They stagnate inside the landfill or leave it in rainy periods, as they can infiltrate under ground causing an insidious degradation of groundwater. The main objective of this present work is to show the impact of leachate produced by the old landfill of the Oujda city on subterranean waters. In this optic, we proceeded to recognition by electric imaging of the site polluted by the landfill and in a characterization physico-chemical of the leachate and groundwater.

STUDY AREA

The study area is located approximately 7 kilometers in the south part of Oujda City center and only some kilometers away from the Algerian border (Figure 1). The total surface covered by waste is 41 ha. The landfill is in exploitation since 1990 and it is rehabilitated n 2006.
The landfill is a basin in calcareous geologic substratum with a calcimagnesic ground and a less important layer of clay and silt, it is situated near a temporary river. The level of groundwater was measured in 30 m under the soil surface and the aquifer flows of the South and the southwest towards the North and Northeast.
Concerning the geology of the study area, the base begins with the Paleozoic which appears at Jbel el Hamra in the South of the Oujda city. In angular conflict come to settle red clays of Trias followed by dolomitic calcareous of Lias constituting the deep aquifer. Above, we find successively, a thick series of Miocene marls, volcanic formations of Plio-Quaternary and alluvial and lakeside formations of the Quaternary (Mortier et *al.*, 1975). on the structural plan, important geological faulting of direction NE-SW affect the area study, tow geological faulting cross the landfill site, the one in its central part and the other one in its north border.

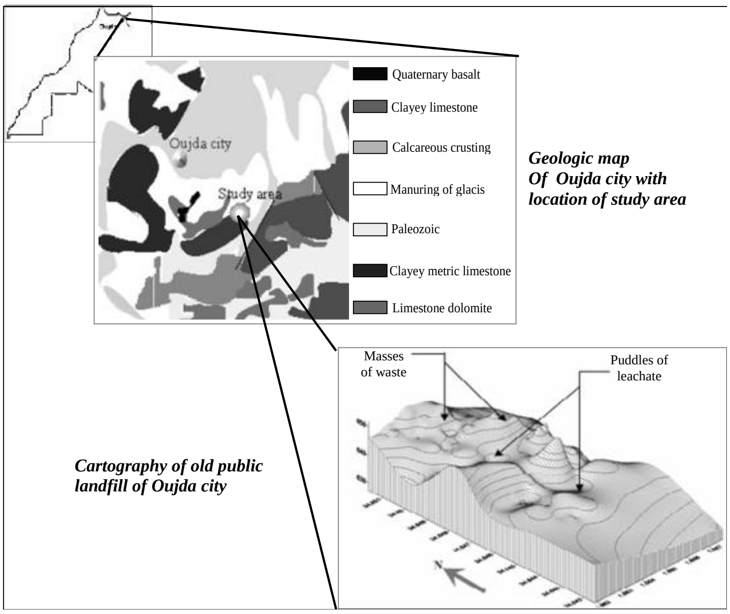

Figure 1: Geological map of the landfill's setting

MATERIALS AND METHODS

Sampling and physico-chemical analyses

To achieve the present study, leachates was sampled during January, February and March, 2005, inside five puddles scattered in the landfill (figure 2). To know if leachate leaves the landfill or not, groundwaters were sampled, during the same period, at three wells deep of 28, 29 and 30m, situated in the approval of the landfill.

The physico-chemical characteristic of leachate and groundwater samples such as pH, temperature, electrical conductivity (EC), were measured in-situ, According to the standards NF ISO 10390 et NF ISO 11265, while chloride (Cl), sulphate (SO_4), nitrites (NO_2), nitrates (NO_3), ammonia-N (NH_3-N) and biological parameters (COD, BOD5) were analysed in the laboratory according to the methods described by Rodier, 1986. The heavy metals (Pb, Zn, Ni, Cr, Cd, Cu, Fe, As, Co) were measured by spectrometry atomic absorption type Varian.

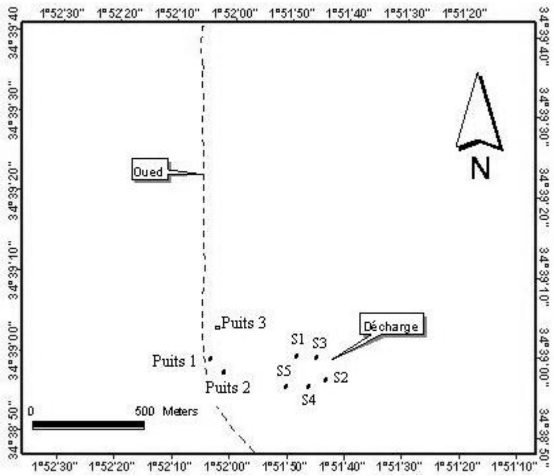

Figure 2: Leachate and ground water sampled

GEOPHYSICAL SURVEY METHOD

In the optic to know the extension of the pollution in the basement of the landfill site and to bound the leachate plumes, we realized on the cleared part of the landfill two profiles 2D of Electrical resistivity tomography , 235 meters in length (Figure 3). The first profile was realized in the North-South direction and the second in the East-West direction. To accomplish this study, stainless steel electrodes are driven into the ground at regular intervals and a multiconductor cable and switching system is connected so that each electrode can be automatically switched on either current transmission or voltage measuring mode. A full profile is measured by sequencing between all possible transmitter and receiving pairs along the cable. A pole–pole array was chosen based on the ability to resolve deeper targets with shorter lines compared to other array types.

For every measure, two electrodes (A and B) constitute the sources of current I and two electrodes (M and N) measure the difference of potential ΔV (Grellier, 2005). The electric method serves to study the resistivity ρ of a complex environment 2D or 3D. Every measure (ΔV) made on the ground is standardized at first in the form of visible resistivity: $\rho_a = K. (\Delta V/I)$. The visible resistivity is not representative of the true resistivity of every element. To obtain an image of the under ground, the data will be inverted to obtain resistivities called interpreted.

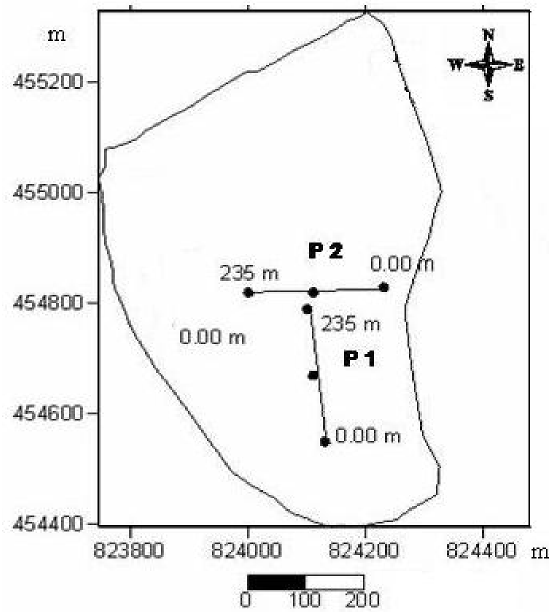

Figure 3: Localization of the electric profiles P1 and P2.

RESULTS AND DISCUSSIONS

Physico-chemical parameters of leachate and groundwater

The results of physico-chimical characterization of the leachate indicated in the Table 1, allowed us to reveal a strong organic pollution presented by a big value of the COD (12780 mg/l of O_2) and of the BOD_5 reached 525, 34 mg/l of O_2.

These two values exceed the acceptable standards. Indeed, they are superior to the values found by chofqi et *al.,* (2004) in the landfill leachate of El Jadida City (Morocco) and those found by Mekaikia Mokhtaria et *al.,* (2007) in the landfill leachate of Tiaret city (Algeria). In this organic pollution, is added a mineral pollution presented by strong concentrations of chlorides (11800 mg / l) and nitrates (29.76 mg /l).
The organic and mineral pollution conveyed by the leachate analyzed echoes on groundwaters circulating below the landfill. Indeed, the treatment of the results indicated in the Table I, showed an important qualitative degradation of groundwater, particularly in sectors situated downstream to the landfill. In these polluted areas, the electric conductivity varies between 2.43 mS/cm and 5.77 mS/cm, it exceeds the French standards of drinkability (1.5 mS / cm). This very variable mineralization of groundwater, in the environmental context of the area, could result from the pollution by the landfill leachate (Elkharmouz et *al.,* 2005). The chlorides oscillates between 350 mg/l and 1450 mg/l, with an average of 710 mg/l. Nitrates in sampled waters, reach 74,62 mg/l, exceeding widely the value guide maximal recommended by the WHO (50 mg/l). The strong contents in chlorides could be only of organic origin, because the ion chlorides accopanies the ion nitrate in the case of groundwater pollution by domestic waste (Tandia, 2000).

Table 1: Physico-chemical characterization of the leachate and ground water.

	Leachate			**Ground water**		
Parameters	*minimum*	*maximum*	*Average*	*minimum*	*maximum*	*Average*
Tem (°)	14.25	14.9	14.54	11.17	13.2	12.46
O_2 (mg/l)	0.18	1.05	0.76	***	***	***
pH	7.91	8.11	7.98	7.3	8.25	7.85
EC (mS/cm)	32.18	63.73	49.49	2.43	5.77	3.9
Cl^- (g/l)	7.98	15.43	11.8	0.35	1.45	0.71
NO_3^- (mg/l)	13.42	39.11	29.76	34.9	170.6	74.62
NO_2^- (mg/l)	1.35	3.01	2.39	0.2	1.5	0.88
PO_4^- (mg/l)	3.49	6.57	4.9	0	0	0
COD (g/l)	7.45	30.76	12.78	144	175	133
BOD_5 (mg/l)	436.6	653.3	525.34	***	***	***

Metallic quality of groundwater

The analysis of the composition in heavy metals of the leachate studied highlighted the important metallic pollution of this leachate, In spite of its typical composition of a landfill with dominant domestic character. The concentrations in Zn, Cu, Ni, Cr and especially iron is abnormally brought up in the leachate, they take average values respectively of 619.22 µg/l, 318.12 µg/l, 233.76 µg/l, 169.16µg/l et de 12940µg/l(Table II). These values are superior to those found by Elkharmouz and al. (2005) in the leachate of the same landfill and found by Djorfi and al. (2010) in the landfill leachate of Annaba city

(Algeria). The analysis of heavy metals in ground water showed that there is almost absence of Cu and Pb in spite of their strong concentrations in the raw leachate. Almost absence of these two metallic species in ground waters is explained by their adsorption by particulaires and organic constituents of the leachate and the basement. Indeed, Pitt and al. (1994), showed that in a pH close to 7 (7+/- 1) (pH of the landfill leachate), the copper is reduced to Cu_2^+ witch is the main shape of the copper had complexes with the organic matter. Musy and al. (1991) showed that Pb presents a very strong affinity for suspension materials, until 99 % of Pb can be fixed there. The contents in Fe, Mn, Zn, Co, As and Ni exceed the French standard values fixed for ground waters (Martens, 1995), whereas the contents in Cd are below this standard.
The metallic load of the lixiviats presents an enormous risk for ground waters because of the shallow depth of subterranean waters circulating in the landfill area, the permeability of the not saturated area and the degraded state and saturated of calci-magnésics soil of the landfill site, favoring the phenomena of infiltration and of percolation of leachate and their metallic load.

Table 2: The contents of leachate and ground water in heavy metals

	Leachate			Ground water		
heavy metals (µg/l)	*minimum*	*maximum*	*Average*	*minimum*	*maximum*	*Average*
Fe	6400	28225	12940	158.2	4761	2938.07
Mn	36.3	635	247.48	53.5	365	256.17
Cr	82.8	274.3	169.16	5.7	13	9.23
Zn	177.1	1184	619.22	41.2	124.7	77.63
Cd	4.1	8.3	5.7	0.5	1.3	0.92
Ni	75.3	369.9	233.76	1.91	2.01	1.97
Pb	28.7	198	83.34	0.75	1.4	1.00
Mo	17.1	51.3	37.57	2	5	3.90
As	48.7	148.5	72.82	5.9	15.6	10.13
Co	21.4	25	23.7	11	17	16
Cu	106.4	694.5	318.12	<20	<20	<20

Electric prospecting results

Let us underline that chemical pollutants, by increasing the rate of the dissolved solid materials, tend generally to decrease the values of the resistivities of the environment which they contaminate, in particular the water (Ogilvy et al., 2002). In the area of study, conductivity electric of the ground waters spread out between 2 mS/cm and 5mS/cm what corresponds to resistivities electric which varies between 2,3 and 3,1 Ωm, While in leachate, the conductivity can go to 60mS/cm, what is amounts to a resistivity of 0,4 Ωm.
The results of the interpretation of two profiles of resistivity are presented on figures 3 and 4. The various sections of resistivity give the variation of the electric resistivity in the basement until a depth of 30m. Altogether we can note the presence of low values of resistivity, lower than 5 Ωm, indicating the

influence of the leachate which is often characterized by very low values of resistivity.

Profile N° 1

In the southern part of the profile, we notice the presence of resistant superficial layers (16-22.6 ohm.m) which get organized in intermittent areas. These layers will appear from a 5 meter depth and are of a big thickness at the level of the distance 95 m. in the north part of the profile (Location of the wells 1 and 3 of sampling) (figure 4), we notice that the low values of the resistivity (5 Ωm) reach big depths going until 22 m. This section shows the extension of the pollution in-depth. The superficial parts of the basement (inferior in 6m) are the most conductive and consequently it is to this level that the mineralization is more pushed.

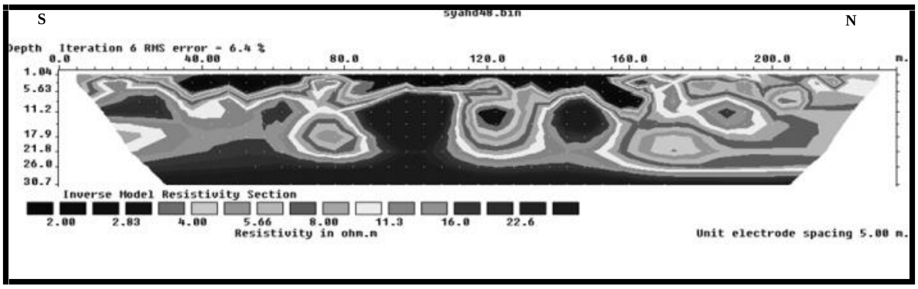

Figure 4: Tomography of resistivity of the first profile

Profile N° 2

It was realized in the center of the basin sheltering the landfill site. In the east extremity of the section, it appears a resistant deeper layer (more than 30 m), testifies of a little altered and probably dry massive structure (Figure 5). It corresponds in reality to the outcrop of dolomites. Towards the West part (situation of the well 3 of the sampling of the water), at a distance of 160m, the conductive layers are deeper and the values of resistivities lower than 5 Om display in depths going until 20 m.

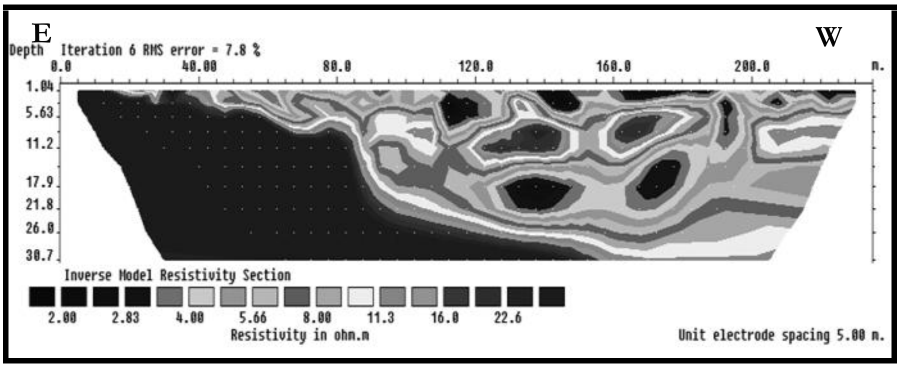

Figure 5: Tomography of resistivity of the second profile

CONCLUSIONS

In the term of this study we can deduct that leachates produced by the old landfill of Oujda city (Eastern Morocco) contains a strong level of pollution. These leachates contain an important mineral and metallic load with contents very high in heavy metals.

In absence of a system of drainage and collection of leachate, and in the presence of a permeable soil land a ground waters circulating in shallow depths (25-30 meters) makes, that after their generation, leachates accumulates at the bottom of waste and infiltrates in depth, in particular in the center of landfill, to reach the ground waters so pulling its contamination and the degradation of its physico-chemical quality.

From the results obtained by the prospecting geophysics, we deduce that the electric imaging is effective in the cartography of the pollution and the determination of its side and vertical extension. In our study, the contamination of the soil is marked well at the level of the landfill, and it by flowing of leachates. These drains laterally of the East part towards the West part of the landfill and also the North and the South in the direction of the inside of the dump, therefore, the site of the landfill is a basin which favours the accumulation of leachate. The compilation of the results of tow profiles of electric tomography, obtained inside the landfill, shows that the contamination of ground waters by leachate takes the aspect of a pollution plume which spreads out all around the landfill Affected wells situated in sectors approval in accordance with the direction of flowing of the ground water.

The results of this Study of recognition show the necessity of realizing a more detailed study of the site, in particular to verify the plan of the weaknesses continuity affecting the circle of acquaintances of the landfill site. These weaknesses could favour the distribution of the contamination towards the ground waters.

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