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Contribution to the study of the geochemical characteristics of the continental waters downstream the Bouregreg Basin case of the Temara Plain (Morocco) and a focus of the impact of Oum Azza Landfill

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Abstract
In the final section of Bouregreg basin (Northern Morocco) a rapidly expanding process of urbanization is in progress, due to its proximity to Rabat, the capital of the Kingdom. This work aims to study water quality of groundwater in an area affected by anthropogenic sources of pollution from a landfill and agricultural activities. On a set of several water samples, main components and selected trace elements were analyzed. Geochemical classification of the waters was carried out. In the alluvial plain of the Bouregreg, the water quality deterioration is due mainly to the tidal seawater intrusion into the river up to 24 km upstream from its estuary on the ocean. This salty water feeds the shallow aquifer beneath to the river. This study has found that there is a significant release of heavy metals from the Oum Azza waste landfill. The shallow waters also show the common contamination by agricultural fertilizers with high values of nitrates in irrigated areas.

Key words: Geochemistry - ground waters-landfill-pollution- nitrates -Heavy metals

1. Introduction
The lower portion of the Bouregreg River is experiencing a rapid increase of urbanization and leisure activities in the areas surrounding Rabat, the administrative center of the Kingdom.This fact has a serious impact on environmental resources in this area. The water supply is high, for this the Moroccan authorities took the decision to enlarge the capacity of the bigger dams on the Bouregreg River (Sidi Mohammed Ben Abdellah [SMBA] dam) (Fig. 1a) and to build new ones, the groundwater resources in the area are highly requested even for agricultural and/or for leisure activities. However the high speed extension of the Rabat city and its related satellite urban agglomeration went to strengthen the environmental stress.
This study aims to study of the quality of ground waters of this area and it focuses to define the impact of the landfill located on the OumAzza plain upstream of the studied zone. The principal components and a set of trace elements in the area were analyzed from 25 shallow water samples.

2. Geological framework
1.1 Lithostratigraphy
This territory belongs to the western coastal plateau consists of geological formations from Paleozoic to the quaternary Chenaoui[1] and Michard et al.[2] The most abundant rocks in the area date back to the Paleozoic. They are sandstones, shales, limestones and are highly tectonised and are topped unconformably by Miocene marl and by Plio-Quaternary Millies Lacroix [3],Akil,[4] and Sitel and Akil [5].
Primary massive eroded into a platform where Quaternary transgressions came Greso drop-sandy sediments thin. Devonian limestones appear at the digging of wadis.
The tectonic instability was highlighted by several authors (Griboulard [6], El Foughali & Griboulard [7],& Griboulard & Prud'homme [8]). The lithostratigraphy of the study area show two characteristics that are easily

recognized (Michard [9] and Attari [10]): a Paleozoic basement and the post-Paleozoic cover, whose descriptions are given in figure 1b and 1c.

Bedrock in the area consists of the primary fields, unconformably above Neogene and quaternary grounds, the normal cutting zone is as follows bottom up :

1. sandstone and shale : Metamorphic series of Bouregreg : Ordovician
2. Massive limestone and black shale : Silurian and Devonian Lower
3. Shale ,sandstone and quartzite : upper Devonian- Carboniferous
4. Sandy marls : Miocene
5. Limestone river-marine and conglomerates : Pliocene
6. limestone and sand dune : Quaternary

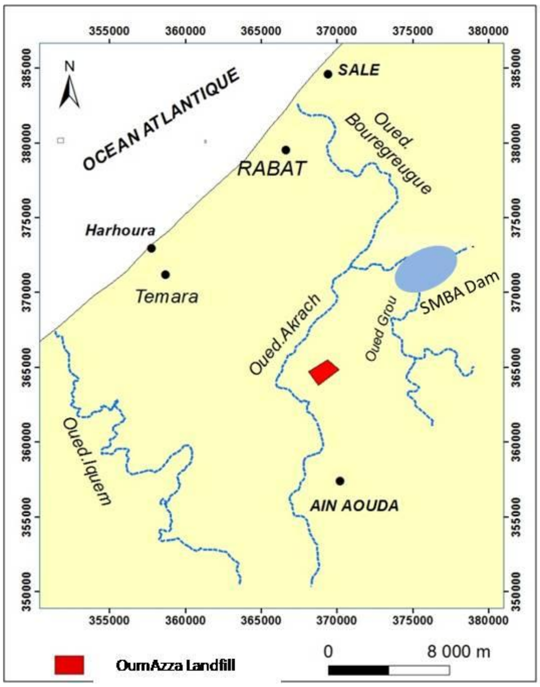

Figure 1a: Map of the study area

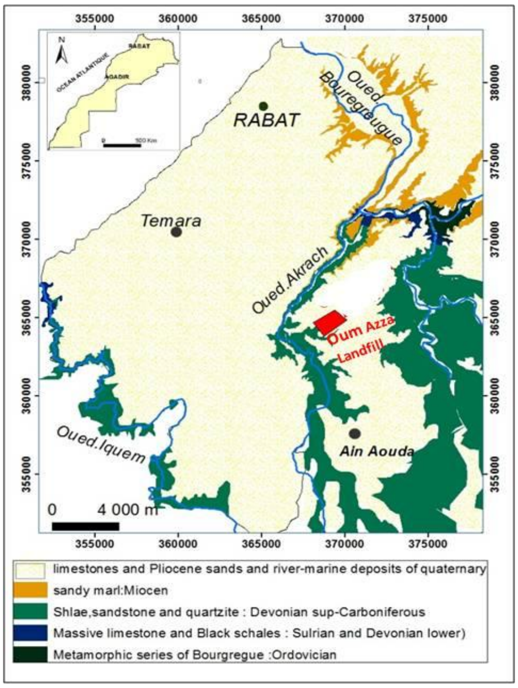

Figure 1b: Geological map of the studied areas. In red the OumAzza landfill localization

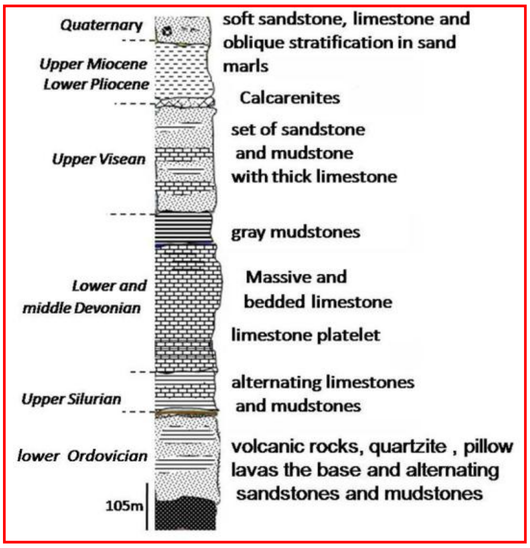

Figure.1c Stratigraphic log of the Akrach area, Amhoud [18] modified.

3. Surface water

Bouregreg basin is located at the north-central of Morocco near to Rabat (Fig 1a). It covers an area of 9570 km² with an elevation ranging from 46 m (SMBA dam) to 1630 m at the southeast mountains. The main rivers are Bouregreg with 125 km length and Grou River 260 km length. The climate of the region is semiarid with average yearly precipitations of 400 mm and annual air temperature varying between 11˚C for minimum temperatures and 22˚C for maximum temperatures. The average volume inflow to SMBA dam is estimated at 600 Mm³/year. [11]

4. Hydrogeological frame

The Bouregreg basin is characterized by the absence of geological substratum which may contain significant water bodies. Thus, almost 85% of the basin comprises land low skills control storage of rainwater, because of their texture and structure not favorising infiltration and underground accumulation of rainwater.

However, two hydrogeological components have been studied: the first one, the aquifer of the Akrach, has a modest surface. It is limited to the West by the plain of Temara, to the North by the forest of Mamora, to the South by the plateau of Oulad Mimoun and to the East by the plateau of Oulad Brahim. The shallow water reservoir occurs in Palaeozoic formations. The aquifer is up to 100 m thick. The water table is found at depths of 8 to 40 metres, depending on the topography.

Measurement of piezometery have been conducted between 1991 and 1996 allowed there cognition of the hydrogeological context of the plateau Ain Aouda and draw the piezometric map below (Fig.2). It appears that a global aquifer system is developed at the interface of the base of the fractured and altered formations from Neogene and Quaternary. The water is circulating from the SE to the NW and boarded by the Akrach wady. The depth of the water table rises Southeast (between 3 and 10 m) to the northwest (greater than 30 m) [12].

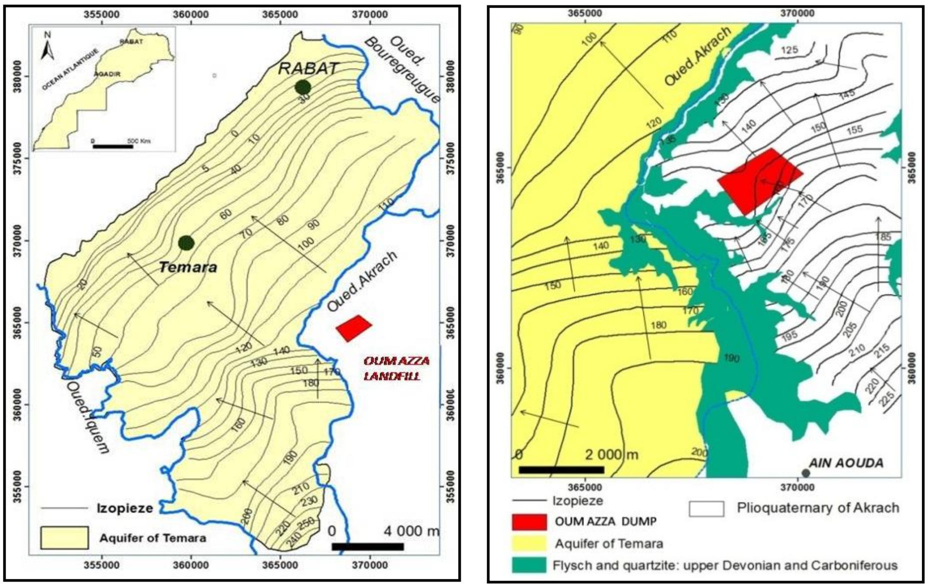

Figure 2: Piezometric map of the study area (Temara plain an Akrach Plateau)

The aquifer of Temara is limited to the west by the Atlantic Ocean, to the North by the estuary of the Bouregreg River, to the East by the O. Akrach and to the South by the O.Iquem. Water circulates through various lithologies of a thick aquifer,Pulido Bosch et al [13] from the Quaternary calcarenites to the Palaeozoic substratum. The large part of the Bouregreg river basin consists of discontinuous medium, consisting essentially of shale’s primary, red clays of the Triassic of quartzites and basalts and do not representing any significant hydrogeological interest, but may contain low flow rates not exceeding 1-2 l / s, in heavy fracturing or alteration.

The structure of the aquifer is very heterogeneous; its porosity is resulted in a slight variation of the porosity accessible to water. It thickness is up to 100 m, with depths ranging from 8 to 34 m depending on the topography.

5. Water geochemistry

a. Sampling and analytical methods

The electrical conductivity, temperature, pH, alkalinity and the redox potential were measured at the sampling point. At the laboratory the anions Cl, SO_4, and NO_3 were measured by ionic chromatography; analyses of Na, Ca, Mg, and Si were made by ICP-AES and a set of some heavy and trace element concentrations were analysed by ICP-AES (Ultima 2 - JobinYvon).

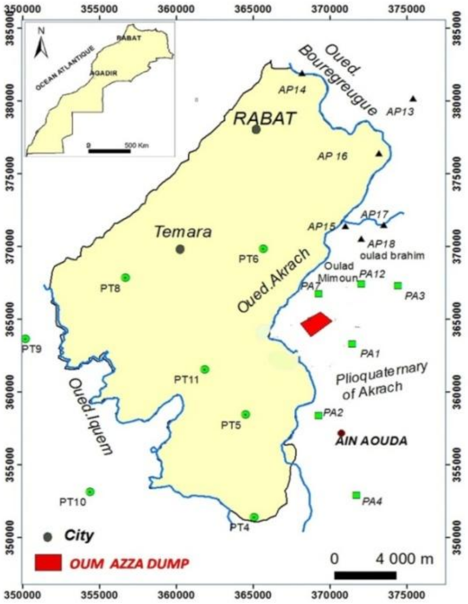

Figure3: Map of sampling point location on de Akrach plateau and the Temara Plain

b. Shallow groundwater

The groundwater geochemistry in the area depends on the lithology of the reservoir. The Palaeozoic facies give the water prevailing calcium bicarbonate chemistry with TDS < 1g/l (PT6, PT8 and PT11 samples). In the coastal formations of Temara plain, made up of calcarenites, sandstones and miocenic marls, waters are of a NaCl type and more saline (up to 3 g/l) (PT4, and PT10), (Fig.4).

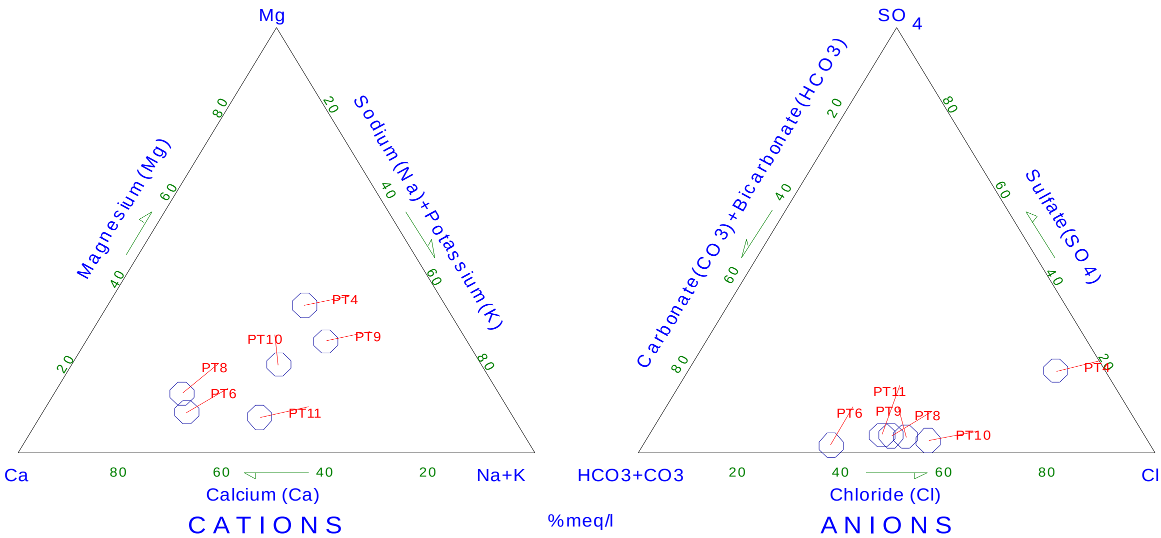

Figure 4: Piper plot showing the water distribution in the Temara plateau

While the alluvial plain of the Bouregreg shows an increasing salinity when getting close to the shore. Here the oceanic salt water intrusion influences the fluvial water chemistry until 24 km inside the continent; this water recharges the shallow aquifer and modifies its chemical characteristics. The piper plots in the figure 4 show the modification of the water chemistry from the Ca- HCO_3 water to slightly NaCl water when moving to the estuary (Fig. 5).

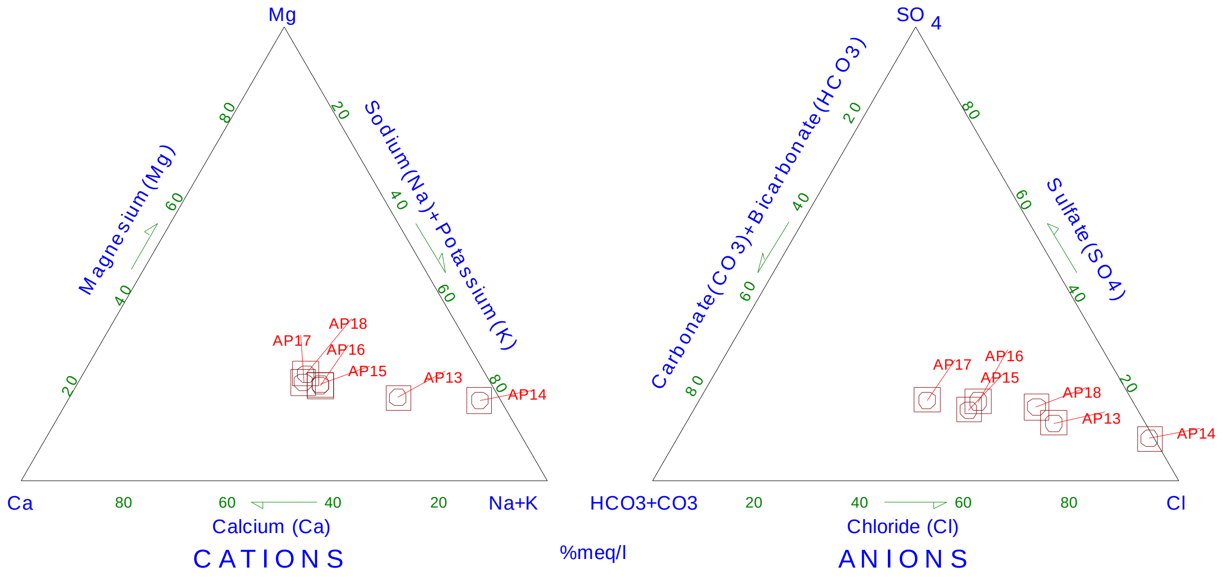

Figure 5: Piper plot showing the water distribution in the alluvial plain of the Bouregreg river

The graph Na vs Cl in figure 6 shows that the marine molar ratio can be different from the expected value of one, because of cationic exchange (Ca/Na) reactions for some samples according to el Mahmouhi et al.[13]

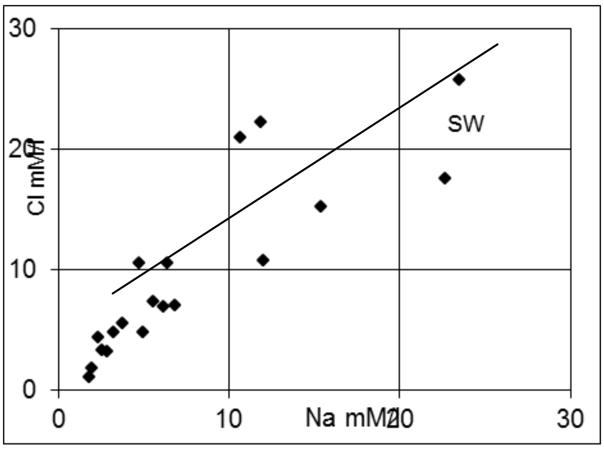

Figure 6: Cl vs Na in the shallow groundwater

c. Trace elements in shallow ground water

The concentrations of trace elements such as Ba, Sr, B, Fe and Mn in the groundwater are related to the salinity and are a result of the natural water/rock interaction processes. Their distribution is always log normal *d. Heavy metals in shallow ground water in the Temara plain*

The levels of some heavy metals in the area are represented in any probability plots of figure 7. They show no significant water contamination of anthropogenic origin. Only three wells have a concentration of mercury above the detection limit (0.1 g/l) and/or higher than the international standards for drinking waters (1µg/l). This contamination is probably related to the use of Hg salts as pesticides in agricultural activities, similar contamination have been reported in several shallow aquifers in Morocco, El Mahmouhi et al [14];Bahaj et al[15], Bahaj et al [16]and Sadiki et al [17].

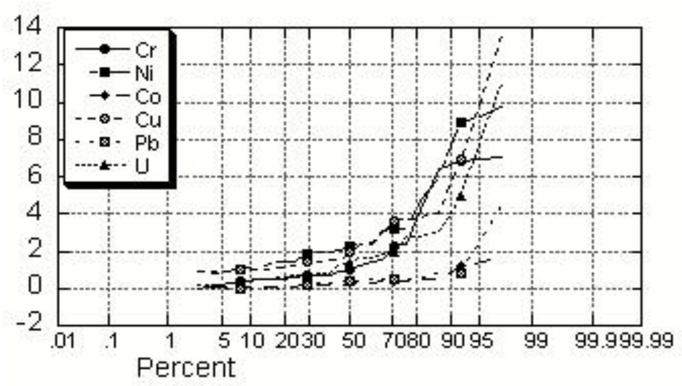

Figure 7: Distribution of the heavy metals concentrationsin the studied shallow groundwater

6. The OumAzza Landfill

Before 2006, the territory of Akrach- OumAzza perched aquifer was exclusively occupied by agriculture and pastoral activity; some small industrial activities have been highlighted in the area and consists on some pharmaceutical implants, and plastic factory. The piezometric map of the Akrach aquifer show a very high similitude with the Temara's, same depth, flow direction and aquifer lithology, they are separated by the valley of Akrach wady (Fig. 1b& 2)

The prospected water samples in 2002 and 2004 (Fig. 3) show a mixed facies with dominance of Calcium bicarbonate waters (piper plot in the figure 8 below).The TDS, is low than 2g/l and no specific contamination form any trace or heavy metals were found.

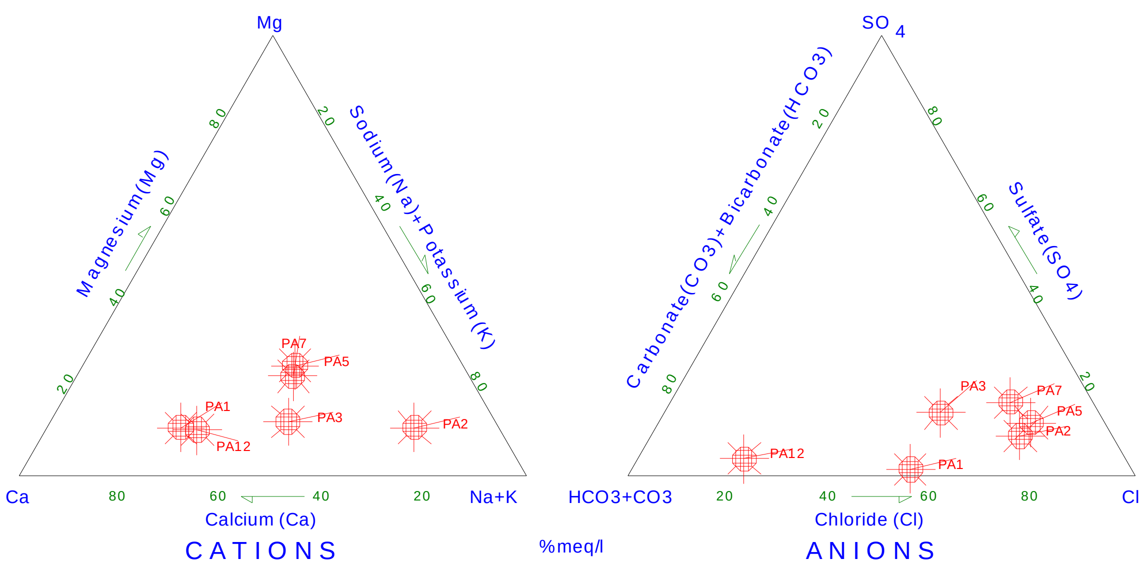

Figure 8: Piper plot showing the water distribution in the Akrach aquifer (case of 2002 and 2004)

The fact that the Akrach landfill is saturated several years ago and could not receive any more solide wastes. In addition it cannot be enlarged because it occupied a very small territory bounded by the Akrach wady and the Bouregreg River.
This uncontrolled landfill was polluting the waters downstream the Sidi Mohammed Ben Abdellah dam and all the alluvial plain of the Bouregreg until it's estuary in the Atlantic ocean, and have, during decades, contribute to the deterioration of the water resources and limited any estuarine development of the Rabat valley.
The Authorities, which became more sensible to the environmental degradation, decide to close this traditional landfill by burying in the same site of Akrach's landfill all the accumulated wastes and put measures to reduce its impact on the environment.
The new landfill, localized in the area of the Akrach shallow aquifer (Fig. 1a and 2), have been chosen after serious studies. It's located on the neighbouring of OumAzza village between the river Akrach in the West and the Sidi Mohamed Ben Abdellah dam in the East. Where it occupies 110 ha. The common purpose is to treat the solid wastes. The common treatment was to bury in conditions where there is no pollution to the environment, so treat them in sealed bins with systems to collect and treat leachate.
Since it's inauguration in 2007 the OumAzza landfill started receiving more than 700 000 tons/year of solid wastes from the Rabat and its satellite agglomerations. The site of the ancient landfill situated more downstream the OumAzza was drained by the O. Akrach, and more than its saturation, it was polluting the surface waters for both O. Akrach and O. Bouregreg, according to Amhoud[18].
To focus the impact of the landfill, the study was conducted on seven wells. The results show that the groundwater flow at low to medium depths from the ground surface: 1 m to 31 m. The landfill is located in the northern part of the region and that groundwater flow is from south to north (Fig. 2).Around the landfill, two water families could be distinguished but show a mixed facies with a tendency to salinization when getting close to the landfill site (Fig.9).

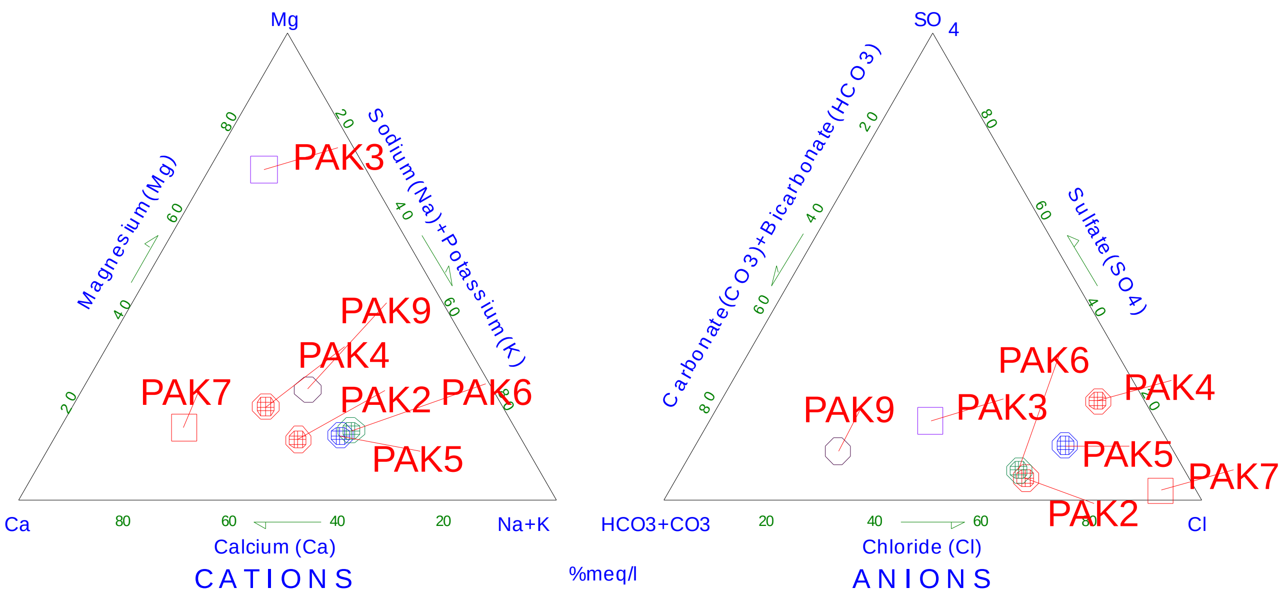

Figure 9: Piper plot showing the water distribution in the Akrach aquifer (case of 2013)

The shallow groundwater surrounding the landfill show high contamination on organic material (Table. 1). In fact both of DBO5, DCO and organic material have been found in the waters all around the OumAzza landfill. Their presence is a whiteness of a contamination by urban wastes, the fact that burying the solid wastes rich in moisture and in anaerobic condition contribute to their fermentation and the organic materials percolate into the shallow aquifer.

Table1: levels organic material in the shallow waters all around the OumAzzaLandfill

samples	DBO5 mg/l	DCO mg/l	MES mg/l	NO2 mg/l	NO3 mg/l
PAK2	4.5	12.1	99	6.7	52
PAK3	3.6	9.7	79.5	7.7	44
PAK4	4.9	13.1	107	3.1	2.5
PAK5	3.4	9.3	76	3.5	981
PAK6 (leachate)	7.1	19	156	<0.5	0.1
PAK7 (leachate)	6.6	17.8	145	<0.5	1,
PAK8	3.3	8.9	73	0.5	0.1
PAK9	5.2	14	115	7.3	5

However, the reduction of the dissolved oxygen in the waters is due to the organic materials fermentation, the diagram pH-pE below show that the polluted waters are in reducing conditions.

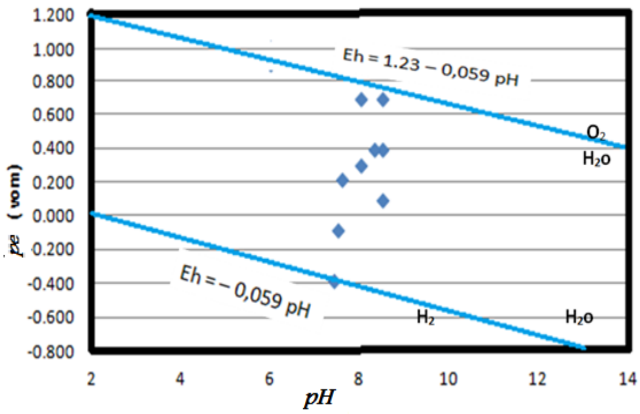

Figure 10: Diagram pH-pE showing the in the shallow waters surrounding The OumAzza landfill reduction of the oxygen

The waters show also different degrees of nitrogen spices reduction and different levels of NO_2^- and NO_3^-have been found.One water sample have reported a very high concentration of NO_3^- that exceeds up to 100 times the recommended value of drinking waters. This contamination is due probably of an agricultural practice, where some farmers use to outpour fertilisant in the well and pump it to irrigate the plant nursery that surround the area of the OumAzza landfill, photo 1 below.
On the other hand, the OumAzza shallow waters show high levels of several heavy metals and trace elements reported inthe table below (Table 2).

Table 2: Concentration of some Heavy metals and trace elements in shallow waters surrounding the landfill.

nom	Al µg/l	Ba µg/l	Co µg/l	Fe µg/l	Mn µg/l	Ni µg/l	Pb µg/l	Si µg/l	Zn µg/l
Sample1	70	360	10	30	50	3770	40	20880	4
Sample2	100	110	430	280	90	100	270	19790	4
Sample3	10	90	10	30	4	20	40	30290	4
Sample4	50	70	10	20	4	10	20	28890	4
Sample5	50	260	50	20	4	30	50	19450	4
Sample6	60	20	120	250	10	40	120	4890	4

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Photo 1 plant nursery localized at just few meters far from the landfill.

The first lecture of this result and the comparison with the separation process that extract from the solid wastes all metallic contents have at least a positive action because trace of metallic corrosive residues are not present in high quantity in water like Fe, Mn, Zn.
While Si, As, Ni, Ba, Pb and Co are present in the water at high levels, which exceeds the OMS recommendation value. All of those contaminants could be leached from the wastes and percolate into the shallow aquifer localized in few meters depth and most of the samples were collected all around the landfill site.
The fact that the water samples were not filtrated have of sure increased the levels of the above cited elements.
On the other hand, it's expected that the landfill could impact negatively its close territory the elements above could have origin the solid wastes the contaminants above like plastic paint cans, para-pharmaceutical and paramedical residues and some industrial wastes that could be collected together with domestic wastes in the city of Rabat. The very high levels of arsenic could be related to the metallurgical wastes, pesticides residues and also from the degradation of the organic material in the landfill.
In order to accurate the assessments of this landfill impact, several controls are programmed in order study quality and quantity a set of selected trace elements and heavy metals. The sampling process will be revised also, with taking non filtrated and filtrated water samples.

Conclusions

In this part of the study, the investigations aimed at assessing the impact of contamination from the landfill on groundwater quality. It showed the existence of organic contamination indices through the presence of nitrites, nitrates and organic carbon in the samples of groundwater.
This research has demonstrated that the release of inorganic contaminants, heavy metals and trace elements pollutants from the OumAzza landfill,(certainly by the vertical infiltration of leachate) is real and will increase because the landfill is projected to receive the solid wastes during the next 20 years at least
The investigations should be continued to detect the presence of other organic contamination parameters (ammonia, dissolved organic carbon, short-chain aliphatic acids, phenols) and indicators of anthropogenic waste (toxic metals, hydrocarbons, chlorinated hydrocarbons, phthalates, pharmaceutical chemicals).
It must clear up the flow and transformation of pollutants assembly through the unsaturated zone of the Akrach aquifer.

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