



Impact of anthropogenic activities on water quality in Ajdir commune (Al Hoceima, Morocco)

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Abstract

The aims of this study is to assess the quality of surface and groundwater resources in Ajdir commune. The studied area is characterized by a cracked soils composed of alternating marl-calcareous-sandstone layers. The Ajdir population used groundwater for agricultural and domestic uses. Accidental contamination of water resources as a result of anthropogenic activities will be a human disaster. Field investigation showed the presence of agricultural activity, car paint shop and car washing units and a controlled landfill (CL). The results of physico-chemical characterization indicate that the surface water and groundwater are chloride-sodium and potassium or sulphate-sodium types. The COD of surface water samples taken upstream and downstream of the CL varies between 153.6 and 249.6 mg / l, indicating an organic contamination. Water samples of some wells used for agricultural and human consumption show high concentration of nitrates and contaminated by Coliforms and Enterococci. Disturbing concentration of mercury ($6.21 \mu\text{g.L}^{-1}$) was detected in groundwater around tolerie and car washing activities . The use of water for human consumption and agriculture in the Ajdir region should be monitored.

1. Introduction

Groundwater has an important socio-economic value as an invaluable natural resource for agricultural, industrial and domestic needs in developed and developing countries [1, 2]. The Moroccans water reserves are limited and strongly solicited. It is currently $720 \text{ m}^3 / \text{hab} / \text{year}$ and will be $520 \text{ m}^3 / \text{hab} / \text{year}$. After 2025, the country should be a situation of water stress and will be in a water shortage situation, as there will be significant problems of quality in relation to erosion, salinization and pollution [3].

Some regions in Morocco are more affected by water shorting than others. The central Rif and precisely in the vicinity of Al Hoceima are very impacted by the poor quality and modest amount of these resources and which is getting worse and worse, with increasing population and anthropogenic activities.

The aims of this study is to assess the surface and groundwater physicochemical and bacteriological quality in the vicinity of Al Hoceima controlled landfill and some anthropogenic activities in the Ajdir region.

2. Materials and methods

2.1. Study area

The studied area is located in the Rhiss-Nekor basin, with an area of 100 km^2 (Fig 1). It is located in the northeast of Morocco in the eastern part of the Rif mountains between latitudes $34^\circ 42'$ and $35^\circ 6'$ North (Lambert 457 and 502) and between longitudes $3^\circ 36'$ and $4^\circ 4'$ West (Lambert 622 and 662). The basin is connected to the Mediterranean Sea by a wide alluvial plain to the east of the town of Al Hoceima [4]. The

geology of the site are the Flyshs (composed by marsh-calcareous-sandstone flysh) [5]. These rocks also contains aquifers that can be exploited locally.

The studied area counted 9323 habitants in 2014 and is characterized by an agricultural activity dominated by cereal agriculture, goat breeding and arboriculture of fig and almond trees. The industrial development is very restrained in the region and is limited to a few metalworking units, quarries, and agro-alimentaries.

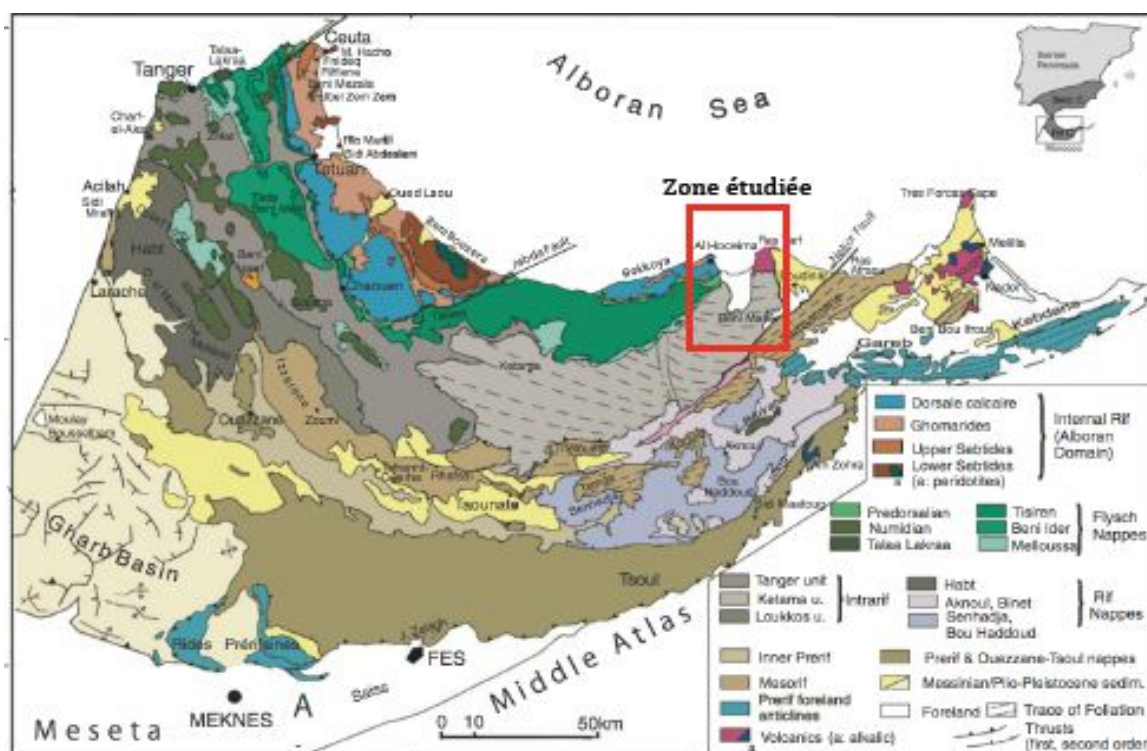


Figure 1: Geological maps of Rif area [4].

2.2. Anthropogenic activities

A survey of the main sources of water pollution in the studied area revealed the following sources: a controlled landfill; Agricultural land; a car washing and car paint shop and lost wells (or septic dumps) for domestic sanitation. The landfill is the main source of pollution and has been the subject of people claiming because of its olfactory nuisances and clandestine releases of leachate.

2.3. Al-Hoceima controlled landfill specifications

The Al Hoceima controlled landfill (CL) has been in operation since 2008. It is located 6 km south-east of the city and covers an area of 34 Ha. It receive 80 t.day⁻¹ (140,000 hab) of wastes from many urban and rural communities: Al Hoceima, Beni Bouayach, Imzouren, Ait Youssef ou Ali, Izmourren and Ait Kamra. It produce 30 m³.day⁻¹ of leachate containing many pollutants (Table 1). Leachate purification plant consisting of denitrification, aeration, sand filters and a membrane treatment.

The CL is located in the vicinity of two wadis with torrential flow during flood. Near the CL, peoples use wells for irrigation and domestic consumption. Unfortunately, accidental contamination of water resources by leachates will be a natural and human disaster.

Table 1: Physico-chemical and bacteriological characteristics of Al-Hoceima's leachate controlled landfill [6].

Parameters	Concentrations (average)	Parameters	Concentrations (average)
pH	8.12	NO ₂ ⁻ (mg/l)	383.1
EC (µs/cm)	28752	Chloride (mg/l)	1221
COD (mg/l)	11312	Coliforms (UFC/100 ml)	15.10 ⁵
PO ₄ ³⁻ (mg/l)	143		
NH ₄ ⁺ (mg/l)	0.42		
NO ₃ ⁻ (mg/l)	1298.4		

2.4. Experimental

2.4.1. Sampling of surface and groundwater

Sampling locations from wadies and wells were selected using GIS tools and in situ investigations. So, 4 stations on wadies (St 1, St 2, St 3 and St 4) and 9 wells (W1 to W9) characteristics for studied area were determined (Fig 2). Sampling was conducted in march and april 2016. CL is surrounded by many wells used for domestic and other purposes. Only three upstream wells of the CL were identified in the agglomeration of Izezfafen (W1; 15 m of depth) and Ait Kamra (W2 and W3; depth is respectively 25m and 40m). Six wells (W4-W9) are identified downstream of the CL in the Ajdir agglomeration. The depth of the wells varies from 60m (W4) to 3m (W8 and W9) and decreases as they approach the sea (Fig. 2).

For surface water, three sampling stations (St 1, St 2 and St 4) were identified on the wadie in front of CL. A control station (St 3) was identified on a wadi further from the CL.

Approximately 5L are sampled and distributed in several vials according to the parameters to be studied, as prescribed by [7]. The samples used for the bacteriological analyzes were collected under aseptic conditions in sterile containers and stored at 4°C and analyzed immediately after the sampling.

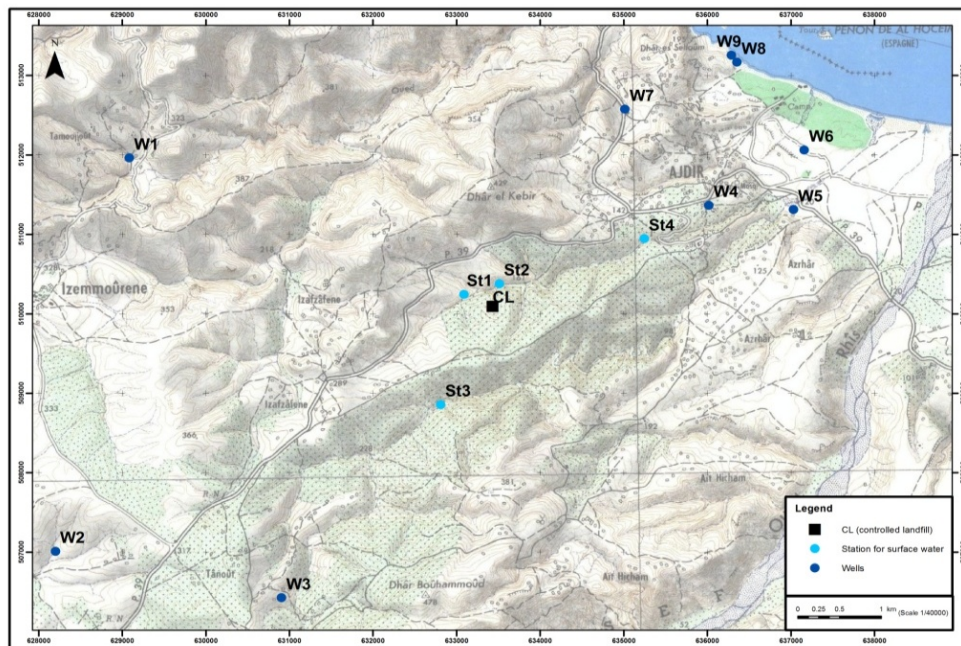


Figure 2: Sampling locations in topographic maps of studied area

2.4.2. Analytical methods

After the sampling, the samples were immediately transferred to the laboratory and were stored in cold room (4°C). The analysis was started without delay based on the priority to analyze parameters as prescribed by [7].

Physico-chemical parameters examined in surface and groundwater samples includes, pH, electrical conductivity (EC), chemical oxygen demand (COD), total alkalinity (TA), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), ammonia (NH_4^+), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), Orthophosphate (PO_4^{3-}).

EC and pH were recorded using a Systronics conductivity meter, mode 306 and μ pH system 361 (Systronics). Estimation of COD was done by reflux titrimetry. TA, TH, Ca^{2+} , Mg^{2+} and Cl^- were estimated by titrimetry [7]. PO_4^{3-} by molybdenum–blue complex formation using spectrophotometer (DR-1900, Hach-Lange) while SO_4^{2-} , NO_3^- , NH_4^+ , NO_2^- were also determined by using either the same spectrophotometer. The concentrations of heavy metals: cadmium (Cd), Manganese (Mn), chromium (Cr), iron (Fe), nickel (Ni), lead (Pb), mercury (Hg) and zinc (Zn) were determined using a SpectrAA-20 (Varian) atomic absorption spectrometer.

Samples for total coliforms (TC) and faecal coliforms (FC) and Enterococci were aseptically taken from the wadies and wells and their estimation was done by the most probable number on lactose broth as described by [7]. All the experiments were carried out in triplicate and the results were found reproducible within $\pm 3\%$ error. The data were statistically analyzed by setting up and calculating a correlation matrix for the various parameters using Statistical Package for Social Sciences (SPSS) software package (Norusis and SPSS Inc, 1997).

3. Results and discussion

3.1. Physico-chemical characteristics of surface water

Results of physico-chemical characteristics of surface water samples are presented in Fig 3.

In situ, near the treated leachate discharge point, at the St 1 and St 2 sampling location, the water is brownish, foaming and has an unpleasant odor (which recalls that of leachate). It was also observed the presence of wastes and algae at the edges and at the bottom of the stream. The water turbidity (Fig 3.a) showed high values at points St 1 ($20.76 \text{ NTU} \pm 12.65 \text{ NTU}$) and St 2 ($24.89 \text{ NTU} \pm 15.15 \text{ NTU}$) compared to the St 4 ($3.01 \text{ NTU} \pm 1.92 \text{ NTU}$) farther from the discharge location and St 3 ($1.35 \text{ NTU} \pm 0.48 \text{ NTU}$) which is a control. The turbulence of the wadis close to the CL confirms the in situ observations and indicates the high presence of suspended matter (organic and inorganic).

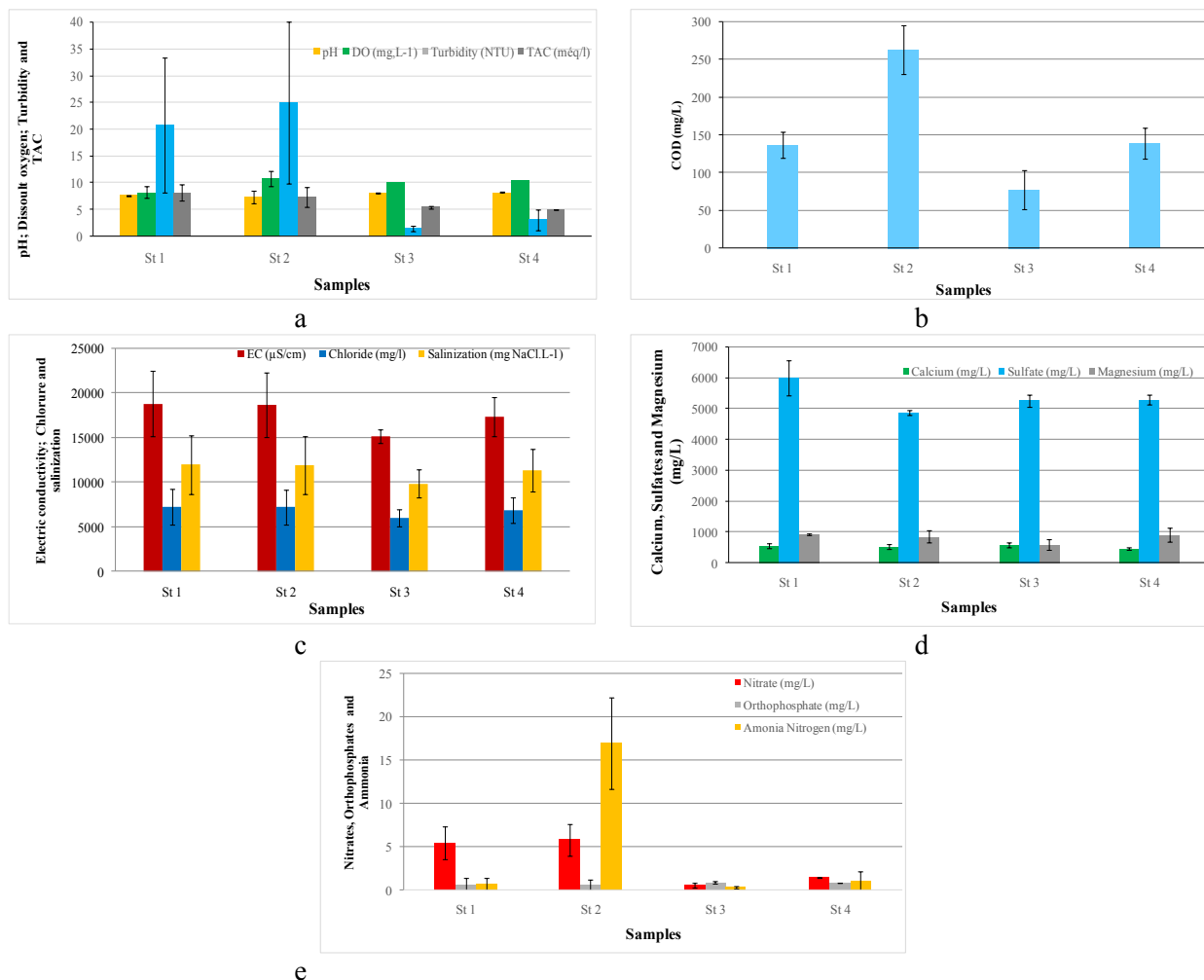


Figure 3: Results of surface water physico-chemical parameters analysis; (a) pH, dissolved oxygen, turbidity and TAC; b) COD; c) EC, Chloride and salinity; d) calcium, sulphate and magnesium ions and e) nitrates, orthophosphates and ammonium

The pH value (Fig 3.a) varies from 7.29 ± 0.01 (close to CL) to 8.18 ± 0.02 (control St 3) and respects the standards of surface water quality. Water neutrality is the result of a balance between the high carbon dioxide and dissolved calcium bicarbonate levels stabilized by the buffer effect resulting from the high water mineralization.

The COD values at St 1 ($136.76 \text{ mg.L}^{-1} \pm 27.15 \text{ mg.L}^{-1}$) St 2 ($262.9 \text{ mg.L}^{-1} \pm 32.10 \text{ mg.L}^{-1}$) and St 4 ($138.95 \text{ mg.L}^{-1} \pm 20.72 \text{ mg.L}^{-1}$) are higher than the measured value at the control St 3 ($77.50 \text{ mg.L}^{-1} \pm 26.16 \text{ mg.L}^{-1}$) (Fig. 3.b). These results indicate the poor quality of the surface water in vicinity of the CL according to the surface water quality standards. In the absence of other activities or releases, water contamination will be, probably, to accidental leakage of leachate from the CL. This finding has been observed by many researchers on similar studies [8, 9, 10].

The EC values in the vicinity of the CL is higher than that recorded at the control station (St 3) (Fig. 3.c). It varies between $18810 \text{ } \mu\text{S.cm}^{-1} \pm 3676.96 \text{ } \mu\text{S.cm}^{-1}$ and $15150 \text{ } \mu\text{S.cm}^{-1} \pm 763.68 \text{ } \mu\text{S.cm}^{-1}$ and indicates a high mineralization of the waters samples.

The total hardness (TH) was measured and is normally expressed as the total concentration of Ca^{2+} and Mg^{2+} in mg.L^{-1} , equivalent CaCO_3 [7]. TH ranged from $77 \text{ mg.L}^{-1} \pm 9.9 \text{ mg.L}^{-1}$ to $104 \text{ mg.L}^{-1} \pm 6.22 \text{ mg.L}^{-1}$ (the average is $94 \text{ mg.L}^{-1} \pm 8.4 \text{ mg.L}^{-1} \text{ CaCO}_3$). Ca^{2+} and Mg^{2+} concentrations of the prospected samples are respectively $530.6 \text{ mg.L}^{-1} \pm 39.6 \text{ mg.L}^{-1}$ and $897 \text{ mg.L}^{-1} \pm 117.7 \text{ mg.L}^{-1}$ (Fig. 3.d). These high concentrations are probably related to the nature of the geological land. Ca^{2+} often comes from carbonate-based minerals, such as calcite and dolomite. Ca^{2+} and SiO_2 may also come from the dissolution of concrete in streets and the sidewalks. Cl^- and SO_4^{2-} are also highly concentrated (Fig. 3.d). Cl^- concentrations ranged from $5990 \text{ mg.L}^{-1} \pm 941.34 \text{ mg.L}^{-1}$ (St 3) to $7277 \text{ mg.L}^{-1} \pm 1945.43 \text{ mg.L}^{-1}$ (St 1 and St 2). SO_4^{2-} concentrations varied between $4860 \text{ mg.L}^{-1} \pm 79.20 \text{ mg.L}^{-1}$ and $6000 \text{ mg.L}^{-1} \pm 572.05 \text{ mg.L}^{-1}$. Chlorides may have a natural origin (marine intrusions or a salt grounds) [11]. Presence of sulphates may be related to gypsum dissolution and soils leaching, sulphides oxidation [12] or anthropogenic activities (industrial or urban pollution) [13].

The values of nitrate and ammonia nitrogen concentrations were higher at St 2 samples ($5.80 \text{ mg.L}^{-1} \pm 1.84 \text{ mg.L}^{-1}$ and $16.95 \text{ mg.L}^{-1} \pm 5.30 \text{ mg.L}^{-1}$, respectively) than at the control St 3 ($0.5 \text{ mg.L}^{-1} \pm 0.28 \text{ mg.L}^{-1}$ and $0.32 \text{ mg.L}^{-1} \pm 0.17 \text{ mg.L}^{-1}$, respectively). According to [8], these elements originate from the degradation of organic matter probably derived from leachate (Tab. 1).

The chemical parameters of surface water as well as those of groundwater (presented below) are interpreted by the Piper diagram (Fig. 4). The diagram indicates that all samples are chloride-sodium and potassium or sulphate-sodium types. Because of the geological formation of the studied area (calcareous-sandstone), these chemical types are resulted from the gypsum (CaSO_4) and halite (NaCl) dissolution [14]. However, it is important to note that the surface waters near the CL (samples: St 1, St 2 and St 4) are higher than those of the control (St 3) and follow the same trend as the EC. In the absence of other anthropogenic activities in upstream, probably the wadie near of CL is subject to additional anthropogenic pollution.

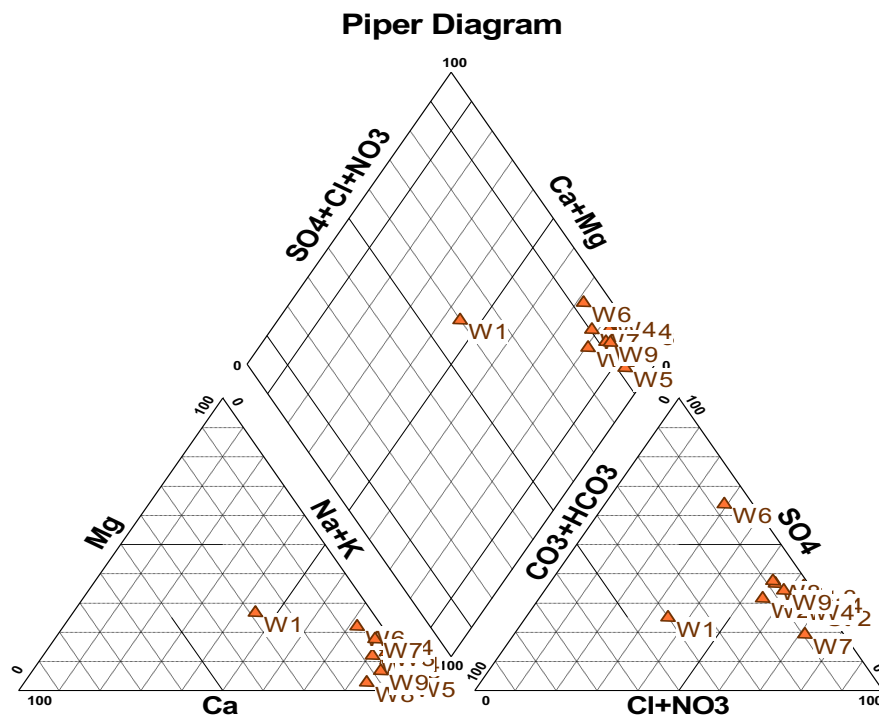


Figure 4: Piper Diagram

The surface water physico-chemical properties on the river close to the CL and in comparison with the control indicate, probably, an accidental contamination with the leaks of CL leachate. These leaks are probably due to the rugged and cracked nature of the land. Do these leaks contaminate existing aquifers?

3.2. Physico-chemical characteristics of groundwater

The phreatic waters are charged with soluble chemical elements, chlorides, carbonates, sulphates, and others, upon contact with the different terrains traversed. These elements may be of geological or anthropogenic origin and are capable to modifying the water quality. Moreover, the presence of local pollution in the vicinity of a water source (wells or sources) can contaminate the aquifer by infiltration or by direct discharge. This contamination is much more pronounced when the well is not protected (absence of curb and lid).

Table 2 presents physico-chemical characteristics of groundwater samples (3 wells in CL upstream (W1-W3) and 6 wells in CL downstream (W4-W9) as shown in Fig. 2.

pH values range from 6.71 to 7.97. These values respect limits recommended by the World Health Organization [15]. However, it is observed that the wells close to the CL (W2, W3 and W4) have a low pH (6.71 to 6.86) while it increases by moving away (7.93 at W9). A reduction in pH marks an increase in CO₂ content, a decrease in O₂ content and an increase in organic matter content.

Samples have generally high conductivity values, far exceeding the World Health Organization guide [15]. EC ranged from 2400 $\mu\text{S}\cdot\text{cm}^{-1}$ at W7 to 12700 $\mu\text{S}\cdot\text{cm}^{-1}$ at W4 (Table 2). The guidelines of the Council of the European Communities on the quality of water intended for human consumption indicate a conductivity level of 2500 $\mu\text{S}\cdot\text{cm}^{-1}$ at 20 ° C [7]. Moroccan standards require a maximum allowable value of 2700 $\mu\text{S}\cdot\text{cm}^{-1}$ for water quality for human consumption [16]. The higher groundwater mineralization could be due either to the existence of a local saline geological formation (flyches phenomena), or more probably by the effect of marine intrusion.

Salinity values ranged from 1210 $\text{mg}\cdot\text{L}^{-1}$ to 8044 $\text{mg}\cdot\text{L}^{-1}$ and they are well above the recommended limits of WHO standards [15] which indicates guideline values from 100 to 500 $\text{mg}\cdot\text{L}^{-1}$.

The salinity and EC results were treated by the Wilcox diagram (Fig. 5.a) to assess the risk of soil salinization [17, 18]. According to the Wilcox diagram, all samples are bad quality with the exception of W7 which is poor quality. Their use in irrigation would have a risk of soil salinization. The salinity and EC of W1 are acceptable and this well is used for alimentation by Al-Hoceima's population.

Table 2: Results of physico-chemical parameters of wells samples

	Units	W1	W2	W3	W4	W5	W6	W7	W8	W9
DO	$\text{mg}\cdot\text{L}^{-1}$	54.00	8.29	2.43	4.64	5.80	3.29	8.29	4.40	3.50
EC	$\mu\text{S}\cdot\text{cm}^{-1}$	973.00	5214.00	12020.00	12700.00	5570.00	5060.00	2400.00	4270.00	5590.00
pH		7.53	6.86	6.71	6.81	7.40	7.36	7.83	7.97	7.93
Turbidity	NTU	0.63	0.57	1.95	0.87	1.23	0.82	1.47	1.24	1.93
Oxidability	$\text{mg O}_2\cdot\text{L}^{-1}$	0.94	5.18	13.25	4.82	2.27	1.88	1.76	4.00	4.94
COD	$\text{mg}\cdot\text{L}^{-1}$	-	48.00	172.80	249.60	153.60	9.60	48.00	38.40	-
HCO ₃ ⁻	$\text{mg}\cdot\text{L}^{-1}$	283.74	668.17	677.32	436.29	835.97	488.16	170.86	347.81	372.22
CL ⁻	$\text{mg}\cdot\text{L}^{-1}$	134.90	1544.25	4792.50	4881.25	2911.00	1171.50	736.63	1313.50	1757.25
Na ⁺	$\text{g NaCl}\cdot\text{L}^{-1}$	222.30	2.54	7.90	8.04	4.80	1.93	1.21	2.16	2.90
TH	$\text{m}\text{eq}\cdot\text{L}^{-1}$	12.00	26.40	71.60	84.40	15.20	32.80	14.40	17.92	21.68
Ca ²⁺	$\text{mg}\cdot\text{L}^{-1}$	6.24	199.26	753.30	996.30	108.86	311.04	143.86	36.94	121.50
Mg ²⁺	$\text{mg}\cdot\text{L}^{-1}$	69.98	199.26	753.30	996.30	108.86	311.04	143.86	36.94	121.50
SO ₄ ²⁻	$\text{mg}\cdot\text{L}^{-1}$	138.00	1211.00	3107.00	3057.00	2986.00	3453.00	268.00	1233.00	1391.00
PO ₄ ²⁻	$\text{mg}\cdot\text{L}^{-1}$	0.90	1.22	1.25	1.30	1.36	1.20	0.91	1.04	1.14
NO ₃ ⁻	$\text{mg}\cdot\text{L}^{-1}$	12.90	19.40	3.10	5.40	770.00	0.30	0.60	1.40	1.00
NH ₄ ⁺	$\text{mg}\cdot\text{L}^{-1}$	2.00	3.20	0.91	0.14	0.12	0.08	0.09	0.04	0.03

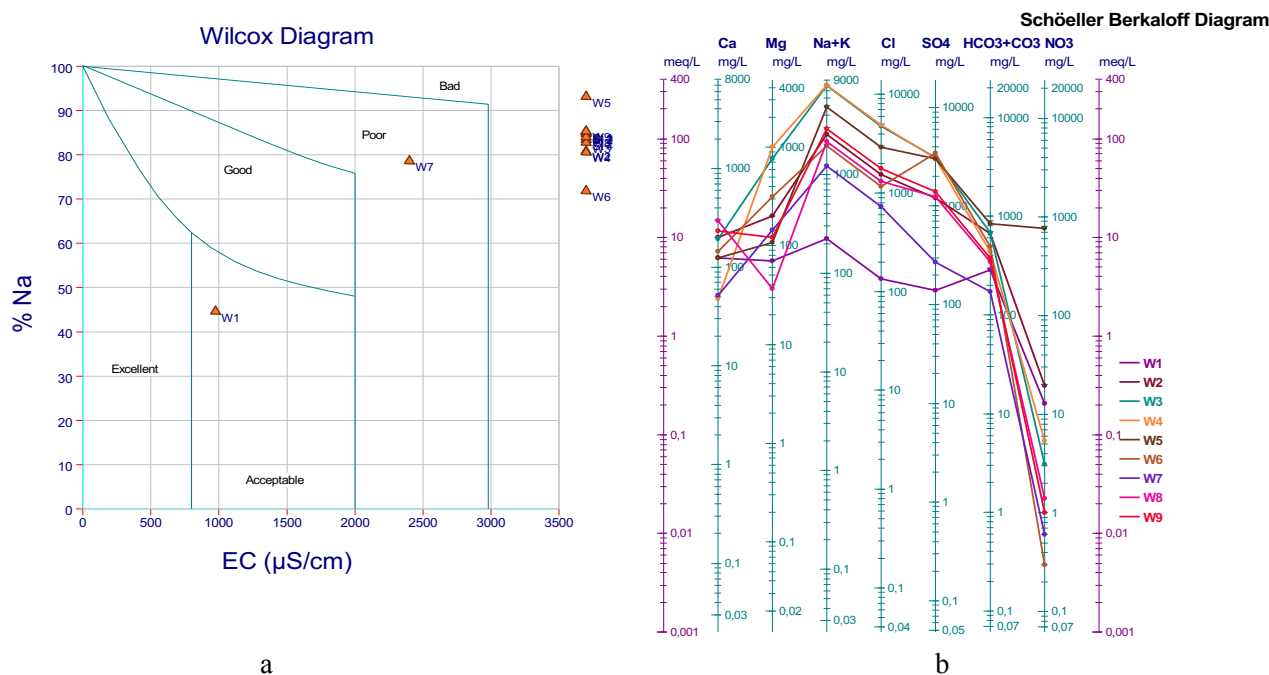


Figure 5: Wilcox Diagram (a) and Schoeller-Berkaloff Diagram (b) of groundwater characteristics

The chemical parameters (Table 2) indicate a dominant concentrations of Cl^- (range from 737 mg.L^{-1} to 4881 mg.L^{-1}); SO_4^{2-} (from 268 mg.L^{-1} to 3107 mg.L^{-1}); Mg^{2+} (from 37 mg.L^{-1} to 996 mg.L^{-1}), HCO_3^- (from 170 mg.L^{-1} to 836 mg.L^{-1}), and Ca^{2+} (from 37 mg.L^{-1} to 996 mg.L^{-1}). These results are treated by the Schoeller-Berkaloff diagram (Fig. 5.b). It is observed that the curves have the same shape and indicate a peak for Cl^- , SO_4^{2-} , Na^+ and K^+ . Results were also interpreted by Piper Diagram (Fig. 4) and shows the incidence of the lithological facies on the water quality and also allows to estimate the percentages of the chemical elements and their classification, an interpretation also evoked by [19] in the region of Taza. Groundwater, as well as surface waters, have chemical facies of chloride-sodium and potassium or sulphate-sodium type. W1 is located in a dorsal limestone and have chemical facies of chloride and sulphated calcium and magnesium.

Fig. 6 shows the results of nitrate, ammonium and orthophosphate analyzes in groundwater samples. A peak of nitrates concentration was observed in W5 (770 mg.L^{-1}). This well is located within an agglomeration and close to a car washing station. Due to the danger of nitrates in drinking water, the risk of methaemoglobinaemia (cyanosis) and formation of nitrosamines (carcinogens) [20], the maximum permissible value for this element was set by WHO at 50 mg.L^{-1} [15]. W5 is well above the WHO recommended limits. The origin of nitrates is mainly the infiltration of wastewater from the wells lost from the habitats adjacent to the aquifer. W2 (19.4 mg.L^{-1}) and W1 (12.9 mg.L^{-1}) also have higher concentrations than other prospected wells but it respect the limits recommended by WHO and international standards. It should be noted that W1 is located near a cemetery and W2 is also a domestic well intended for human uses and irrigation. They are also lower than those cited in the Haouz Plain by, which nitrate concentrations ranged from 50 mg.L^{-1} and 70 mg.L^{-1} or those reported by Somaratne [11] which varied between 55 mg.L^{-1} and 135 mg.L^{-1} of nitrate. Elevated nitrate values are reported by El Haji et al. [22] on groundwater in the region of Taza. Indeed, this work indicated concentrations of 147 mg.L^{-1} as the maximum value of nitrates.

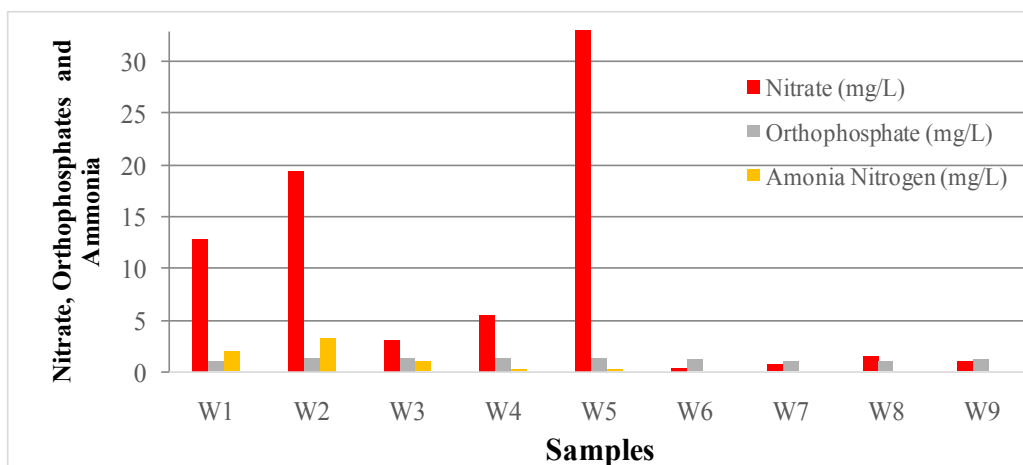


Figure 6: Nitrates, Ammonium and Orthophosphate in groundwater samples

In groundwater, ammonium can be originated from the nitrates reduction, agricultural supply, urban or industrial effluent discharge. The presence of ammonium ions in water is often the sign of incomplete degradation of organic matter in relation to the lack of available oxygen. It is indicative of contamination from human or industrial releases [7]. Ammonium is present in all samples and ranged from 0.03 mg.L^{-1} at W9 to 3 mg.L^{-1} at W2.

Orthophosphates values are low in most samples (ranged from 0.9 mg.L^{-1} at W7 to 1.3 mg.L^{-1} at W4). Orthophosphates most often have an urban origin (detergent) or an agricultural (fertilizer); They are a major nutrient in plants, which in aquatic environments can cause their proliferation from 0.2 mg.L^{-1} . It is generally considered that variations in phosphate concentrations are the limiting element of eutrophication phenomena [27].

3.3. Heavy Metals

Samples were analyzed for heavy metals such as Cd, Fe, Mn, Hg, Ni, Cr, Pb and Zn, which are characterized as undesirable metals in drinking water. Results of heavy metals concentrations, Moroccan and WHO standards are presented in Table 3. Comparing these results with the WHO Guidelines for Drinking Water Quality, there is evidence of overshooting of some elements. Indeed, a slight deposition of the manganese concentration is observed at W5 and W6, respectively 0.04 mg.L^{-1} and 0.09 mg.L^{-1} . Hg concentrations are detectable in all analyzed samples except for W5 where it exceeds the limit value established by WHO. This well is located close to the car wash and car paint shop and it is probably the mean source of mercury pollution.

Cr concentrations are well below recommended concentrations in WHO guidelines except for W3. This well is located upstream of CL (about 300 m) and is used for the irrigation of agricultural land. Because of carcinogenicity by inhalation, the limit for chromium is much lower than the toxic dose, but it is believed that this element should be absent from water [7].

Table 3: Results of heavy metals concentrations in water samples.

	St 1	St 2	St 3	St 4	W2	W3	W4	W5	W6	W7	W8	WHO standards	Moroccan standards
Cd (mg.L ⁻¹)	<0.2	<0.2	<0.2	<0.2	-	<0.2	<0.2	<0.2	<0.2	<0.2	-	0.003	0.003
Mn (mg.L ⁻¹)	<0.01	0.02	0.02	<0.01	-	<0.01	<0.01	0.04	0.09	<0.01	-	0.04	0.5
Fe (mg.L ⁻¹)	<0.01	<0.01	0.03	<0.01		0.24	0.05	<0.01	0.02	0.05		-	0.3
Zn (mg.L ⁻¹)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.34	0.03	0.05	<0.01	3	3
Hg (µg.L ⁻¹)	0.21	0.15	0.14	0.15	-	0.13	0.31	6.21	0.33	0.21	-	6	1
Ni (µg.L ⁻¹)	<5	<5	<5	<5	-	13	<5	<5	<5	<5	-	70	20
Pb (µg.L ⁻¹)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	10	10
Cr (µg.L ⁻¹)	<5	<5	<5	<5	<5	66	<5	<5	13	<5	<5	50	50

3.4. Microbial contamination

Coliforms bacteria are present in high numbers in the faeces of humans and animals and they are used as indicator for water quality [8]. Enterococci are spherical bacteria, in pairs or in chains, with Gram positive. According to the WHO, Enterococci are the main indicators of faecal pollution and their main interest is that they are resistant to desiccation and persist longer in water [24]. They are originated from human and may also be derived from animal feces such as *Streptococcus bovis*, *S. equinus*, *S. gallolyticus* and *S. alactolyticus* [25, 26]. Results of the most probable number of TC, FC (or thermo-tolerant coliforms represented by *Escherichia coli*) and Enterococci (or faecal streptococci) are presented in Fig. 7. Concerning surface water, it can be seen that St 2, located close to the discharge of CL treated leachate, is loaded with pathogenic germs compared to other samples. It contains 571 CFU/100mL of TC, 561 CFU/100mL of FC and 10⁺⁵ CFU/100mL of the Enterococci. This indicates the presence of human pollution or leachate contamination.

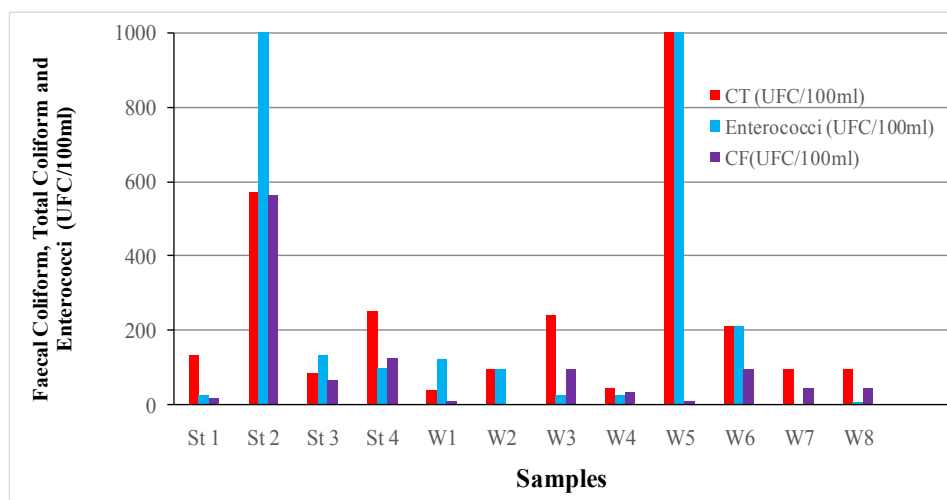


Figure 7: Most probable number of TC, FC and Enterococci in surface and groundwater samples.

Concerning groundwater samples, it show high levels of TC and Enterococci at W5, respectively 4.3.10⁺⁵ CFU/100mL and 1.1.10⁺⁷ CFU/100mL. This well is contaminated by wastewater from the habitats in vicinity. The presence of germs in the other wells does not respect the Moroccan standard on the quality of water for human consumption (NM 03.7.001). Unfortunately most of these wells are used for domestic consumption and agricultural irrigation. Studies of Mor et al. [8] about leachate characterization and assessment of groundwater

pollution near municipal solid waste landfill site, indicate the presence of TC and FC in most samples, indicating the contamination of groundwater by leachate percolation in groundwater. The presence of faecal contamination is an indicator that a potential health risk exists for individual exposed to this water. The coliform bacteria can multiply where leachate enters an oxygenated system found that when leachate was diluted with the bacteria-free groundwater there was an increase in the number of thermotolerant coliform and the bacteria were able to survive for up to two weeks under laboratory conditions [23].

3.5. Correlation Analysis

Correlation matrix between various parameters, of surface and groundwater samples, is shown in Table 4. Indeed, correlation analysis is a preliminary descriptive technique to estimate the degree of association between all variables. Most parameters are statistically significant correlation with each other indicating close association of these parameter with each other.

As shown in Table 4, there is a strong correlation between EC and a number of parameters: Cl⁻, Na⁺, TH, Ca²⁺, Mg²⁺ and SO₄²⁻ indicating the high mobility of these ions. This parameters are also strongly correlated between them. HCO₃⁻ was found to be positively correlated with NO₃⁻, PO₄, TC and Enterococci. An excellent correlation value of NO₃⁻ with TC and Enterococci indicating that samples are unsafe.

Table 4: Correlation matrix for different water quality parameters

Variable	Correlations (Donnée CET)																
	Marked correlations are significant at p < .05000 N=12 (Casewise deletion of missing data)																
	EC	pH	Turbidity	COD	HCO3	Cl-	Na	TH	Ca2+	Mg2+	SO4	PO4	NO3	NH4	TC	FC	Enterococci
EC	1.00																
pH	0.27	1.00															
Turbidity	0.56	0.30	1.00														
COD	-0.25	-0.11	-0.19	1.00													
HCO3	-0.09	-0.65	-0.09	-0.18	1.00												
Cl-	0.99	0.30	0.56	-0.23	-0.06	1.00											
Na	0.99	0.30	0.56	-0.23	-0.06	1.00	1.00										
TH	0.98	0.22	0.48	-0.19	-0.16	0.96	0.96	1.00									
Ca2+	0.83	0.58	0.54	-0.22	-0.23	0.82	0.82	0.75	1.00								
Mg2+	0.93	0.08	0.41	-0.16	-0.13	0.91	0.91	0.98	0.59	1.00							
SO4	0.91	0.27	0.39	-0.34	0.05	0.91	0.91	0.87	0.79	0.81	1.00						
PO4	-0.02	-0.75	-0.02	-0.26	0.86	-0.01	-0.01	-0.06	-0.29	0.02	0.11	1.00					
NO3	-0.21	-0.09	-0.07	-0.02	0.65	-0.13	-0.13	-0.33	-0.24	-0.32	-0.03	0.49	1.00				
NH4	0.22	0.05	-0.06	0.21	-0.02	0.21	0.21	0.22	0.40	0.14	0.12	-0.28	-0.28	1.00			
TC	-0.20	-0.08	-0.06	-0.03	0.64	-0.12	-0.12	-0.32	-0.23	-0.31	-0.02	0.48	1.00	-0.29	1.00		
FC	0.54	0.41	0.85	-0.10	-0.18	0.52	0.52	0.51	0.52	0.45	0.36	-0.19	-0.15	0.08	-0.14	1.00	
Enterococci	-0.21	-0.08	-0.06	-0.03	0.64	-0.12	-0.12	-0.32	-0.23	-0.32	-0.02	0.48	1.00	-0.29	1.00	-0.14	1.0

4. Conclusions

The physicochemical characterization of surface water and groundwater in vicinity of Al Hoceima controlled landfill has shown that these waters are mineralized. The high concentration of EC, Cl⁻, SO₄²⁻, NO₃⁻, Na⁺, etc. in surface and groundwater near landfill deteriorates its quality for drinking and other domestic purposes. The samples were also found to be bacteriological unsafe. The presence of TC and FC in most samples, indicating the contamination of surface water possibly due to leachate percolation in surface water and effect of human activities for other well samples. The presence of faecal contamination is an indicator that a potential health risk exists for individual exposed to this water.

As there is no natural or other possible reason for high concentration of these pollutants, it can be concluded that, possibly, leachate has an impact on surface water quality near the CL wadie. Also, human activities have an effect on groundwater quality in the studied area.

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