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Contamination of heavy metals and metalloids of groundwater in the vicinity to the wild landfill of El Hajeb city (Morocco)

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Abstract

Many previous studies have shown that leachate from uncontrolled landfills are among the most polluting source of groundwater. In this context, the quality of groundwater regarding metallic trace elements has been studied near the wild dump of El Hajeb city (Morocco). At the first campaign of sampling (May-2015 to January-2017), eighty-six water samples were collected from the groundwater of stations (wells, boreholes and springs) around the dump and along the water table flow. The contents in Cd, Cr, Cu, Mn, Ni, Pb, As, Zn, Hg, Ag, Sn and Fe were determined by ICP-AES technique. The results showed that the waters of the stations located very close to the wild landfill contained a high metal load (Cd max = 5.43 µg/L, Cr max = 254.16 µg/L, Mn max = 663.12 µg/L, Ni max = 261.07 µg/L, Pb max = 91.11 µg/L) exceeding the peremptory Moroccan norms. On the other hand, some high correlations have been revealed, like the lead and the arsenic that are negatively correlated with SO_4 and the strong positive correlation between Fe and Mn. The present study provides a characterization of groundwater in heavy metals and Metalloids intended for irrigation and human consumption.

Keywords: Groundwater, metals elements, correlation, leachates, landfill, pollution.

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1. Introduction

Metals are omnipresent in natural waters; however, their concentrations are generally very low, which explains their designation as "trace metals". They are commonly present in the Earth's crust, also the alteration and erosion of the rocks naturally feeds natural waters into trace metals (Elder, 1988). On the other hand, the problem of contaminated water is now very worrying because inputs from anthropogenic activities to have increased the levels of heavy metals and metalloids in the environment tremendously (Prater, 1975; Sayyed and Sayadi, 2011). They cannot be biodegraded and therefore persist in the environment for long periods.

Moreover, even though trace metals are needed by the body to satisfy its nutritional requirements, high doses led to health hazards, which are sometimes lethal (Ackah et al., 2011). The main threat comes from exposure of lead, cadmium, cobalt, nickel, mercury, arsenic. Other trace elements have been extensively studied and many authors (Larocque and Rasmussen, 1998; US EPA, 2002; WHO, 2008) have reviewed their effects on human health regularly. The World Health Organization estimates that more than ten percent of preventable diseases are due to poor quality of the local environment, whose inadequate waste management is a major contribution element. Leachate generated is the main vehicle for the transport of metallic pollution. It contains a significant amount of both organic and inorganic pollutants plus heavy metals. So soil and groundwater pollution, by percolation of these waste liquids, are two major risks to be feared and the highest concentrations of heavy metals occur in leachate from young landfills in the acid fermentation phase and at low pH (Erses and Onay,2003). This issue also even deteriorated with the improper disposal of electronic products, leading to the release of high levels of heavy metals (Awasthi et al., 2016; Wittsiepe et al., 2017).

The quantity and quality of leachate are influenced by several factors, such as the composition of the waste, biochemical processes that occur in the degradation stages of the waste, amount of moisture, and the local parameters (Ma et al., 2018). Leachate migration in open dumping sites is a dominant source of heavy metals in surface and groundwater, soil, and plants (Esakku et al., 2003; Kanmani and Gandhimathi, 2012; Slack et al., 2005).If plants uptake heavy metals from polluted soil, there is a high possibility of heavy metals transferring to the human food chain through the consumption of vegetation or animals (Chary et al., 2008; Nica et al., 2012). Indeed, according to a recent study carried out near Municipal Solid Waste Landfill Vientiane, Laos (Vongdala et al., 2019) the vegetable aquatic, which is consumed by the nearby villagers, was seriously contaminated by Cr, Pb, Cu, and Zn, as the accumulation of these toxic metals was elevated to much greater levels as compared to the WHO standards. Therefore, areas close to landfills have a greater chance of water pollution due to the possible contamination source of leachate originating from the dumpsites. Thus, leakage of leachate can cause pollution of nearby groundwater and surface water, agriculture, and natural ecosystems, especially when the leachate is released uncontrolled, and hence, can cause environmental health issues in many developing countries (Adamcová et al., 2017; Oyeku and Eludoyin, 2010; Samadder et al., 2017). In addition to the large amount of heavy metal pollution originating from leachate, the degradation of a large amount of biodegradable material in the landfills also played a role (Liao et al., 2016).

Biodegradation involves the use of a large amount of oxidant, for example, oxygen, in the aquifer matrix, which is in a relatively poorly ventilated groundwater table. This induces reducing conditions in the groundwater table, and the existing state of the affected groundwater by heavy metals is disturbed. This results in the heavy metals covering unusually high quantities of large particles, activated and non-activated colloids, and dissolved small particles. This can cause the heavy metals to be adsorbed on the pore of the aquifer (Boatenget al., 2019).

This study contributes to the existing literature by providing a better understanding of the groundwater potential pollution from leachates generated by wild landfill by exploring a hypothesis to show that the influence of leachates on ecosystems can be compounded by the infiltration through the soil. The paper contributes also the first logical analysis of the groundwater quality parameters near the wild landfill of El Hajeb city. In addition, the study demonstrates the preliminary ecosystem condition of the groundwater and highlights adverse environmental and public health consequences of co-disposal of metals and electronic wastes at improperly engineered municipal landfills. The research results provide a scientific foundation for protecting and managing groundwater resources in El Hajeb-area and similar areas, and we hope provides a good example for further groundwater contamination research by heavy metals and metalloids in Morocco in the coming years.

2. Materials and methods

Although the city of El Hajeb (Morocco) occupies an important place, both by its geographical location between the Atlas Mountains and the plain of Saïs (Fig. 1) and by its water resources huge, it has not escaped the problem of the leak of leachates. Its dump is uncontrolled and open-air, where all types of waste are discarded in the raw state. More or less informally, this discharge was put into operation at the beginning of the year 2005. Since then, its institutional status has not clarified; sometimes described by some as "wild dump", sometimes presented by others as a "public dump". It receives around 35 tons of waste daily, of which 78.1% is organic matter. The sources of solid waste include household waste at 90% (Gamar et al., 2017a).

Its current state is one of the major problems that the study area is experiencing in terms of environmental damage. The accumulation of waste does not find internal and external stability. Indeed, the internal contact of the wastes by uncontrolled fires produce fumes containing dioxins and other toxic substances and the external contact of the wastes with the soil permeable generate the formation of leachates flow unnoticed to the surface and groundwater where they are lost by transferring the whole and the quintessence of their lethal poisons. The detection in the region of the city of El Hajeb of significant levels of heavy metals and metalloids in waters destined for human consumption has led to the realization of a study to identify potential risk areas. This area has already been the subject of a detailed potential investigation program including:

- A study characterizing the leachates generated by the wild landfill of the city of El Hajeb (Gamar et al.,2017a, 2017b, 2017c & 2017d),
- A study of the physicochemical quality of groundwater adjacent to the same landfill (Gamar et al., 2018).

These two studies have demonstrated the correlation between the abnormal values of certain physicochemical parameters in groundwater and the existence of significantorganic and inorganic concentrations in leachates generated by waste from the wild landfill.

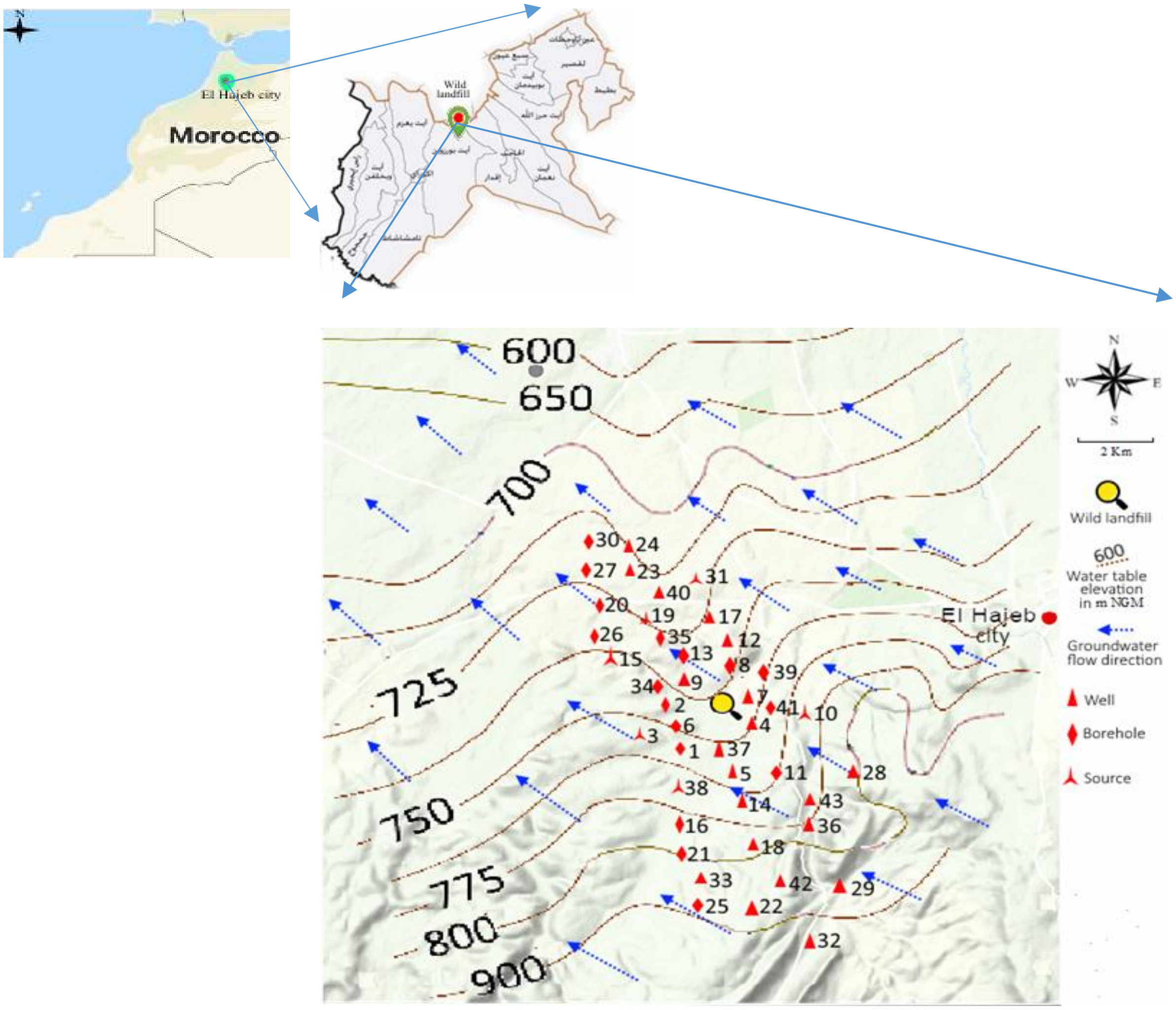

Fig. 1. Location of landfill and of groundwater stations

The investigation program presented in this study therefore consists of verifying the possible presence of undesirable elements in groundwater for the whole region by carrying out the following operations:

- The establishment of an inventory of the main water points for human consumption (wells, springs and boreholes number of 43) upstream and downstream of the landfill,
- The sampling and multi-element analysis (14 analysed elements) covering the entire sector studied.

The sampling campaign took place during 5 seasons, from the beginning of 2015 until the end of 2017 and concerned 43 sampling stations (wells, boreholes and springs), with a total of 86 samples. Their description and their geographic position (Lambert coordinates) on the Table 1. The analyses to the number of 1204 are carried out as follows:

- The portions are taken of the samples of 50 ml filtered at 0.45 µ and acidified with HNO_3 ($pH < 2$) then exposed to digestion, at high temperature;
- The instrument Perkin Elmer Optima 5300 DV ICP-OES system was calibrated with a commercial multi-element standard solution;
- Five aqueous standard solutions of concentrations: 0, 10, 25, 50, and 100 µg/L was prepared using ultra-pure (Fig. 2) water in 2% (v/v) HNO_3 (purity 65%); the curve was obtained with regression coefficient, $R^2 = 0.999$;
- The HP Column was used for analysis of the samples and temperature was maintained at the range 7000-8000 K for ionization of the elements.

Table 1. Technical data sheet of the sampling stations indicating their coordinates in space, their name, their depth and their distance from the wild dump (First campaign of sampling)

Sample Number	Coordinates (km)		Place said
	X	Y	
B1	495	342.2	MouAmchane
B2	494.2	343.6	BouKjor
S3	494.2	342.8	BouKjor
W4	495.8	342.7	AnouOmhieff
W5	469.3	342.0	Ait Bourzouine
B6	495	342.9	BouKjor
W7	496.1	343.8	AnouOmhieff
B8	495.9	344.4	Jebel M’Inegmar
W9	495.1	344.6	Kef Errih
S10	496.5	343.1	Ain Boucharmou
B11	497.5	342.2	Meggardo
W12	496.2	345.1	Jebel M’Inegmar
B13	494.8	345.1	Jebel M’Inegmar
W14	495.8	342.8	Ait Bourzouine
S15	493.1	345.2	Kef Errih
B16	494.9	341	MouAmchane
W17	495.1	346.1	Jebel M’Inegmar
W18	496.8	340.4	MouAmchane
S19	493.8	346.1	Kef Errih
B20	492.9	346.5	Sidi Omar
B21	494,8	340	MouAmchane
W22	496.8	339.0	Timlouka
W23	494.1	347.1	BouTechmadit
W24	494.2	347.7	BouTechmadit
B25	495.6	339	BouIkhba
B26	492.7	345.9	Kef Errih
B27	492	346.9	BouTechmadit
W28	498.9	342.2	BouLàachbt
W29	497.9	339.3	BouCherme
B30	492.6	347.7	BouTechmadit
S31	495.5	347	Jebel M’Inegmar
W32	496.5	337.8	Ben Darhou
W33	495.5	339.5	BouIkhba
B34	494.9	344.3	Mouchenkour
B35	494.4	345.6	Kef Errih
W36	496.4	340.9	BouCherme
W37	495.8	342.4	BouLàachbt
S38	494.2	344	MouAmchane
B39	494.4	344.7	Jebel M’Inegmar
W40	494.2	346.5	Sidi Omar
B41	495.8	343.4	BouLàachbt
W42	496.2	340	BouCherme
W43	495.3	341.8	BouLàachbt

B: Borehole, W: Well, S: Source

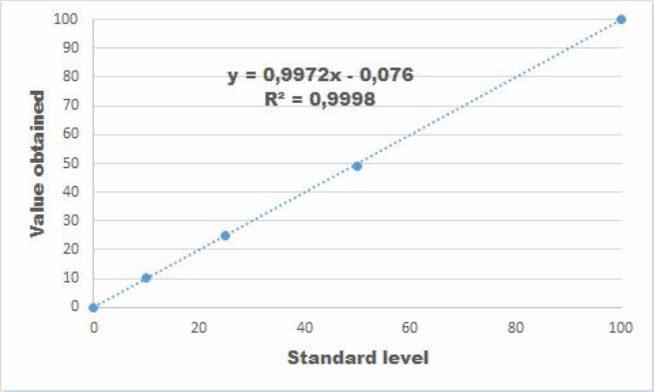

Fig. 2. Graph of the quality assurance/ quality control of sample analysis with ICP-AES

We measured, in the waters via ICP-AES technique, the following heavy metals and metalloids : Cd, Cr, Cu, Mn, Ni, Pb, As, Zn, Hg, Ag, Sn and Fe, which are the most worrying and already found in high concentrations inthe leachate ofthe wild discharge subject of a previous study (Gamar et al., 2017b).

3. Results and discussion

The study of the groundwater analyses of the El Hajeb region has shown that the metals studied here can be classified in increasing order of their relative abundance determined in average concentration as follows: Hg <Cd <As <Ag <Pb<Ni <Sn <Cr <Cu <Mn<Zn <Fe <B (Table 2). For the cadmium, its contents ranged from 0.0 µg/L in the wells W29 (depth = 15m; discharge distance = 2042 m) and W32 (depth = 28.5 m; distance to the dump = 2152 m) to 5.43 µg/L in the borehole B8 (depth = 14.5 m; distance to the dump = 429.77 m) and in well W9 (depth = 16.5 m; distance to the dump = 466.63 m). The calculated average was 0.91±0.12 µg/L below and very far from the threshold set by the Moroccan standard. In the present study, as the pH< 8 therefore the Cd^{2+} predominates (Hem,1985). As for copper, it is referenced as an undesirable element, but its toxicity is not certain. The results show that its grades ranged from 11.05 µg/L found in B25 (depth = 30.5 m; distance to the dump = 1624 m) to 582.34 µg/L in the well W37 (depth = 15 m; distance to the dump = 358.06 m), while remaining in the guideline of Moroccan standards of 2000 µg/L. Its presence is in relation to the geological environment. A result that is consistent with the work of Mansouri et al. (2014) in wells downstream of municipal solid waste landfill site in the city of Mashhad. These authors found that Cd and Cu concentrations in all of the wells did not pose any significant water quality problems since these concentrations were below the standard acceptable levels of drinking water.

Regarding the lead, according to the results, the obtained average was about of 12.99±2.13 µg/L (table 2). This value greatly exceeded the imperative limit of 1.0 µg/L set by the Moroccan standard for water intended for human consumption and was slightly above the World Health Organization maximum potable water limits of 10 µg/L (Table 2), making this water unsuitable for drinking. However, this metal was not detected either in the B39 (depth = 31 m; distance to the dump = 504.40 m) despite its proximity of the dump, which could be explained by its great depth, nor in the more distant stations (S3, B21, B30, W12 and W36) to the wild dump during the rainy season. The maximum level of 91.11 µg/L was recorded in drilling B6 (depth = 17 m; distance to the dump = 302.82 m) during the dry season, due to its shallow depth and close proximity to the wild dump. The results agree with those from Teta and Hikwa (2017) who monitored metal levels in groundwater from boreholes located in a residential area in the vicinity and downgradient of the landfill within a range of 800 – 2135 m. These authors reported that groundwater from nearby boreholes had high levels of lead (Pb) and cadmium (Cd), which were negatively correlated to distance from the landfill (p<0.01), indicating that the contamination is from the landfill. By contrast, in Pakistan (Aimanet al.,2016), Pb concentrations were reported higher than the present study.The adverse human health effects of lead include neurological disorders, kidney, and brain damage (WHO, 1993; Mcmichael et al.,1985). Furthermore, Fig. 3 shows that Pb is negatively correlated with SO_4 ($R^2 = 0.7$). The highest concentrations in Pb were observed in the water deficient in SO_4.

Table 2. Quantification of metallic elements and metalloids in groundwater during the first campaign

Parameters	Mean ± SE	Min	Max	p-Value	Standards	
					WHO	MDW
Cadmium (Cd)	0.91±0.12	0.00	5.43	< 0.0001	3	5
Lead (Pb)	12.99±0.13	0.00	91.11	< 0.0001	10	1
Arsenic (As)	4.85±0.21	2.27	8.45	< 0.0001	10	50
Mercury (Hg)	0.22±0.01	0.00	0.37	< 0.0001	1	1
Silver (Ag)	8.37±0.46	7.12	12.01	< 0.0001	10	-
Chromium (Cr)	83.35±1.99	0.12	254.16	< 0.0001	50	50
Copper (Cu)	109.29±2.91	11.05	582.34	< 0.0001	2000	2000
Aluminium (Al)	79.15±1.7	0.00	1340.11	< 0.0001	200	-
Manganese(Mn)	126.81±2.58	15.06	663.12	< 0.0001	400	500
Nickel (Ni)	55.42±1,02	11.07	261.07	< 0.0001	70	20
Zinc (Zn)	314.66±4.58	115.4	753.60	< 0.0001	3000	3000
Tin (Sn)	59.93±2.7	1.07	283.63	< 0.0001	-	-
Boron (B)	0.69±0.05	0.03	1.78	< 0.0001	2.4	0.3
Iron (Fe)	0.32±0.04	0.01	1.25	< 0.0001	0.2	0.3

All parameters are expressed in µg/L except B and Fe in mg/L

*MDW :Moroccan Drinking Water (*MDW, *2006)*
*WHO : World Health Organization (*WHO, *2011)*
Min: Minimal value; Max: Maximal value; Mean: Average value; SE: Standard Error

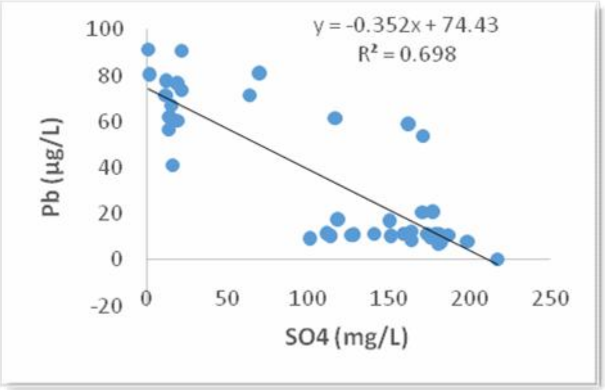

Fig. 3. Scatter diagram of Pb concentrations as a function of SO_4concentrations during the first campaign of groundwater sampling

The oxidation states of chromium ranging from +2 to +6 but only +3 and +6 are more stable in the environment. The Cr (VI) is more toxic due to carcinogenic and teratogenic effects (Kaim et al.,2013). In present study, chromium levels were highly variable in groundwater and ranged from 0.12 µg/L recorded in the source S10 (distance to the dump = 508 m) to 254.16 µg/L in the borehole B2 (depth = 13.5 m; distance to the dump = 512.66 m). The calculated average was 83.35±1.99 µg/L value higher than 50 µg/L recommended by Moroccan drinking water standards (MDW, 2006) (Table 2). These results were similar to those found in the study carried out near Municipal Solid Waste Landfill Vientiane,Laos (Vongdala et al,2019). According to these authors, the levels of Cr and Pb in the groundwater significantly exceeded the basis of WHO in both seasons although noimpact of pollution on the surface water was observed.

For the case of nickel, it is known as a human carcinogen and causes serious health problems (Dieter et al., 2005). Its concentration ranged from 11.07 µg/L measured in well W28 (depth = 26 m;distance to the dump = 1310 m) and 261.07 µg/L in wellW9 (depth = 16.5 m; distance to the dump =466.63 m)with an average of 55.42±1.02 µg/L well above of 20 µg/L limit set by Moroccan standards. Nonetheless, high concentrations were spotted near the wild landfill. Other studies in Africa found similar results, in Nigeria Michaela et al.(2018) reported that the soil and ground water samples from various sites have a high level of heavy metals concentration as compared to the permissible limits.Concerning the dissolution chemistry relative to chromium and nickel, Fig. 4 indicates that no correlation was observed between Cr and pH (R^2 = 0.15) for the 43 groundwater stations of the first campaign.

The literature states that an alkaline pH and an oxygenated medium promote the dissolution of chromium VI (Van Der Putte et al., 1981). This was not the case here, these groundwater with a low redox potential were under-oxygenated (deeper and/or polluted), suggests that we are in reducing conditions, hence the presence Cr (III) in abundance. For the Ni, according to the literature his evolution is unpredictable because without the knowledge of the mechanism of dissolution of nickel (and therefore of its chemical form in solution), it is not possible to predict the evolution of its concentration.

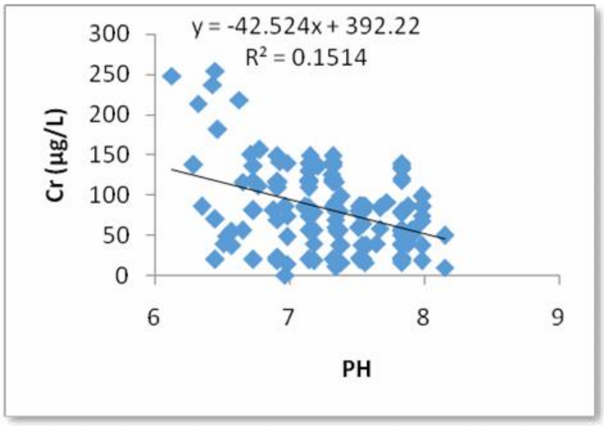

Fig. 4. Scatter diagram of Cr concentrations as a function of PH during the firstcampaign of groundwater sampling

For zinc, mercury and arsenic, the threshold values set by the Moroccan standards for the definition of good water are respectively 3000 µg/L, 1 µg/L and 50 µg/L. All 43 points in the sampling network were in norms for these three metals. Although the Zn shows a high grade, consistent with the observation of Christensen et al. (2001) that Zn^{2+} usually occurs in orders of magnitude higher than other heavy metals (Table 2),the geochemistry of zinc is relatively uncomplicated and chalcophile behaviour is quite marked by a frequent association with sulphur (Mahan et al.,2017). It should be noted that Zn levels recorded in well water sources close to landfill sites from the Tiruchirappalli District, India (Kanmani and Gandhimathi, 2013) were lesser than those found in this study. By contrast, the concentrations of Cd, Pb, Zn, and Cr in the studied groundwater samples were comparable with earlier studies (Aiman et al., 2016;Chakraborty&Kumar, 2016;Deshmukh, &Aher, 2016;Nagarajan et al., 2012;Wijesekara et al.,2014).

The presence in groundwater of As has been reported by other authors in several Moroccan cities, as an example in El Jadida (Chofqi et al., 2007) and abroad in France (Grisey et al., 2010) and in India (Chakraborti et al., 2018). Arsenic is commonly found in the form of sulphur compounds and many metals. The highest concentrations of As have been observed in water deficient in SO_4(Fig. 5). Aluminium and tin were considered undesirable contaminants. For aluminium, its concentration found regularly in groundwater is about 0.4 mg/L. Aluminium is present in soils in the form of the less exchangeable hydroxide, ($Al(OH)_2^+$, $Al(OH)_2^+$) and insoluble in water. When the pH value is under 4.5. The Al^{3+} ion is released by alteration and solubility increases rapidly, increasing the aluminium concentration above 5 mg/L. However, in the presence of suspended solids (high turbidity), it is possible to correlate and determine if the aluminium comes from soils.

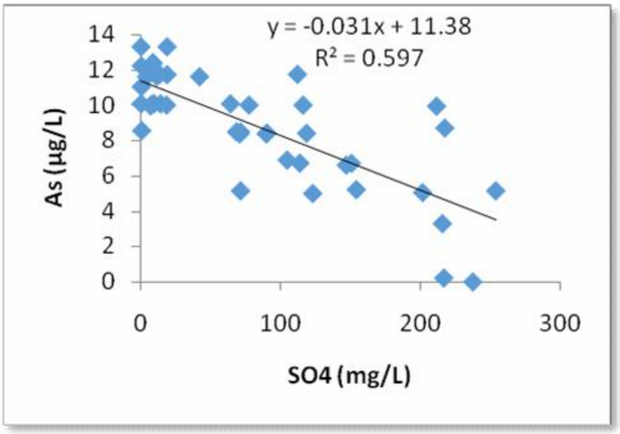

Fig. 5. Scatter diagram of As concentrations as a function of SO_4 concentrations during the 1st campaign of groundwater sampling

The study, conducted for these two metals showed that their contents in groundwater were characterized by a great variability in space and time. Aluminium levels ranged from undetectable to wells W24 (depth = 17 m, distance to the dump = 1907 m) and W32 (depth = 28.5 m, distance to the dump = 2152 m) to 1.34 mg/L to boreholes B1 (depth = 15.5 m, distance to the dump = 462.13 m) and B6 (depth = 17 m, distance to the dump = 302.82 m). While the tin ranged from 1.07 µg/L in well W29 (depth = 15 m, distance to the dump = 2042 m) to 283.63 µg/L in borehole B6 (depth = 17 m, distance to the dump = 302.82 m). In the absence of Moroccan standards of these two metals, statistics show that 31% of the groundwater samples exceeded the WHO (2011) standards set.

For iron, it is one of the most abundant metals in the earth's crust. Iron is a trace element essential for human health. Its concentrations, even high, do not pose a risk to human health. However, when its content in water exceeds 0.3 mg/L, iron can change the taste and colour of water, stain washed clothes, and damage household appliances. In this study, its concentrations ranged from 0.01 mg/L in source S10 (distance to the dump = 508 m) to 1.25 mg/L found in borehole B2 (depth = 13.5m; distance to the dump = 512.66 m) (table 2). The analyses showed that 14% of the stations inspected did not comply with Moroccan standards for water intended for human consumption set at 0.3 mg/L. In addition, the concentrations of Fe in the present study were very low that those reported by Chofqi et al. (2004) in well water samples collected from El Jadida (Morocco).

For manganese, high concentrations can cause mental illnesses (ATSDR, 2000; WHO, 1993). In the present study, manganese was found to range from 15.06 µg/L measured in well W29 (depth = 15 m, distance to the dump = 2042 m) to 663.12 µg/L in W9 (depth = 16.5 m; distance to the dump = 466.63 m) with an average of 126.81±2.58 µg/L. This average was well below the limit of 500 µg/L set by the Moroccan standard (Table 2). Results in perfect agreement with those found by Zhai et al.(2019) who found that the concentration of total Fe and Mn in the downstream groundwater increased of several orders of magnitude because of the leachate, during a study carried out in NE China.

In addition, the measurements carried out during the first sampling campaign made it possible to see a link between iron and manganese concentrations. The strong positive correlation (R^2 = 0.73) indicated that these two metals could have the same origin (Fig. 6). Moreover, the redox potential was weakly negatively correlated with Fe (R^2 = 0.49) (Fig. 7) and with Mn (R^2 = 0.52) (Fig. 8). Results in agreement with Virkutyte and Sillanpää(2006) that showed that the variations of Fe and Mn in water are mainly controlled by oxidation-reduction and acid-alkali equilibrium conditions.

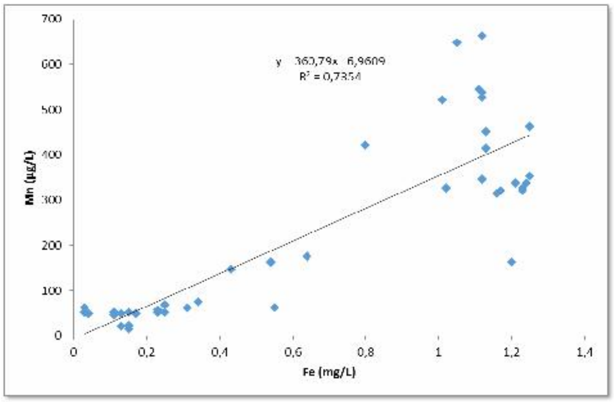

Fig. 6. Scatter diagram of Mn concentrations as a function of Fe concentrations during the first campaign of groundwater sampling

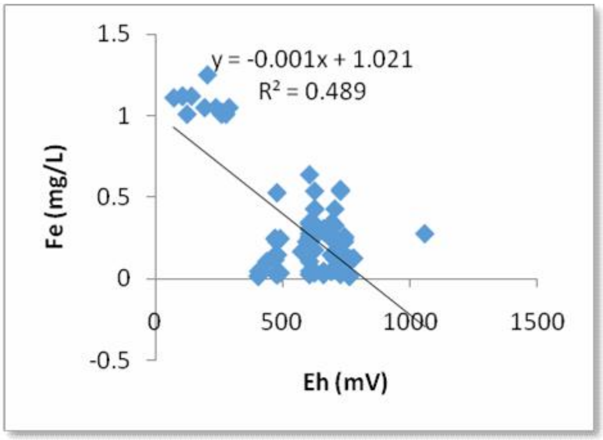

Fig. 7. Scatter diagram of Fe concentrations as a function of Eh during the first campaign of groundwater sampling

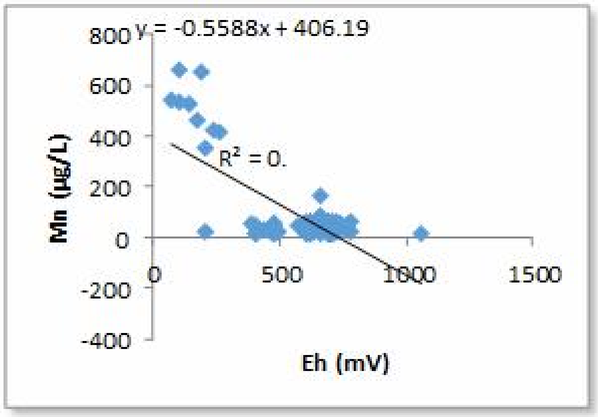

Fig. 8. Scatter diagram of Mn concentrations as a function of Eh during the first campaign of groundwater sampling

On the other hand, the pH was weakly negatively correlated with the Fe (R^2 = 0.06) (Fig. 9) and with the Mn (R^2 = 0.17) (Fig. 10). The pH also seems to be a factor controlling more or less the distribution of Fe and Mn. However, under low-pH and low-Eh conditions, the Fe and Mn concentrations in groundwater were relatively high. These results corroborated those obtained by Pitt et al.(1999) who stated that the Fe and Mn can be oxidized by anaerobic bacteria and under low-pH conditions, therefore concentrations would increase. While, the Mn had a positive low correlation (R^2 = 0.28) with sulphates (Fig. 11) and even less between Fe and SO_4 (R^2 = 0.02) (Fig. 12),which is not in agreement with Olías et al.(2004),who found that Mn had a strong correlation with sulphates resulting from sulphide oxidation.The last metal sought in this study was silver (Ag). The Ag content in groundwater ranges from 7.12 µg/L in well W33 (depth = 13.5 m; distance to the dump = 1480 m) during the wet season to 12.01 µg/L recorded at well W23 (depth = 24.5 m; distance to the dump = 1854 m) during the dry season with an average of 8.37±0.46µg/L.

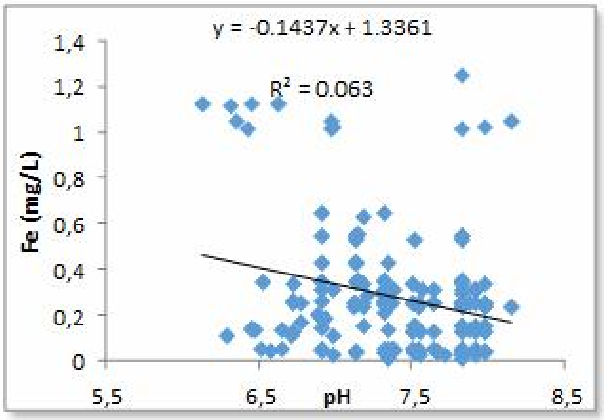

Fig. 9. Scatter diagram of Fe concentrations as a function of pH during the first campaign ofgroundwater sampling

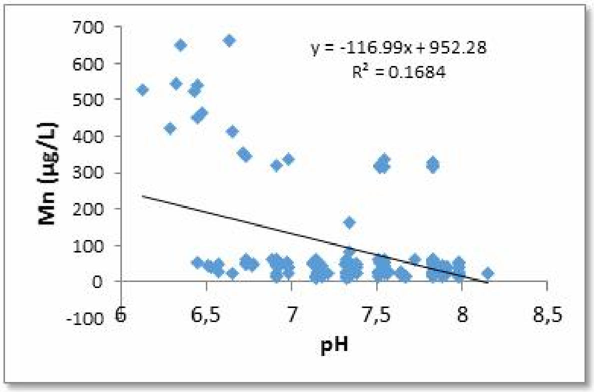

Fig. 10. Scatter diagram of Mn concentrations as a function of pH during the first campaign of groundwater sampling

In the absence of a Moroccan standard, the WHO (2011) standard stipulates that water of optimal quality to be consumed must not exceed the concentration of 10 µg/L. Statistics show that 33% exceed this standard. The field survey indicated that this pollution is related to the practice of cloud seeding since decades to combat drought. Each year, it releases a large amount of chemical particles including silver iodide (AgI) and sodium iodide (NaI) sprayed to inseminate the clouds and therefore to increase the rate of precipitation in the atmosphere. These particles reach the water table and accumulate there.

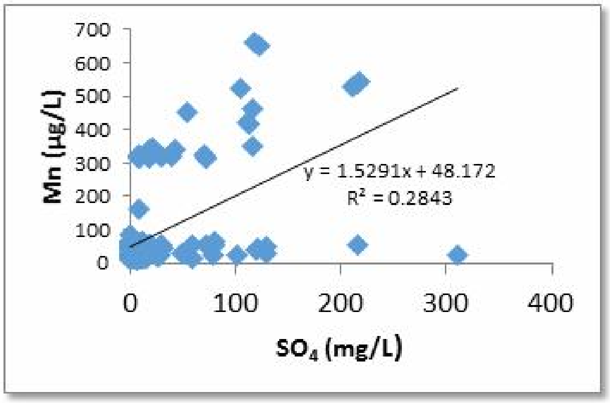

Fig.11. Scatter diagram of Mn concentrations as a function of SO_4 concentrations during the first campaign of groundwater sampling

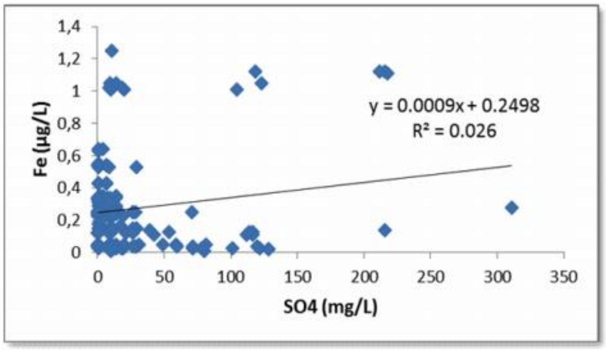

Fig.12. Scatter diagram of Fe concentrations as a function of SO_4 concentrations during the first campaign of groundwater sampling

4. Conclusion

This study is the first to examine the heavy metals and metalloids contamination of water in vicinity the wild landfill of El Hajeb (Morocco). It provided detailed information of pollution presence by the metals and metalloids and as well as their levels and revealed that the groundwater covering most of the water resources near the wild dump is contaminated and generally appears of poor quality. Indeed, the investigations carried out on groundwater unequivocally have revealed the presence of pollution especially in Cd, Cr, Al, Mn, Ni, Fe and Pb, which are mainly linked to the leachate of the wild landfill and, a lesser degree, to the excessive and irrational use of chemical fertilizers and phytosanitary products.

On the other hand, some high correlations have been revealed, as the lead and Arsenic that are negatively correlated with SO_4 and have been observed in water deficient in SO_4 and the strong positive correlation between Fe and Mn, which indicated that these two metals could have the same origin. For metal of silver, his detection is probably related to the practice of cloud seeding that the region has known for decades.

At the end of this study, and in order to contribute to sustainable development in the region and to improve the quality of life of citizens through respect for the environment, we would like to make the following suggestions:

-Urgently undertake the rehabilitation work or the closure of the landfill and the opening of another controlled;

-Establish a system of continuous monitoring of groundwater quality in the study area.

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