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Assessment of lead and cadmium in groundwater sources used for drinking purposes in Jijel (Northeastern Algeria)

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Abstract

Groundwater is one of the important sources of drinking water In Jijel (northeastern Algeria). Various analyses have shown critical concentrations of lead and cadmium in several groundwater sources used for drinking. The aim of this study is to evaluate the contamination by lead and cadmium of boreholes and hand-dug wells located in the catchment of the Nile River. Therefore, chemical analysis was performed on drinking water samples from eight boreholes; tow hand dug wells and one spring supplying Jijel city in drinking water. The water samples were examined for the presence of cadmium and lead using the SAA- 6200 Atomic Absorption Spectrophotometer (*Shimadzu Corporation*). The results of this study show high concentrations of lead (ranged from 72.84±0.26 to 458.95±0.55 $\mu g.L^{-1}$) and cadmium (ranged from 12.41±0.88 to 33±0.38 $\mu g.L^{-1}$) in all water samples. These concentrations far exceeded permissible values according to the WHO's drinking water posing a potential health risk for the public. The water quality in the studied area of Nile River basin must be considered very low.

Keywords: boreholes, cadmium, drinking water, groundwater; hand-dug wells, lead, Nile River.

1. Introduction

Environmental pollution like drinking water and soil pollution by heavy metals is one of the most important issues in the world due to no-biodegradability of the metals and their impact on living organisms in concentration greater than thresholds (Naghipour *et al.* 2018).

Lead and cadmium are two heavy metals toxic to humans and hazardous to the environment (Prokopowicz *et al.,* 2014; Jones *et al.,* 2017). In humans, severe health implications such as cardiovascular and skeletal diseases, infertility and neurotoxicity are associated with the exposure to heavy metals (WHO, 2011). Moreover, the oncogenic properties of such metals have been demonstrated in several studies (WHO 2011; Colak *et al.,* 2015; Gil and Hernandez, 2015; USEPA, 2015; Fallahzadeh *et al.,* 2017). The oncogenic effects of Cd and Pb are aggravated by chronic exposure to these elements due to their long biological half-life and cumulative properties (Monroy *et al.,* 2014; Cabral *et al.,* 2015).

In the general population, food and water are the most common sources of lead and cadmium exposure (ATSDR 2014; Zang, 2016). Cigarette smoking is another source of exposure to heavy metals such as Cd and Cr (ATSDR, 2014); it can also potentiate the effects of exposure to other sources (Fairbrother *et al.,* 2007b).

The subject of safe drinking water is important topic in the world (Alimoradi *et al.,* 2018) and groundwater is one of the most valuable freshwater drinking water sources being used for the drinking purposes throughout the world (Chabukdhara *et al.,* 2017). However, many chemicals, especially those of through anthropogenic activities origin, can contaminate groundwater. The contamination chain usually follows a cyclic order: industry, atmosphere, soil, water, foods and humans (Usman *et al.,* 2014; Gil and Hernandez, 2015; Geng *et al.,* 2016). Among the various pollutants that affect water resources, pollutants containing heavy metals are particularly important due to their high toxicity, even at low concentrations (Vatandoost *et al.,* 2018). According to the World Health Organization (WHO), heavy metals represent a major group of contaminants in drinking water, and they are considered a serious threat to human health (WHO, 2011). The health risks posed by oral intake of heavy metals are the highest among all other exposure pathways (Zhang *et al.,* 2014a; b).

In Algeria as well as in other developing countries, contamination of drinking water sources by heavy metals has been triggered by rapid urbanization, industrialization and excessive use of agricultural pesticides and chemical fertilizers during the last decades. The geogenic sources also contribute to the wide distribution of heavy metals such as arsenic, lead and cadmium in ground and surface water (Bhowmik *et al.,* 2015). Hence, small and rural communities and individuals in these countries regularly consume water with levels of heavy metals above the guideline values (WHO, 2011; Khan *et al.,* 2012). The control of drinking water quality thus continues to be a priority for the government authorities to ensure compliance with health and sanitation requirements (Zhao *et al.,* 2002; WHO, 2011). Yet, there are no regular programmes to monitor heavy metal levels in drinking water sources in Algeria.

Jijel is located in northeast part of Algeria, covering 2398 Km^2, and has a 2008 census population of 636.948 inhabitants, with 465822 are 15 years old and more (NSO, 2008), the mean annual temperature is ranging from 11.6 to 26.5 °C and mean annual precipitation from 9.5 to 189.1 mm. The region is characterized by a number of factors that may increase the risk of the contamination of ground waters with Pb and Cd from natural or anthropogenic sources. The goal of this study was to determine the lead and cadmium concentrations in groundwater.

2. Material and Methods

2.1 Sample collection

The drinking groundwater samples were collected (during dry seasons from 2011 to 2013) from the Nile River bassin in Taher city, approximately twenty kilometres from Jijel area (Fig.1a, 1b). The Jijel area is characterised by sedimentary Mesozoic and Cenozoic land covering metamorphic terrains. Thus, the tertiary coverage is on the Kabyle base or on the Cretaceous flysch series (Djellit, 1987).

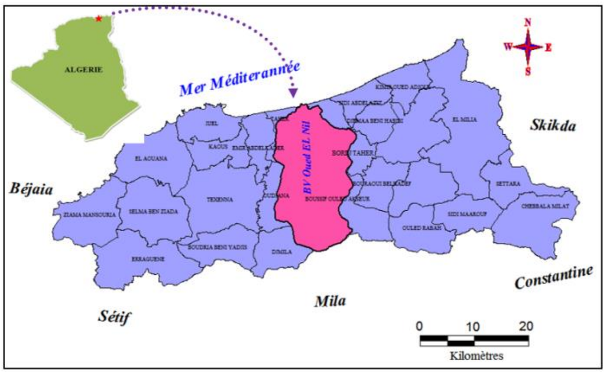

Figure 1a. Jijel area (Zahi *et al.,* 2016).

Ten sampling points were selected for our study. Samples 1 to 7 were collected from different boreholes distributed throughout the Nile River catchment. Samples 8 and 9 were collected from two hand-dug wells, used for drinking water in Redjla, a small village in Taher region. Sample 10 was taken from Bachelot spring near the boreholes, intensively exploited by the local population in Taher city (fig. 2). Three samples were taken from each of these 10 sampling points.

During sampling, the standard guidelines were followed to avoid any possible contamination. Water samples were collected into 250 ml sterile polythene bottles. Once the sample was taken, the bottle was closed immediately, to minimize the formation of air bubbles, and labelled. The bottles were placed in a portable cooler (4 °C) and transported to the laboratory.

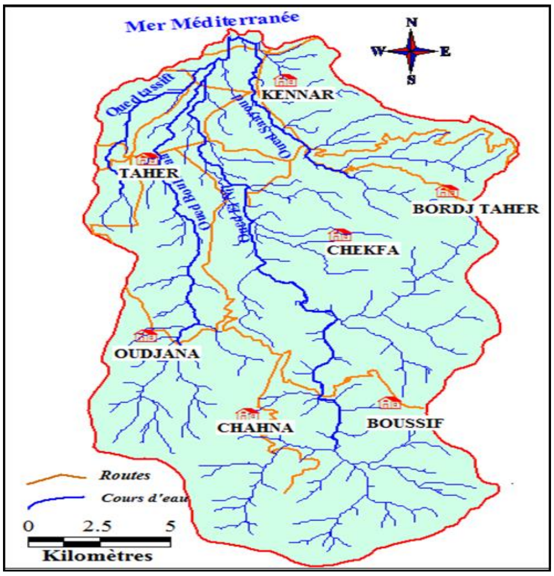

Figure 1b. Nile river catchment (Hammadi and Harendi, 2015).

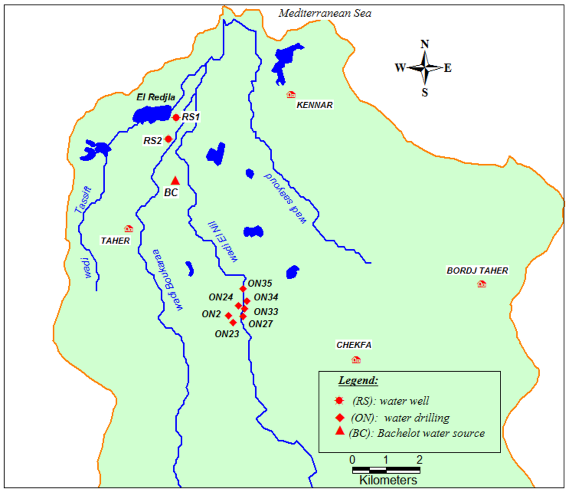

Figure 2. Location of the water-sampling sites.

2.2. Sample preparation

Water samples were filtered through 0.45-µm filters (Sartorius Stedin, Germany), and the pH of the filtrate was set to 2 ± 0.2 using ultrapure HNO_3 (acidification minimises the adsorption of metals into the walls of the container) and stored at approximately 4 °C in the dark until the analysis.

To ensure the removal of organic impurities from the samples and thus prevent interference in the analysis, the samples were digested according to the ISO 82 88-1986 EC method (Japanese Industrial Standard JIS K-102-1993).

2.3. Analysis methods

The water samples were examined for the presence of cadmium and lead using the SAA- 6200 Atomic Absorption Spectrophotometer (*Shimadzu Corporation*). The detection limits were 10 ug.L^{-1} for lead and 2 ug.L^{-1} for cadmium. The samples were nebulised in an air/acetylene flame, which atomises the metal elements.

The stock solutions of the reagents were prepared using ultrapure water, and all standard solutions were made daily by diluting the appropriate stock with 0.01M nitric acid (Tamsi and Cini, 2004). Calibration solutions of the target metal ions were prepared from the standard stocks by serial dilution.

For water samples, 1000 mg.L^{-1} stock solutions of Cd and Pb (AVS Titrinorm, EC) were prepared with 5 % nitric acid and diluted to obtain the calibration curves. The ranges of concentrations chosen corresponded to the concentrations most commonly encountered in drinking water samples.

2.4. Statistical analysis

Statistical analysis were performed using Statistical Package for Social Science (SPSS, version 20). The results are expressed as mean±SD (SD: standard deviation), with the average concentration of the metal displayed in µg.L^{-1} after extrapolation from the standard curve. The one-way ANOVA and Scheffe Multiple Comparison method were used to establish if the differences between the concentrations of lead and cadmium at the different sites, during the three years, were significant.

3. Results

3.1. Lead and cadmium concentrations in groudwater samples

Table1 displays the lead and cadmium concentrations and the descriptive statistics for the groundwater samples from the study area.

The analysis showed hazardous concentrations of lead and cadmium in the groundwater samples collected from different sites, with significantly higher concentrations of lead than cadmium. The highest average level of lead (458.95±0.55 µg.L^{-1}) was detected in samples collected during 2013 from borehole ON_{24}, and the lowest (72.84±0.26 µg.L^{-1}) was observed in water samples obtained from Bachelot spring in 2011 (Fig.3a, 3b). Furthermore, all the tests showed the lead levels higher than the drinking water guideline value of 10 µg.L^{-1} recommended by WHO (2011) and by standards Algerian (NA) (JORA, 2011), which might have a detrimental effect on the health of the local population.

Table 1. Lead and cadmium concentrations (µg.L^{-1}) in the groundwater samples.

Locations of sampling sites	**Lead**			**Cadmium**		
	2011	2012	2013	2011	2012	2013
Oued Nile's Boreholes						
ON_2 (mean±SD)	348.51±0.31	354.90±0.24	431.66±0.92	28.76± 1.02	29.80±0.60	28.57±0.99
(95% CI)	347.18-349,85	353.83-355.97	427.69-435.64	24.35-33.16	27.20-32.40	26.10-31.04
ON23(mean±SD)	258.74±0.38	267.12±0.17	272.53±1.12	14.46±1.04	19.91±0.55	20.12±0.49
(95% CI)	257.08-260.40	266.37-267.86	267.69-277.36	9.96-18.95	17.51-22.31	18.88-21.35
ON_{24}(mean±SD)	452.89±0.89	458.89±0.41	458.95±0.55	32.00±1.02	32.86±1.29	32.80±1.09
(95% CI)	451.77-454.00	457.1-460.67	456.54-461.35	27.58-36.41	27.30-38.41	30.07-35.52
ON_{27}(mean±SD)	335.26±0.09	335.68±0.77	335.81±0.87	24.93±0.78	25.82±0.51	26.20±0.57
(95% CI)	334.84-335.68	332.36-339.01	332.03-339.59	21.54-28.33	23.59-28.04	24.78-27.62
ON_{33}(mean±SD)	378.7±0.38	396.10±0.44	404.13±0.80	30.92±1.66	32.80±0.62	33.00 ± 0.38
(95% CI)	377.1-380.46	394.18-398.01	400.68-407.58	23.77-38.07	30.09-35.50	24.78-27.62
ON_{34}(mean±SD)	318.89±0.28	321.68±1.04	321.90±0.97	13.90±0.72	16.93±0.26	17.61±0.89
(95% CI)	317.67-320.1	317.17-326.20	317.84-326.10	10.78-17.02	15.77-18.09	15.38-19.83
ON_{35}(mean±SD)	275.71±0.18	283.00±0.28	294.56±0.55	12.41±0.88	12.98±0.61	13.25±0.70
(95% CI)	274.91-276.51	281.79-284.20	292.15-296.96	8.62-16.19	10.34-15.62	11.50-15.00
Redjla's wells						
RS_1(mean±SD)	179.26±0.32	179.84±1.5	181.17±1.03	24.54 ±0.32	25.19 ±0.16	25.22±0.45
(95% CI)	178,21-181,02	173,35-186,33	179,92-182,42	23,14-25,93	24,48-25,89	24,09-26,36
RS2(mean± SD	168.34±0.56	170.04±0.18	206.02±0.51	13.69 ± 0.93	13.87 ±0.68	13.94±0.52
(95% CI)	165.89-170.79	169.24-170.84	204.00-208.40	9.65-17.72	10.92-16.82	13.34-14.54
Bachelotspring						
BC(mean±SD)	72.84±0.26	72.89±0.63	74.32±0.32	19.13 ± 0.35	19.18±0.58	19.22±0.37
(95% CI)	71.70-73.99	70.15-75.64	72.91-75.72	17.59-20.66	17.73-20.62	18.28-20.16

***SD*: standard deviation; 95% *CI* : 95% confidence interval**

The Scheffe Multiple Comparison test showed that the mean lead levels significantly differed between most study sites, except for the comparison between borehole ON_{35} and hand-dug well RS_1 during 2011. For cadmium levels, the ANOVA test showed significant differences between the site groups (boreholes, hand-dug wells and Bachelot spring) during the three years. Moreover, the Scheffe test revealed a significant increase in cadmium and lead levels during this time. These findings confirm the local variations in lead levels and, to a lesser degree, in cadmium levels in the water sources analysed in this study.

An abnormally high concentration of cadmium was found in all the water samples from boreholes and wells, above the permissible limit of 3 µg.L^{-1} (WHO, 2011) and the Algerian limit estimated by 2 µg.L^{-1} (OJAR, 2011). This was particularly pronounced in the borehole ON_{33} (33±0.38 µg.L^{-1}).The lowest concentration was reported for borehole ON_{35}: 12.41 ± 0.88 µg.L^{-1}, during 2011.

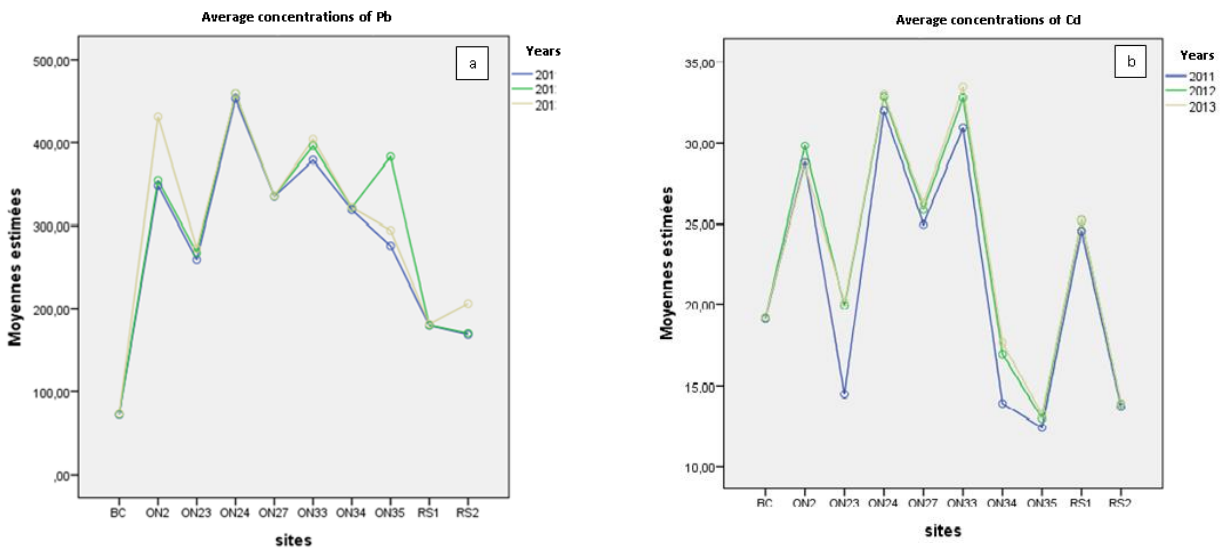

Figure 3. Variations in mean concentrations of lead (a) and cadmium (b) over the three years of the study

Previous studies have shown lower levels of lead in the borehole ON_{34}, Bachelot spring (BC) and two hand-dug wells (RS1 and RS2); they were 82.6, 72.9, 79.6 and 68.3 µg.L^{-1}, respectively. However, the cadmium levels reported in those studies for the same sites (14.4, 19.1, 24.6 and 13.7 µg.L^{-1} (Belli *et al.,* 2010) were similar to our results. Benhamza, (1996) and Alligui and Boutaleb, (2013) have found very high concentrations of lead in a hand-dug well in Azzaba District in North-East of Algeria, in the range of 0.7 mg.L^{-1} to 0.8 mg.L^{-1}. High lead and cadmium levels have also been reported in other countries.

Lead concentrations exceeding the permissible WHO limits have been found in Assam (127.2 µg.L^{-1}, Borah *et al.,* 2010). Frisbie *et al.,* (2009) have demonstrated excessive levels of lead (17 µg.L^{-1}) and other heavy metals in the water from some boreholes wells in Bangladesh. Arain *et al.,* (2014) and Rasool *et al.,* (2016) also have found cadmium concentrations (12.7 and 67.68 µg.L^{-1}, respectively) higher than the permissible limits.

4. Discusssion

Lead and cadmium found in water may come from both natural (weathering of bedrock) and anthropogenic (mining, industry and agriculture) sources (Krishna and Mohan, 2014). In our study area, this contamination could be of geogenic origin, a result of natural conditions in the aquifers. Metal leaching is a naturally occurring process; however, if the concentrations of trace elements are anomalously high, they may have a negative impact on the environment (Perkins *et al.,* 1995). Natural or geogenic background concentrations of heavy metals vary significantly from one area to another (Bradl, 2005). No data for the background heavy metal levels in the examined region are available. However, the overall geochemical report on the Taher area, published by Afalfiz *et al.,* (1998), suggests that the metals are mostly of natural origin. According to that study, in the western part of the crystallophyllian basement of the Petite Kabylie (an internal part of Maghrebide chain), there is a polymetallic ore area, in the Taher region (Southeast of Jijel). This area contains celsian, magnetite and barite deposits.

A comparison of Taher mineralisation with some similar Pb-Zn deposits elsewhere in the world suggests a syngenetic hydrothermal origin for these mineral concentrations. The presence of this type of mineralisation in the massif of Petite Kabylie indicates an old metallogenic event, typical of the Northern Algerian socles (Afalfiz *et al.,* 1998).

The natural processes alone may not be a sufficient explanation of the observed metal concentrations. The results of this study clearly demonstrate that the concentration of lead and cadmium increases yearly; this suggests some anthropogenic effects. Heavy metals such as lead and cadmium are mainly introduced into the groundwater by agricultural and industrial activities, landfilling, mining and transportation. The transport and final fate of these metals in the groundwater might follow several distinct paths (Adriano, 2001).

All boreholes and wells analysed here were located in the area used for intensive agriculture (Nile River basin). In some countries, lead added to petrol has also accounted for some of the increase in its concentration in the environment (Petit *et al.,* 2015, Kira *et al.,* 2016). In Algeria, the concentration of lead in the petrol is 0.45 g.L^{-1} (Semadi and Deruelle, 1993). One of the other sources of lead might be the waste from old mines of precious metals (gold and silver) and marble. These mines ceased production and were abandoned in 1993. They have been run by Algerian Society of Mines SONAREM in the Nile River basin Ain Tizi in Chahna mountains in the south of Taher. The Bachelot spring and Nile basin boreholes, located downstream from this site, are particularly affected. The domestic sewage and atmospheric deposits are likely to be other anthropogenic sources of this contamination.

The results of this study show that the groundwater from boreholes in the Nile River basin is not safe for human consumption. The water from the boreholes and hand-dug wells was heavily contaminated, with more than permissible levels of lead and cadmium. This contamination is about 30 times higher than Algerian standards for lead and about 12 times the Algerian cadmium standards.

Among all heavy metals, lead (Pb) has recently gained increased interest due to its potential to cause various toxicological effects in humans, such as anemia, liver and kidney damage, cardiovascular and haematological damage, central nervous system damage and cancer (Kira *et al.,* 2016; Naghipour *et al.,* 2017). The first manifestation of Cd toxicity is renal tubular dysfunction, a major cause of end-stage renal disease. Long-term exposure has been associated with bone diseases, alteration in lung function, lung cancer, prostate cancer and renal cancer. However, the kidney is the critically affected organ (Verougstraetea *et al.,* 2003; Nair *et al.,* 2013; Arain *et al.,* 2014).

Our analysis exposes serious toxicological threats to the health of the Jijelian population.

5. Conclusion

This study was carried out to examine the quality of groundwater from certain boreholes and collective hand-dug wells, intensively exploited by the local Jijelian population as sources of drinking water. The data showed that the levels of lead and cadmium in water samples examined in this study did not meet the international safety standards. Thus, the water quality in the studied area of Nile River basin must be considered very low.

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