www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.141555
2022, No. 54 (VII–IX): 59–67

Risk assessment of irrigation with water contaminated by trace metals on the soil–plant complex in the El Madher plain, north-east Algeria

Farida Benfarhi ✉, Mohamed Redha Menani

University of Batna 2, Faculty of Sciences, Department of Earth and Universal Sciences,
Water Resources Mobilisation and Management Laboratory (MGRE), 53, Route de Constantine, Fésdis, 05078, Batna, Algeria

RECEIVED 11.08.2021 ACCEPTED 20.12.2021 AVAILABLE ONLINE 28.09.2022

Abstract: Polluted water poses significant health risks when it is part of the water sources used for irrigation, leading to the contamination of soil and plants by various pollutants. This work aims, firstly, to assess the degree of pollution of Wadi El Gourzi water (Batna, Algeria), and then to verify the consequences on their use for the irrigation of market garden plants for everyday consumption (lettuce, cilantro, parsley and spinach), both in the aerial part (stems and leaves) and in the soil where they are grown. This study focuses on trace metals (Cr, Pb, Zn and Cd). Soil pollution was assessed by calculating the soil pollution index (*PI*), while the uptake of these elements by plants was monitored by the transfer factor (*TF*). The analyses of the Wadi El Gourzi water with the flame atomic absorption spectrophotometer (FAAS) show a maximum abnormal concentration of Cr (17.37 mg·dm^{-3}), Pb (0.71 mg·dm^{-3}) and Cd (0.45 mg·dm^{-3}). For the analysis of the soils irrigated by these waters, the results of the *PI* show that the soils used for the cultivation of parsley and lettuce are polluted by several metals (*PI* > 1). The concentrations of trace metals elements (TMEs) in the sampled plants show a significant accumulation of Zn, Cd, Pb and Cr by the vegetables (coriander, parsley, spinach and lettuce). These concentrations are above the permitted standards.

Keywords: agricultural soil, El Madher plain, irrigation wastewater, trace metals, vegetable crops, Wadi El Gourzi

INTRODUCTION

The use of wastewater in agriculture is a very old and widespread practice worldwide [Chang *et al.* 2002; WHO 1989]. More than 20 mln ha in 50 countries are currently irrigated with treated or raw wastewater [Scott *et al.* (eds.) 2004]. In Pakistan, 80% of the urban community uses raw wastewater in agricultural production and 26% of vegetable production is achieved through the reuse of often raw wastewater [Scott *et al.* (eds.) 2004]. In Morocco, most cities are equipped with sewerage systems and the collected wastewater is used for agricultural purposes [Bazza 2002]. Algeria has an essentially arid to semi-arid climate, with low and irregular rainfall and very limited water resources [MRE 2001]. Population growth, the frequency of occurrence of droughts, and economic growth have led to increased water needs and increased pressure on conventional water resources [MRE 2001]. This situation has led to searching for other non-conventional resources such as the reuse of treated wastewater.

The El Madher plain located in the territory of the Wilaya of Batna (Algeria) is an agropastoral area. The crops grown here are generally market gardening (lettuce, carrots, etc.) or fodder crops (oats, alfalfa, etc.) and cereals are the main crops (wheat, barley, etc.). Like all agricultural areas in semi-arid regions, this plain is exposed to the scarcity of rainfall, the annual average of which does not exceed 400 mm. The problem which is seriously posed, these last years is undoubtedly, the use of Wadi El Gourzi contaminated water by industrial and domestic wastewater for the irrigation of the cultures, knowing that the wastewater treatment plant located at the outlet of the city is experiencing malfunctions due to the fact that its purification capacities are largely exceeded.

This use presents significant health and environmental risks, such as soil and groundwater contamination [Jeannot *et al.* 2001]. Indeed, the lettuce, coriander, parsley and spinach plots are irrigated with contaminated water, as we noticed during our field visits, following the nauseating odours felt in the surroundings. In this region, several motor pumps are installed on the banks of the Wadi El Gourzi, supplying the sprinklers fixed in these plots. The agricultural production resulting from this irrigation is intended for the needs of Batna, Djerma, El Madher and Fesdis. The use of polluted water is considered by farmers as an alternative source of water available all year round, free of charge, and even as a source of nutrients essential for crop growth (good yields). However, this practice is punished by Algerian law. Article 130 of the Water Law enacted in 2005 states that "the use of raw wastewater for irrigation is prohibited" and sanctions for this violation are also mentioned in the same text [Godden 2005]. Despite the fact that public services have repeatedly sanctioned farmers who use Wadi El Gourzi water, but they return to their practices each time.

The Wadi El Gourzi, which is of particular interest to us in this study, is a small but principal river that drains surface water after raining periods and also industrial and domestic wastewater city of Batna city towards the El Madher plain, where it spreads over a vast area. Moreover, the wastewater treatment plant installed at the city's outlet has been overtaken by the city's urban expansion and neighbouring localities. It only ensures the treatment of a part of these discharges. Added to this is the lack or malfunctioning of specific treatment stations at the level of most of the factories in the industrial zone, which further contributes to the pollution of the Wadi's water by dangerous substances, particularly trace metal elements (TMEs).

The soils in the El Madher plain (Fesdis region) are calcisols world data. They are composed of 48% clay, 43% silt and 9% sand with high total limestone content. Land devoted to agriculture occupies 2755 ha, representing 32.10% of the municipality's total area, forests cover more than 4041 ha and non-agricultural land approximately 1784 ha. Of the 2755 ha of agricultural land, 2407 ha are considered useful; 32.4% of the agricultural land is irrigated with groundwater (wells) and 67.6% with contaminated water from Wadi El Gourzi. Some plots are irrigated with both groundwater and contaminated water from the Wadi [Tamrabet 2011].

Domestic and industrial wastewater is rich in organic matter and fertilising elements, but it also contains undesirable chemical elements, particularly trace metals [Chaney 1988]. These metals and other non-biodegradable inorganic compounds accumulate in the soil [Mench *et al.* 2002] depending on biogeochemical conditions. They pass into the soil solution and then can be taken up by plants. They can then be incorporated into the food chain when they exceed maximum allowable concentrations (MACs). For example, cadmium, mercury and lead are toxic, even in small concentrations, to plants, animals and humans. They accumulate in the soil due to their long biological half-life [Göthberg *et al.* 2002]. The degree of trace metal contamination in the soil depends on the physico-chemical properties (texture, percentage of clay, pH and organic matter content, etc.), the load and type of heavy metals present in the irrigation water and the time during which the soil has been subjected to irrigation.

This study aims, first of all, to assess the degree of pollution of the Wadi El Gourzi water, then to verify the consequences on the use of this water for the irrigation of plants (parsley, spinach, cilantro and lettuce) and to identify the interaction between the soil and the concentration of metals in the crops. The concentrations of metals (Cr, Pb, Cd and Zn) in soil, vegetables and water of Wadi El Gourzi were compared with the safety limits.

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY SITE

The El Madher plain, is located 15 km north-east of Batna, about 450 km south-east of Algiers, between 35.5° and 35.7° N latitude (Fig. 1). It is bounded to the east by the Djebel Bou Arif, to the west by the Monts de Batna, and to the north communicates with the Gadaine plain, an area of sebkhas. The two mountainous massifs that limit the plain to the east and west (Djebel Bou Arif and the Mounts of Batna) converge in the south to enclose the basin drained by the Wadi El Madher. Numerous watercourses with a temporary regime and coming from secondary catchment areas are joined in the center of the plain by the Wadi El Madher, which drains all the water towards the basin's outlet. The Wadi El Gourzi drains the surface water of the Batna basin towards the Wadi El Madher, which is its natural extension. It drains wastewater during the rainy season and also collects runoff from the many sub-catchments. More than 35 industrial units are concentrated in the industrial zone of Batna K'chida. These are located upstream of Wadi El Gourzi. Among the many industries, there is the textile production, a tannery, battery manufacturing, gas bottle manufacturing, steel processing as well as various food industries, a red meat slaughterhouse, a milk and by-products unit. Most of these units have treatment units but which function poorly or not at all, due to frequent breakdowns. In addition to the washing stations connected to the city sewerage networks.

HYDROGEOLOGICAL CONTEXT OF THE EL MADHER PLAIN

The El Madher plain is characterised by a water table exploited by numerous wells (over 300 wells). Its depth varies between a maximum of 30 m near the limits of the plain and a minimum of ≤5 m near the basin outlet at Merdja Mezouala. The aquifer varies from free to semi-free, depending on the location. It is made up of sand, gravel and pebbles packed in a clay matrix and covers about 90 km^2. These formations represent a filling of Mio-Plio-Quaternary age and extend between the Cretaceous Mountains of Batna and the Djebel Tafraout and Koudiat-Tfouda to the north. The substratum of this aquifer is made up of Cenomanian and Miocene marl and locally of Tortonian clay. This thick marl formation, as a whole, limits perfectly the aquifer studied from a hydraulic point of view over its entire extent. Similarly, it constitutes the roof of the Cretaceous confined aquifer (Barremian sandstone and Aptian limestone) [Menani 1991].

SITES D'ECHANTILLONNAGES

As part of this work, four rounds of sampling were carried out: in February, April, June 2017 and January 2018.

To assess the quality of the Wadi El Gourziwater, samples were taken at four different points:

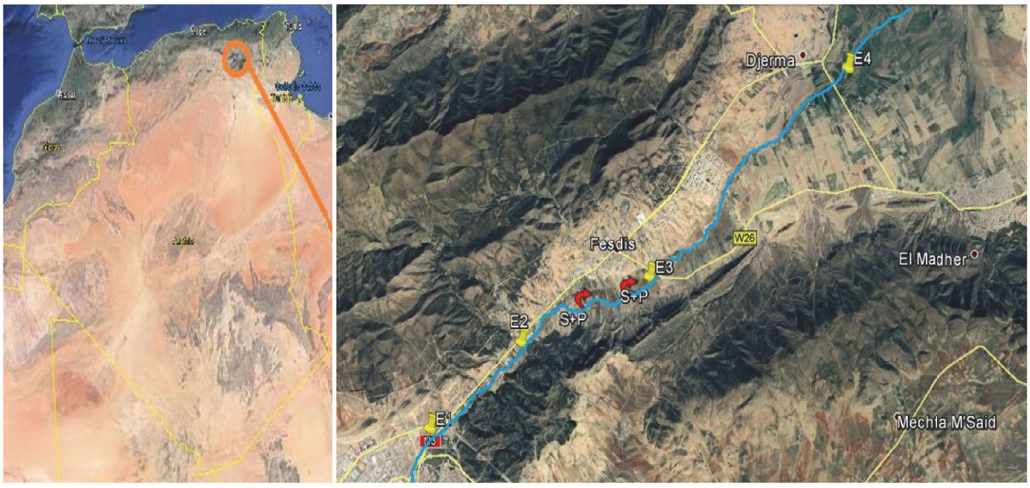

Fig. 1. Study site and location of sampling stations in Wadi El Gourzi; E = wastewater, S+P = soil + plant; source: own elaboration based on map on Google Earth

- E1 – before the treatment plant where water is mixing of Wadi El Gourzi water and water coming from industrial units discharges;
- E2 – it is mixing point of Wadi Bouzourane water with that of Wadi El Gourzi and the discharges are: domestic, industrial and treated water of the station plant;
- E3 – in Fesdis, this site is characterised by the use of motor pumps at the level of the Wadi for irrigation;
- E4 – in the basin outlet at Merdja Mezouala.

Concerning the soil sampling sites, as well as the crops irrigated by the Wadi El Gourzi water, they were carried out in an open field, in the middle of the vegetation and near Wadi El Gourzi (same type of soil). The plant samples were taken with the soil in which they were planted and randomly between the centre of the field and the edges of the Wadi.

SAMPLING OF SAMPLES

At each site, water samples are taken from the middle of the watercourse in polyethylene bottles, previously disinfected with nitric acid and then with distilled water to avoid any contamination. Samples were stored at 4°C in the presence of 2.5 cm^3 of pure nitric acid (65%) to avoid the absorption of the elements to be analysed by the walls of the vials.

The choice of plant samples was mainly based on those available and widely consumed by the population: spinach, lettuce, parsley and coriander aerial parts (stem and leaf). The crop samples were taken carefully by hand and also placed in sterile bags at 4°C. 500 g of cultural soil sample was taken at a depth of 15 cm around the root zone of each sampled plant and then placed in sterile bags and stored at 4°C.

SAMPLE PROCESSING AND ANALYSIS METHOD

Mineralisation of Wadi El Gourzi water, soil and plants

The procedure for Wadi water mineralisation is as follows: take 100 cm^3 sample to be acidified with nitric acid (pH < 2); add 5 cm^3 hydrochloric acid; heat with a hot plate until the volume is reduced to 15 cm^3 (without boiling). The sample is filtered through a cellulose nitrate membrane (0.45 μm). Finally the filtrate is collected in a 100 cm^3 bottle.

The soil samples were dried in an oven at 40°C for at least 16 h. They were then crushed before being passed over a 2 mm sieve. The part smaller than 2 mm was crushed with a porcelain mortar to obtain a powder with a granulometry smaller than 250 μm. Mineralisation was carried out on 0.5 g of this powder with 6 cm^3 of hydrochloric acid and 2 cm^3 of nitric acid (aqua regia). This step was carried out at 95°C for 75 min on a heating block. The mineraliser was adjusted to 50 cm^3.

The samples of the collected plants are washed with tap water and then with distilled water, the different parts of the plant (stems and leaves) were dried in an oven at a temperature of 105°C for 24 h, the sample is crushed with a mortar to obtain a fine powder. 1 g of dried plant material was introduced into a capsule and placed in an oven at a temperature of 500°C for 5 h, after cooling, the ashes were moistened with a few drops of distilled water and then 5 cm^3 of hydrochloric acid was added, left in contact for 10 min and filtered into 100 cm^3 flasks.

Determination of trace metals

The determination of metallic trace elements present in Wadi El Gourzi water, soil and plants was carried out on the mineralised samples after dilution. Chromium, cadmium, lead and zinc were determined by flame atomic spectrophotometer type SHIMADZU AA7000 at the mobilisation and water resources management laboratory of Batna 2 University (Algeria). The working range is of the order of μg·dm^{-3}. Before each analysis, the apparatus is calibrated by certified standard solutions to trace the calibration curve (precise standards of 1000 ppm). Each sample was analysed in triplicate and an average value was obtained. The analyses were carried out with wavelengths of 535 nm for Zn, 540 nm for Cr, 530 nm for Cd and 630 nm for Pb.

Electrical conductivity *(EC)*, pH and temperature were measured in situ with a multi-parameter probe type CONSORT C 5010. Soil pH was measured using a WTW type pH meter with a combined glass electrode on a soil/water suspension after stirring for 2 h (5 g of sieved soil in 50 cm^3 of demineralised water). Chemical oxygen demand (*COD*) was determined by spectrophotometer with a wavelength of 420 nm after oxidation with potassium dichromate. Biological oxygen demand (BOD_5) was analysed by the OxiTop method [ISO 5815-2:2003].

RESULTS AND DISCUSSION

Concerning the chemical parameters pH, electrical conductivity and organic matter, the results are shown in Table 1.

Table 1. Water characteristics of Wadi El Gourzi (irrigation water)

Sampling site	pH	Conductivity ($mS \cdot cm^{-1}$)	BOD_5	COD
			mg $O_2 \cdot dm^{-3}$	
E1	7.89–8.55	2.08–3.88	820	1277
E2	7.8–7.9	1.4–1.7	140	314
E3	7.2–7.6	1.8–2.1	180	460
E4	7.92–8.67	1.5–2.7	160	287

Source: own study.

The pH values vary between 7.2 and 8.67. The Wadi water is characterised by pH values close to neutrality. This is probably attributed either to the neutralisation of the industrial water before discharge [HASSOUNE *et al.* 2006]. The alkalinity reflects the nature of the sediments dominated by a calcareous parent rock. Similar results have been obtained by [KHELIF 2018; TAMRABET 2011] in this area. Thus, the values obtained in the present study remain comparable to those reported by LAAZIRI *et al.* [2015] in the Meknes-Tafilalet region and the Wadi Boumerzoug effluent [KEDDARI *et al.* 2019]. In general, the Wadi El Gourzi effluent does not have an adverse effect on crops that tolerate pH values between 6.5 and 8.4 [NISBET, VERNEAUX 1970]. Electrical conductivity values vary between 1.4 and 3.88 $mS \cdot cm^{-1}$, these high values are attributed to industrial and/or urban discharges characterised by very high mineralisation (>1 $mS \cdot cm^{-1}$).

The concentration of oxidisable matter ($OM = 1/3COD + 2/3BOD_5$) represents the parameter generally used indirectly to describe the organic load of wastewater. Overall, for all sampling sites, the BOD_5, COD and OM values show a decreasing gradient from upstream to downstream flow, from 1277 to 287 mg $O_2 \cdot dm^{-3}$ for COD, from 820 to 140 mg $O_2 \cdot dm^{-3}$ for BOD_5 and from 972.33 to 197.33 mg $O_2 \cdot dm^{-3}$ for OM, which can be explained by a self-cleaning process. The site E1 characterised by high BOD_5, COD and OM values represents the raw effluent from industrial water discharges. It is rich in organic matter (e.g. poultry slaughterhouse). In general, all the sampling stations have BOD_5 and COD values higher than the Algerian discharge standard, fixed at 40 and 120 mg $O_2 \cdot dm^{-3}$ respectively [Décret exécutif n° 93-160].

CONCENTRATION OF HEAVY METALS IN IRRIGATION WATER

The concentrations of trace metals recorded in the irrigation water of Wadi El Gourzi are listed in Table 2.

The contents vary in the range, from 0.002 to 17.37 $mg \cdot dm^{-3}$ for Cr, from 0.01 to 0.71 $mg \cdot dm^{-3}$ for Pb and from 0.15 to 3.06 $mg \cdot dm^{-3}$ for Zn, while for Cd the contents are lower than 0.45 $mg \cdot dm^{-3}$. The average concentrations of Cr, Pb, Zn and Cd are respectively 2.88, 0.10, 1.06 and 0.056 $mg \cdot dm^{-3}$. They are similar to the concentrations of heavy metals in irrigation waters of Titagarh, West Bengal, India [GUPTA *et al.* 2008]. The results obtained reveal the following order of abundance: Cr > Zn > Pb > Cd. The average concentrations of Cr, Pb and Cd are above the WHO [1996] limits: 0.05 for Cr, 0.01 for Pb, 3 for Zn and 0.003 for Cd in $mg \cdot dm^{-3}$.

In natural waters, heavy metals are found in different chemical forms: free ions, complexes, particulate forms [IDLAFKIH *et al.* 1995]. The form we determined concerns the total form. The spatial variations of heavy metals in Wadi El Gourzi show the symmetrical distribution of Cr, Cd and Zn (Fig. 2). A similar evolution of the curves representing the evolution of the variable concentrations of these ions from upstream to downstream; this can be attributed to the water/sediment contact during the course of the water flow along the Wadi and changes according to environmental conditions depending on the case, there can be precipitation, oxidation, complexation. Certain factors favour the desorption of metals, such as a drop in pH, complexation by organic or inorganic ligands (hydroxides). Station E3 is characterised by relatively higher concentrations of dissolved trace metals (Cr, Cd and Zn) than stations E1, E2 and E4. In addition to the pollution of the Wadi, we note that station E3 is close to an irrigated agricultural area, precisely with polluted water. We believe that the surplus water used, after leaching from the soil rich in heavy metals, returns to the Wadi and thus contributes to the enrichment of the water of this station in these elements. Concerning lead, the highest average content was recorded at E1 site with 0.2 $mg \cdot dm^{-3}$ (Fig. 2). This can be explained by the fact that it is placed before the water purification plant (WWTP), where the effluents are loaded with industrial waste (batteries, tanneries, metallurgy, etc.) without pre-treatment.

Table 2. Content of trace metals elements ($mg \cdot dm^{-3}$) in Wadi El Gourzi water (irrigation water)

Metal	Content in														
	February 2017				April 2017				June 2017			January 2018			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E1	E2	E3	E4
Cr	**11.37**	**5.96**	**17.37**	**5.05**	**0.19**	**0.19**	**0.17**	**0.15**	0.01	0.002	0.003	**1.39**	**2.21**	**0.06**	**0.19**
Cd	**0.003**	**0.004**	**0.01**	**0.01**	**0.01**	**0.005**	**0.004**	**0.005**	**0.05**	**0.02**	**0.01**	**0.01**	**0.18**	**0.45**	**0.10**
Pb	0.01	0.01	**0.02**	**0.05**	**0.07**	0.01	0.01	**0.10**	**0.01**	**0.01**	**0.02**	**0.71**	**0.16**	**0.16**	**0.16**
Zn	2.68	2.41	3.06	2.75	0.47	0.17	0.17	0.19	0.46	0.15	0.15	0.52	1.01	1.45	0.35

Explanation: values in bold represent values that exceed threshold limits.
Source: own study.

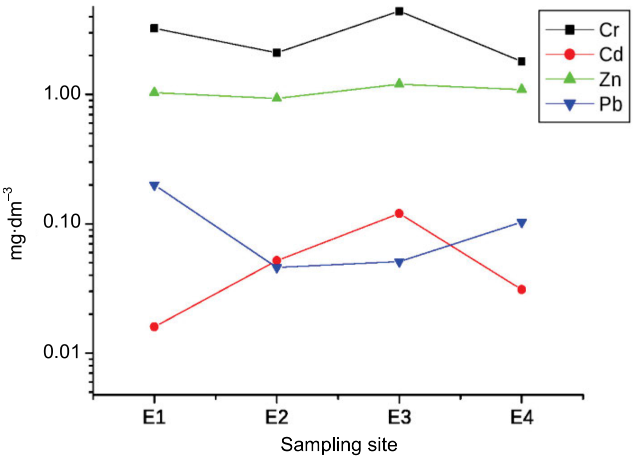

Fig. 2. Spatial variations of metal concentrations in Wadi El Gourzi for Cr, Cd, Pb and Zn; source: own study

For the temporal variations (Fig. 3), we found correlations between the months characterised by heavy metals abundance (Pb, Cd in January and Cr, Zn in January–February). The period of high water (January–February) is due to rainfall, which produces oxidising conditions and makes the dissolved form appear in the water. However, during low water periods (July–August), we note a decrease favouring the precipitation of heavy metals in the sediments. According to the criteria adopted for the global evaluation of water quality multi-usage grid (Adour-Garonne Basin Agency), water quality is considered well if Cd ≤ 0.001, Pb ≤ 0.05 and Zn ≤ 0.5 mg·dm^{-3} [Ngaram 2011]. According to the values, of Cr, Pb, Zn and Cd of the Wadi El Gourzi water can be classified at level 3, i.e. of poor quality. The high level of heavy metals in Wadi El Gourzi is due to domestic and industrial discharges.

CONCENTRATION OF HEAVY METALS IN AGRICULTURAL SOIL IRRIGATED BY POLLUTED WATER FROM WADI EL GOURZI

The soil pH is a very important parameter in the evolution of the concentration of heavy metals in the soil it influences several precipitation / solubilisation reactions, adsorption / desorption on soil solids and metals speciation, and thus the bioavailability [Babich, Stotzky 1977]. When the soil pH decreases by one unit the concentration of free metal elements increases twice in the soil solution [Sanders *et al.* 1986]. The pH values of agricultural soils vary between 6.8 and 8.3 at the 0–15 cm surface horizons, which is in line with the results reported by Tamrabet [2011] and Khelif [2018]. The recorded soil pH is almost neutral (slightly alkaline), limiting the passage of heavy metals from the solid phase to the soil solution and then to the plant [Thornton 1996]. The increase in pH values is attributed to the calcareous nature of the studied soils and following prolonged irrigation time with wastewater [Schipper *et al.* 1996].

In agricultural soils irrigated by Wadi El Gourzi water, the concentration of heavy metals (mg·kg^{-1} dry soil) varied from 3.72 to 1038 for Cr, 70.8 to 262.62 for Zn, 0.06 to 31.93 for Cd and 7.34 to 31.06 for Pb. The results obtained in the following order of abundance are: Cr > Zn > Pb > Cd. This is the same ranking as for irrigation water by Wadi El Gourzi. The concentrations of Cr in soils (spinach and parsley) and Cd in soils (parsley and lettuce) shown in Table 3, exceed the permissible levels [Kabata-Pendias, Pendias 1992].

The levels of Cr and Cd recorded in the studied soils are close to those recorded in the irrigation water, which is a source of contamination. In soils, cadmium is considered a mobile element compared to other metals [Bourrelier *et al.* 1998]. In general, apart from polluted irrigation water, the origin of Cd in the soil is household waste containing batteries and other non-degradable metals, fertilisers (phosphate) and recycling of lead from batteries or paint production. Cr is more abundant in neutral or basic soils than in acid soils. In the soils of our study area (neutral to slightly alkaline), the Cr content of the parsley soil is 1038 mg·kg^{-1}. It is derived from its use in metallurgy and tanning. Cr exists in the soil in the form of Cr^{3+} and little Cr^{6+}, Cr^{3+} is more easily absorbed than Cr^{6+}, the latter being more water-soluble, bioavailable and potentially toxic [Pichard *et al.* 2004]. According to Landreau [1987] heavy metals present in wastewater are generally fixed in the soil, but a small quantity remains in solution in irrigation water.

POLLUTION INDEX (*PI*)

Several authors have introduced the *PI* to identify multi-elemental contamination leading to increased metal toxicity; This index is calculated as the average of the ratios of metal

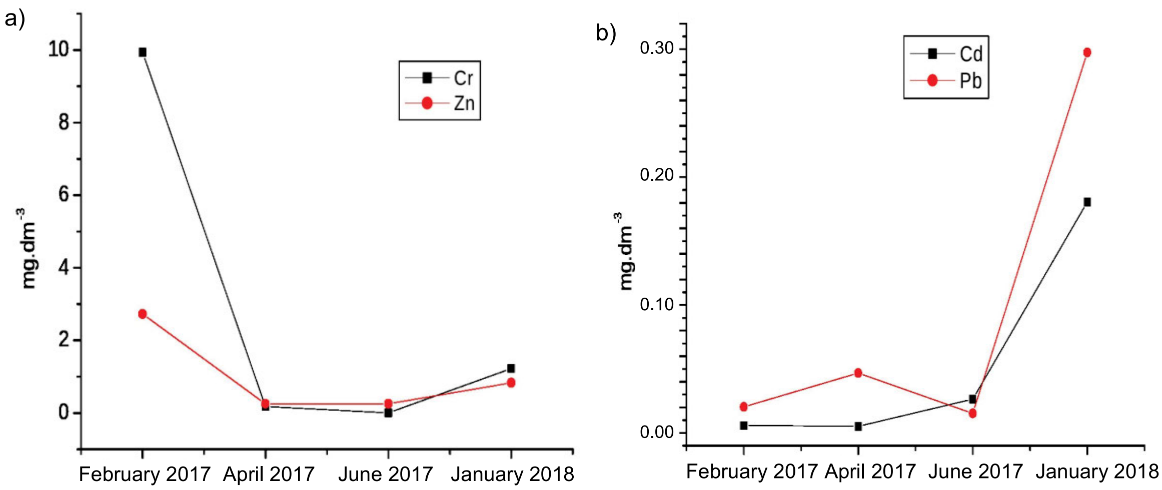

Fig. 3. Temporal variations of metal concentrations in Wadi El Gourzi for: a) Cr, Zn, b) for Cd, Pb; source: own study

Table 3. Trace metal content (mg·kg^{-1}) and pollution index (*PI*) in soils

Metal	Value in								
	February 2017		April 2017				June 2017		
	soil under cultivation of								
	spinach	parsley	spinach	parsley	lettuce	cilantro	spinach	lettuce	cilantro
Cr	**355.83**	1038.00	22.50	28.00	38.40	22.00	3.91	3.72	4.30
Zn	262.62	250.13	99.00	130.05	153.12	182.16	72.60	70.80	75.11
Pb	9.81	31.06	11.22	7.34	14.70	12.40	12.01	13.07	13.42
Cd	0.85	**26.12**	0.26	0.14	0.06	0.20	1.03	**31.93**	2.40
PI	0.91	**4.19**	0.17	0.18	0.23	0.23	0.18	**2.76**	0.30

Explanations: *PI* = pollution index, values in bold represent values that exceed threshold limits.
Source: own study.

concentrations in soil samples to limit values [Chon *et al.* 1998]. A pollution index greater than the value of 1 means that soils are considered to be contaminated by several metals and should be treated; the pollution index in our case is then:

$$PI = (Pb/100 + Cd/3 + Zn/300 + Cr/150)/4 \qquad (1)$$

Among the soils studied, the pollution index is higher than 1 except in two plots, the lettuce and parsley soil. These two soils are considered to be polluted by several metals. The variation explains the difference between the pollution index values from one soil to another in the frequency and duration of irrigation and the number of years the land has been irrigated. Furthermore, the fact that the level of pollution by one metal is not always the same as another can be explained by the use of wells and boreholes for irrigation in summer when the Wadi level decreases. Another factor is the chemical composition of the daily wastewater, which depends on whether or not the industries and the treatment plant function. The capacity to assimilate heavy metals varies according to the type of plants, which directly influences the level of metallic elements in the soil.

ASSESSMENT OF METALLIC ELEMENTS IN VEGETATION

The concentration of heavy metals in plants reflects the availability and transfer of metals from soil to plant. The concentrations of heavy metals in the aerial parts (leaves + stems) of plants (Tab. 4) collected in the Fesdis area were compared with other heavy metal contents of plants obtained by researchers worldwide.

Chromium is detected in the majority of plant samples with very high concentrations ranging from 0.5 to 62.47 mg·kg^{-1} exceeding the SEPA [2005] standard 0.5 mg·kg^{-1}, higher than those obtained in lettuce grown in the Gounti valley in Niamey, Niger 1.81 to 3.73 mg·kg^{-1} [Dan-Badjo *et al.* 2013], lower than those reported in vegetables 34.83 to 96.30 mg·kg^{-1} in Tatigarh, India [Gupta *et al.* 2008]. According to McKenzie [1980], Cr in basic soil will be more available to plants grown in acidic soil.

Cadmium is the most toxic metal as it accumulates biologically and has a long half-life, the concentrations of this metal in the plants sampled vary from 0.2 to 1.73 mg·kg^{-1}, higher than the critical value 0.2 mg·kg^{-1} acc. to CSHPF [1996] and Règlement (CE) N 466/2001. These concentrations are similar to those obtained in plants grown in the metal areas of Noyelles-Godault and Auby in France, which reach 1.50 mg·kg^{-1} [Douay, Sterckeman 2002] and higher than Cd levels in market gardening sites in Cocody, Ivory Coast 0.12–0.41 mg·kg^{-1} [Kouakou *et al.* 2005]. The use of contaminated water for irrigation and fertilisers can increase Cd uptake in plant tissue [Jackson, Alloway 1991].

The lead concentrations detected in the plants tissues studied ranged from 1.06 to 11.47 mg·kg^{-1}, higher than the regulatory guide values for heavy metals in aerial parts 0.1 mg·kg^{-1} [WHO 1989]. They are higher than the levels reported by

Table 4. Trace metal elements content (mg·kg^{-1}) in the aerial parts (leaves + stems) of plants grown in soils irrigated by polluted Wadi El Gourzi water (Batna, Algeria)

Metal	Content in								
	February 2017		April 2017				June 2017		
	spinach	parsley	spinach	parsley	cilantro	lettuce	spinach	cilantro	lettuce
Cr	**62.47**	–	**24.50**	**14.00**	**14.50**	**16.00**	**1.52**	**0.50**	**0.50**
Zn	**283.07**	**256.16**	95.62	**138.90**	86.32	60.15	33.10	18.58	32.21
Pb	**1.63**	**6.54**	**7.80**	**8.26**	**11.47**	**5.96**	**1.06**	**2.47**	**2.47**
Cd	**1.73**	**1.23**	**0.43**	**0.20**	**0.20**	**0.36**	**0.52**	**0.20**	**0.86**

Explanation: values in bold represent values that exceed threshold limits.
Source: own study.

AL-CHAARANI [2009] which are in the order of 0.055 to 3.0904 mg·kg^{-1}. The high levels of Pb in plants can be explained by the relationship between irrigation water and atmospheric deposition. The soil/plant transfer of Pb is less important than the direct deposition on the aerial parts of dust [ADRIANO 2001].

located in the upper part of the soil [SANDERS 1986]. The transfer of TMEs from the soil does not follow a particular logic. It varies from one species to another, depending of the mobility, availability and total concentration of each element in the soil [BARMAN *et al.* 2000].

Table 5. Transfer factor values

Metal	Transfer factor in								
	February 2017		April 2017				June 2017		
	spinach	parsley	spinach	parsley	cilantro	lettuce	spinach	cilantro	lettuce
Cr	0.17	nd	**1.09**	0.50	0.37	0.72	0.39	0.13	0.11
Zn	**1.07**	**1.02**	**0.96**	**1.06**	0.56	0.33	0.45	0.26	0.43
Pb	0.16	0.21	0.69	1.12	0.78	0.48	0.09	0.19	0.18
Cd	**2.03**	0.04	**1.65**	**1.28**	**3.33**	**1.80**	0.50	0.01	0.35

Explanation: nd = no data, values in bold represent values that exceed threshold limits.
Source: own study.

The two highest concentrations of zinc were found in parsley and spinach, above the SEPA [2005] regulatory value 100 mg·kg^{-1}, these levels are close to the Zn concentration in vegetables in Titagar, West Bengal, India [GUPTA *et al.* 2008]. In this study, the values of heavy metals were compared with the regulatory guideline values published by [WHO 1989], the French Higher Council of Public Health [CSHPF 1996], the European Commission [EC 2001] and the Chinese Environmental Protection Agency [SEPA 2005], to determine the risk to human health after consumption of these contaminated vegetables.

The Cd, Cr, and Pb contents in all analysed plants are above the FAO/WHO maximum limit and the EC and SEPA limit values. Concerning Zn, we note that two samples (spinach and parsley) show concentrations exceeding the 100 mg·kg^{-1} limit value set by SEPA. It is, therefore, necessary to prohibit the marketing and consumption of these vegetables.

CALCULATION OF THE TRANSFER FACTOR (*TF*)

The transfer factor (*TF*) from the underground to the above-ground parts can be used to assess the adsorption capacity of heavy metals by plants [LIU *et al.* 2014]. The ratio of metal element concentrations between the two levels (plant/soil – soil where the plant is grown) can be written as follows:

$$TF = [HM]_{\text{plant}}/[HM]_{\text{soil}} \tag{2}$$

where: [*HM*] = heavy metal concentration (mg·kg^{-1}).

According to SEKABIRA *et al* [2011], *TF* values above the value of 1 are classified as hyper-accumulative plant species for heavy metals, namely spinach (Cd, Zn and Cr), parsley (Zn, Cd) and cilantro, lettuce (Cd) – Table 5. Indeed, Cd and Zn are transferred to the aerial parts more easily than Pb which remains complex in the roots [GREGER 1999]. Cadmium and zinc are most mobile in the same soil pH range of 5.5 to 6.0. Zinc in plants is linearly related to its concentration in the soil because it is an indispensable element for many cellular processes [LOUÉ 1993]. On the other hand, the low availability of Pb and Cr due to the high affinity of organic matter means that they are generally

CONCLUSIONS

The evaluation of the trace metals elements (TMEs) content in the complex (water, soil, plant) shows that the vegetative part seems to be in equilibrium with the concentrations recorded in the water and the soil.

The concentrations of Pb and Cr in soils are higher than their concentrations in plants. Indeed, as their solubility in the soil is low, they can accumulate in the roots for Pb and be deposited in the soil for Cr. The concentrations of Pb in plants are correlated to those in the soil on which they grown, but they depend on the organ (root, stem, leaf and fruit). For Cd, the concentrations in the aerial parts of spinach and coriander are the same as in the soils. The mobility of Cd will largely depend on the pH. In general, Zn concentrations in soil are higher than in plants, about 2.5 times higher for lettuce and coriander. There is a linear relationship between the two Zn concentrations obtained for plant and soil for spinach and parsley.

In conclusion, according to the limit values admitted in human safety terms, the marketing and consumption of these vegetables have to be prohibited.

REFERENCES

ADRIANO D.C. 2001. Trace elements in terrestrial environments. Biogeochemistry bioavailability and risks of metals. Vol. 1. 2nd ed. New York, Berlin, Heidelberg. Springer. ISBN 978-1-4684-9505-8 pp. 867.

AL-CHAARANI N., EL-NAKAT J., OBEID P.J., AOUAD S. 2009. Measurement of levels of heavy metal contamination in vegetables grown and sold in selected areas in Lebanon. Jordan Journal of Chemistry (JJC). Vol. 4(3) p. 303–315.

BABICH H., STOTZKY G. 1977. Sensitivity of various bacteria, including actinomycetes, and fungi to cadmium and the influence of pH on sensitivity. Applied and Environmental Microbiology. Vol. 33(3) p. 681–695. DOI 10.1128/aem.33.3.681-695.1977.

BARMAN S.C., SAHU R.K., BHARGAVA S.K., CHATERJEE C. 2000. Distribution of heavy metals in wheat, mustard, and weed grown in field irrigated with industrial effluents. Bulletin of Environmental

Contamination and Toxicology. Vol. 64(4) p. 489–496. DOI 10.1007/s001280000030.

BAZZA M. 2002. Wastewater reuse in the near East region: Experiences and issues [online]. In: Regional symposium on recycling in the Mediterranean region. 26–29.09.2022 Iraklio, Crete, Greece pp. 21. [Access 10.07.2021]. Avaialable at: https://www.fao.org/3/ae528e/ae528e.pdf

BOURRELIER P.H., BERTHELIN J., PEDRO G. 1998. Contamination des sols par les éléments en traces: les risques et leur gestion [Soil contamination by trace elements: Risks and their management]. Rapport n° 42. Académie des sciences. ISBN 2743002913 pp. 440.

CHANG A.C., PAN G., PAGE A.L., ASANO T. 2002. Developing human health-related chemical guidelines for reclaimed waste and sewage sludge applications in agriculture. Geneva. WHO pp. 105.

CHANEY R.L. 1988. Effective utilisation of sewage sludge on cropland in United States and toxicological considerations for land application. In: Land application of sewage sludge. Tokyo. Association for the Utilisation of Sewage Sludge p. 77–105.

CHON H.T., AHN J.S., JUNG M.C. 1998. Seasonal variations and chemical forms of heavy metals in soils and dusts from the satellite cities of Seoul, Korea. Environmental Geochemistry and Health. Vol. 20(2) p. 77–86. DOI 10.1023/A:1006593708464.

CSHPF 1996. Plomb, cadmium et mercure dans l'alimentation: évaluation et gestion du risque [Lead, cadmium and mercury in food: risk assessment and management]. Paris. Conseil Supérieur d'Hygiène Publique de France. ISBN 2-7430-0085-6 pp. 236.

DAN-BADJO A.T., GUERO Y., LAMSO N.D., BARAGE M., BALLA A., STERCKEMAN T., EVARRIA G.E., FEIDT C. 2013. Évaluation des niveaux de contamination en éléments traces métalliques de laitue et de chou cultivés dans la vallée de Gounti Yena à Niamey, Niger [Evaluation of trace metal contamination levels of lettuce and cabbage grown in the Gounti Yena valley in Niamey, Niger]. Journal of Applied Biosciences. Vol. 67 p. 5326–5335. DOI 10.4314/jab.v67i0.95056.

Décret exécutif n° 93-160 du 10 Juillet 1993 réglamentat le deversement des huiles et lubrifiants dans le milieu naturel [Executive decree No. 93-160 of July 10, 1993 regulate the discharge of oils and lubricants into the natural environment] [online]. Journal Officiel N° 46 du 14 Juillet 1993, 5. [Access 10.07.2021]. Available at: https://www.energy.gov.dz/Media/galerie/decret_executif_93-161_5b6862a591c1b.pdf

DOUAY F., STERCKEMAN T. 2002. Teneurs en Pb, Cd et Zn dans les végétaux cultivés aux alentours d'usines métallurgiques. En : Approches fonctionnelles et spatiales [Pb, Cd and Zn contents in plants grown in the vicinity of metallurgical plants. In: Functional and spatial approaches]. Paris. INRA Editions p. 505–521.

GODDEN L. 2005. Water law reform in Australia and South Africa: Sustainability, efficiency and social justice. Journal of Environmental Law. Vol. 17(2) p. 181–205. DOI 10.1093/envlaw/eqi016.

GÖTHBERG A., GREGER M., BENGTSSON B.E. 2002. Accumulation of heavy metals in water spinach (*Ipomoea aquatica*) cultivated in the Bangkok region, Thailand. Environmental Toxicology and Chemistry. Vol. 21(9) p. 1934–1939. DOI 10.1002/etc.5620210922.

GREGER M. 1999. Metal availability and bioconcentration in plants. In: Heavy metal stress in plants. Berlin, Heidelberg. Springer p. 1–27. DOI 10.1007/978-3-662-07745-0_1.

GUPTA N., KHAN D.K., SANTRA S.C. 2008. An assessment of heavy metal contamination in vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. Bulletin of Environmental Contamination and Toxicology. Vol. 80(2) p. 115–118. DOI 10.1007/s00128-007-9327-z.

HASSOUNE E.M., BOUZIDI A., KOULALI Y., HADARBACH D. 2006. Effets des rejets liquides domestiques et industriels sur la qualité des eaux souterraines au nord de la ville de Settat (Maroc) [Effects of domestic and industrial liquid discharges on groundwater quality north of the city of Settat (Morocco)]. Bulletin de l'Institut Scientifique. Section Sciences de la Vie. Vol. 28 p. 61–71.

IDLAFKIH Z., COSSA D., MEYBECK M. 1995. Comportements des contaminants en trace dissous et particulaires (As, Cd, Cu, Hg, Pb, Zn) dans la Seine [Behavior of dissolved and particulate trace contaminants (As, Cd, Cu, Hg, Pb, Zn) in the Seine]. Hydroécologie appliquée. Vol. 7 p. 127–150. DOI 10.1051/hydro:1995008.

ISO 5815-2:2003. Détermination de la demande biochimique en oxygène après n jours (DBOn). Partie 2: Methode pour échantillons non dilués [Water quality – determination of biochimical oxygen demandafter n days (BODn). Part 2: Method for undiluted samples].

JACKSON A.P., ALLOWAY B.J. 1991. The bioavailability of cadmium to lettuce and cabbage in soils previously treated with sewage sludges. Plant and Soil. Vol. 132(2) p. 179–186. DOI 10.1007/BF00010398.

JEANNOT R., LEMIÈRE B., CHIRON S. 2001. Guide méthodologique pour l'analyse des sols pollués [Methodological guide for the analysis of polluted soils]. Orleans. BRGM pp. 110.

KABATA-PENDIAS A., PENDIAS H. 1992. Trace elements in soils and plants. Boca Raton, FL. CRC Press. ISBN 0849366437 pp. 356.

KEDDARI D., AFRI-MEHENNAOUI F.Z., SMATTI-HAMZA I., DJEDDI H., SAHLI L., MEHENNAOUI S. 2019. Évaluation du niveau de contamination par les éléments traces métalliques (cadmium, cuivre, nickel et zinc) des sédiments de l'oued Boumerzoug et ses affluents, et leur transfert vers la chénopodiacée *Spinacia oleracea* (L.) [Evaluation of the level of contamination by metallic trace elements (cadmium, copper, nickel and zinc) of the sediments of the Wadi Boumerzoug and its affluents, and their transfer to the Chenopodiacea *Spinacia oleracea* (L.)]. Revue des Sciences de l'Eau / Journal of Water Science. Vol. 32(3) p. 255–273. DOI 10.7202/1067308ar.

KHELIF S. 2018. Impact de l'irrigation avec les eaux usées sur la qualité des sols agricoles et des eaux souterraines de la région de Fesdis – Région nord de Batna [Impact of irrigation with wastewater on the quality of agricultural soils and groundwater in the Fesdis-Northern region of Batna]. PhD Thesis. Université El Hadj Lakhdar Batna pp. 211.

KOUAKOU K.J., BEKRO Y.A., SIKA A.E., BAIZE D., DOGBO D.O., BOUNAKHLA M., … MACAIGNE P. 2005. Diagnostic d'une contamination par les éléments traces métalliques de l'épinard (*Spinacia oleracea*) cultivé sur des sols maraîchers de la ville d'Abidjan (Côte d'Ivoire) amendés avec de la fiente de volaille [Diagnosis of trace metal contamination of spinach (*Spinacia oleracea*) grown on market garden soils in the city of Abidjan (Ivory Coast) amended with poultry manure]. European Journal of Scientific Research, EuroJournals. Vol. 21(3) p. 471–487.

LAAZIRI A., ASNAOUI H., KHALIS M. 2015. Etude préliminaire de l'impact de certains métaux lourds sur des plantes maraichères dans la région Meknès – Tafilalet [Preliminary study of the impact of some heavy metals on market garden plants in the Meknes – Tafilalet region]. International Journal of Innovative Research in Advanced Engineering (IJIRAE). Vol. 2. Iss. 1 p. 335–340.

LANDREAU A. 1987. La réutilisation des eaux usées épurées par le sol et le sous sol: Adéquation entre la qualité de l'eau, l'usage et la protection du milieu naturel [The reuse of wastewater treated by the soil and subsoil: Adequacy between water quality, use and protection of the natural environment]. [Séminaire sur les eaux usées et milieu récepteur, Casablanca (Maroc)]. [Seminar on wastewater and receiving environment, Casablanca (Morocco)] p. 1–13.

LIU C.W., CHEN Y.Y., KAO Y.H., MAJI S.K. 2014. Bioaccumulation and translocation of arsenic in the ecosystem of the Guandu Wetland, Taiwan. Wetlands. Vol. 34(1) p. 129–140. DOI 10.1007/s13157-013-0491-0.

LOUÉ A. 1993. Oligo-éléments en agriculture [Trace elements in agriculture]. Paris. Nathan pp. 339.

MCKENZIE R.M. 1980. The adsorption of lead and other heavy metals on oxides of manganese and iron. Soil Research. Vol. 18(1) p. 61–73. DOI 10.1071/SR9800061.

MENANI M.R. 1991. Étude hydrogéologique de la plaine d'El Madher (Algérie orientale): géologie, climatologie, hydrogéologie et modélisation des écoulements souterrains de l'aquifère mio-plio-quaternaire [Hydrogeological study of the El Madher plain (eastern Algeria): Geology, climatology, hydrogeology and modeling of underground flows in the mio-plio-quaternary aquifer]. PhD Thesis. Nancy 1 pp. 409.

MENCH M., MANCEAU A., VANGRONSVELD J., CLIJSTERS H., MOCQUOT B. 2000. Capacity of soil amendments in lowering the phytoavailability of sludge-borne zinc. Agronomie. Vol. 20(4) p. 383–397. DOI 10.1051/agro:2000135.

MRE 2001. Les ressources en eau d'Algérie. Rapport de synthèse [Water resources in Algeria. Synthesis report]. Algiers. Ministère des Ressources en Eau pp. 73.

NGARAM N. 2011. Contribution à l'étude analytique des polluants (en particulier de type métaux lourds) dans les eaux du fleuve Chari lors de sa traversée de la ville de N'Djamena [Contribution to the analytical study of pollutants (in particular heavy metals) in the waters of the Chari River as it flows through the city of N'Djamena]. PhD Thesis. Université Claude Bernard-Lyon I, Université de N'Djaména pp. 164.

NISBET M., VERNEAUX J. 1970. Composantes chimiques des eaux courantes. Discussion et proposition de classes en tant que bases d'interprétation des analyses chimiques [Chemical components of running waters. Discussion and proposal of classes as a basis for interpretation of chemical analyses]. Annales de Limnologie – International Journal of Limnology. Vol. 6. No. 2 p. 161–190. DOI 10.1051/limn/1970015.

PICHARD A., BISSON M., DIDERICH R., HOUIEX N., HULOT C., LACROIX G., ..., PEPIN G. 2004. Fiche de données toxicologiques et environnementales des substances chimiques: Chrome et ses dérivés inorganiques [Toxicological and environmental data sheet of chemical substances: Chromium and its inorganic derivatives]. Paris. INERIS pp. 80.

Règlement (CE) N 466/2001 de la Commission du 8 mars 2001 portant fixation de teneurs maximales pour certains contaminants dans les denrées alimentaires [N 466/2001 of 8 March 2001 setting maximum levels for certain contaminants in foodstuffs]. JO L 77 du 16.3.2001 pp. 13.

SANDERS J.R., MCGRATH S.P., ADAMS T.M. 1986. Zinc, copper and nickel concentrations in ryegrass grown on sewage sludge-contaminated soils of different pH. Journal of the Science of Food and Agriculture. Vol. 37(10) p. 961–968. DOI 10.1002/jsfa.2740371003.

SCHIPPER L.A., WILLIAMSON J.C., KETTLES H.A., SPEIR T.W. 1996. Impact of land-applied tertiary-treated effluent on soil biochemical properties. Journal of Environmental Quality. Vol. 25(5)+ p. 1073–1077. DOI 10.2134/jeq1996.00472425002500050020x.

SCOTT C.A., FARUQUI N.I. RASCHID-SALLY L. (eds.) 2004. Wastewater use in irrigated agriculture: Confronting the livelihood and environmental realities. Wallingford. CAB International. ISBN 0851998232 pp. 193.

SEKABIRA K., ORYEMNDASH H., MUTUMBA G., KAKUDIDI E., BASAMBA T.A. 2011. Heavy metal phytoremediation by *Commelina benghalensis* (L.) and *Cynodon dactylon* (L.) growing in urban stream sediments. International Journal of Plant Physiology and Biochemistry. Vol. 3(8) p. 133–142. DOI 10.5897/IJPPB.9000025.

SEPA 2005. The limits of pollutants in food. China: State Environmental Protection Administration. GB2762-2005.

TAMRABET L. 2011. Contribution à l'étude de la valorisation des eaux usées en maraichage [Contribution to the study of wastewater reclamation in market gardening]. PhD Thesis. Université Batna 2 pp. 146.

THORNTON I. 1996. Risk assessment related to metals: The role of the geochemist. In: Report of the International Workshop on Risk Assessment of Metals and their Inorganic Compounds. Angers, France p. 13–15.

WHO 1989. L'utilisation des eaux usées en agriculture et en aquaculture: recommandations à avisées sanitaires. Rapport d'un groupe scientifique de l'OMS [Wastewater use in agriculture and aquaculture: recommendations for health. Report of a WHO Scientific Panel] [online]. Série de rapports techniques. No. 778. Geneve. Organisation mondiale de la santé pp. 82. [Access 10.07.2021]. Available at: https://apps.who.int/iris/bitstream/handle/10665/37549/WHO_TRS_778_fre.pdf?sequence=1&isAllowed=y

WHO 1996. Permissible limits of heavy metals in soil and plants. Vol. 2. 2nd ed. Geneva, Switzerland. World Health Organization.