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Accumulation of Heavy Metals in Soils Irrigated by Treated Wastewater: A Case Study from the Northwest of the Haut Chelif Plain, Algeria

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Abstract
Long-term irrigation by treated wastewater (TWW) can lead to the accumulation of heavy metals (HM) in the soil inducing negative effects on the pedo-environment. In this study, plots irrigated with TWW were studied to estimate the accumulation trends of HM and their impact on the physicochemical properties of the soil over a period of four years under a gravity irrigation system on turf with no fertiliser input. Soil samples were taken at two depths (0 to 20 cm: H1 and 20 to 40 cm: H2). The results of this study show that TWW are a main source of increase in HM in the soil by well-identified conditions, the degradation of the environment in general and on the physicochemical quality of soils in particular. It was concluded that the use of TWW in long-term irrigation enriches the soils with heavy metals, by main factors such as TWW composition, climatic conditions, soil type, and irrigation frequency.

Keywords
Heavy metals, treated wastewater, irrigation, soil, Haut Chelif

1 Introduction

Many factors such as the overall increase in population growth observed in recent years and pollution and climate change have led to water scarcity[1,2] and the problem of availability of natural freshwater resources.[3] Algeria is also one of the countries that have recently suffered from water shortages. For this reason, several projects have been studied and approved in order to reuse treated wastewater (TWW) to preserve natural water. The reuse of TWW is an important practice in agricultural irrigation adopted by several countries,[4] particularly in arid and semi-arid areas[5,6] marked by low rainfall.[7,8] In 2011, more than 10,000 hectares of agricultural land were irrigated by TWW estimated at 17 million m^3/year, whereas this quantity was 300 million m^3 in 2014 (MRE, 2012; ONA, 2014). TWW irrigation creates problems in the agricultural sector[9] and can affect the physicochemical properties of soils,[10–14] particularly an excessive accumulation of heavy metals (HM) in the soil,[15,16] due to their high presence in TWW and the difficulty of their decomposition,[17–22] which leads to its long presence in the soil, in particular Cu, Zn, Pb, Cd and Ni[23] which have an effect on environmental stability.[24–27] TWW promotes deep migration depending on soil chemical properties, such as pH,[28,29] organic matter (OM), and cation exchange capacity (CEC)[15,30,31] as well as physical properties, such as porosity, permeability, and structure.[32] The research that we present is a contribution to the evaluation of TWW used in irrigation at the level of the irrigated perimeter of the region of Ain Defla (WWTP) and under well-defined climatic conditions. The main objective of our study was to characterise in more detail the rate of accumulation of HM in the soil after four years of irrigation using TWW, and to evaluate their effect on the physicochemical properties of the soil at different depths.

2 Material and methods

2.1 Study area

The trials were carried out in the wastewater treatment plant located in the municipality of Ain Defla, northwest of the Haut Chelif Plain (36°16′48.67″N and 1°58′50.62″E) (Fig. 1), which is a low-load activated sludge plant with a treatment capacity of 12 900 m^3 d^{-1}. The region has a Mediterranean climate, characterised by an average annual precipitation of 420 mm and average air temperature of 20 °C.

The study was carried out between September 2015 and March 2018, over a period four years: September 2015 (Y1), September 2016 (Y1), March 2017 (Y3), and March 2018 (Y4) on land covered by grass. During each year, we monitored the soil samples and laboratory analyses of chemical parameters and HM at the start and at the end of treatment.

To evaluate the accumulation of HM in soils irrigated by TWW and the effects of these waters on soil contamination, we compared the concentrations with the monitoring

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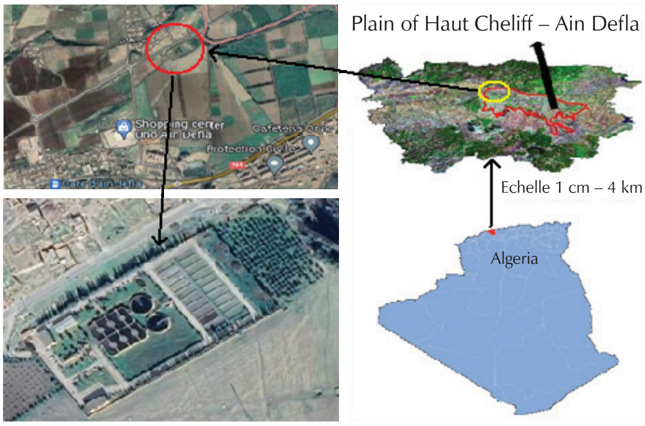

Fig. 1 – Location of the study area

of treatment at the beginning and the end of the years. No fertiliser was added to the treated plots.

2.2 Sampling and water analysis

Water samples were taken directly from the recovery basin after the treatment was carried out by the WWTP. This water was put in tightly closed plastic bottles, coded, and kept in a cooler until analysis. The pH-value and conductivity of irrigation water were analysed by pH meter and conductivity meter (WTW multi 340i), and HM concentrations (Cd, Fe, Cr, Zn, Ni) were determined by atomic absorption spectrophotometer (AAS). The samples were prepared for AAS analysis as follows: 100 ml of the sample was placed in a 250-ml Erlenmeyer flask, then 5 ml of HNO_3 and 2 ml of hydrogen peroxide (H_2O_2) were added and digested for 2 h on a hot plate with a cooling system. After cooling, the samples were filtered and transferred to 100-ml volumetric flasks with the addition of distilled water to a volume of 100 ml. The analysis was then conducted directly on the ASS device. The other parameters, such as Mg and Ca, were dosed by titrimetry using standard EDTA, and Na^+ and K^+ were measured by flame photometry, according to the standards recommended by ISO, AFNOR, and Rodier, 2009.

2.3 Irrigation

Irrigation was carried out using a gravity irrigation system. The factors determining the accumulation of HM in soils irrigated by TWW and their effects on the physical properties of the soil are the volume of water and frequency of irrigation, as well as the irrigation system (Table 1).

Table 1 – Features of irrigation using TWW

Irrigation system	Irrigation flow / $m^3\,d^{-1}$	Irrigation frequency		
		Summer	Spring	Autumn
Gravity	43.2	3 times / week	1 time / week	1 time / week

2.4 Soil sampling and analysis

Soil sampling was carried out in accordance with internationally recommended procedures (Afnor NF x31-100) in September 2015 and 2016 after the summer season, and in March 2017 and 2018 after the winter season. Soil samples were taken systematically (Fig. 2) using an agricultural auger. Soil samples were stored in polythene bags, and tagged with codes, and transferred to the laboratory for analysis. The soil was air-dried and then sieved (2 mm). Physical analysis of the soil, to determine the textural classes using the "Robinson pipette" method, complies with the standards NEN5357 and ISO/DIS 11277. The HM (Cu, Cd, Pb, Zn, Cr, Ni, and Fe) were analysed by the atomic absorption spectrophotometer (AAS) after filtration of the saturated paste extract of 1 g of soil, which was placed overnight in a 250-ml Erlenmeyer flask, with addition of 7 ml of HNO_3 and 21 ml of HCl. Thereafter, mineralisation was carried out for two hours on a hot plate with a cooling system. After digestion, the samples were filtered and transferred to 100-ml volumetric flasks, and brought to a volume of 100 ml by addition of distilled water. The pH and electrical conductivity (EC) were measured with a pH meter and a conductivity meter (WTW multi 340i) in a soil-water suspension (1/2.5 and 1/5 soil/water), respectively. Organic matter (OM) was determined by the weight loss method using an oven at 375 °C for 16 h,[33] and calculated using Eq. (1):

$$OM = ((A-B)/(A-C)) \cdot 100 \quad (1)$$

OM: Percentage of organic matter at 375 °C or loss on ignition (%);

A: Capsule weight + sample dried at 150 °C (g);

B: Capsule weight + sample calcined at 375 °C (g);

C: Capsule weight (g);

100: Conversion factor in percentage.

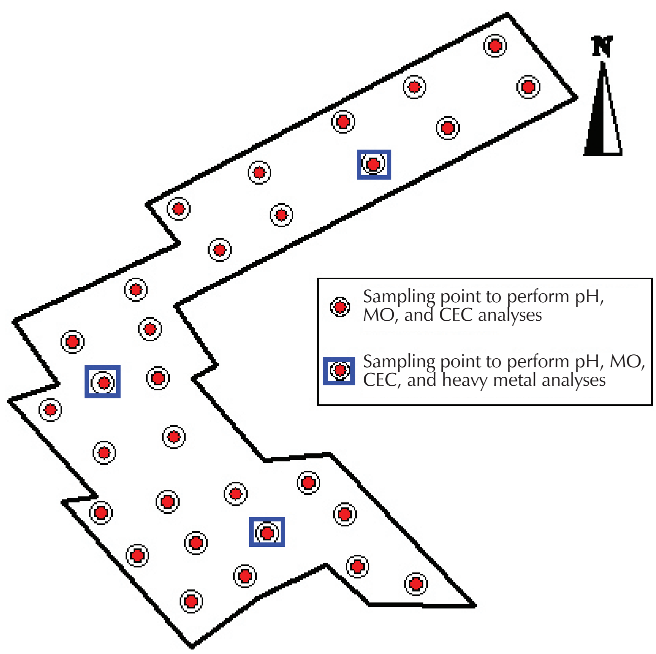

Fig. 2 – Soil sampling scheme

2.5 Pollution indices

According to researchers in the field of irrigation, there are many ways to evaluate the effect of HM on the physical and chemical properties of the soil irrigated with TWW.[34–37]

2.5.1 Contamination factor

The contamination factor (CF) is the ratio obtained by dividing the concentration of each metal in the soil by the reference or background value.[38] This was calculated as shown in Eq. (2):

$$CF = \frac{\text{heavy metal (parameter)/reference value}}{\text{(limit value)}} \quad (2)$$

2.5.2 Pollution index

Several authors have introduced the soil pollution index (PI) to identify soil contamination by HM.[39–41] Thus, according to *Chon et al.*[40] and *Tomlinson et al.*,[42] PI is defined as the average of the ratios of metal concentrations in soil samples compared to limit values:

$$PI = (CF1 \cdot CF2 \cdot \bullet \bullet \bullet \cdot CFn)^{1/n} \quad (3)$$

where CF is the contamination factor corresponding to each of the *n* HM.

2.5.3 Nemerow index

According to *Qingjie*,[43] the Nemerow Index (NI) can reflect the loads of HM in soil pollution, highlighting the influence of the species with the highest single pollution index(PI_{max}). The index is calculated as shown in Eq. (4):

$$NI = \frac{\sqrt{PI^2 + PI_{max}^{\;2}}}{2} \quad (4)$$

3 Results and discussion

3.1 Physicochemical proprieties of TWW

Table 2 summarises the results obtained from the physicochemical and heavy metal properties of irrigation water (WWT) that were monitored periodically over three years, with a comparison by the standards for the reuse of treated wastewater according to the FAO (1985), the Algerian Executive Decree (2012) and the tolerant concentration limits set by the European Commission for irrigation water (Catchment Management Agencies (CMA), recommendation 91-692).

Table 2 – Physicochemical and heavy metal analyses of TWW

Parameter	2015	2016	2017	Norm	
				Long term (a/b)	Short term (b)
Pb (mg l^{-1})	< 0.2	/	< 0.2	5	10
Ni (mg l^{-1})	< 0.2	/	< 0.2	0.2	2
Fe (mg l^{-1})	< 0.2	/	< 0.2	5	20
Cu (mg l^{-1})	< 0.1	/	< 0.1	0.2	5
Zn (mg l^{-1})	< 0.03	/	< 0.03	2	10
Cd (mg l^{-1})	/	/	< 0.03	0.01	0.05
Cr (mg l^{-1})	< 0.2	/	< 0.2	0.1	1
pH	7.72	7.64	7.86	6.5–8.5 (c/a)	
EC (µS cm^{-1})	1970	1860	1870	< 3 (c) or 3 (a)	

a: FAO; b: US Nat. Acad. Sc. (1973); c: WHO.

The average pH and EC values of TWW, respectively in the 6.5–8.5 categories and less than 3000 µS cm^{-1}, make the waters acceptable for irrigation use (JORA, 2012).[44,45] Moreover, depending on the short- or long-term irrigation period, the concentrations of HM are lower than the standard for irrigation water (US Nat. Acad. Sc., 1973) and will have no toxic effect on the soil characteristics.[46]

3.2 Effects of TWW on soil proprieties

3.2.1 Physical proprieties

Textural analysis shows high sand contents compared to the other two fractions for both horizons (Fig. 3).

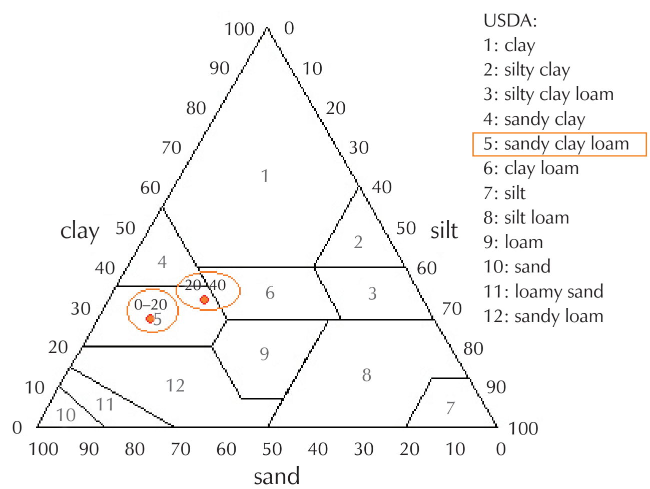

Fig. 3 – Textural triangle of soil in the experimental site at two depths

The soil of the experimental site is classified as sandy clay loam according to the American USDA classification (Fig. 3). The textural characteristics of soils play a key role in the accumulation and mobility of HM in the soil.[31,47,48] The accumulation and adsorption capacity of HM is lower in sandy soils but they are more mobile as opposed to clayey and loamy soils.[49,50] Therefore, we concluded that this plot contributed to the migration of HM to the depth (H2) with the difficulty of retaining at the surface (H1). Moreover, according to *Urbano et al.*,[51] long-term TWW irrigation causes a change in the physical properties of the soil by reducing the infiltration rate,[52] decreasing porosity,[53,54] and soil structure.[55] These factors influence the mobilisation and immobilisation of HM in the soil.

2.2 Chemical proprieties

The main descriptive statistical parameters of the chemical properties of the soil, following their irrigation by TWW, are presented in Table 3.

Soil pH plays a very important role in the accumulation and mobility of HM in the soil.[31,56,57] The average pH values vary between 8.04 (Y1) and 8.83 (Y4) in H1, and between 8.17 (Y1) and 8.72 (Y3) in H2 (Table 3). These concentrations place the soils between moderately and highly alkaline soils according to the USDA classification.[58] This is related to the high concentration of cations in TWW used in irrigation.[59] Thus, TWW irrigation, for four years, led to an increase in soil pH.[60,61]pH, size distribution, exchangeable cations and chloride, hydraulic conductivity The alkaline soil pH reduced the leaching and mobility of HM in the soil.[57,62]

The average EC values of TWW irrigated soil extract are highly variable; this is due to several factors such as the sampling period, the irrigation frequency, and the EC value in the irrigation water.[63,64] Indeed, irrigation by TWW leads to an accumulation of soluble salts (EC) in the soil,[65–67] which results in an increase in absorption and precipitation of HM in soils by fixation with ions.

The average OM values indicate that the soils are moderately alkaline according to the LANO/CA interpretation program of Lower Normandy with an increase in OM in soils irrigated by TWW during the four-year treatments (Table 3).[68,69] Moreover, the same remark was observed in H2 with washout at depth.[19,61,70] Some studies have shown that the increase in MO can cause a metal complex to immobilise in the soil by the accumulation of HM,[15,71] but a temporary immobilisation.[72]

The soil CEC values are between light and medium.[73] There is an unstable variation of the CEC in the soils irrigated by TWW, this is due to the sampling period: It was noted that during the sampling after the summer, the values of the CEC were constantly high, whereas they decreased after winter due to dissolution and migration of minerals at depth (Table 3). It was concluded that the CEC played a role of trapping by accumulation and distribution of metal ions in the soil.[30,74,75]

Table 3 – Descriptive statistical parameters of the physicochemical analyses of the soil

Year H1		pH		EC / mS cm^{-1}		OM / %		CEC / meq 100g$_{DM}$$^{-1}$	
		H2	H1	H2	H1	H2	H1	H2	
Y1	minimum	7.17	7.40	0.12	0.10	0.46	0.38	13.61	12.93
	maximum	8.46	8.48	0.72	0.37	3.61	2.53	15.20	14.91
	mean	8.04	8.17	0.29	0.23	1.54	1.18	14.43	14.07
	SD	0.23	0.20	0.13	0.15	0.85	0.60	0.46	0.50
Y2	minimum	7.86	7.98	0.30	0.37	0.95	0.91	13.52	14.24
	maximum	8.28	8.43	0.51	0.46	3.10	2.61	16.08	16.60
	mean	8.10	8.21	0.38	0.42	1.60	1.32	14.95	14.98
	SD	0.11	0.10	0.61	0.21	0.60	0.46	0.68	0.74
Y3	minimum	8.80	8.60	0.10	0.10	0.10	0.10	12.14	12.97
	maximum	9.10	9.90	0.20	0.30	2.20	2.70	15.17	15.85
	mean	8.90	9.00	0.10	0.20	1.20	1.70	14.32	14.78
	SD	0.07	0.24	0.02	0.04	0.61	0.59	0.74	0.83
Y4	minimum	8.30	8.10	0.28	0.20	0.90	1.00	7.32	8.11
	maximum	9.91	9.02	0.54	0.40	3.94	2.10	9.64	6.55
	mean	8.83	8.72	0.36	0.28	1.75	1.35	8.27	7.07
	SD	0.29	0.25	0.07	0.04	0.05	0.10	0.53	0.89

EC: electrical conductivity; OM: organic matter; CEC: cation exchange capacity; Y1–Y4: years 2015 to 2018; H1 and H2: 0–20 and 20–40 cm depths; SD: standard deviation.

Table 4 – Concentrations of heavy metals in soil

Year	Horizon	Heavy metals / mg kg_{DM}^{-1} $n=3$						
		Cd	Pb	Cu	Ni	Zn	Co	Fe / g kg^{-1}
2016	H1	3	20	10	20	60	20	14.5
2017	H1	3	20	10	26	84	20	NC
2018	H1	3	20	10	40	130	20	40
	H2	3	20	10	50	150	20	55
Norm (a*)		2	100	100	50	300	ND	ND
Directive (b*)		1 to 3	50 to 300	50 to 140	30 to 75	150 to 300	ND	ND
CEC (c*)	CEC<5	5	560	140	140	280	ND	ND
	5≤CEC<15	10	1120	280	280	560	ND	ND
	CEC≥15	20	2240	560	560	1120	ND	ND
pH (d*)	pH<5.5	ND	ND	80	50	200	ND	ND
	5.5≤pH<6.0	ND	ND	100	60	250	ND	ND
	6.0≤pH≤7.0	ND	ND	135	75	300	ND	ND
	pH>7.0	ND	ND	200	110	450	ND	ND
Texture (e*)	Sandy	0.5	20	5	2	10	ND	ND
	Loamy	0.5	60	14	6	30	ND	ND
	Clayey	5	110	30	10	60	ND	ND

a*: NF U 44-041 norm (mg kg^{-1} of DM); b*: European directive n° 86–278 of 12 June 1986;
c*: cumulative content in soil as function of CEC (kg ha^{-1}) (pH > 6.5; US EPA, 1987);
d*: maximum permitted concentrations of HM in the soil as function of soil pH (mg kg^{-1} DM; UK Environment Department, 1989); e*: Maximal Quantity that can be accumulated in soil as function of texture (*Baker et al.*, 1985). NC: not computed. ND: not declared. *n*: frequency of analysis. H1 and H2: 0–20 and 20–40 cm depths.

3.3 Soil heavy metals

The concentrations of HM in soil due to irrigation with TWW at the beginning and at the end of treatment during four years are shown in Table 4. All values for HM were lower than the values generally considered critical.[76] Concentrations of Ni, Zn, and Fe increased slightly in the irrigated soil with time, and there was more accumulation at depth H2 than at surface H1. These slight variations, however, can hardly be linked to specific processes, due to the duration of irrigation and the quality of the TWW in relation to HM.

Cu concentrations showed similar distributions throughout the treatment period, with more stable mean values at 10 mg kg_{DM}^{-1} in the top layer and at depth at the end of treatment (Table 4). These values are lower than the limit values defined by the European Union in soils (100 mg kg_{DM}^{-1}), and may be linked to the concentration of Cu in the TWW, the absence of plant cover, the fungicide treatment with copper sulphate, and climatic conditions, knowing that Cu has a relationship associated with the CEC[75] and the OM,[77] so the low variation of CEC and OM during the treatment thus appear as the major elements of stabilisation of Cu in the soil.[78–80] Generally, Cu is found in the highly insoluble form of CuS or oxygenated $CuSO_4$ in most natural environments.[81] We conclude that the application of non-industrial TWW had no increase in the amount of Cu in the soil compared to the initial phase for four years.

The levels of Pb and Co in the irrigated soil during the treatment period are given in Table 4. The same remark given, with stabilisation of Pb and Co as Cu during the treatment. The mean values of Pb and Co were high compared to those found for Cu of 20, 20, and 10 mg kg_{DM}^{-1} respectively, but they remained well below the maximum tolerated as declared by the European Commission. The stability of Pb and Co concentration cannot be linked only to TWW, but also to the possible absence of hydrocarbon releases. For example, the solubility of Pb is controlled by very insoluble and geochemically stable minerals, such as hydroxypyromorphite.[82,83] However, probably linked to other factors responsible for concentration stability, such as the absence of fertilisers, because fertilisers play a key role in increasing Pb and Co in the soil[61,84] and still that Pb and Co have a linked relationship with pH, CEC, and OM[15,85–87] and the duration of the soil being subjected to irrigation. This could explain the application of non-industrial TWW with conditions that had no effect on the amount of Pb and Co in the soil compared to the initial phase for four years.

The concentrations of Cd were more stable, like Pb, Cu, and Co during the treatment period, with the average values more stable at 3 mg kg_{DM}^{-1} for the two horizons H1 and H2 (Table 4), which were above the limit values defined by the NF U 44-041 and European Union standards (2 mg kg_{DM}^{-1}). These results are opposed to those of *Singh et al.*,[88] who found that irrigation with TWW significantly increased the Cd content. The presence of Cd in the soil

Table 5 – Calculation of the pollution indices of the soils

Year	Horizon	Heavy metals											
		Cd	CF*	Pb	CF*	Cu	CF*	Ni	CF*	Zn	CF*	PI*	NI*
2016	H1	3	1.5	20	0.2	10	0.1	20	0.4	60	0.2	0.48	0.35
2017	H1	3	1.5	20	0.2	10	0.1	26	0.52	84	0.28	0.52	
2018	H1	3	1.5	20	0.2	10	0.1	40	0.8	130	0.43	0.6	
	H2	3	1.5	20	0.2	10	0.1	50	1	150	0.5	0.66	

CF*: Contamination factor, PI*: Pollution index, NI*: Nemerow index, H1 and H2: 0–20 and 20–40 cm depth.

is attributable, on the one hand, to the percentage of its presence in the EUTs with frequency of irrigation and, on the other hand, to the pH which reacts significantly on the solubility and retention of Cd in the soil,[89] as well as the nature of the OM[90] and the CEC.[91,92] However, these concentrations remained constant during the treatment in the two horizons due to the organometallic complex composition rate[93] and the low acidity of the soils. The irrigation time of four years is very short for the accumulation of Cd, because, the average life of Cd without degradation in the soil is 15–1100, 310–1500 and 740–5900 years, respectively, according to soil characteristics and physicochemical parameters.[94]

The average values of Ni and Zn during the treatment period were below the norms, with a small increase in the four years. This result contrasts with those reported in several studies,[95,96] which noted that soil irrigated by TWW experienced an accumulation of Ni and Zn over time. The increase in the values of Ni and Zn is probably the consequence of the high concentrations of Zn and Ni in the TWW, the variation of the values of CEC and OM in the soil, and the pH.[15] The concentration of Ni and Zn in the H2 layer at the end of treatment was higher than in the surface layer. This slight increase in Ni and Zn at depth is due to the lack of OM with an increase in pH in H2. Conversely, the very fast mobility of Ni and Zn with the presence of large quantities of OM is important because of the acidity of the medium and the textural nature of the soil, particularly clay. The water used for irrigation being non-industrial water, knowing that domestic treated water is loaded with detergent products, phosphate is also considered as an inhibitor of the mobility of HM in soils.[97,98]

As for iron, we also noticed a slight increase in concentrations over the irrigation time, in contrast to *Boutin et al.*[99], who found retention of some metals like iron. This is due to the water quality with the iron-rich soil type according to its red colour because of iron oxidation. In general, the distribution of iron in the soil is strongly dependent on the type of soil.[100] This allows us to say that the quality of TWW and the percentage of dissolved oxygen in the water play an important role in the oxidation of iron, and it depends on the quality of the soil. The long-term use of TWW can be considered safe with respect to the accumulation of HM in the soil, because we observed stability of the concentrations of certain elements with a slight increase in other elements like Ni, Zn, and Fe during the four-year treatment period, but the permitted limit values were never exceeded, due to the short irrigation period and the chemical components present in the water.

3.4 Pollution indices

The results of the contamination factors (CF), the pollution index (PI), and the Nemerow index (NI) are presented in Table 5.

According to the classification of Hakanson,[38] the highest CF values for the metals were found for Cd corresponding to moderate contamination ($1 < CF < 3$), while the CF values for Pb, Ni, Cu, and Zn were < 1 during the treatment period, indicating low contamination by TWW used for irrigation.

PI values varied between 0.48 and 0.66 (Table 5). All the values during the treatment time were less than 1, therefore, these soils could be considered non-contaminated by HM according to the pollution classification,[101] but it was noticed that over time the pollution index increased due to TWW irrigation. This water must be monitored.

According to the classification of *Gong et al.*,[43] the value of NI during the treatment period was less than 0.7, therefore, these soils are considered non-contaminated by HM and are harmless.

According to the previous comments on the accumulation of HM and other studies, we can conclude that, before using TWs, it is necessary to know all the factors to evaluate the danger of this water and its consequences on the soil after its use;

- Concentrations of HM in irrigation water
- Physicochemical composition of soils (texture, structure, acidity, salinity, ...)
- Duration and frequency of irrigation
- Climatic condition (irrigation season)
- Quality and quantity of fertilisers and pesticides used.

4 Conclusion

In order to maintain the quality and quantity of water in the Ain Defla region located on the west of the Haut Chlef watershed, we discussed the possibility of using treated wastewater in irrigation and its effect on the environment in general and soils, particularly with regard to heavy metals. The use of non-industrial treated wastewater from the Ain Defla WWTP indicates a very slight increase and accumulation of heavy metals in the soil. However, comparing these results with other results, we noticed a difference in the concentrations of heavy metals. This difference is due to several factors, which have been mentioned before, and vary depending on several factors, and among them, the quality and concentrations of heavy metals in the irrigation water, duration of irrigation, soil physicochemical properties, which play a very important role in the accumulation and leaching of heavy metals, with the study of climatic conditions. Finally, it can be said that the TWW of Ain Defla can be used as an alternative to irrigation if necessary, but for a short period of up to four years.

Contributions of authors

Rata Y. and Douaoui A. designed and performed the experiments, performed the statistical analysis and wrote the original manuscript. Douaoui A., Rata M., and Douaik A. reviewed the manuscript. All authors have read and approved the final manuscript.

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List of abbreviations

AAS – atomic absorption spectrophotometer
CEC – cation exchange capacity
CF – contamination factors
DM – dry matter
EC – electrical conductivity
FAO – Food and Agriculture Organization
H1, H2 – depth
HM – heavy metals
JORA – Official Gazette Algeria
MRE – Ministry of Water Resources, Algeria
NI – Nemerow index
OM – organic matter
ONA – National Sanitation Office
PI – pollution index
TWW – treated wastewater
WWTP – wastewater treatment plant
Y1, Y2 – years

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SAŽETAK

Akumulacija teških metala u tlima navodnjavanim obrađenom otpadnom vodom: Slučaj sjeverozapadnog dijela ravnice Haut Chelif u Alžiru

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Dugotrajno navodnjavanje obrađenom otpadnom vodom može dovesti do nakupljanja teških metala u tlu izazivajući negativne učinke na okoliš. U ovom radu proučavana su područja gravitacijski navodnjavana obrađenom otpadnom vodom (bez unosa gnojiva) da bi se procijenili trendovi akumulacije teških metala i njihov utjecaj na fizikalno-kemijska svojstva tla tijekom razdoblja od četiri godine. Uzorci tla uzeti su na dvije dubine (0 do 20 cm i 20 do 40 cm). Rezultati ove studije pokazuju da je obrađena otpadna voda glavni izvor povećanja koncentracije teških metala u tlu i da dugotrajno navodnjavanje obrađenom otpadnom vodom obogaćuje tla teškim metalima, na što utječe sastav obrađene vode, klimatski uvjeti, tip tla i učestalost navodnjavanja.

Ključne riječi
Teški metali, obrađena otpadna voda, navodnjavanje, tlo, Haut Chelif

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