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Impact of Irrigation Water on Heavy Metal Content in Irrigated Soils and Plants – Spatial and Vertical Distribution

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ABSTRACT

It is essential to monitor the evolution of pollutants including heavy metals found in water intended for irrigation. Since they have a crucial impact on living beings. In this study, the contents of heavy metals were analyzed by ICP-AES on the three levels of irrigation water, soil and plants (olive tree and cardoon) and those in four different terrains. The Cd, Cu and Pd found in the water of the downstream Oued Fès and the treated wastewater are out of the norm. We found Pd in higher concentrations in both plants. For Cu it is more assimilated by the olive tree. Regarding the soil, the content of Cr is very high in the plot irrigated by water from Oued Fès located downstream and less high in the plot irrigated by treated wastewater. The cardoon of this last plot present an increased concentration in Cr more than the others. These variations depend on the type of plants and their different characteristics of absorption according also to the accumulation of metals in the soil adding also anthropic factors.

Keywords: irrigation water, heavy metals, treated wastewater, soil, olive tree, cardoon.

INTRODUCTION

Agriculture in the region Fez-Meknes is a real economic lever with a contribution of 21.1% to the regional GDP, ranking it second in terms of contribution to the national agricultural GDP. As an example, the year 2018/2019, the useful agricultural area for olive cultivation is 360,000 ha which represents 33% of the national area for market gardening an area of 33,850 ha equivalent to 13%. When the total agricultural area is about 1.3 million ha, of which 15% irrigated (Mohssine et al., 2020).

The succession of years of drought since the 1980s and the anarchy of water use have led to an overexploitation of groundwater and surface water. Indeed, the annual balance of the Fez-Meknes water table records a deficit of about -100 Mm3/year. The reuse of purified wastewater in irrigation is among the management for the protection of groundwater and surface water resources in addition to wastewater is a water value and a potential contribution of fertilizing materials. As a result, wastewater reuse can add valuable plant nutrients and organic matter to the soil (Liu et al., 2005). On the other hand, wastewater effluent reuse for agriculture is a potential health and environmental risk associated with it and thus a major risk to human health (Kumar et al., 2012; Zhou et al., 2016; Flouchi et al., 2021). Parmi les composants des eaux usées à risque figurent les métaux lourds. Ils provoquent la perturbation de cycles biochimiques complexes, ce qui peut menacer la survie de la vie végétale et animale, y compris celle des humains (Kaluli et al., 2014 ; Kayira et al.,2021). Les métaux lourds sont des polluants environnementaux comme leur toxicité, leur durabilité et leur caractère bioaccumulatif. Examples of these heavy metals are Zn, Cu, Fe, Cd, Cr and others. Certainly, for plants Zn and Cu are essential for their growth, however, they usually become harmful at high concentrations. However, some heavy metals, namely cadmium (Cd), lead (Pb) and chromium (Cr), are even harmful at low concentrations. Accumulation of heavy metals in plants depends on the plant species, and the efficiency of different plants in absorbing heavy metals is assessed either by plant uptake or by soil-to-plant transfer factors of heavy metals (Rattan et al., 2005; Abosede et al., 2018). For soils, heavy metal accumulation includes atmospheric deposition from industrial emissions, vehicle exhaust and degradation, mining wastes, and agricultural wastes such as various fertilizers and pesticides (Obbard, 2001; Smith, 2009). Heavy metals are non-biodegradable and therefore persist for a long time in aquatic and terrestrial environments. They can be transported from soil to groundwater or taken up by plants (Jamali et al., 2009). In this regard, the increasing volume of wastewater generated from domestic, industrial and commercial sources is often used for urban and peri-urban agriculture (Singh et al., 2012).

Because of the risks associated with wastewater used in irrigation, it is always necessary to control its composition. Therefore, we conducted a study on four plots in the region of Fez. The first one is a land irrigated by well water and the next two lands are irrigated by surface water Oued Fès before and after the industrial zones Doukkarat and Ain Noukbi and the third one by treated wastewater from the wastewater treatment plant.

For the purpose of determining the levels of heavy metals, Cd, Cr, Cu, Ni, Pd, Fe and Zn in these waters, the plants: perennial such as olive tree and vegetable such as cardoon and the soils in which these plants have been grown.

MATERIALS AND METHODS

Study area

Fez, the second industrial city of Morocco, has 526 industries in 2016. This city contains four main industrial zones Bensouda, Sidi Brahim, Doukkarat and Ain Noukbi; whose main activities are: tanneries, textiles and food processing. The last two industrial areas are not very long from Oued Fès which suffers and those for several years of pollution becoming a collector of wastewater due to domestic and industrial activities. Therefore, we have chosen 4 lands:

- T: The first land located between 34°04’02.18” Latitude N and -5°06’35.41” Longitude W near Oued Fès and irrigated by well water.
- SI: The second land irrigated by surface water Oued Fez, located between 34°02’35.9” Latitude N and 5°03’19.3” Longitude W before the industrial area Doukkarat.
- SII : The third is a land irrigated by the downstream Oued Fez before its meeting with Oud Sebou is located after the industrial area Ain Nourbi between 34°04’21.1” Latitude N and 4°56’18.4” Longitude W.
- SIII: The fourth plot irrigated by treated wastewater from the Fez

These four plots cultivate olive trees and cardoons and use the same irrigation method. The irrigation is done by gravity on the surface according to a system of stripes. Thus, irrigation water flows from the irrigation intake to the end of the plot. The three sites are shown in Figure 1.

Sample collection and preparation

For each field, we took two samples, the low water period corresponding to the dry season of August 2019 and the flood period corresponding to January 2020. All our samples were carefully labeled and placed in a cooler containing ice and then transported to the laboratory.

Water

Water samples were collected in thoroughly cleaned PVC bottles and rinsed with 500 ml distilled water. Our samples were filtered and then we added 2.5 ml of concentrated nitric acid to lower the pH to < 2 to avoid precipitation and any microbial activity during storage (Jabeen et al., 2018). Thereafter, they were stored tightly closed at 4 °C to minimize chemical alteration until analysis.

Soil

Three soil samples were taken from the different selected plots. The samples consisted of a systematic sampling with a stainless steel auger between 0 and 20 cm depth. We took 1 kg of each sample in polyethylene bags. Each sample was a composite of three samples taken from three different locations spaced equilaterally at 7 to 10 m. They were then air-dried, crushed, and sieved through a 1.18 mm sieve, and stored in polyethylene bags for later analysis (Leblebici and Kar, 2018; Chabukdhara et al., 2016).

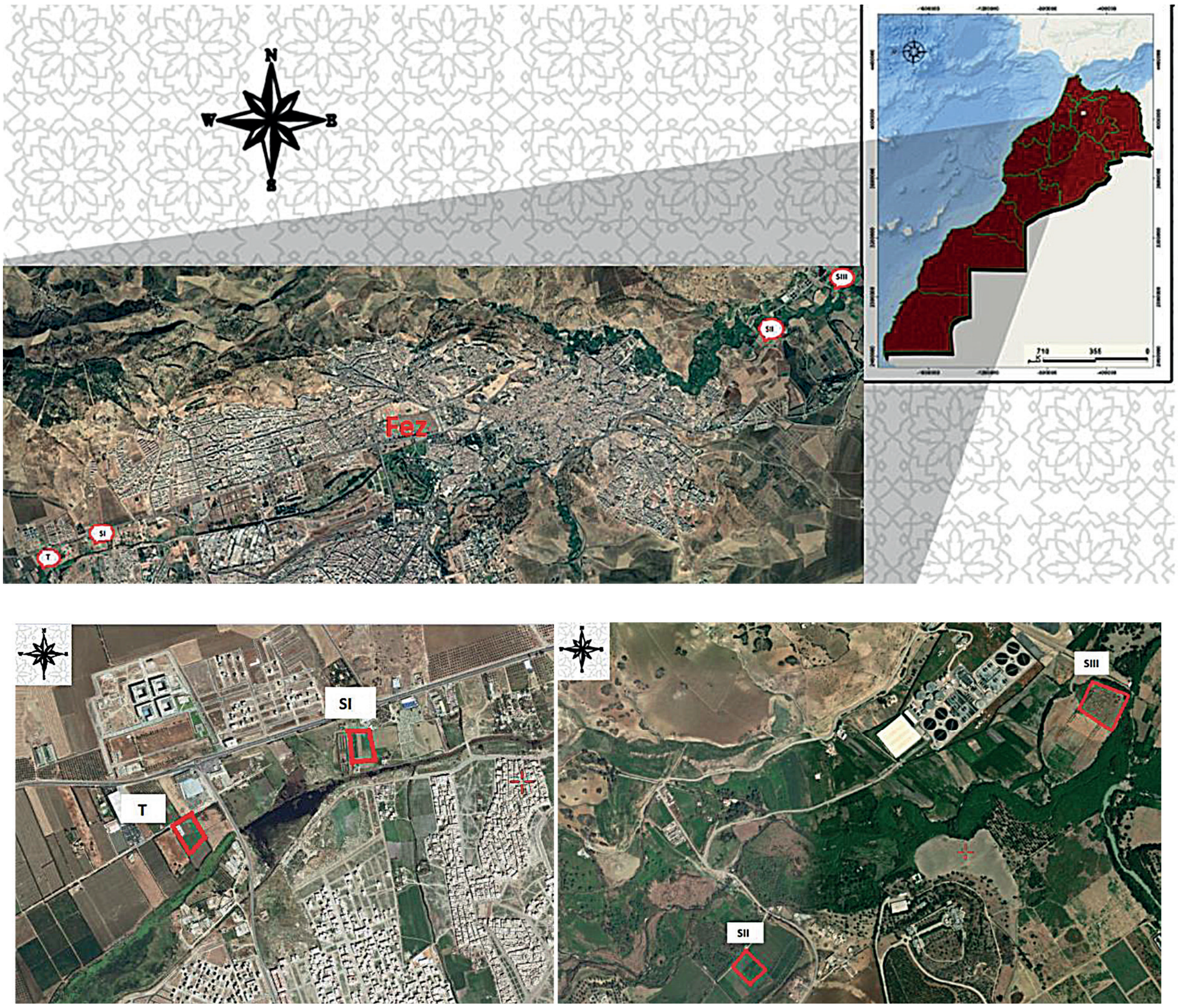

Figure 1. A figurative map of the study area and sample collection locations

Plants

Two types of plants were sampled, olive and cardoon. The sampling concerned the aerial part (stems + leaves). The samples were taken at the same time and in the same places as the soil samples taken with an auger. They were washed and rinsed with distilled water to eliminate peripheral pollutants. These samples were then air-dried for two days to reduce water content and finally oven-dried at 70 °C to remove all moisture without thermal decomposition (Chabukdhara et al., 2016).

Analysis

For soil and plants, the studied mineral elements were measured in the residue of the product calcined at 500 °C for 5 h, with a test sample of 25 g for leaves and barks, and 30 g for teguments and pulps. The determination of the studied trace elements (Cd, Cr, Cu, Ni, Pd, Fe, and Zn) was carried out by the aqua regia method and analysis by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). The aqua regia method is based on the principle of dissolving the sample in a mixture of hydrochloric and nitric acid according to the following procedure: 0.15 g of the mineral material is weighed, 2 to 3 ml of aqua regia are added, the sample is placed on a hot plate and allowed to evaporate to dryness. Then 25 to 30 ml of hydrochloric acid (2M) are added until total dissolution then analyzed by ICP-AES. The analyses of heavy metals in soil and plant water were carried out by ICP-AES at the Centre Universitaire Régional d'Interface (CURI) at the University Sidi Mohamed Ben Abdellah (USMBA) of Fez.

Statistical analysis

Experiments followed a randomized design with three replicates for each analysis. Results were expressed as mean ± SE. Data were evaluated by one-way analysis of variance (ANOVA) to determine significant values. Fisher's minimum significant difference (LSD) test was used as a post hoc test for multiple comparisons at α = 0.05

RESULTS AND DISCUSSION

Heavy metal content in water for irrigation

In Table 1, in the dry season the heavy metal contents of Cd, Cr, Cu, Fe, Ni, Pb and Zn are higher than in the rainy season for all four sites. The maximum average concentration of heavy metals is Fe with a value of 1.41 mg/l in the treated wastewater. The minimum average concentration of heavy metals is Zn at 0.005 mg/l recorded in the dry season at our well water control site.

The lowest concentrations of heavy metals in both seasons are the well water followed by the upstream Oued Fès water. In winter, the Oued Fès waters located downstream present higher average concentrations of heavy metals Cr, Cu, Fe, Ni and Zn compared to the treated wastewater with the respective concentrations 0.054 mg/l, 0.503 mg/l, 0.049 mg/l, 0.204 mg/l and 0.198 mg/l. On the other hand, in summer, the average concentrations of Cd, Cr, Cu, Fe, Ni, Pb and Zn in the treated wastewater are higher compared to the downstream Oued Fès waters with the respective concentrations 0.854 mg/l, 0.366 mg/l, 0.689 mg/l, 1.405 mg/l, 0.471 mg/l, 0.618 mg/l and 0.073 mg/l. The same was found for metals Zn, Cd and Pd in treated wastewater at Kinya (Sayo et al., 2020). These high average concentrations could be due to the presence of metal compounds in the waste directed to the treatment plant, which are not removed effectively during the treatment process (Nzeve, et al., 2014). By making a comparison with the Moroccan standards of the quality of water intended for irrigation, we noted that the concentration of Cd of the irrigated water located in the four sites is out of standard except for the well water in winter period. The most important contents are 0.852 mg/l and 0.854 mg/l detected in the water of Oued Fès located downstream and the treated wastewater respectively in dry period. However, the source of Cd may be from industrial activities in the chemical industries and in the manufacture of pesticides and herbicides used in agriculture (Alloway and Ayres, 2010). At the same period, the average Pd content is out of the norm in the upstream and downstream Oued Fès waters and treated wastewater with the respective concentration of 0.309 mg/l, 0.606 mg/l and 0.618 mg/l. However, it should be noted that the main sources of lead pollution are pesticides, impurities from fertilizers, discharges from mines and smelters and atmospheric fallout from fossil fuel combustion (Hong et al., 2009).

Heavy metal content in irrigated soils

Table 2, shows the average concentrations for all the metals studied in the soil of both winter and summer seasons. The values of heavy metals in summer are higher than in winter. In winter, the soil irrigated by well water contains higher average concentrations of Cd, Cr and Fe than the soil irrigated by Oued Fès water upstream and downstream, the values are respectively 0.066 mg/l, 0.306 mg/l and 67.34 mg/l. These results can be explained by the accumulation of metals in

Table 1. Concentrations of Cd, Cr, Cu, Fe, Ni, Pb and Zn in mg/L in irrigation water in dry and rainy seasons

Season	Parameter	Cd	Cr	Cu	Fe	Ni	Pd	Zn
Rainy season	T	0.007±0.001[a]	0.025±0.004[a]	0.015±0.001[a]	0.008±0.001[a]	0.007±0.001[a]	0.006±0.001[a]	0.005±0.001[a]
	SI	0.012±0.001[b]	0.039±0.001[b]	0.025±0.005[b]	0.009±0.001[a]	0.007±0.001[a]	0.009±0.001[b]	0.006±0.001[a]
	SII	0.012±0.001[b]	0.054±0.002[c]	0.503±0.03[c]	0.049±0.009[b]	0.204±0.01[b]	0.007±0.001[a]	0.198±0.021[b]
	SIII	0.012±0.001[b]	0.035±0.009[b]	0.023±0.009[b]	0.01±0.001[a]	0.04±0.002[c]	0.008±0.002[b]	0.008±0.001[a]
Dry season	T	0.023±0.002[a]	0.022±0.008[a]	0.017±0.002[a]	0.0204±0.007[a]	0.014±0.001[a]	0.074±0.008[a]	0.053±0.006[a]
	SI	0.428±0.003[b]	0.177±0.007[b]	0.237±0.03[b]	0.554±0.09[b]	0.606±0.095[b]	0.309±0.015[b]	0.257±0.01[b]
	SII	0.852±0.007[c]	0.283±0.02[c]	0.402±0.05[c]	1.052±0.11[c]	1.13±0.22[c]	0.606±0.032[c]	0.036±0.008 [a]
	SIII	0.854±0.009[c]	0.366±0.005[d]	0.689±0.54[d]	1.405±0.14[d]	1.157±0.21[c]	0.618±0.018[c]	0.073±0.006[c]
Moroccan standards		0,01	1	0,2	2	5	0,2	2
FAO (1994)		<0,01	<0.1	<0,2	<5	<0.2	<5	<2

Note: Each number represents the average standard error of three replicates. Means in a column (within each group) followed by the same letter are not significantly different and means followed by different letters are significant at P < 0.01 according to the LSD test (α = 0.05).

Table 2. Concentrations of Cd, Cr, Cu, Fe, Ni, Pb and Zn in mg/L in irrigated soil during the dry and rainy seasons

Season	Parameter	Cd	Cr	Cu	Fe	Ni	Pb	Zn
Rainy season	T	0.066±0.008[a]	0.306±0.01[a]	0.222±0.01[a]	67.34±3.44 [a]	< 0.01	< 0.01	< 0.01
	SI	0.034±0.003[b]	0.102±0.011[b]	0.45±0.021[b]	25.51±0.31 [b]	< 0.01	< 0.01	< 0.01
	SII	0.054±0.005[a]	0.22±0.031[c]	0.15±0.01[c]	35.51±0.31 [c]	< 0.01	< 0.01	< 0.01
	SIII	0.065±0.002[a]	0.614±0.019[d]	0.233±0.012[a]	51.17±0.06 [d]	< 0.01	< 0.01	< 0.01
Dry season	T	0.438±0.014[a]	0.354±0.02[a]	2.371±0.3[a]	123.23±0.7 [a]	0.646±0.051[a]	0.29±0.01[a]	1.645±0.12[a]
	SI	0.427±0.022[b]	0.352±0.011[a]	2.806±0.19[b]	107.73±0.207 [b]	0.741±0.036[b]	0.303±0.01[a]	1.729±0.103[a]
	SII	0.423±0.012[b]	1.8±0.02[b]	0.428±0.101[c]	156.35±0.05 [c]	0.809±0.01 [c]	0.297±0.02[a]	0.988±0.09[b]
	SIII	0.428±0.02[b]	0.702±0.061[c]	0.599±0.032[d]	123.34±0.01 [a]	0.783±0.02[b]	0.308±0.03[a]	1.047±0.17[b]
Normes Norme AFNOR N F U 44-041		2	150	100	-	50	100	300

Note: Each number represents the average standard error of three replicates. Means in a column (within each group) followed by the same letter are not significantly different and means followed by different letters are significant at $P < 0.01$ according to the LSD test ($\alpha = 0.05$).

the soil following the contribution of well water contaminated by Oued Fès water located nearby. Also added is the dilution effect of rainwater in winter (Aslam et al., 2017; Woldetsadik et al., 2017). While the soil irrigated with treated wastewater has a higher average Cr concentration than the control soil with a value of 0.614 mg/l. Also at the same season, Ni, Pd and Zn contents are lower than 0.01 mg/l in the soil of the four sites.

In summer, the soil irrigated by Oued Fès water downstream contains maximum average concentrations of Cr, Fe, Mn and Ni as follows 1.8 mg/l, 156 mg/l, 3.6 mg/l and 0.81 mg/l, respectively. This increase in heavy metal levels in the soil is due to the long-term use of wastewater for irrigation (Mutune et al., 2014; Meng et al., 2016). The maximum values for Cu and Zn are recorded at the soils irrigated by Oued Fés water upstream and well water 2.81–2.37 mg/l and 1.73–1.65 mg/l respectively. The values of Cd 0.4 mg/l and Pd 0.3 mg/l are identical in the soil of the four sites. It has been reported that chemical use of chemical fertilizers, pesticides and fungicides were the potential source of lead pollution in soil (Wei et al., 2011; Deribachew et al., 2015).

Heavy metal content in plants

The Tables 3 and 4 present the heavy metal contents studied in cardoon and olive tree and those for the 2 seasons, winter and summer. We noticed that in winter the average concentrations of heavy metals Cd, Cr, Cu, Fe, Ni and Pb are less important than in summer except for Zn where it is the opposite. In the same season, Ni and Pd have a content lower than 0.01 mg/l in the two plants cultivated in the four fields. Both the cardoon and the olive tree, which are irrigated by well water in both seasons, have lower average concentrations of heavy metals than the other plants, with the exception of Fe, which has a value of 21.96 mg/l, the highest in summer in the olive tree.

The accumulated quantity of Cd in the tissues of cardoon and olive tree irrigated by Oued Fès downstream is the same in winter with a value of 0.015 mg/l. In summer, it presents the maximum value 0.114 mg/l in the cardoon and 0.149 in the olive tree. Similarly for Pd, in summer, the accumulated amount is the maximum for cardoon with a value of 0.295 mg/l. The same for a study done (Sayo et al.; 2020), for kale and spinach irrigated with wastewater effluent was found to be slightly below the acceptable limits of 0.3 mg/L (WHO, 2006). For olive tree the value recorded is 0.612 mg/l which is well above the accepted limits (0.3 mg/l). And Pd is much more assimilable in olive tissues than in cardoon tissues. Remembering that the olive tree is a perennial plant that has undergone irrigation much more than the vegetable plants.

Ni is widely present in the environment and is a normal component of plant tissue. Many plant species naturally accumulate relatively high levels of Ni in their tissues, although, as with many trace metals, levels in different plant tissues are influenced by soil characteristics and the form in which Ni is found (Yusuf et al., 2011). Our results show a concentration slightly lower than the acceptable limits of 0.2 mg/L of Ni in the tissues of the cardoon irrigated

Table 3. Concentrations of Cd, Cr, Cu, Fe, Ni, Pb and Zn in mg/L in cardoons in dry and rainy seasons

Season	Parameter	Cd	Cr	Cu	Fe	Ni	Pd	Zn
Rainy season	T	0.012±0.001[a]	0.029±0.001[a]	0.282±0.012[a]	3.354±0.4 [a]	< 0.01	< 0.01	0.555±0.013[a]
	SI	0.015±0.001[a]	0.039±0.006[b]	0.288±0.004[a]	2.89 ±0.13 [a]	< 0.01	< 0.01	0.575±0.01[a]
	SII	0.015±0.002[a]	0.054±0.002[c]	0.24±0.021[b]	17.2±0.99 [b]	< 0.01	< 0.01	0.566±0.017[a]
	SIII	0.013±0.002[a]	0.042±0.002[b]	0.185±0.019[c]	2.636±0.05 [a]	< 0.01	< 0.01	0.637±0.101[b]
Dry season	T	0.099±0.001[a]	0.128±0.013[a]	1.419±0.19[a]	28.763±2.12 [a]	0.176±0.011[a]	0.188±0.013[a]	0.058±0.003[a]
	SI	0.101±0.01 [a]	0.108±0.015[b]	0.932±0.025[b]	39.06±3.44 [b]	0.169±0.008[a]	0.182±0.09[a]	0.05±0.002 [b]
	SII	0.114±0.009[a]	0.169±0.011[c]	0.915±0.01[b]	27.076±1.9[a]	0.18±0.012[a]	0.295±0.008[a]	0.057±0.002[a]
	SIII	0.099±0.008[a]	0.381±0.014[d]	0.561±0.03 [c]	40.16±1.86[b]	0.197±0.01[b]	0.203±0.003[b]	0.056±0.001[a]
Normes WHO (1996)		0.2	1.3	10	-	0.2	0.3	300

Note: Each number represents the average standard error of three replicates. Means in a column (within each group) followed by the same letter are not significantly different and means followed by different letters are significant at P < 0.01 according to the LSD test (α = 0.05).

Table 4. Cd, Cr, Cu, Fe, Ni, Pb and Zn concentrations in mg/L in olive trees in dry and rainy seasons

Season	Parameter	Cd	Cr	Cu	Fe	Ni	Pd	Zn
Rainy season	T	0.01±0.002[a]	0.037±0.001[a]	0.137±0.01[a]	11.03±1.5 [a]	< 0.01 [a]	< 0.01 [a]	0.53±0.13 [a]
	SI	0.013±0.002[a]	0.059±0.001[b]	0.233±0.01[b]	9.03 ±0.77 [b]	< 0.01 [a]	< 0.01 [a]	0.636±0.09 [a]
	SII	0.015±0.001[b]	0.057±0.002[b]	1.622±0.24 [c]	17.04±0.91 [c]	< 0.01 [a]	< 0.01 [a]	1.05±0.11 [b]
	SIII	0.014±0.002[ab]	0.010±0.004[c]	0.039±0.001[c]	10.06±1.55 [b]	< 0.01 [a]	< 0.01 [a]	1.05±0.201 [b]
Dry season	T	0.108±0.002[a]	0.141±0.002[a]	0.8±0.01[a]	21.96±3,05 [a]	0.184±0.02 [a]	0.284±0.04[a]	0.056±0.001[a]
	SI	0.111±0.006[a]	0.147±0.001[a]	0.62±0.01[a]	10.15±2.14 [b]	0.195±0.04[b]	0.302±0.06 [a]	0.05±0.002[a]
	SII	0.149±0.005[b]	0.141±0.002[a]	1.613±0.32[b]	18.153±4.04[a]	0.196±0.03[b]	0.612±0.02[b]	0.058±0.01[a]
	SIII	0.105±0.001[a]	0.124±0.001[b]	0.964±0.17 [c]	11.247±1.16[b]	0.251±0.073[c]	0.211±0.04[c]	0.059±0.009[a]
Normes WHO (1996)		0.2	1.3	10	-	0.2	0.3	300

Note: Each number represents the average standard error of three replicates. Means in a column (within each group) followed by the same letter are not significantly different and means followed by different letters are significant at P < 0.01 according to the LSD test (α = 0.05).

with treated wastewater a value of 0.197 mg/l in summer. At the same season and on the same land the olive tree exceeds the limit standard of 0.25 mg/l. This difference can be explained by the different absorption characteristics (Kabata-Pendias and Mukherjee, 2007).

Cardoon accumulates the highest average concentrations of Fe > Cr compared to olive tree with the respective values 40.16 mg/l > 0.381 mg/l. On the other hand, olive tree accumulates the highest average concentrations of Pb > Ni > Cd compared to cardoon with the respective values 0.612 mg/l > 0.251 mg/l > 0.114 mg/l. The translation of Pb from the roots to the aerial parts leads to its accumulation in leaves and stems (Wies and Weis, 2004), this is the case for olive tree as our samples were stems and leaves.

High levels of heavy metals in plants can significantly affect their nutritional quality and lead to health risks for consumers (Khan et al., 2016).

CONCLUSIONS

This study highlighted the Cd and Cu pollution of the irrigation water of Oued Fès. According to the Moroccan standards of water quality used in irrigation and FAO (1994). The concentrations of these elements exceed the critical threshold of 0.01 mg/l and 0.2 mg/l respectively. Regarding irrigated soils, the spatial distribution of heavy metals available in the soil showed that irrigation by these waters in the long term caused the accumulation of Cr and Ni compared to the soil irrigated by well water. This contamination could reach the olive trees located downstream of Oued Fès mainly in Pd, Cu and Zn whose contents are sometimes twice as polluted as those irrigated by well water. The cardoon when being a vegetable plant the excessive absorption is observed at the level of Pd and Cr cultivated in the ground which was irrigated with waste water for a long period, located downstream of oued Fès, and the ground irrigated by treated waste water. We thus note that this pollution varies according to the land and the types of plants. The high availability of these pollutants presents a real sanitary risk and many harmful effects in humans.

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