International Journal of Recycling of Organic Waste in Agriculture (2021)10: 309-317
Doi: 10.30486/IJROWA.2021.1901411.1085

SHORT COMMUNICATION

Effects of irrigation with municipal treated wastewater on soil's heavy metals accumulation and turf leaves under drip and sprinkler systems (Case study: Agadir, Southern Morocco)

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Received: 04 June 2020 / Accepted: 23 April 2021 / Published online: 21 August 2021

Abstract

Purpose Treated wastewaters are reused in agriculture to deal with the water deficit, especially in arid and semi--arid regions. However, they may contain contaminants such as heavy metals that can adversely affect the soil quality and life health. This work aimed to assess the degree of contamination of the soil and the turf leaves of a golf course irrigated in the long term (10 years) by treated wastewaters.

Method Analysis of eight heavy metals (Cd, Co, Cr, Cu, Ni, Mn, Fe and Zn) was carried out at two sites. The first was irrigated by sprinkling (site 1), the second by a drip system (site 2).

Results The results showed a generalized contamination of the soil at the two sites. Fe and Mn recorded the highest levels. Cd and Cr contents were significantly higher in the soil of site 1. However, all the heavy metals recorded values below the limits set by the FAO / WHO standards for soil. Turf leaves also exhibited high values of Fe and Mn contents in the two sites. Mn content was significantly higher in the turf leaves from site 1. The results showed an accumulation of all the metals in turf leaves in which the Fe and Cd contents exceeded the FAO / WHO standards.

Conclusion Long-term irrigation results in an accumulation of heavy metals in the soil and in turf leaves. Particular attention should be paid to Cd and Fe for the use of treated wastewater in agriculture. Drip irrigation system would minimize crop contamination.

Keywords Heavy metals, Irrigation, Reuse, Soil, Treated wastewater, Turf

Introduction

Treated wastewaters (TWWs) represent an available source of water to meet the growing demand for agriculture. The reuse of TWW for crop irrigation has grown in importance in several regions (Qadir et al. 2010; Pedrero et al. 2010; Tabatabaei et al. 2017a). This practice also has the advantage of contributing to the preservation of drinking water resources and the reduction of pollution of aquatic environments receiving the discharges of effluent (Aiello et al. 2007; Pedrero et al. 2010; Agrafioti and Diamadopoulos 2012). Moreover, the spreading of TWW allows the supply of mineral nutrients and organic matter to the soil (Meli et al. 2002; Munir et al. 2007; Tabatabaei et al. 2017b). However, TWW can contain toxic components and pathogens microorganisms, which represent a risk of contamination to soil and crops (Aiello et al. 2007; Qadir et al. 2010: Jaiswal et al. 2018; Tabatabaei et al. 2020). Among chemical contaminants, heavy metals (HM) can accumulate in soils and crops (Mapanda et al. 2005; Cheshmazar et al. 2018; Rai et al. 2019), posing food safety and health concerns.

The city of Agadir, regional capital of the Souss-Massa region, produces a volume of wastewater close to 70,000 M^3/day (Elame et al. 2013). This wastewater is treated by the M'Zar treatment plant since 2010. The TWW is reused to irrigate golf courses and green spaces. The long-term impact of irrigation with TWW on the microbiological quality of the soil and the turf has recently been studied (Chahouri et al. 2019). On the

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other hand, no study has concerned the effects of long-term irrigation (10 years) on HM contamination of soils and plants, even if the wastewater includes both domestic discharges and industrial discharges from food industries (notably fish and vegetable canning factories) based in the quarters of Anza and Hay Sinai. The aim of our study is to assess the accumulation of HM in the soil and the turf leaves of a golf course (Golf *Ocean*) following long-term irrigation with TWW. Eight HM were considered (Cd, Co, Cr, Cu, Ni, Mn, Fe and Zn) in two sites irrigated by two different irrigation systems, sprinkling and drip irrigations.

Materials and methods

Study site

The study was conducted in the golf course (30°21′51.1″ North, 9°34′35.0″ West) located in the south of Agadir, Morocco (Fig. 1). This space is a sporting and tourist place, spread over 90 Ha. The golf area is covered with turf, besides Eucalyptus, Tamaris, Cypresses, Mimosas and Palm trees. This vegetation is irrigated by TWW provided by the station of M'zar (RAMSA) since 2010.

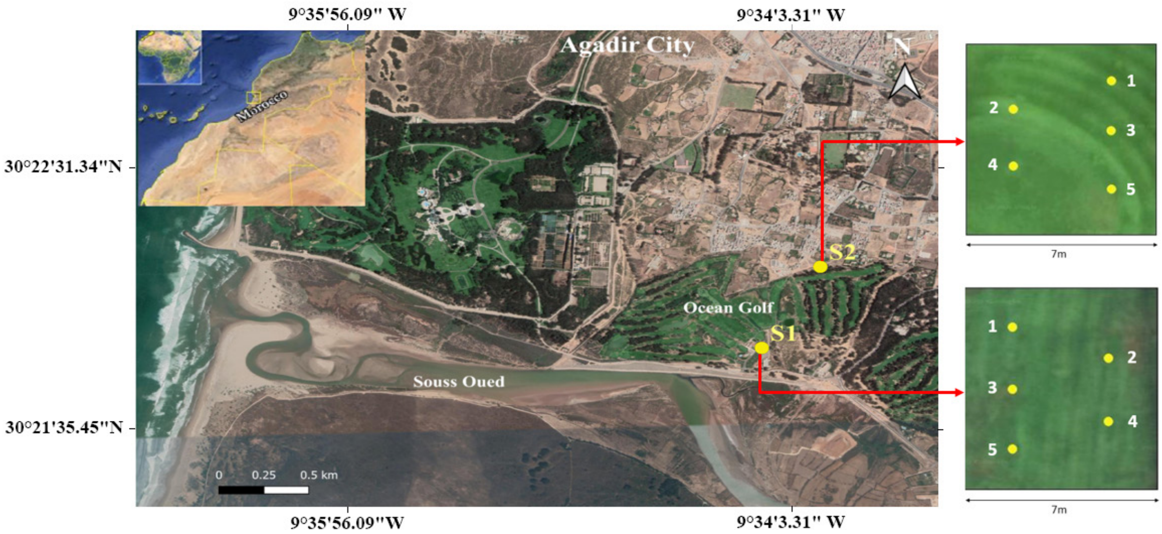

Fig. 1 Study area showing sampling sites

S1: Site 1. S2: Site 2.

1, 2, 3, 4 and 5: Sampling points at S1 and S2.

Composition of treated wastewater

Table 1 summarizes the HM content in the tertiary TWW of the station M'Zar plant. All the concentrations of HM were below the limit values set by Moroccan and FAO standards.

Method of sampling

Two sampling sites were considered (Fig. 1). The site 1 (S1) is used as a sod for repairing the sports space and is irrigated by a sprinkler system. The site 2 (S2) consists of plots irrigated by an underground drip system. For each site, five sampling points were considered (n = 5) respecting a minimal distance of 2.5 m between two neighboring points (Fig. 1). The soil and the turf leaves were collected at the same sampling points in each site. Turf leaves samples were collected using sterile scissors at the sampling points over an area of 20 cm x 20 cm. The soil was sampled using a core-drilling tool with a diameter of 2.5 cm and a depth of 20 cm. The samples (soil and turf leaves) were placed in sterile plastic bags and transported to the laboratory under isothermal conditions.

Soil granulometry and organic matter

The particle size was determined on a 200 g portion of soil sample dried and subjected to separation of the particles by vibration on a series of superimposed sieves of 20 to 500 µm. The total organic matter content was determined by the loss of mass during calcination of the sample for 6 hours at 550 ° C (CEAEQ 2003).

Table 1 Heavy metals contents in M'Zar treated wastewater compared to FAO (2003) and Moroccan norms limits (CNS 1994)

Parameters	M'Zar treated wastewater	Moroccan irrigation standards (CNS 1994)	limits recommended (FAO 2003)
Temperature	25	35	-
pH	7.7	6.5-8.5	-
Fe (mg/kg)	<0.01	5	20.0
Mn (mg/kg)	<0.01	0.2	10.0
Co (mg/kg)	-	0.05	5.0
Cd (mg/kg)	<0.01	0.01	0.05
Cr (mg/kg)	<0.01	0.1	1.0
Cu (mg/kg)	0.09	0.2	5.0
Ni (mg/kg)	<0.01	0.2	2.0
Zn (mg/kg)	<0.01	2	10.0

Heavy metals analysis

Samples previously collected and stored at – 30 ° C were oven dried at 40 ° C. For the sediment, a series of sieves were used to wash the 63 µm fraction with distilled water. Once dried (at 40 ° C), this fraction was recovered and then homogenized in a mortar until a fine powder was obtained. The turf leaves also were grinded into a fine powder after drying at 40 ° C during 48 h. All samples were kept away from light and moisture.

Aliquots from the dried samples (200 mg) were digested with a mixture of nitric acid, perchloric acid, and hydrofluoric acid (Zhuang et al. 2009). Cd, Co, Cr, Cu, Ni and Zn were analyzed by ICP-OES atomic absorption spectrometry in a graphical oven (VARIAN, model AA800). Fe and Mn were analyzed by flame atomic absorption spectrometry (VARIAN, model AA600).

Transfer factor

The transfer factor (TF) of HM from soil to turf leaves was determined as follow: TF = Cp / Cs

Cp was the concentration of a given metal in the plant leaves and Cs the concentration of this metal in soil (Kabata- Pendias 2004).

Statistical analysis

Mean values and standard deviations were calculated from five replicates (n = 5). The values obtained for the two sites were compared using ANOVA (Statistica 6 software). Differences were considered as significant for $p < 0.05$.

Results and discussion

Table 2 shows the granulometric composition of the soil at the two sites. A high fraction of coarse sand was recorded (89.35 and 90.45% for S1 and S2, respectively). Silt represented 9.43 and 8.38% respectively in S1 and S2. A low content of clay characterized the soil of the golf course (1.21 and 1.17% respectively). The organic matter represented 1.37 and 1.00% respectively for S1 and S2.

Table 2 Granulometric composition, organic matter

Granulomeric composition (%)	Site 1	Site 2
Sand	89.35	90.45
Silt	9.44	8.38
Clay	1.21	1.17
Organic matter	1.37 ± 0.31	1 ± 0.26

Fig. 2 shows the HM content in the soil of the two sites. Cu recorded a value of 20.24 mg/kg for S1 and 38.23 mg/kg for S2. The mean content of Zn was 102.88 mg/kg for S1 and 110.94 mg/kg for S2. Fe showed high values of 22,333 and 21,852 mg/kg respectively for S1 and S2. Those of Cr were 95.64 and 65.73 mg/kg for S1 and S2, respectively. The content in Cd was 2.37 and 1.56 mg/kg in the two sites, respectively. The mean concentrations of Ni recorded were 27.29 and 25.94 mg/kg respectively for S1 and S2. Co and Mn marked respectively values of 14.25 and 14.42, and 373.55 and

534.20 mg/kg for the two sites. These results showed the following order of presence in the soil of the two sites: Fe > Mn > Zn > Cr > Ni > Cu > Co > Cd. Cd and Cr recorded values significantly higher in S1. Cu and Mn were significantly more concentrated in S2. Interestingly, no heavy metal exceeded the limits set by FAO / WHO (2007). Several studies have reported that long-term TWW use results in an accumulation of HM in soil (Fosu-Mensah et al. 2017; Kebonye et al. 2017; Rezapour et al. 2019; Chaoua et al. 2019; Mkhininia et al. 2020). This accumulation is faster if the irrigation is carried out by untreated wastewater (Xu et al. 2010). If the concentration of HM exceeds the capacity of the soil to adsorb them, they end up in the mobile phase, which allows their absorption by plants or their leaching towards the water table (Mapanda et al. 2005; Sharma et al. 2007; Olaniran et al. 2013). The accumulation of HM in the soil and their bioavailability depend on the composition of the soil, in particular its richness in clay, limestone and organic matter, which increase their retention capacity (McLaren et al. 2005; Elgallal et al. 2016; Sayo et al. 2020). In addition, the pH of the soil plays an important role. The mobility and bioavailability of HM increase with the acidity of the medium (WHO 2006; Xu et al. 2010). On the other hand, neutral or alkaline soils are characterized by a low bioavailability of HM. Generally, the pH of the soil is conditioned by that of the wastewater used for irrigation (Xu et al. 2010).

Data in the literature on the accumulation of HM in sandy soils and their transfer to crops are not numerous. For conditions comparable to that of our study, Boudinar et al. (2015) reported HM contents lower than ours in sandy soil and turf leaves after irrigation by TWW from Agadir. This difference seems to be due to the duration of irrigation that is only 2 years for the study by Boudinar et al. (2015), and 10 years for our work. The sandy soils are characterized by a low adsorption and significant capillary effect which lead to an important water flow (Tuller and Or 2005). This is in favor of the results that we obtained for the golf soil where the HM contents remained below the standards set by FAO/WHO (2007). In fact, the soil of the studied golf course is sandy and would not allow a strong retention of metals that would be leached towards the water table.

Fig. 3 summarizes the average content of HM measured in the turf leaves at the two sites. The mean contents were Cu (7.13 and 8.92 mg/kg), Mn (136.38 and 70.52), Fe (786.80 and 558.41 mg/kg), Cr (2.73 and 1.71 mg/kg), Zn (17.47 and 20.05 mg/kg), Cd (0.69 and 0.31 mg/kg), Co (0.95 and 0.36 mg/kg), Ni (1.82 and 1.55 mg/kg for S1 and S2 respectively). These results allow establishing a trend of HM concentration in plants for the two sites: Fe > Mn > Zn > Cu > Cr > Ni > Co > Cd. This order is the same as that obtained for the soil.

The results also showed that the content of HM was generally higher in S1 with a significant difference for Cd and Mn ($p < 0.05$). All metals had contents below the standards of FAO/WHO (represented in Table 3), with the exception of Fe and Cd in the two sites. Fe is a trace element involved in many biological processes as an enzyme co-factor or as part of the heme of proteins such as hemoglobin and cytochromes. As a result, high concentrations of Fe are tolerated by international standards (FAO/WHO 2007), whether for TWW or soils and crops. On the other hand, Cd poses a health problem that is due to its toxicity, its high mobility in soils and its high bioavailability for crops even at low concentrations (WHO 2006; Khan et al. 2016; Chen et al. 2018). In this regard, several studies carried out on the effects of irrigation with treated or untreated wastewater showed that Cd is one of the main metals that posed a risk to human health (e.g. Khan et al. 2016; Ali et al. 2019).

As for the transfer factor (Table 4), the results showed differences between the HM studied. The most important value was recorded for Mn, Cu and Cd in S1 (0.29 – 0.35), and for Cu in S2 (0.23). Zn had values of 0.17 and 0.18 in the two sites respectively. The other metals (Fe, Cr, Ni and Co) recorded low values between 0.02 and 0.07. These results are in agreement with those of Bao et al. (2014) who reported TF highest values for Cu, Cd and Zn. Several factors affect the TF of heavy metals, including their concentration in the soil, their chemical forms and the absorption capacity of plants (Farrag et al. 2016; Cheshmazar et al. 2018; Seleiman and Kheir 2018). Consequently, the value of the TF of the heavy metals in the turf leaves showed a variation depending on the metal considered. In general, the values obtained for S1 were higher than that for S2. Similarly, the HM contents were generally higher in S1. This could be explained by the sprinkler irrigation system in site 1, which allows additional absorption of HM by the leaves of the plant due to the direct contact with the TWW.

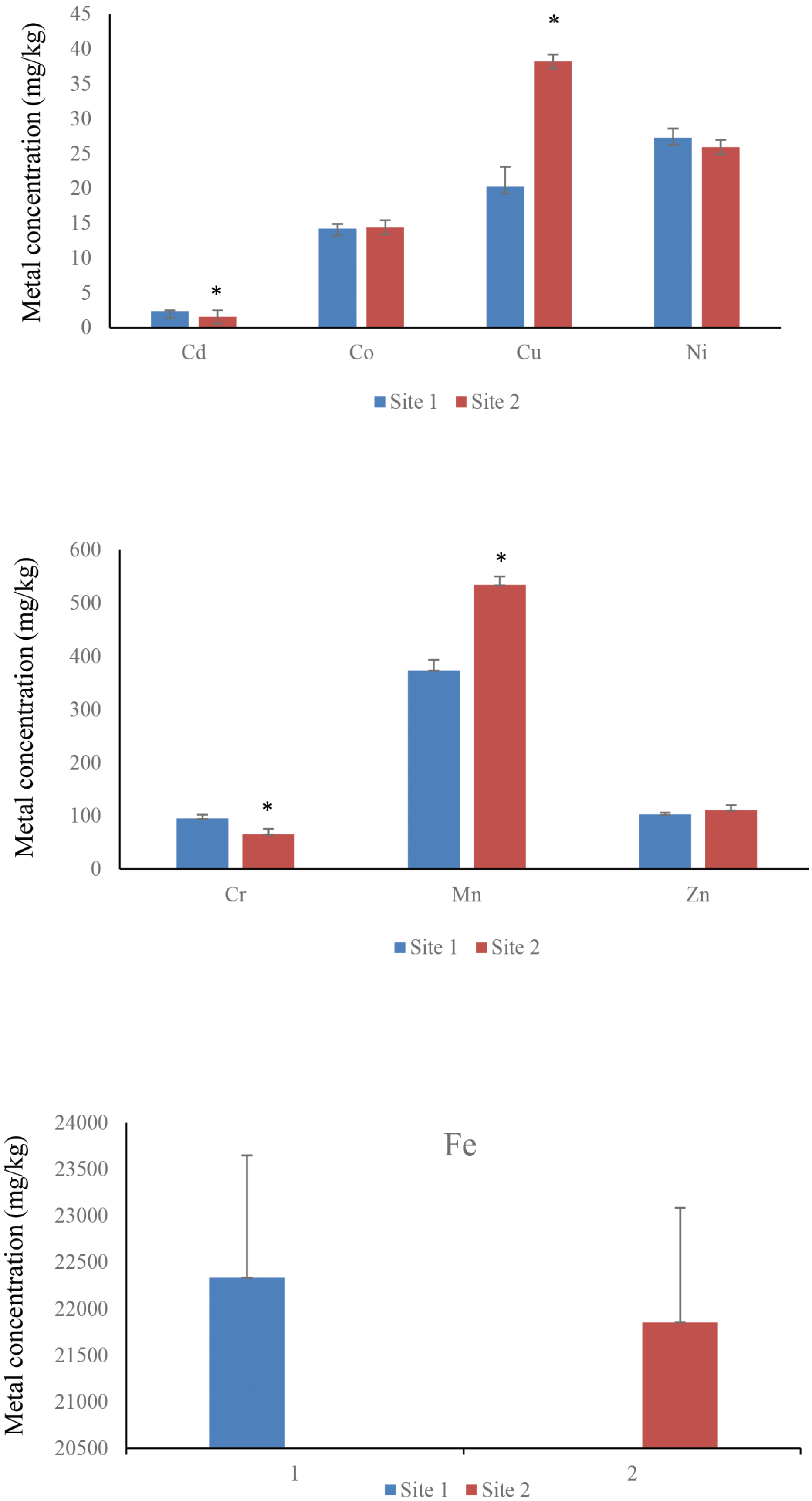

Fig. 2 Soil content in heavy metals

* Value significantly different (p<0.05) from S1.

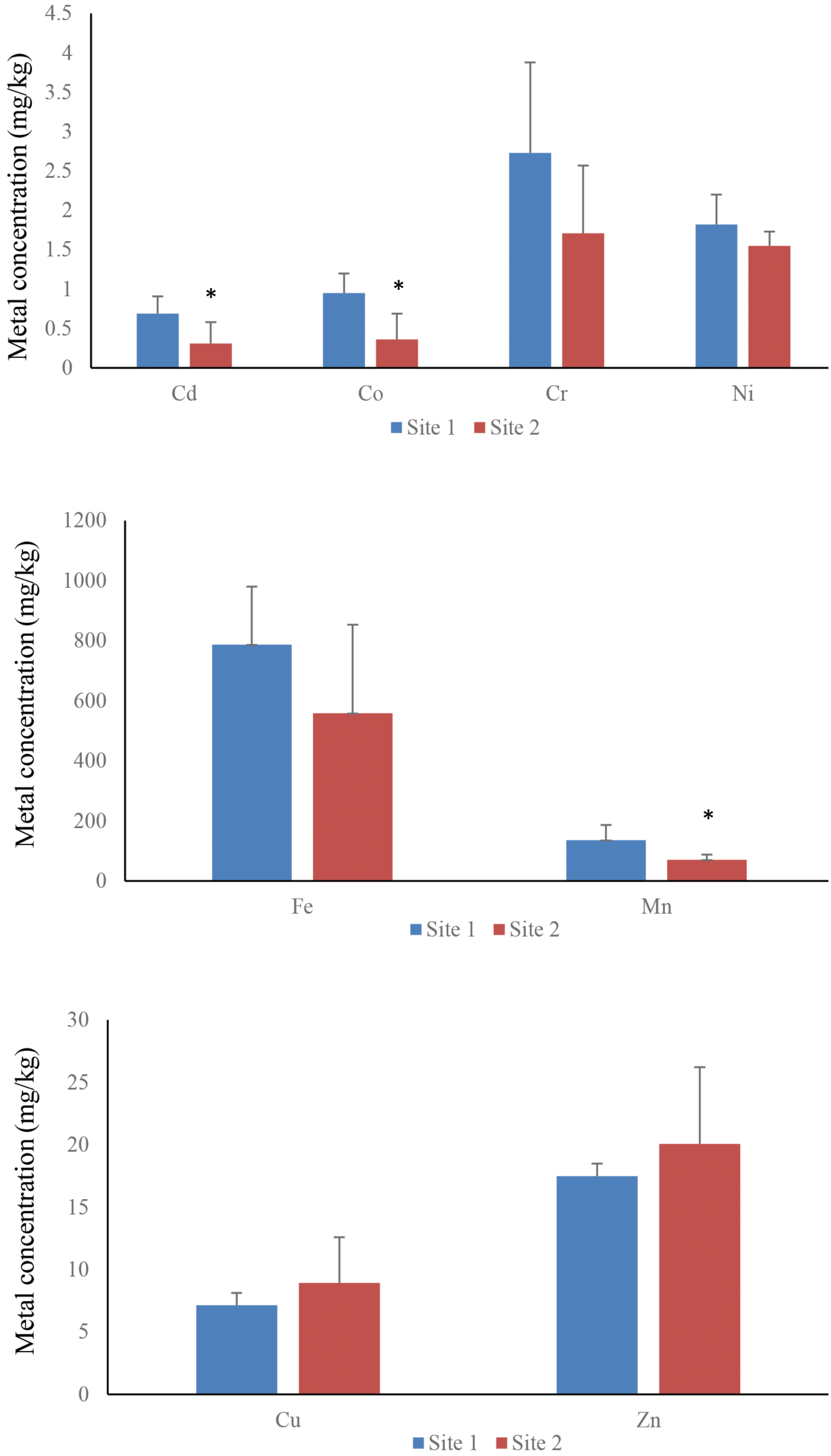

Fig. 3 Heavy metals contents in turf

* Value significantly different ($p<0.05$) from S1.

Table 3 Heavy metal content in soil and turf leaves compared to limit values set by FAO/WHO (2007)

Heavy metals	Soil (mg/kg)			Turf leaves (mg/kg)		
	Site 1	Site 2	FAO/WHO limits for soil	Site 1	Site 2	FAO/WHO limits for crops
Cu	20.24 ± 2.84	38.23 ± 5.84*	135-270	7.13 ± 0.88	8.92 ± 3.66	40
Zn	102.88 ± 3.23	110.94 ± 9.5	300-600	17.47 ± 1.56	20.05 ± 6.17	60
Mn	373.55 ± 19.69	534.20 ± 15.46*	-	136.38 ± 50.36	70.52 ± 17.89	500
Fe	22,333 ± 1,315	21,852 ± 1,233	50,000	786.8 ± 193.4	558.4 ± 295.03	450
Cd	2.37 ± 0.13	1.56 ± 0.18*	3-6	0.69 ± 0.22	0.31 ± 0.27	0.2
Cr	95.64 ± 6.79	65.73 ± 9.99*	150	2.73 ±1.15	1.71 ± 0.86	5.0
Ni	27.29 ± 1.31	25.94 ± 2.43	107	1.82 ± 0.38	1.55 ± 0.18	-
Co	14.25 ± 0.63	14.42 ± 0.7	-	0.95 ± 0.25	0.36 ± 0.33	-

Values are mean ± SEM (n = 5). *: Significantly different ($p<0.05$) from site 1.

Table 4 Transfer factor of heavy metals

Heavy metals	Site 1	Site 2
Cu	0.35	0.23
Zn	0.17	0.18
Mn	0.36	0.13
Fe	0.04	0.03
Cd	0.29	0.20
Cr	0.03	0.03
Ni	0.07	0.06
Co	0.07	0.02

Conclusion

The present work showed that long-term irrigation of the golf *Ocean* by TWW led to the accumulation of HM in the soil and turf leaves. The HM contents of the soil remained in line with international standards. It was not the same for turf leaves that showed Cd and Fe contents higher than the standards set by FAO/WHO for crops. At present, TWW of the city of Agadir are reused for the irrigation of golf courses and green spaces, which does not pose a direct risk to human or animal health. However, given the growing deficit in irrigation water in the Agadir region, it is not excluded to exploit TWW in agriculture in the future. Additional studies on the contamination of edible plants would make it possible to better assess the health risks incurred by the potential use of TWW from the city of Agadir in agriculture.

Acknowledgement We would like to thank Mr. Mohamed Zyati (RAMSA Engineer) who made available to us the heavy metal content of the treated wastewater.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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