Effect of polluted water on soil and plant contamination by heavy metals in El- Mahla El-Kobra, Egypt

Esawy Mahmoud[1] and **Adel Mohamed Ghoneim**[2, 3]

[1]Soil and Water Sciences Department, Faculty of Agriculture at Tanta, Tanta University, Egypt.

[2]Soil Science Department, College of Food and Agricultural Sciences, King Saud University, P. O. Box 2460, Riyadh 11451, Saudi Arabia.
[3]Agricultural Research Center, Field Crops Research Institute, Rice Research and Training Center, Sakha, 33717, Kafr El-Sheikh, Egypt
Corsspondance to: E. Mahmoud, E-mail: esawy.rezk@agr.tanta.edu.eg

Abstract

The discharge of untreated wastewater in drain Zefta and drain No.5 is becoming a problem for many farmers in El- Mahla El-Kobraarea, Egypt. The discharging water contains high levels of contaminants considered hazardous to the ecosystem. Some plants, soil, water, and sediment samples were collected from El- Mahla El-Kobra area to evaluate the contamination by heavy metals. The results showed that the heavy metals, pH, sodium adsorption ratio (SAR), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in the water of drain Zefta and drain No.5 exceeded permissible limits for irrigation. In rice and maize shoots grown in soils irrigated by contaminated water from Zefta drain and drain No.5, the bioaccumulation factors for Cd, Pb, Zn, Cu and Mn were higher than 1.0. The heavy metals content of irrigated soils from Zefta drain and drain No.5 exceeded the upper limit of background heavy metals. In this study, the mean contaminant factor values of the drain No.5 sediments revealed that Zn, Mn, Cu, Cd, Pb and Ni > 6, indicating very high contamination. The high bioaccumulation coefficients of *Cynodon dactylon, Phragmites australis* and *Typha domingensis* aquatic plants growing in Zefta drain. These species can be considered as hyperaccumulators for, decontamination of contaminated water.

Keywords: wastewater; bioaccumulation; contaminant factor; pollution; heavy metals, hyper accumulators; irrigation

Introduction

Contamination of soils by heavy metals such as Cd, Ni, Zn, Pb and Cu, has increased dramatically during the last few decades (Chibuike and Obiora 2014) due to mining, smelting, manufacturing, use of agricultural fertilizers, pesticides, municipal wastes, traffic emissions, and industrial effluent (Ha et al., 2009; Cherif et al., 2012; Morgan, 2013; Chibuike and Obiora 2014). Contamination of soils by heavy metals is now widespread (Al-Nagger et al., 2013). Dispersion of heavy metals in irrigated soils and plants growing result in contamination of food that may be hazardous to humans and animals (Mapanda et al., 2007; Jolly, Islam, and Akbar 2013). Heavy metals in effluents are poorly soluble in water, and cannot be degraded, these tend to accumulate in soils and remain available with subsequent accumulated in plants (Alam et al., 2003; Allsopp, Kenneth, and Christine 2004; Ghoneim et al., 2014). In addition, heavy metals persist in soil which then leaches down into the groundwater and may induce enhanced antioxidant enzymatic activities in plants or become adsorbed with solid soil particles (Iannelli et al., 2002). According to Roy and McDonald (2013) carrots grown in contaminated soils by Cd have the potential to cause toxicological problems in men, women, and young children, at which point, Cd uptake by carrot roots was about five times more than the regulatory limits for men, eight times more for women, and 12 times more for children. High levels of Cd in soil were identified as causing itai-itai disease in Toyama Prefecture, Japan, however, soil solution levels similarly high in Cd do not seem to cause health problems for people living in Shipham, England (Morgan, 2013). For the Cu-contaminated soils planted with tomato (*Solanum* *lycopersicum* L.) assayed, these values would range between 32.9 and 1696.5 mg kg^{-1}, depending on soil properties (Sacristán et al., 2015). Accumulation of toxic heavy metals in plant living cells results in various deficiencies, reduction of cell activities and inhibition of plant growth (Kabir et al., 2008; Farooqi et al., 2009).

Transfer of heavy metals from soils to plants is one of the key pathways for exposure of humans via the food chain. In order to assess risks to health associated with metals in soils, it is necessary to predict transfer of heavy metals from soil to tissues of plants for subsequent use in phytoremediation (Tu et al., 2002; Hough et al., 2003; Khan et al., 2008; Zhuang et al., 2009; Roy and McDonald, 2013; Cho et al., 2013; Ye et al., 2014). Heavy metal pollution is persistent, covert and irreversible (Wang et al., 2011). This kind of pollution not only degrades the quality of the food crops, atmosphere, water, but also threatens the health of human and animals (Nabulo et al., 2010; Dong et al., 2011). Excessive intake of the Pb to human body can damage the nervous, skeletal, endocrine, enzymatic, circulatory, and immune system (Zhang et al., 2012). The chronic effects of Cd consist of lung cancer, pulmonary adenocarcinomas, prostatic proliferative lesions, kidney dysfunction, bone fractures and hypertension (Żukowska and Biziuk, 2008; Brevik and Sauer, 2015).

Soils have been used to detect the deposition, accumulation, and distribution of heavy metals in different locations (Alirzayeva et al., 2006; Onder et al., 2007), but little quantitative information is available on the contamination of agricultural soils in El- Mahla El-Kobra, Egypt by heavy metals. To close this knowledge gap, this study investigated contamination of agricultural soil and plant with heavy metals in resident and industrial area in El- Mahla El-Kobra, Egypt.

Materials and methods

Site Description, Samples and Analysis

In El- Mahla El-Kobra (Fig. 1) is located at 30°34¯N Latitude, 30°45¯E Longitude, the dominant sources of heavy metal pollution are wastewater irrigation, manure and sediment applications for metallic ores. El- Mahla El-Kobra area is density populated (4.5 million/462683 km^2) and contains 183 industrial factories such as textile, food, oil, and other industries. The quantity of industrial and municipal wastewater is around 243500 m^3 day^{-1} (107500 m^3 day^{-1} of municipal sewage and 136000 m^3 day^{-1} of industrial wastewater), which discharge into Zefta drain (flow, 354240 m^3 day^{-1}) and drain No.5 (flow, 265248 m^3 day^{-1}) without treatment except 63627 m^3 day^{-1} of municipal wastewater can be treated in Dawakhlia plant.

Seventy represented soil samples (0–30 cm) in summer 2012 were collected from cultivated lands of El- Mahla El-Kobra, Egypt which are irrigated with drainage water from Zefta drain, drain No.5, and fifteen samples which are irrigated from Baher El Mlah canal (fresh water). The soil samples were air-dried and ground to pass through 2 mm screen for chemical analysis. The soils, pH was determined in saturated soil paste extract (Richards, 1954). Calcium and magnesium were determined titrimetrically using versenate (Jackson, 1973). Sodium was determined using flame photometer (Richards, 1954). Total carbonate was determined using the calcimeter as $CaCO_3$ % according to Loeppert and Suarez (1996). The total heavy metals (Cd, Pb, Zn, Fe, Mn, Cu, and Ni) were measured by the atomic absorption spectrophotometer after digestion the soil samples with concentrated mixtures of HNO_3 and $HClO_4$ acids (Page, 1982). Samples of rice and maize cultivated crops (age 65 days in summer 2012) that are grown in the studied soils, and other three aquatic plant species (*Cynodon dactylon*, *Phragmites australis* and *Typha domingensis*) which are grown in Zefta drain were also collected at different times. The plant samples were dried in oven at 75° C for 72 hours. The total heavy metals content in plant shoot were measured using the atomic absorption spectrophotometer after digestion the plant samples with concentrated H_2SO_4 and H_2O_2 (Chapman and Pratt, 1961).

Transfer of Heavy Metals

Bioconcentration factor (BF) of each metal in plants was calculated by dividing the total content in plant by the total content in soil (Brooks, 1998). In addition, seventeen water samples were collected from Zefta drain and drain No.5 at different times (March 2012 to March 2013) at about 20 cm below water surface and chemically analyzed for pH, EC, sodium adsorption ratio (SAR), biological oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals content (APHA, 2005). The bioaccumulation coefficients of each heavy metal in aquatic plants were calculated by dividing the total heavy metal content in aquatic plants by the concentration in water.

Contaminant factor (Cf) for soil is the ratio obtained by dividing the concentration of each heavy metal in the sediment by the background values (Håkanson, 1980).

$Cf = C_{\text{Heavy metal}}/C_{\text{Background}}$

According to Håkanson (1980): the values of $Cf < 1$ indicates low contamination; $1 < Cf < 3$ is moderate contamination; $3 < Cf < 6$ is considerable contamination; and $Cf > 6$ is very high contamination.

Results and discussion

Effect of contaminated water on plant and soil contamination

Heavy metals content were higher in rice and maize shoots grown in the soil around Zefta drain than the same crops in soil of drain No.5 (Fig. 2). This was due to the high total heavy metal contents in that soils (Table 1). The maize shoot contains more Fe, Cd, Mn and Pb than rice shoot, and this may be attributed to planting rice under the flooded conditions. Under the flooded conditions, Fe, Cd, Mn and Pb could be precipitate as FeS_2, CdS, MnS and PbS, respectively due to the reducing conditions. Heavy metals content in rice and maize shoots exceeded the defined limits reported by Kabata–Pendias and Pendias (1992) and above those acceptable for elemental composition of uncontaminated plant tissue. Alloway, (1990) reported that in angiosperms, uncontaminated plant tissue contains 0.64, 2.4, 160 and 14 mg kg^{-1} for Cd, Pb, Zn and Cu, respectively. It is clear from (Fig. 2 and Table 1) the higher concentrations of Cd in rice and maize shoots than other heavy metals compared with the maximum limits according to Kabata-Pendias and Pendias (1992). Li et al., (1994) found that plants absorb readily Cd more than other heavy metals and often reaches levels that are hazardous to human healthy before any stress symptoms appear. Chitdeshwari et al., (2002) reported that used of sewage water increased the uptake of Cd and Cr in *Amaranthus* crop. Phosphate fertilizers as sources for Cd used in fertilization of rice and maize plants in this study area. Phosphate fertilizers were even cases of 200 mg Cd kg^{-1} (Nziguheba and Smolders, 2008). The city of El- Mahla El-Kobra is densely populated and is the capital of the local textile industry. Large amounts of industrial and contaminated water are discharged directly without treatment into irrigation canals which often contain heavy metals that contributed to metals enrichment in soil (Fakayode and Onianwa 2002). In addition, rice and wheat ash fertilization is carried out in El- Mahla El-Kobra on a large scale (Abou-Sekkina et al., 2010). Application of ash to agricultural soils contributes significantly to the greater concentration of Cd in agricultural soil from El- Mahla El-Kobra. The higher concentration of Zn observed might be due to abrasion of tires, barks, and Zn-containing compounds, which are used in some manufactured goods, such as paints, cosmetics, automobile tires, and batteries (Imperato et al., 2003).

The range of pH, EC and heavy metal contents in soil samples which irrigated by water from Zefta drain, drain No.5 and Baher EL Mlah as compared with limit of background (Table 3). The soils irrigated by contaminant water from Zefta drain and drain No.5 induces increase of soil pH with comparison to soils irrigated from Baher EL Mlah (fresh water). Similar results were noticed by (Gupta et al., 2010; Saffari and Saffari 2013) they reported that after irrigation with sewage water, pH increased significantly. The reason for increasing soil pH may be attributed to high pH values in Zefta drain and drain No.5 (Table 3). The soils irrigated by contaminated water from Zefta drain and drain No.5 affect the TDS (Table 3). Indeed, in comparison to soils which irrigated from Baher EL Mlah, TDS value is greater compared with Zefta drain and drain No.5. These results were in agreement with (Kiziloglu et al., 2008; Rana et al., 2010; Mollahoseini, 2013; Khaskhoussy et al., 2013) they reported that irrigating with sewage water, increased soil salinity, exchangeable Na, K, Ca, Mg and available P. In general, the concentrations of heavy metals in soils irrigated from Zefta drain and drain No.5 was exceeded the upper limit of background of total heavy metals (Chen et al., 1992). Contents of Mn, Cd and Ni in soils at Zefta drain were higher than these in soils at drain No.5 which is due to high concentration of heavy metals in Zefta drain water (Table 3). The level of heavy metals of soils irrigated from Zefta drain and drain No.5 were higher than those of the around soils of Baher EL Mlah canal. Similar results were reported by Chen et al., (1992) who found that high levels of heavy metals in soils, which are irrigated from polluted industrial wastewater. These results coincided with El-Gendi et al., (1997) who indicated that irrigating sandy soil in the Abou- Rawash area with drainage water increased total Cu, Zn and Fe, which reached 125, 170 and 5 times that of the virgin soil in the same area. Both Cd and Pb levels in soils measured during this study were higher than those reported by (Nassef et al., 2006; Suciu et al., 2008). These differences might be related to different anthropogenic activities and concentrations of urbanization at each site.

Bioconcentration factors (BF)

The BF values in the rice and maize shoots are presented in (Table 2). In rice and maize grown in soils irrigated by water from Zefta drain and drain No.5, the BF value for Cd, Pb, Zn, Cu and Mn were higher than 1.0. This indicates that concentrations of Cd, Pb, Cu and Mn were high bioconcentration in studied plants. Fe was an exception because, its BF value was lower than one, indicating low accumulation in studied plants. The BF value for Zn and Cu of rice shoots were higher than maize shoots grown in the same soils irrigated by water from Zefta drain and drain No.5. These concentrations were attributed to using $ZnSO_4$ as Zn fertilizer in rice cultivation. Zhao et al., (2010) reported that BF values tend to decrease with increasing soil heavy metal concentration, and values lower than 0.20 are considered normal when plants are grown on polluted soils (McGrath and Zhao, 2003). The differences in the obtained BF values are depending on the heavy metals and the plant species. The higher BF value for Cd indicated that Cd accumulated in rice and maize shoots. These differences might be related to heavy metal-binding capacity to roots (Singh and Agrawal, 2007; Toth et al., 2009), available metals, interactions between of physico-chemical parameters and the plant species grown in that soils (Bose and Bhattacharyya, 2008).

Quality of drainage water

Concentrations of BOD and COD ranged from 442 and 978 mg L^{-1} to 632 and 2445 mg L^{-1} in Zefta drain, while the BOD and COD value ranged from 540 and 882 mg L^{-1} to 723 and 2301 mg L^{-1} in drain No.5, respectively (Table 3). This water would be classified as high strength (Metcalf and Eddy, 2003). These results were in agreement with (Pescond, 1992) who reported that chemical properties of water include total dissolved solids (TDS), BOD and COD showed higher values in untreated sewage water compared to groundwater. The BOD/COD ratio in Zefta drain and drain No.5 ranged from 0.25 and 0.31 to 0.45 and 0.61, respectively. The wastewater with a BOD/COD ratio below 0.50 contains some toxic components such as dyes and heavy metals (Linsley et al., 1992).

The average of TDS was 1016 mg L^{-1} in drain No.5, 1130 mg L^{-1} in Zefta drain and 334 mg L^{-1} in Baher El Mlah canal. The SAR in water of drain Zefta and drain No.5 were above 12, which it considered potential for aggregate slaking, soil swelling, and clay dispersion, and thus reduction in hydraulic conductivity (Mace and Amrhein, 2001). The heavy metals in the two drains were higher than in water of Baher El Mlah canal which could be attributed to discharge of industrial wastewater into the two drains without treatment. The level of heavy metals exceeded the criteria limits for irrigation water (FAO, 2010; E.C.S, 48/1992). Similar results were reported by Matloub and Mehana (1998) showed that sewage has often high values of temperature, pH, hardness, alkalinity, COD, TDS, NO_3^-, NO_2^{--}, Na, K, Ca and Mg (Chitdeshwari et al., 2002) reported that increased levels of sewage water increased the uptake of Cd and Cr in *Amaranthus* crop.

Heavy metal concentrations in sediments

The high heavy metal concentrations in sediments of drain No.5 (Table 4) would be attributed to higher pH in water which can form ions of insoluble precipitates. Heavy metals may be also bound to humic substance in sediments and settling in the drain (Lasheen et al., 1981). The measured concentrations of heavy metals are higher than US EPA toxicity value (US EPA, 1999). Similar finding were reported by Thuy et al., (2007) they found that heavy metals in sediments of five canals received untreated industrial wastewater were exceeded the US EPA toxicity level. The partitioning of heavy metals between sediment and water can be expressed as distribution coefficients (Kd) value (L kg^{-1}). Kd values of sediment samples were the highest for Zn, Cd, and Mn, and lowest for Pb, Cu and Ni. The higher Kd value indicates that the sorption of heavy metals by sediments was strong (Salomons and Forstner, 1980). Kd is found to be sensitive to low pH and redox conditions (Stephenson et al., 1995). Heavy metals may be released from settling sediments under hypoxic or acidic conditions (Stephenson et al., 1995). Sediments are both carriers and potential sources of contaminants in aquatic system and these materials also affect groundwater quality and agricultural products when disposed on land. In this study, the mean Cf values of the drain No.5 sediments revealed that Zn, Mn, Cu, Cd, Pb and Ni > 6, indicating very high contamination due to the direct discharge of wastewater from the resident and industrial area.

Bioaccumulation coefficients of aquatic plants

The bioaccumulation of heavy metals in plants of *Cynodon, dactylon, Phragmites australis* and *Typha domingensis* grown in Zefta drain are shown in (Fig. 3). The bioaccumulation coefficients of metals in *Cynodon dactylon* were higher than in *Phragmites australis* and *Typha domingensis*. These plant species can be considered as hyperaccumulators, and used for decontamination of contaminated water. The use of plants for decontamination of polluted waters had been described as rhizofiltration (Brooks, 1998). The three species would be useful for phytoremediation of contaminated water in a particular area. Bonanno, (2013) showed that *Phragmites australis* and *Typha domingensis* species may be used as biomonitors of trace element contamination in sediment. Overall, *T. domingensis* and *P. australis* showed a greater capacity of bioaccumulation as well as a greater efficiency of element removal than *A. donax*. In particular, *T. domingensis* and *P. australis* may be used for Hg phytostabilization, the former acted also as a hyperaccumulator for trace elements phytoextraction and phytostabilization. In contaminated wetlands, the presence of *T. domingensis* and *P. australis* may increase the general retention of trace elements. Wafaa et al., (2010) demonstrated that *Phragmites australis* and *Tamarix aphllya* species are significant as vegetation filter and for cleaning the soils from contamination with heavy metals by phytoextraction. Antioxidant thiolic compounds were probably involved in the mechanisms used by *P. australis* to alleviate metal toxicity. As *P.australis* is considered suitable for phytostabilising metal-contaminated sediments, understanding its tolerance mechanisms to toxic metals is important to optimize the conditions for applying this plant in phytoremediation (Rocha et al., 2014).

CONCLUSION

Delta drains often receive high amounts of organic and inorganic pollutants from industrial, domestic wastewater as well as diffuse agricultural drainage. High priority should be given to Zefta drain and drain No.5 sites which receive high loads of pollutants. This was confirmed by the lower water quality and polluted soils with heavy metals in the El- Mahla El-Kobra area. Industrial and municipal wastewater sources in El- Mahla El-Kobra area must be treated before it discharge in Zefta drain and drain No.5. Using heavy metals-contaminated agricultural soils in cultivation of rice and maize crops for human consumption may result in health hazards.

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Table 1. Total concentrations of heavy metals in soils irrigated by contaminated water from Zefta drain, drain No.5 and Baher EL Mlah canal.

Parameters	Unit	Soils around Drain No. 5	Zefta drain	Baher EL Mlah	Upper limit of total heavy metals in soils (Chen et al.,1992)
pH	-	7.80- 8.30	7.80 - 8.50	7.30	-
$CaCO_3$	%	4.10-8.20	3.28 - 5.74	4.10	-
Fe	mg kg^{-1}	1226- 4989	1790- 4757	933	-
Zn	mg kg^{-1}	102-187	184 - 449	54	120
Mn	mg kg^{-1}	341- 800	172 - 853	264	-
Cu	mg kg^{-1}	82 - 167	123 - 386	60	35
Cd	mg kg^{-1}	13- 28	21 - 33	11	3
Pb	mg kg^{-1}	48- 92	55 - 80	53	120
Ni	mg kg^{-1}	55 - 133	104- 164	31	60

Table 2. Bioconcentration factors of heavy metals in maize and rice shoots grown in soils irrigated by wastewater from Zefta drain, drain No.5 and limits of heavy metals.

Elements	Drain No. 5		Zefta drain		
	Rice	Maize	Rice	Maize	Limits of heavy metals * mg kg^{-1}
Fe	0.29	0.35	0.54	0.34	-
Mn	3.40	2.97	1.71	1.51	300–500
Cu	0.59	1.54	1.75	1.83	20–100
Zn	2.82	1.71	1.44	1.32	100–400
Pb	6.73	6.83	5.26	5.66	30–300
Cd	6.14	6.45	6.55	2.26	5–30

* Kabata-Pendias and Pendias (1992)

Table 3. The chemical analysis of water collected from Zefta drain, drain No.5 and Baher El Mlah canal.

Parameters	Units	Drain No. 5	Zefta drain	Baher EL Mlah	Water criteria for irrigation water
pH	-	9.80	12.2	7.20	6.5-8.4
TDS	mg l^{-1}	1016	1130	334	2000
SAR	-	17.3	18.2	6.00	6-12
BOD	mg l^{-1}	540-723	442-632	0.00	40 *
COD	mg l^{-1}	882-2301	978-2445	0.00	60 *
Fe	mg l^{-1}	0.09	0.56	0.01	5.0
Zn	mg l^{-1}	0.02	0.037	0.00	2.00
Mn	mg l^{-1}	0.68	2.91	0.03	0.20
Cu	mg l^{-1}	0.15	0.28	0.12	0.20
Cd	mg l^{-1}	0.03	0.07	0.001	0.01
Pb	mg l^{-1}	1.05	0.18	0.05	5.00
Ni	mg l^{-1}	0.12	0.31	0.02	0.20

* Egyptian chemical standards (48/1992)

Table 4. Average of heavy metal concentrations, contaminant factor and distribution coefficients (Kd) in sediments of drain No.5 compared with toxicological reference value (US

EPA, 1999).

Element	Conc. ($mg\ kg^{-1}$) Mean ± SD	Et	Cf	Kd ($L\ kg^{-1}$)
Zn	647.5 ± 36.7	110	6.25	32375.0
Mn	2125.0 ± 74.3	-	12.7	3125.0
Cu	425.0 ± 12.4	16	4.25	2833.3
Cd	97.5 ± 4.6	0.6	9.55	3250.0
Pb	145.0 ± 4.5	31	4.80	138.10
Ni	195.0 ± 9.8	-	7.33	1625.0

Et: US EPA Toxicity reference value; Cf: Contaminant factor; Kd: Distribution coefficients ($L\ kg^{-1}$)

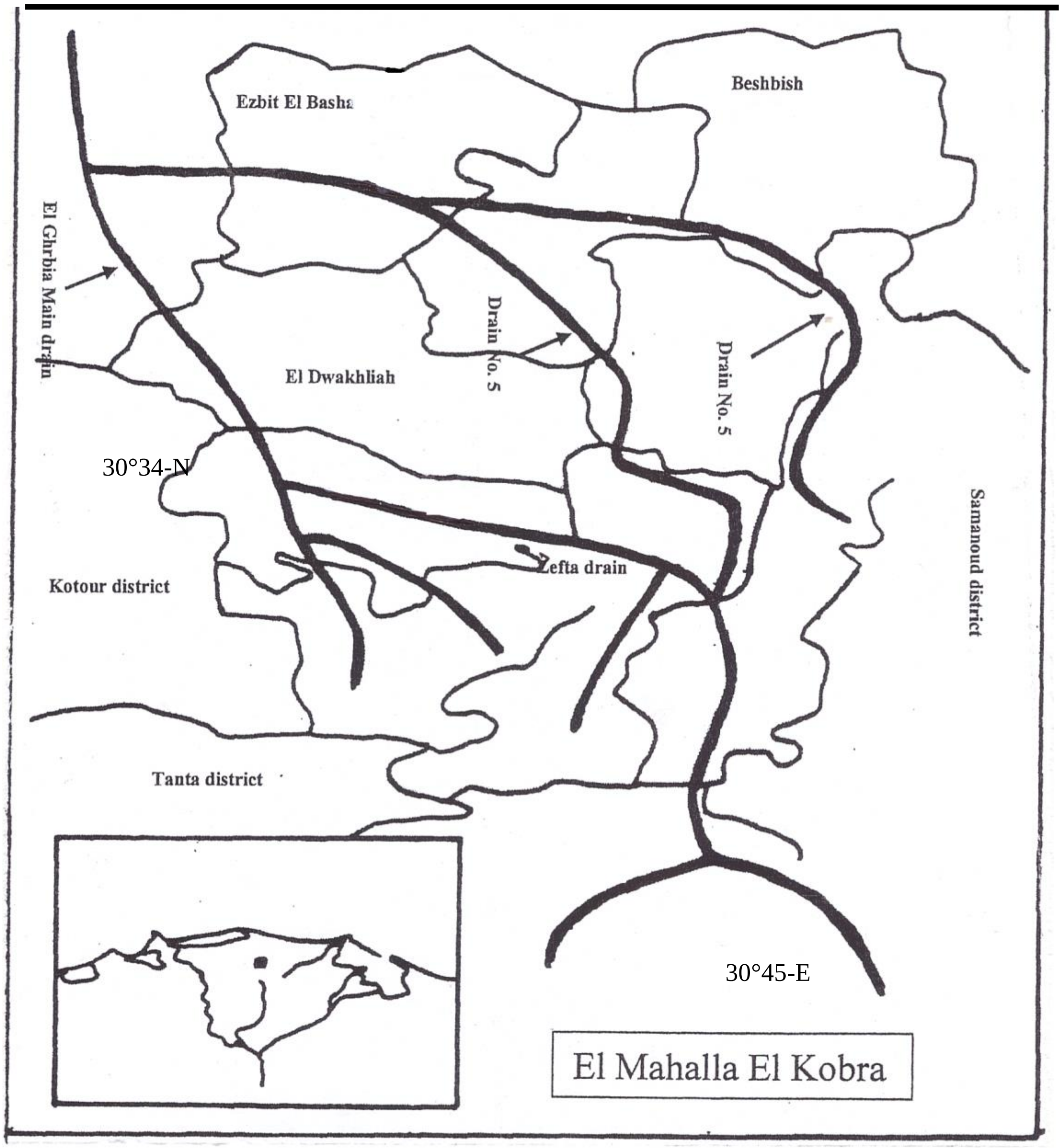

Figure 1. Location of study area.

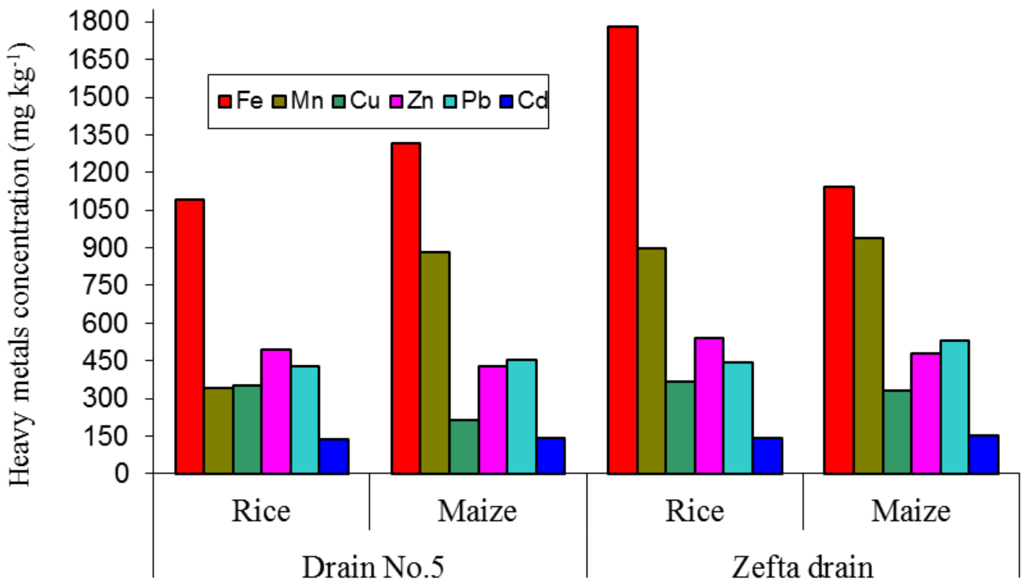

Figure 2. Concentration of heavy metals in maize and rice shoots grown in soils irrigated from Zefta drain and drain No.5.

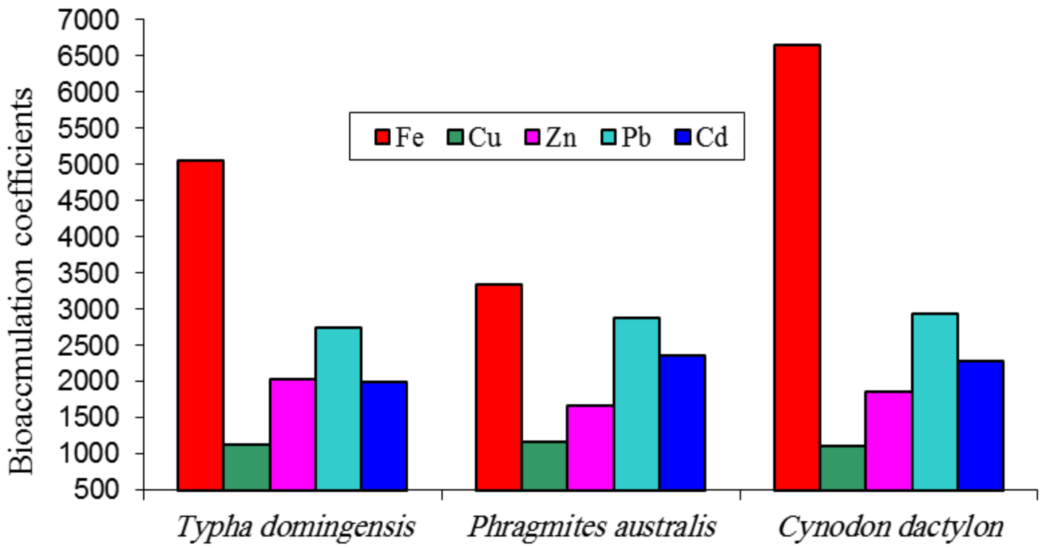

Figure 3. Bioaccumulation coefficients of heavy metals in *Typha domingensis*, *Phragmites australis* and *Cynodon dactylon* plants grown in Zefta drain.