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Research Article
Biomonitring of Drainage Water Quality by *Eichhornia crassipes* (Mart.) Solms in Bahr El-Baqar Drain, Egypt

Ghada Abd Allah El-Sherbeny and Samah Mahmoud Ramadan

Department of Botany, Faculty of Science, Mansoura University, Egypt

Abstract

Background and Objective: Egypt is considered as an arid country and drainage water reuse is used on a broad range. The government is seeking to develop a monitoring program aiming at evaluating the drainage water quality. **Methodology:** Biomonitoring is considered as most accurate tool in the assessment of water quality and most expressive for the status of the environment. Bahr El-Baqar drain from the most polluted drains in Egypt. **Results:** Results showed a pronounced spatial variation in metal concentrations along Bahr El-Baqar drain gradient in sequences of Ni>Pb>Co>Fe>Zn>Mn>Cu>Cd. The mean values of Zn, Fe, Mn, Cu, Cd, Co, Ni and Pb concentrations in water were relatively high in downstream section compared to the other sections of the drain as follow, 0.45, 0.6, 0.22, 0.2, 0.06, 0.66, 2.61 and 0.80 ppm, respectively. Meanwhile, the lowest mean values of these metals were observed at upstream section of drain (0.15, 0.33, 0.09, 0.07, 0.03, 1.14 and 0.34 ppm, respectively) while the lowest mean values for Co (0.45 ppm) observed at the middle section of drain. According to Food and Agriculture Organization, Cd, Co and Ni mean concentration were out permissible levels at all drain sections. The heavy metals concentrations were higher in plant root than that found in the plant shoot. The Ni concentrations in *E. crassipes* was within critical ranges at all drain sections while, Mn was critical ranges at middle and downstream sections. Bioaccumulation factor (BAF) values of the metals showed spatial variation and the plant root exhibited higher BAF than the plant shoot. **Conclusion:** In conclusion, the results indicated the ability of the *E. crassipes* to absorb and accumulate high level of heavy metals which qualified the plant to be a good biomonitor for drainage water quality. In addition, using this aquatic plant is succeeded in biomintoring process and reflect the heavy metals status in the drain.

Key words: Bioaccumulation factor, biomonitring, heavy metals, regression analysis

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Corresponding Author: Ghada Abd Allah El-Sherbeny, Department of Botany, Faculty of Science, Mansoura University, Egypt

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Water is the lifeline where it is necessary for survival of all living creatures. The expansion of industrialization and releasing of numerous chemical compounds has led to great damage in the quality of the environment (Chakravarty *et al*., 2010). To overcome the challenges of our future needs from water, water quality management and control of water pollution are a must.

From the major burdens facing us, increasing population and their food needs that lead to increase the agricultural areas and intern require plenty of water. Egypt is considered as an arid country where, Nile river; ground water and seldom rainfall are the main conventional water resources (Abdel-Shafy and Aly, 2002; Mostafa *et al*., 2005). In addition to these resources there are some other non-conventional resources as, agricultural drainage water and treated wastewater. Drainage water reuse is used on a broad range in Egypt. This is considered as a cheaper option because its relatively less-infrastructure requirements to be constructed (Mostafa *et al*., 2005).

One of the main targets of Ministry of Water Resources and Irrigation is to develop a monitoring program aiming at evaluating the drainage water quality in Egypt that provide the decisions makers about drainage water reuse possibilities. Since then, extensive attention has been given to water quality monitoring program (Awadallah *et al*., 2011). Biological monitoring (Biomonitoring) is considered as an essential tool in the management of water resources. It relies on the response of biota to assess variations in their environment, especially variations from anthropogenic activities (Kennish, 1992). The pollutants biomonitoring process depends on using accumulator species (plants or animals) which have the capacity to accumulate relatively large quantities of pollutants, without exhibiting great harmful impacts on it (Doust *et al*., 1994). The biomonitoring may be achieved by native organisms and this called passive biomonitoring or by introducing organisms which called active biomonitoring (Chaphekar, 1991). Aquatic plants with their ability of heavy metal accumulation have received a wide concern (Prasad and Freitas, 2003).

Bahr El-Baqar drain from the most polluted drains in Egypt; it pours into Manzala lake which is an important source of fisheries (Mohamed, 2001). Furthermore, in many areas, the nearby fields using the water of the drain in irrigation and in the fish farming. Ali *et al*. (1993) and Abdel-Azeem *et al*. (2007) studied the effect of using drainage water for irrigation on the soil heavy metals content in south Port-Said. The effects on lake Manzala water and living organisms caused by Bahr El-Baqar drain water has been also studied (Ezzat, 1989; Hamed *et al*., 2013). This study aimed to assess and provide reliable information about the water quality status of Bahr El-Baqar drain using aquatic plants (*Eichhornia crassipes*).

MATERIALS AND METHODS

Study area: The study area is located in the Northern part of Egypt, where Bahr El-Baqar region is situated between 32°05′ to 32°16′ longitude and 30°56′ to 31°07′ latitude (Fig. 1). The area is an arid region, which subjected to different practices, owing to an extensive irrigation system (Omran and El Razek, 2012). Bahr El-Baqar drain system consists of a main drain that starts near the city of Zagazig where it collects the effluents from two secondary drains: Bilbeis drain and the Qalubeya drain. From Zagazig city Bahr El-Baqar drain transports water for about 100 km to the Ginka subbasin in the Southeast sector of lake Manzala which is located on the North-eastern edge of the Nile Delta region (Stahl *et al*., 2009).

Sampling and analysis: Surface water samples and *Eichhornia crassipes* plants were sampled during summer 2012 from 31 sites along Bahr El-Baqar drain representing all parts of the drain as follows: Upstream (1-10), middle stream (11-22) and downstream (23-31). Water samples were acidified immediately in the field with nitric acid for heavy metals determination. *Eichhornia crassipes* was chosen for this study where it was found in all studied sites. Immediately after collection of plant samples, the plant parts (shoots and roots) of each sample were handily cleaned and washed, first with tap water then by distilled water. The samples were dried at 60°C till constant dry weight. The dried samples were ground into fine powder and stored in a tightly closed paper bag until metals investigations. About 0.1 g of each dried powder was digested by using concentrated HNO_3 and heated gently until the solution turned quite clear. The clear samples were made up to a known volume using distilled water (Allens, 1989). Concentrations of zinc, iron, manganese, copper, cadmium, cobalt, nickel and lead in water and plant samples were estimated by a flame atomic absorption spectrophotometer (A Perkin-Elmer, Model 2380.USA).

Statistical analysis: BAF = C in plant tissue/C in water, where C is the metal concentrations (Wilson and Pyatt, 2007).

Simple linear regression analysis used to evaluate a linear relationship between the metal concentration in the plant shoot ($Metal_s$), plant root ($Metal_r$) and in water ($Metal_w$).

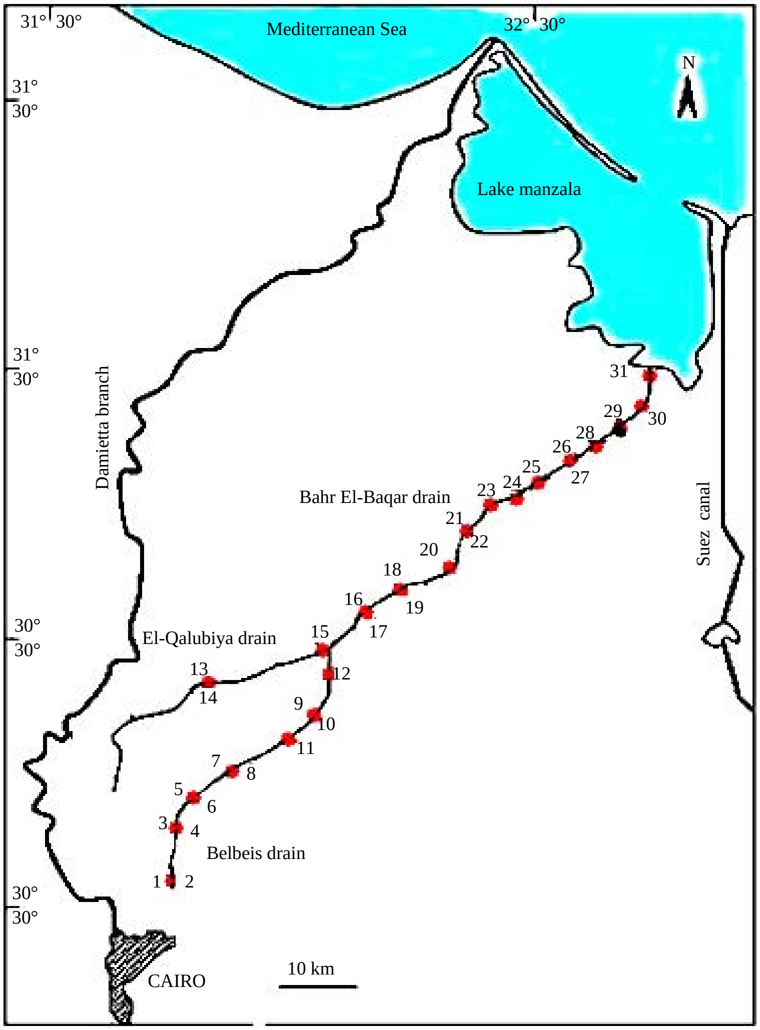

Fig. 1: Location map showing the studied sites along Bahr El-Baqar drain, study sites: El Kalag (1, 2), Seriakous (3, 4), Abu-Za'bal (5, 6), Az Zawamil (7, 8), Bilbeis (9, 10), Khess (11), Saft Bilbeis (12), Lamol (13,14), Saft Qalubeya (15), Kafr Awlad Wafi (16, 17), Fakous (18,19), Saaud (20), Bahr El-Baqar (21, 22), Before Shader Azam (23, 24, 25), After Shader Azam (26, 27, 28), Estuary of drain (Abeed village 29, 30, 31)

RESULTS

Heavy metal concentrations in water samples at spatial gradient: The results obtained indicated a pronounced spatial variation in metal concentrations along Bahr El-Baqar drain gradient Table 1. Heavy metal concentrations in water samples decreased in the sequences of Ni>Pb>Co>Fe >Zn>Mn>Cu>Cd. The mean values of Zn, Fe, Mn, Cu, Cd, Co, Ni and Pb concentrations in water were relatively high in downstream section compared to the other sections of the drain as follow, 0.45, 0.6, 0.22, 0.2, 0.06, 0.66, 2.61 and 0.80 ppm, respectively. Meanwhile, the lowest mean values of these metals were observed at upstream section of drain

Table 1: Mean heavy metals concentrations along Bahr El-Baqar drain gradient compared with the MPL of FAO

	Mean water concentrations (ppm)			
Metals	Upstream section	Middle stream section	Downstream section	MPL
Zn	0.15	0.26	0.45	2.00
Fe	0.33	0.37	0.60	5.00
Mn	0.09	0.12	0.20	0.20
Cu	0.07	0.07	0.20	0.20
Cd	0.03*	0.04*	0.06*	0.01
Co	0.45*	0.44*	0.66*	0.05
Ni	1.14*	2.67*	2.61*	0.20
Pb	0.34	0.51	0.80	5.00

MPL: Maximum permissible level of heavy metals in waste waters to be used as irrigation water, FAO: Food and agriculture organization, *Means within non permissible level

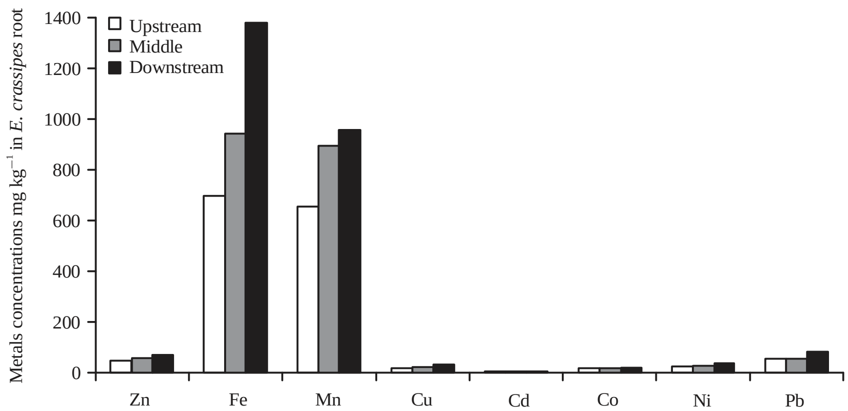

Fig. 2: Heavy metals concentrations in *Eichhornia crassipes* root along Bahr El-Baqar drain gradient

Table 2: Means of heavy metal contents and toxicity status in *Eichhornia crassipes* along Bahr El-Baqar drain gradient

	Mean metal concentrations in shoot of *Eichhornia crassipes* (mg kg^{-1})				
Metals	Upstream section	Middle stream section	Downstream section	Normal ranges in plants (mg kg^{-1})	Critical ranges in plants (mg kg^{-1})
Zn	26.5	37.6	48.7	27-150	100-400
Fe	363.4	563.2	842.8	-	-
Mn	287.9	428.0*	556.3*	30-300	400-1000
Cu	7.8	12.3	19.5	5-30	20-100
Cd	1.3	2.0	2.9	0.05-0.2	5-30
Co	5.3	6.4	13.5	0.02-1	15-50
Ni	15.2*	14.2*	19.7*	0.1-5	10-100
Pb	14.6	13.8	20.1	5-10	30-300

Normal and critical ranges in plants according to Kabata-Pendias (2011), *Mean the metal concentration in the critical range

(0.15, 0.33, 0.09, 0.07, 0.03, 1.14 and 0.34 ppm, respectively) while the lowest mean values for Co (0.45 ppm) observed at the middle section of drain. According to Food and Agriculture Organization (FAO), Cd, Co and Ni mean concentration in upstream, middle and downstream were out permissible levels.

Heavy metal analysis of selected plant for pollution monitoring: This topic includes assessment of eight heavy metals (Zn, Fe, Mn, Cu, Cd, Co, Ni and Pb) and evaluating the toxicity status in tissues of the monitor plant (*E. crassipes*). The results in Table 2 and Fig. 2 revealed that the concentrations of heavy metals were higher in plant root than that found in the plant shoot (aerial parts). It is noticed that shoot and root of water hyacinth growing at downstream section had the highest mean values of Zn, Fe, Mn, Cu, Cd, Co, Ni and Pb along the drain gradient. The Zn ion concentrations in shoot ranged from 26.5 mg kg^{-1} dry weight at upstream section to 48.7 mg kg^{-1} dry weight at downstream section. While, concentrations of Zn ion in plant root, varied from 48.3 mg kg^{-1} dry weight at upstream section to 72.6 mg kg^{-1} dry weight at downstream section of drain.

The Fe is the most highly accumulated metal by water hyacinth where, it's concentrations in shoot ranged from 363.4 mg kg^{-1} dry weight at upstream section to 842.8 mg kg^{-1} dry weight at downstream section. Meanwhile, Fe ion concentrations in plant root varied from 700 mg kg^{-1} dry weight at upstream section to 1379.3 mg kg^{-1} dry weight at downstream section of drain. The Mn ion concentrations in shoot ranged from 287.9 mg kg^{-1} dry weight at upstream section to 556.3 mg kg^{-1} dry weight at downstream section while concentrations of Mn ion in plant root varied from 654.4 mg kg^{-1} dry weight at upstream section to 958.4 mg kg^{-1} dry weight at downstream section of drain. As regards Cu concentrations, it is noticed that, the lowest concentrations of Cu ion (7.8 mg kg^{-1} dry weight) in shoot observed at upstream section while the highest concentrations (19.5 mg kg^{-1} dry weight) observed at downstream section. Concentrations of Cu ion in plant root varied from 15.6 mg kg^{-1} dry weight at upstream section to 33.9 mg kg^{-1} dry weight at downstream section of drain.

The Cd is the lowest metal accumulated by water hyacinth. Its concentrations in shoot ranged from 1.3 mg kg^{-1} dry weight at upstream section to 2.9 mg kg^{-1} dry weight at

Table 3: Bioaccumulation factor of heavy metals in root and shoot of *Eichhornia crassipes* along Bahr El-Baqar drain gradient

		Plant organs	
Elements	Sections	Roots	Shoots
Zn	Upstream	497.0	291.4
	Middle	380.8	221.5
	Downstream	170.6	114.4
Fe	Upstream	2070.6	1049.4
	Middle	2642.5	1549.1
	Downstream	2445.7	1474.8
Mn	Upstream	7006.0	3101.1
	Middle	8061.1	3901.4
	Downstream	4361.7	2609.9
Cu	Upstream	373.2	187.6
	Middle	483.3	229.6
	Downstream	196.1	112.2
Cd	Upstream	69.7	46.2
	Middle	78.8	56.0
	Downstream	72.1	53.0
Co	Upstream	45.3	14.7
	Middle	52.5	19.7
	Downstream	35.9	20.9
Ni	Upstream	20.75	14.74
	Middle	12.1	6.2
	Downstream	13.6	7.5
Pb	Upstream	193.8	49.0
	Middle	120.7	29.8
	Downstream	94.6	24.6

downstream section. Concentrations of Cd ion in plant root varied from 1.9 mg kg^{-1} dry weight at upstream section to 3.9 mg kg^{-1} dry weight at downstream section of drain. The maximum Co concentrations (13.5 mg kg^{-1} dry weight) in the shoot were attained at downstream section while the minimum concentrations observed at upstream section (5.3 mg kg^{-1} dry weight). Co concentrations in root ranged from 15.5-13.5 mg kg^{-1} dry weight Ni ion concentrations in shoot exhibited the highest mean value (19.7 mg kg^{-1} dry weight) at the downstream section of drain while the lowest mean value (15.2 mg kg^{-1} dry weight) in shoot observed at upstream section of drain. Concentrations of Ni in root ranged from 23.7 mg kg^{-1} dry weight at upstream to 35.7 mg kg^{-1} dry weight at downstream section.

Pb ion concentrations in plant shoot ranged from 14.6 mg kg^{-1} dry weight at upstream section to 20.1 mg kg^{-1} dry weight at downstream section. Concerning the concentrations of Pb ion in plant root, concentrations varied from 57.2 mg kg^{-1} dry weight at upstream section to 77.1 mg kg^{-1} dry weight at downstream section of drain.

Regarding the toxicity status of the biomonitor plant, by comparing the heavy metals concentrations in *E. crassipes* with the standard normal and critical ranges according to Kabata-Pendias (2011), Ni was within critical ranges at the upstream section, whereas Mn was within critical ranges in the middle and downstream (Table 2).

Bioaccumulation factor (BAF): Table 3 revealed that, bioaccumulation factor (BAF) values of the metals showed spatial variation and the plant root exhibited higher BAF than the plant shoot. The bioaccumulation factor of Zn ion in plant root varied from 170.6 at downstream section of drain to 497.0 at upstream section, whereas BAF of Zn ion in plant shoot varied from 114.4 at downstream to 291.4 at upstream section. On the other side, BAF of Fe ion in water hyacinth root ranged from 2070.6 at upstream section to 2642.5 at middle section. Meanwhile the highest BAF of Fe ion in plant shoot was 1549.1 recorded at middle section and the lowest value was 1049.4 recorded at upstream section. As regards BAF of Mn ion in the plant root, it ranged from 4361.7 at downstream to 7006 at upstream section, but the BAF of Mn ion in shoot recorded the maximum value of 3901.4 at middle section and the lowest value of 2609.9 at downstream section.

On the other hand, the BAF of Cu in plant root fluctuated from 196.1 at downstream section to 483.3 at the middlestream section meanwhile, BAF of Cu in plant shoot ranged from 112.2 at the downstream section to 229.6 at the middle section. Again, the BAF of Cd ion in plant root varied from 69.7 at the upstream section to 78.8 at the middle section; whereas, BAF of Cd recorded the highest value (56.0) at site middle section and the lowest value (46.2) at upstream section. On the other hand, the BAF of Co ion ranged from 35.9 at downstream to 52.5 at middle section, but the BAF of Co ion in plant shoot ranged from 14.7 at upstream section to 20.9 at downstream section.

The BAF of Ni ion in plant root ranged from 12.1 at middle section to 207.5 at upstream section while, BAF of Ni ion in *E. crassipes* shoot, it recorded the highest value of 14.74 at upstream section and the lowest value of 6.2 at middle section. Concerning BAF of Pb ion in plant root, it exhibited the highest value of 193.8 at upstream section and the lowest value of 94.6 at downstream where, BAF of Pb ion in *E. crassipes* in shoot varied from 24.6 at downstream to 49 at upstream section.

Regression relationships between heavy metal concentrations: The relationship between the heavy metal concentrations in *E. crassipes* organs (shoot and root) and in water were evaluated by simple linear regression analysis. Where we could predict the metal concentrations in water (explanatory variables) by estimating metal concentrations in plant organs (response variable).

The Zn_w concentrations in water (Fig. 3a) showed a very high significant correlation ($r = 0.804$, $p \leq 0.001$) with Zn_s in the plant shoot ($Zn_s = 47.354\ Zn_w + 24.372$) and high significant positive correlated ($r = 0.772$ at $p \leq 0.001$) with Zn_r in plant

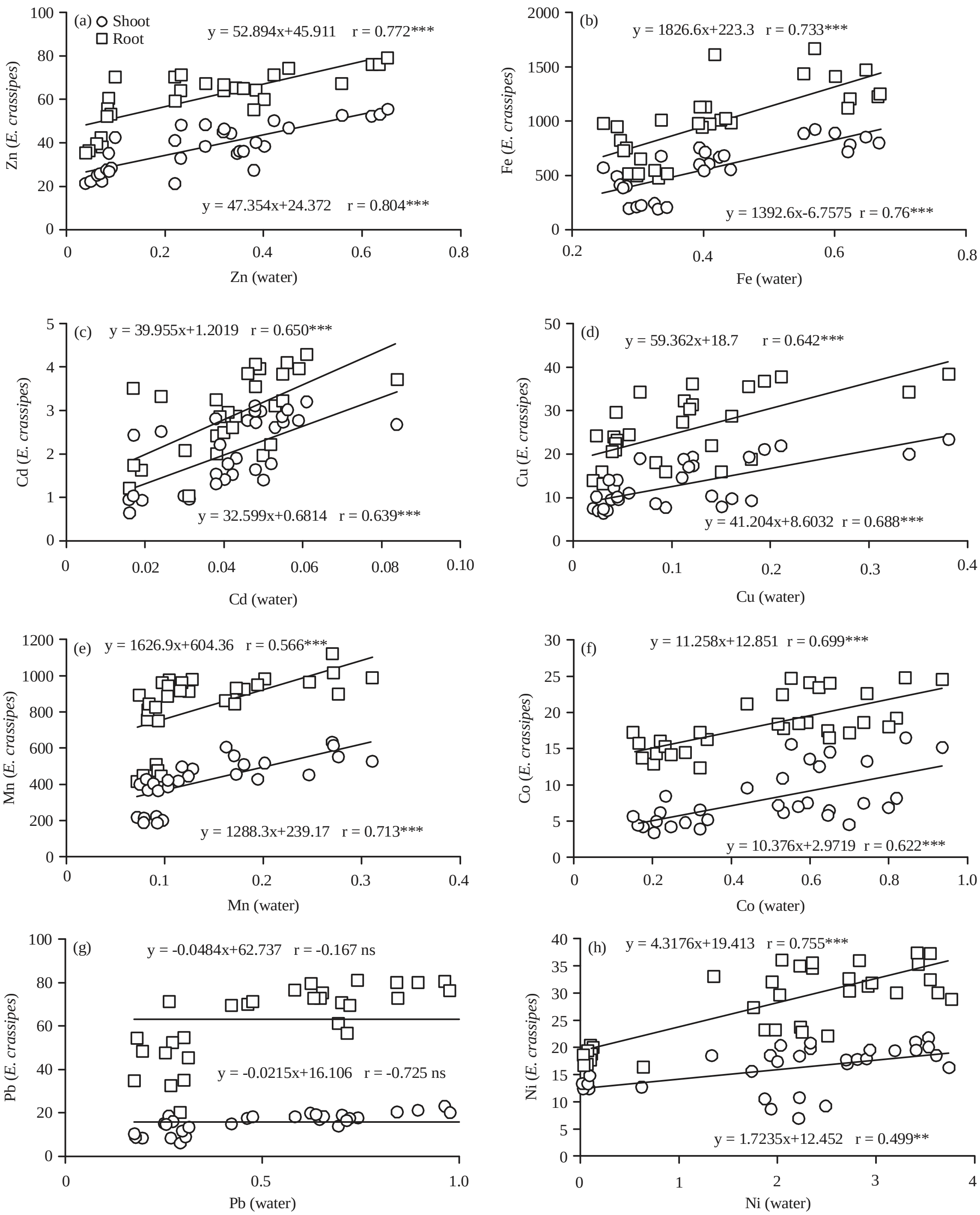

Fig. 3(a-h): Fitted line plot of heavy metals concentration in *Eichhornia crassipes* (shoot and root) and water

root (Zn_r = 52.894 Zn_w+45.911). The Fe_w concentrations in water (Fig. 3b) exhibited high significant correlation (r = 0.76 at $p \leq 0.001$) with Fe_s concentrations in water hyacinth shoot (Fe_s = 1392.6 Fe_w -6.7575) and with Fe_r concentrations in hyacinth root (r = 0.733 at $p \leq 0.001$) with a regression equation of Fe_r = 1826.6 Fe_w+223.3.

Concentrations of Mn_s in plant shoot showed very high significant positive of r = 0.713 at $p \leq 0.001$ with Mn concentrations in water (Fig. 3c). The Mn concentrations in water were used as explanatory variable for estimating Mn concentrations in shoot of water hyacinth Mn_s = 1.2883 Mn_w+0.2392. Meanwhile, Mn_r concentrations in plant root, it exhibited no correlation with Mn_w concentrations in water. It is clear from the obtained data (Fig. 3d) that, as Cu_w concentrations in water increase, there is a corresponding increase in Cu_s concentrations in plant shoot where, there was a very high significant positive correlation of $r = 0.688$ at $p \leq 0.001$ ($Cu_s = 41.204\ Cu_w + 8.6032$). The relationship between Cu concentrations in water and in root was very high significant positive correlation of $r = 0.642$ at $p \leq 0.001$. The Cu concentrations in water also used as explanatory variable for determination of Cu concentrations in plant root ($Cu_s = 59.362\ Cu_w + 18.7$).

As observed in Fig. 3e, the relationship between Cd_w concentrations in water and in Cd_s shoot was very high significant positive correlation ($r = 0.639$, $p \leq 0.001$) with a regression equation of $Y = 32.599X + 0.6814$. The relationship between Cd_w concentrations in water and Cd_r in root was very high significant positive correlation ($r = 0.650$, $p \leq 0.001$) $Cd_r = 39.96\ Cd_w + 1.2$. While, Co_w concentrations in water were highly correlated ($r = 0.622$ at $p \leq 0.001$) with Co_s concentrations in plant shoot ($Co_s = 10.38\ Co_w + 2.97$) and with Co_r concentrations in root ($r = 0.699$ at $p \leq 0.001$) with a regression equation of $Co_r = 11.26\ Co_w + 12.85$ (Fig. 3f).

Figure 3 g and h showed no significant correlation between Pb concentrations in water and that in shoot and root of water hyacinth. The relationship between Ni_w concentrations in water and *E. crassipes* shoot was a high significant positive correlation of $r = 0.499$ at $p \leq 0.01$ ($Ni_s = 1.72\ Ni_w + 12.54$) where, it showed very high significant correlation ($r = 0.755$ at $p \leq 0.001$) with Ni concentrations of root ($Ni_r = 4.32\ Ni_w + 19.41$).

DISCUSSION

Heavy metals are from the most hazardous pollutants since they are accumulating in water and biota tissues, through bioconcentration in an organism and biomagnification through the food chain (Chaphekar, 1991; Zhou *et al*., 2008). In the present study, the heavy metal content of water show spatial variations since most elements had high concentrations at the downstream section. On the other hand, the lower values of element concentrations were recorded at the upstream section, where the downstream section of Bahr El-Baqar drain is polluted with heavy metals to various degrees. This local variation of metals, mainly attributed to different anthropogenic activities. These results in line with those obtained by Abdel-Shafy and Aly (2002) who referred that deterioration of water quality towards the downstream may be due to mixing the untreated or poorly treated wastewater with drains water.

Using aquatic plants in biomonitoring has some advantages such as high tolerance to metal toxicity and easy sampling (Zhou *et al*., 2008). One marophyte which a typical biomonitor is *E. crassipes* which used in this study. Jackson (1998) reported that aquatic plants can sequester heavy metals through all their organs contacting the surrounding water. In this study the different parts of *E. crassipes* showed varied accumulation rate of different metals and the metal accumulation was m ore in roots as compared to shoots. Ernst *et al*. (1992) and Shanker *et al*. (2005) interpreted these results, where the roots of the plants act as a barrier against heavy metal translocation by sequestration of most metals in its vacuoles which may be a natural toxicity response of the plant. In addition, Denny (1987) stated that in emergent and floating plants as *E. crassipes* the heavy metal uptake was mainly through the roots. These results confirmed by some studies as those carried out by Samecka-Cyerman and Kempers (2001), Cardwell *et al*. (2002), El-Sherbeny (2003, 2009) and Lu *et al*. (2004).

Zinc is an essential micronutrient required in physiological processes of plants, but increased concentrations impair plant growth and metabolism causing toxicity (Shier, 1994; Welch and Shuman, 1995). The Zn may spread into the environment through mine tailings, smelters wastes and fertilizers (El-Bady, 2014). In this study Zn attained its maximum mean value at downstream section. This is mainly due to the agricultural and domestic effluent disposal. The results indicated that Zn concentrations in water at all drain sections were below the permissible level of Food and Agriculture Organization (FAO), this may be due to seepage of metals to the deeper layers of soil (El-Bady, 2014).

The results obtained revealed that iron concentrations in water and water hyacinth tissue had the highest value at downstream section which was below permissible and critical level of FAO and Kabata-Pendias (2011), respectively. The Fe accumulation in the tissues of plant is a rare event where excess Fe concentration cause severe damage to the cells (Mishra and Dubey, 2005).

Manganese is also from the essential micronutrient for plants, it is ubiquities metal in the environment. The anthropogenic sources of Zn include steel, alloys, ceramics, pigments and glass industries (Kabata-Pendias, 2011) as well as discharges of municipal wastewater, mining and mineral processing (CICAD., 2004). The Mn concentration in water attained its maximum mean value at downstream section which didn't exceed the permissible limits of FAO, while Mn concentration in water hyacinth tissue was in critical ranges (Kabata-Pendias, 2011). This result reflects the importance of biomnitoring, where plant retains the metals for long period than the water that exchanged through the water follow or by sudden discharge of wastes. Hence, the aquatic plant could provide more accurate status for water quality.

Copper known as an essential micronutrient for plants, but excessive concentrations are highly toxic. The Cu distributed in the natural environment through mining, agricultural practices as fertilizers and fungicides containing Cu and industry as smelting (Peng *et al*., 2005). The concentration of Cu in water acquired its maxima at downstream section that didn't exceed permissible limits of FAO. Agriculture fields around the studied sites may be the main reason for high concentrations of Cu as it is used in the manufacturing of fertilizers. The maximum Cu concentration was in water hyacinth tissues at downstream section which was within the normal level (Kabata-Pendias, 2011). The ability of water hyacinth for Cu sorption has been reported by Tiwari *et al*. (2007) and Buta *et al*. (2011). Furthermore, roots of water hyacinth attained higher Cu concentrations than shoots; this is in line with the findings of Fawzy *et al*. (2012).

Cadmium is non-essential toxic element and it is a major environmental pollutant. The Cd spread by manufacturing, mining and agricultural fertilizer and pesticides (Mishra and Dubey, 2005). Results of the present study showed that water Cd level exceeds the permissible level according to FAO. This is may be due to the greatest mobility of Cd from sediment to the above water layer (Gohar, 1998) as well as to the affinity of Cd to be adsorbed on the suspended matter (Laxen, 1985). On the other side, Cd accumulated in all plant organs (shoot and root), that is in agreement with Harrison and de Mora (1996) who reported the high sorption of Cd by zooplankton and phytoplankton in water. In addition, Kabata-Pendias (2011) recorded the rapid translocation of Cd from roots to shoots.

Cobalt liberation to the environment encourages through coal and oil burning, transportation exhausts and industrial processes (El-Bady, 2014). While nickel released into water and soil through waste discharges, whether industrial or municipal (Karam *et al*., 1998) as well as agricultural fertilizers that contain phosphate (McGrath, 1995). In this study, both elements exhibited the highest concentrations at downstream section and exceeded the permissible limits for irrigation according to FAO. They accumulated in water hyacinth tissue root more than in shoot. Their concentrations in plant shoot were above normal ranges given by Kabata-Pendias (2011). This result reflects the great industrial and agricultural disposal into the Bahar El-Baqar drain through different point or diffused sources.

Lead is a nonessential toxic element, where it is one of hazardous heavy metals released to the environment (Salt *et al*., 1998). The Pb hazards may be due to its high persistence in the environment and because it produced by enough amount that permit its accumulation (Chen *et al*., 2006). The Pb produced by mining and smelting processes, through some industries as paint, pigments and storage batteries as well as releasing by transportation that using gasoline (Ghinwa and Bohumil, 2009). In the present study, the highest Pb concentrations in water and *E. crassipes* plant were at downstream section which may be attributed to the agricultural and municipal disposal as well as deposition of aerial Pb from adjacent heavy traffic roads. This agrees with EPA (2006) that reported the release of Pb to the environment by anthropogenic means. The higher Pb concentrations in plant roots than that of shoots in this study was also informed by Kabata-Pendias (2011).

The ambient metal concentration in water was the major factor influencing the metal uptake efficiency (Rai and Chandra, 1992). Bioaccumulation factor (BAF) is applied for hazard classification and considered one of the simplest tools for bioaccumulation potential (Newman, 1994; McGeer *et al*., 2003). The BAF and bioconcentration factor (BCF) (Newman, 1994; McGeer *et al*., 2003) calculation is the same, but BCF is estimated under the laboratory conditions and BAF is measured in the natural environment as in this study (McGeer *et al*., 2003). In general BAF is an effective model in evaluating the plant capacity of heavy metal accumulation (Yoon *et al*., 2006). In this study the BAF of the estimated metals (Zn, Fe, Mn, Cu, Cd, Co, Ni and Pb) in the shoot and root of water hyacinth was higher in the upstream section than in the downstream section. This confirmed with McGeer *et al*. (2003) who reported an inverse relationship between the BAF of metal and concentrations in water or soil, in addition Lu *et al*. (2004) recorded an increase of metal concentration in *Eichhornia crassipes* with increases the amount of metal in water, whereas the BAF values were decreased.

Regression analysis indicated that concentrations of elements (Zn, Fe, Cu, Cd, Co and Ni) in water were used as explanatory variables for estimating the concentrations of these metals in water hyacinth shoot and root. Pb concentrations in water had no correlation with Pb concentrations in water hyacinth organs; this may be elucidated by assuming that the Pb resulting from air pollution had the significant effect on the environment. Generally, the heavy metal concentrations estimated in the Bahr El-Baqar drain reflect the huge amount of agricultural, municipal and industrial wastes disposed into the drain.

CONCLUSION

In conclusion, this study evaluates the importance of using the aquatic plants particularly, *Eichhornia crassipes* in easier and more expressive monitoring of water quality. Where, the studied drain is from the most polluted drain in Egypt and its water used in irrigation and in fish farming, which may cause serious harmful impacts on human and heavy metals from the major environmental hazardous pollutants, so its quantity in the environment (water) must be evaluated. *Eichhornia crassipes* plant not the target of this study, but it is the only plant that found in all studied sites therefore, it used as reprehensive for aquatic plants and the results indicate the ability of the aquatic plants (*E. crassipes*) to absorb and accumulate high level of heavy metals which qualified the plant to be a good biomonitor for drainage water quality.

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