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The accumulation of heavy metals in *Typha latifolia* L. grown in a stream carrying secondary effluent

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ABSTRACT

Typha latifolia L. from aquatic plants is widely found throughout Kehli Stream (Elazig, Turkey). This study examined the uptake of some metals by *T. latifolia* and the transfer from roots to other plant parts. The accumulation of Mn in *T. latifolia* L. can be suggested as a tolerance strategy due to its transfer factor higher than 1.0. The enrichment coefficients in the leaves of *T. latifolia* L. were higher than 1.0 for Zn and Mn and often lower than 1.0 for other metals. Similarly, the enrichment coefficients of all metals, except for Cr, in roots of *T. latifolia* L. were higher than 1.0. This study demonstrated that *T. latifolia* L. could be considered as either a bio-indicator or a bio-accumulator for sediments and water polluted by metals.

1. Introduction

Heavy metal contamination in aquatic and soil environments is a serious environmental problem, which threatens aquatic ecosystems, agriculture, and human health (Srivastav et al., 1994; Lasat, 2002; Fediuc and Erdei, 2002; Overesch et al., 2007). Units of metal removal and mobilization include sedimentation, adsorption, complexation, uptaking by plants, and microbially mediated reactions including oxidation and reduction (Dunbabin and Bowmer, 1992). Some aquatic plants can remove nutrients (Rogers et al., 1991; Moshiri, 1993; Mungur et al., 1997; Miretzky et al., 2004; Bastviken et al., 2005; Maine et al., 2006; Gottschall et al., 2007; Chung et al., 2008) and heavy metals (Rai et al., 1995; Zhulidov, 1996; Deng et al., 2004; Miretzky et al., 2004; Maine et al., 2006; Upadhyay et al., 2007) from liquid environments (Iqbal and Tachibana, 2007). Many scientists have focused on accumulation of heavy metals by aquatic macrophytes (Ye et al., 1997; Mays and Edwards, 2001; Göthberg et al., 2002; Manios et al., 2003; Demirezen and Aksoy, 2004; Kamal et al., 2004; Espinoza-Quinones et al., 2005; Saygideger and Dogan, 2005; Fritioff and Greger, 2006; Skinner et al., 2007; Licina et al., 2007). In addition, some have also studied the phytoremediation of aquatic macrophytes for contaminated sediment and water environments (Hinchman et al., 1998; Osmolovskaya and Kurilenko, 2001; Panich-Pat et al., 2004; Gratao et al., 2005; Audet and Charest, 2007).

Among aquatic macrophytes, *Typha latifolia* L. is a common wetland plant that grows widely in tropic and warm regions (Ye et al., 1997). *T. latifolia* L. has a high capacity for taking heavy metals into its body (Mc Naughton et al., 1974). Pip and Stepaniuk (1992) investigated some aquatic plants as pollution indicators due to their abilities to absorb and tolerate heavy metals. *Typha* tolerates enhanced levels of metals in its tissue without serious physiological damage. Dunbabin and Bowmer

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(1992) reported metal concentrations to increase in the following order: roots > rhizomes > non-green leaf > green leaf. They reported that the metal uptaking by plants was highest in the roots in contaminated cases, and the green leaves have lowest concentrations in copper (Cu), zinc (Zn), lead (Pb) and cadmium (Cd).

The *T. latifolia* L. was the dominant plant along Kehli Stream. However, the effluents of the Elazig City Wastewater Treatment Plant discharged to Kehli Stream have flowed into Keban Dam Lake after about 3 km since 1994. In this study, the objectives are to determine heavy metal concentrations in water environment, sediment, and plant in the studied area, and to evaluate mobility according to the transfer factor and the enrichment coefficient for leaf and root in *T. latifolia* L. Analyzed metals were manganese (Mn), copper (Cu), cadmium (Cd), cobalt (Co), zinc (Zn), lead (Pb), nickel (Ni), and chromium (Cr).

2. Material and methods

2.1. *Definition of the studied area*

The study area is located in a part of Uluova plain (east of Elazig, Turkey) and its drainage area is between 38°17′–38°43′ latitudes and 38°36′–39°07′ longitudes (Fig. 1). Kehli Stream has a length of about 10 km and drainage area of 500 km^2, which reaches from the southeast of Elazig City to Keban Dam Lake. The stream transports sewage of many small villages and effluent of the treatment plant to Keban Dam Lake. The study included nine sites along Kehli Stream. In these sites, *T. latifolia* L. plant, root sediment (bottom sediment), and water samples were collected from nine sites throughout 3 months. The selection of sampling points was designed according to different water mass input as seen in Fig. 1.

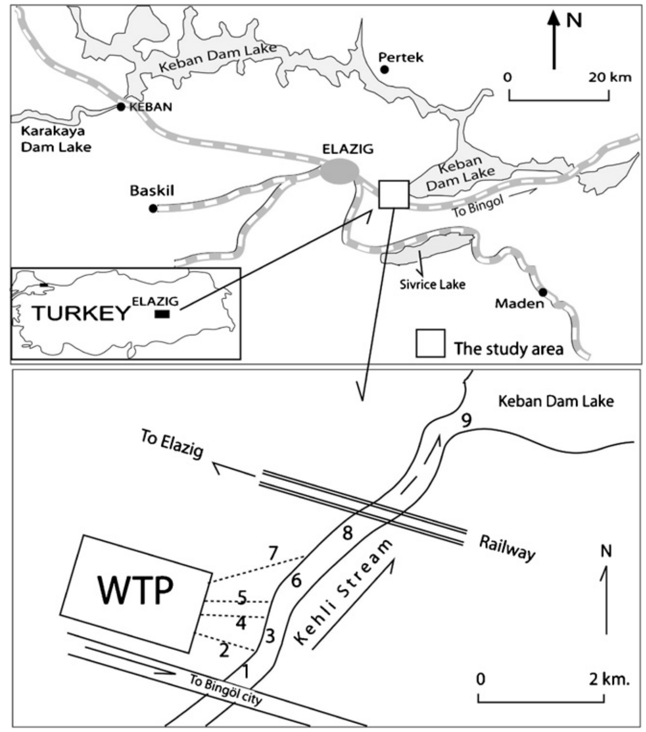

Fig. 1 – Location and sampling map of the study area. WTP means Wastewater Treatment Plant. Site 1 is the point before any water mass from WTP discharged to Kehli Stream. Site 2 is the line of filtrate of primary settled solids. Site 3 is Kehli Stream just after Site 2. Site 4 is the effluent discharging line. Site 5 is by-pass line. Site 6 is Kehli Stream that contains the Sites 2, 4, and 5. Site 7 is filtrate line from sludge drying beds. Site 8 is Kehli Stream that contains all effluents of WTP, and point at a distance of about 2 km from Site 1. Site 9 is just before the point where Kehli Stream falls into Keban Dam Lake.

2.2. *Preparation of samples*

2.2.1. *Plant samples*

Three samples of bodies and roots of *T. latifolia* L. were collected from each sampling site. The root samples were taken from the depth of 10–20 cm. The body (leaf) and root samples were thoroughly washed with tap water followed by distilled water and dried at room conditions. The dried plant samples were ground using a hand mortar. Approximately 2.5–3.0 g samples were ashed by heating at 250 °C and the temperature was gradually increased to 500 °C in 2 h. The ashed samples were digested in HNO_3 for 1.0 h followed by the mixture of $HCl–HNO_3–H_2O$ for 1.0 h (6 ml of the mixture of 1/1/1 was used for 1.0 g of the ashed sample) at 95 °C. The samples were digested using the mixture $HCl/HNO_3/H_2O$.

2.2.2. *Sediment samples*

Triplet sediment samples were collected from around the plant roots. After the sediment samples were dried in an oven and stone pieces were removed, they were ground by using a hand mortar. For digestion of sediment samples, the mixture of $HCl–HNO_3–H_2O$ (6 mL of mixture of 1/1/1 was used for 1.0 g) was used at 95 °C and 1 h.

2.2.3. *Water samples*

Triplet water samples were collected and then acid was added on the samples after each pH was measured in situ. In the laboratory, the samples were filtrated through 0.45 μm.

2.3. *Instrumentation*

All samples were analyzed by using the inductively coupled plasma mass spectroscopy (ICP/MS- Perkin-Elmer ELAN 9000) technique at ACME Analytical Laboratories Ltd. in Canada (http://www.acmelab.com/cfm/index.cfm). Acme is currently registered with ISO 9001:2000 accreditation. The operation conditions as recommended by the manufacturers (Elan 9000, 2001) are given in Table 1.

3. Results and discussion

3.1. *Variations of heavy metals in all matrixes*

Figs. 2 and 3 show standard errors and metal contents of all studied materials. The water samples included all heavy metals in ppb, and pH values were between 7.15 and 7.95. Organs of

Table 1 – Operation conditions for ICP-MS

Inductively coupled plasma	PerkinElmer Elan 9000
Nebulizer	Crossflow
Spray chamber	Ryton, double pass
RF power (W)	1000
Plasma gas flow rate (L min^{-1})	15
Auxiliary gas flow rate (L min^{-1})	1.0
Carrier gas flow rate (L min^{-1})	0.9
Sample uptake rate (L min^{-1})	1.0
Detector mode	Auto

T. latifolia L. included different metal concentration from each other. The concentrations of Zn, Mn, Pb, Co, and Cd in the root of *T. latifolia* L. were often higher than that in sediment, except for a few cases. In addition, Mn and Zn concentrations in the leaf of *T. latifolia* L. were higher than that in the sediment, but other metal concentrations were often higher in the sediment than in leaf, except for Mn on Site 8. The metal concentrations in roots were significantly higher than that in leafs; except for Mn, and also Pb on only Site 1. Mn accumulation in the leaf of *T. latifolia* L. was interesting because its concentration was often higher in leaves than that in roots.

While the mean Zn concentrations were 70 mg kg^{-1} in the sediment, 340 mg kg^{-1} in root, and 215 mg kg^{-1} in leaf of *T. latifolia* L, the mean Ni concentrations were 50 mg kg^{-1} in the sediment, 55 mg kg^{-1} in the root, and 40 mg kg^{-1} in the leaf. Zn and Ni are essential micronutrients with 100 and 1.5 mg kg^{-1} dry weight of tissue, respectively. Pais and Jones (2000) reported that the critical Zn value was 15 mg kg^{-1} for most crops although 10 mg kg^{-1} was able to be sufficient and Zn accumulated in older leaf at some conditions. Kabata-Pendias and Pendias (2001) reported Ni moved easily from sediment to plant, especially to hyperaccumulator plants such as *Alyssum sp*.

Cu concentrations averaged to be 45 mg kg^{-1} in the sediment, 50 mg kg^{-1} in the root, and 30 mg kg^{-1} in the leaf. Cu is not only an essential nutrient for plants, but also it is highly phytotoxic at high concentrations. Kabata-Pendias and Pendias (2001) reported Cu levels of various plants from unpolluted regions in different countries changed between 2.1 and 8.4 mg kg^{-1}. This means *T. latifolia* L. have a great tolerance to high Cu concentrations and Cu can excessively accumulate in the tissues of *T. latifolia* L.

Pb has recently received attention as a major chemical pollutant of environment and as an element that is toxic to plants. Kabata-Pendias and Pendias (2001) reported that Pb contents of plants grown in uncontaminated areas varied in between 0.05 and 3.0 mg kg^{-1}. Carranza-Álvarez et al. (2008) also reported Pb concentration ranged from 10 to 25 mg kg^{-1}, and the maximum accumulation of Pb was detected in roots. Concentrations of Pb in the plant were higher than the average concentrations reported as phytotoxic (<5 mg kg^{-1}) by Markert (1992). Pb concentrations were found to be 10 mg kg^{-1} in the sediment, 13 mg kg^{-1} in the root, and 8 mg kg^{-1} in the leaf. Pb values were a few times higher than that in uncontaminated areas.

Although Co has some beneficial effects on some plants (Pais and Jones, 2000), it is not an essential element to plant growth but are required for animals and human beings (He et

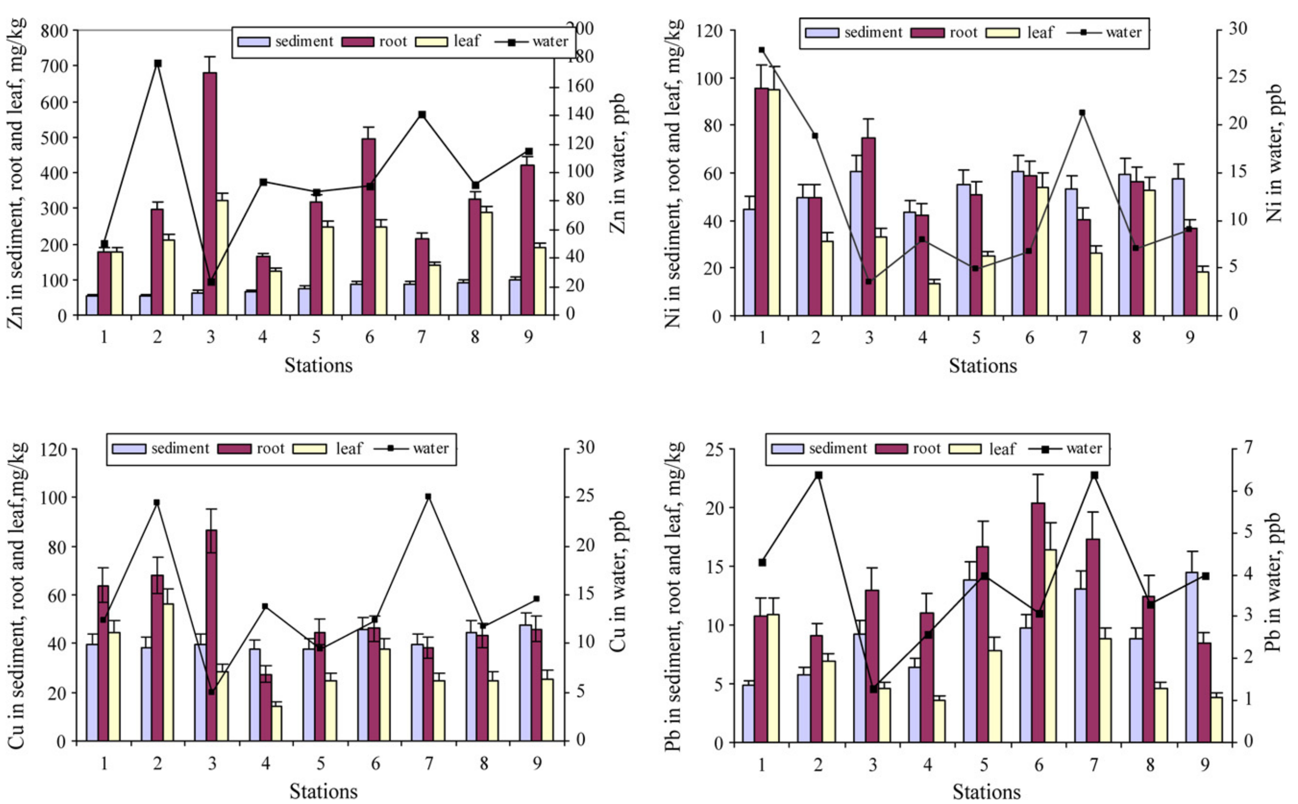

Fig. 2 – Average Zn, Ni, Cu and Pb concentrations in roots and leaf of *Typha latifolia* together with water and sediment concentrations.

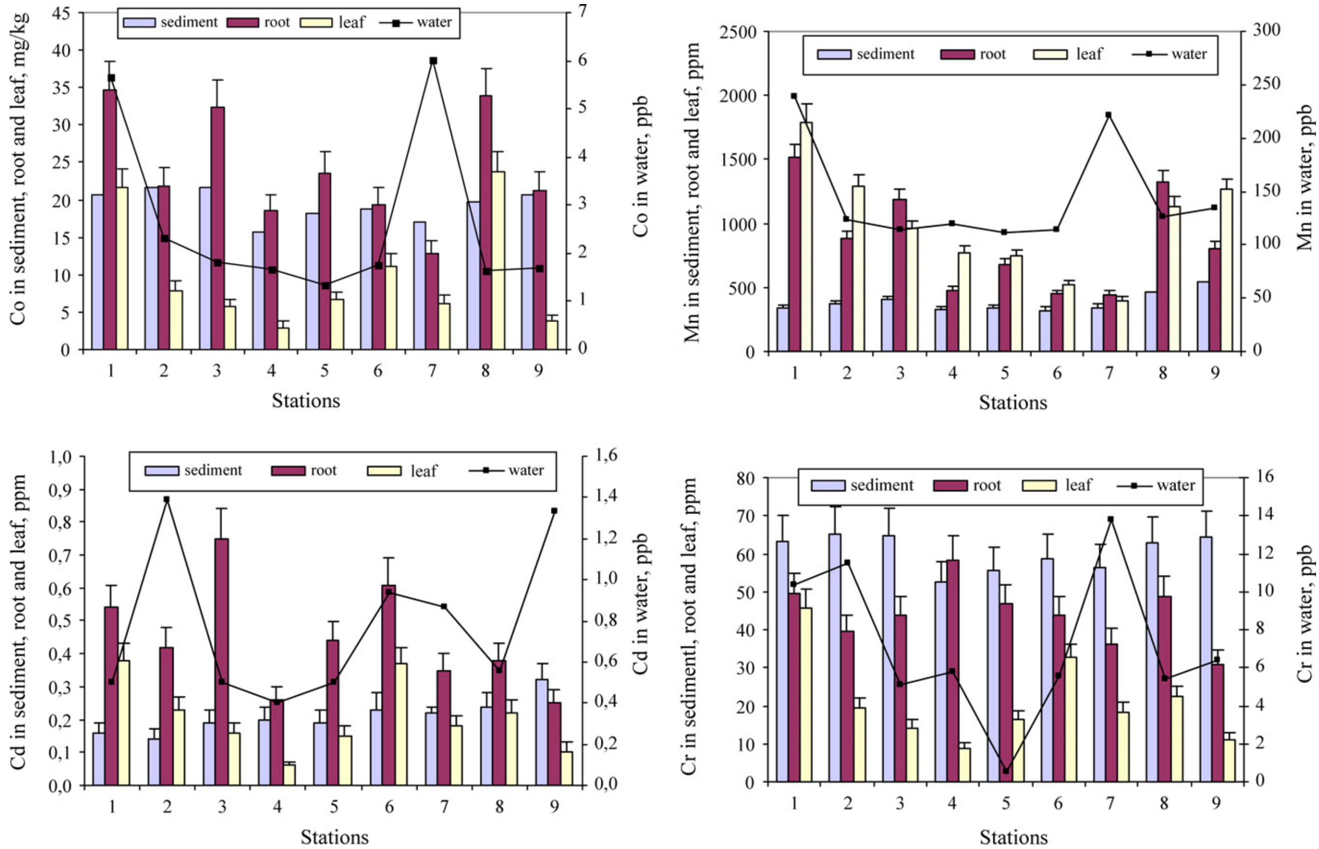

Fig. 3 – Average Co, Mn, Cd and Cr concentrations in roots and leaf of *Typha latifolia* together with water and sediment concentrations.

al., 2005). High Co concentrations are toxic for many plants, but its toxic concentration varies widely in the range of 6–143 mg kg^{-1}, by depending on plant species (Pais and Jones, 2000). Mean Co concentrations were 17 mg kg^{-1} in the sediment, 24 mg kg^{-1} in the root, and 10 mg kg^{-1} in the leaf. The Co values in roots of *T. latifolia* L. were often higher than both that in leaves of *T. latifolia* L. and that in sediment, except for site 7. This means the root of *T. latifolia* L. could be used as an indicator of cobalt pollution.

Mn is an essential element for plants necessary in many redox enzymatic processes and in photosynthesis (Memon et al., 2001; Carranza-Álvarez et al. (2008). Mn has a range between 20 and 300 mg kg^{-1} in most plants, while it levels may be as high as 1500 mg kg^{-1} without harm to some plant (Pais and Jones, 2000). Mn was highest among the metals determined in *T. latifolia* L. Mean Mn concentrations were 450 mg kg^{-1} in the sediment, 860 mg kg^{-1} in the root, and 990 mg kg^{-1} in the leaf. Mn concentrations in leafs were often higher than that in roots and sediments, except for the sites 3, 7, and 8. This means that the leaf of *T. latifolia* L. can be considered for Mn as bioindicator organs.

Cd is not an essential element for metabolic processes and cumulative poison. Kabata-Pendias and Pendias (2001) reported that both root and leaf absorbed Cd effectively. Demirezen and Aksoy (2004) reported that Cd accumulated at lowest level in *Typha angustifolia* in Sultan Marsh. Similarly, we also found that Cd was the lowest metal in *T. latifolia* L. due to lowest Cd content of sediments. Carranza-Álvarez et al. (2008) also reported the root of *T. latifolia* accumulated 25 mg kg^{-1}, which means an exceeded 50 times the phytotoxic values (<0.5 mg kg^{-1}) reported by Markert (1992). Mean Cd concentrations were 0.23 mg kg^{-1} in the sediment, 0.44 mg kg^{-1} in the root, and 0.21 mg kg^{-1} in the leaf. The roots of *T. latifolia* L. adsorbed a significant proportion of cadmium in sediment and the Cd concentrations in the roots were often higher than that in sediments, except for site 9. This means the root of *T. latifolia L.* could be used as an indicator of cadmium pollution in soil.

Pais and Jones (2000) reported that Cr concentrations higher than 10 mg kg^{-1} had a phytotoxic effect on plants. On the other hand, chromium in hexavalent form is a potential carcinogenic element for humans and plants (WHO, 1988). Mean Cr concentrations were 60 mg kg^{-1} in the sediment, 44 mg kg^{-1} in the root, and 21 mg kg^{-1} in the leaf. This means *T. latifolia* L. tolerates more chromium relatively than other plants reported by Pais and Jones (2000).

3.2. *Transfer factor (TLF)*

Transfer factor can be used to estimate a plant's potential for phytoremediation purpose. Transfer factors of metals in *T. latifolia* are shown in Table 2. The TLFs changed between 0.39 and 1.18. The mean TLF for Mn in *T. latifolia* L. was higher than 1.0, but mean TLFs for other metals were generally lower

Table 2 – Transfer factor and enrichment coefficients for leaves, roots and sediments of *Typha latifolia* for heavy metals at all sites

Site	Zn			Ni			Cu			Pb			Co			Mn			Cd			Cr		
	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF	ECL	ECR	TLF
1	3.29	3.28	1.01	2.10	2.12	0.99	1.13	1.62	0.69	2.25	2.25	1.00	1.04	1.67	0.62	5.30	4.51	1.17	2.38	3.38	0.70	0.72	0.78	0.92
2	4.10	5.75	0.71	0.63	1.00	0.63	1.47	1.77	0.83	1.19	1.58	0.76	0.37	1.01	0.36	3.49	2.39	1.46	1.64	3.00	0.55	0.30	0.61	0.49
3	5.27	11.18	0.47	0.54	1.23	0.44	0.72	2.18	0.33	0.5	1.41	0.35	0.26	1.49	0.18	2.37	2.94	0.81	0.84	3.95	0.21	0.22	0.67	0.32
4	1.91	2.51	0.76	0.31	0.97	0.32	0.38	0.73	0.52	0.56	1.73	0.33	0.19	1.18	0.16	2.37	1.46	1.62	0.30	1.30	0.23	0.17	1.11	0.15
5	3.36	4.32	0.78	0.45	0.93	0.49	0.66	1.19	0.55	0.56	1.21	0.46	0.37	1.30	0.28	2.19	1.99	1.10	0.79	2.32	0.34	0.29	0.84	0.35
6	2.94	5.83	0.50	0.89	0.97	0.92	0.83	1.02	0.82	1.69	2.1	0.81	0.59	1.04	0.57	1.61	1.39	1.16	1.61	2.65	0.61	0.56	0.75	0.75
7	1.63	2.48	0.66	0.50	0.76	0.65	0.62	0.97	0.64	0.68	1.33	0.51	0.36	0.75	0.48	1.18	1.30	0.90	0.82	1.59	0.51	0.33	0.65	0.51
8	3.15	3.57	0.88	0.88	0.95	0.93	0.57	0.97	0.58	0.52	1.41	0.37	1.20	1.72	0.70	2.45	2.86	0.86	0.92	1.58	0.58	0.36	0.77	0.46
9	1.94	4.28	0.45	0.32	0.64	0.50	0.54	0.97	0.56	0.26	0.58	0.46	0.18	1.03	0.18	2.32	1.47	1.58	0.31	0.78	0.40	0.17	0.48	0.36
AVR	3.07	4.80	0.69	0.74	1.06	0.65	0.77	1.27	0.61	0.91	1.51	0.56	0.51	1.24	0.39	2.59	2.26	1.18	1.07	2.28	0.46	0.35	0.74	0.48

ECL: enrichment coefficient for leaf = leaf/sediment, ECR: enrichment coefficient for root = root/sediment, TLF: transfer factor = leaf/root.

than 1.0. *T. latifolia* did not effectively transfer heavy metals from root to body. The excluder ability was in the order of Co > Cd > Cr > Pb > Cu > Ni > Zn. The differences in TLFs values indicated that each metal has different phytotoxic effect on *T. latifolia*. Baker (1981) and Zu et al. (2005) reported that TLFs higher than 1.0 were determined in metal accumulator species whereas TLF was typically lower than 1.0 in metal excluder species. TLF higher than 1.0 indicates an efficient ability to transport metal from root to leaf, most likely due to efficient metal transporter systems (Zhao et al., 2002), and probably sequestration of metals in leaf vacuoles and apoplast (Lasat et al., 2000).

3.3. *Enrichment coefficient for the leaf of T. latifolia L. (ECL)*

Enrichment coefficients are a very important factor, which indicate phytoremediation of a given species (Zhao et al., 2003). In this study, the enrichment coefficients of Zn and Mn in the leaf of *T. latifolia* L. were higher than 1.0 (Table 2). On the other hand, ECLs for all other metals were generally lower than 1.0. Although mean ECL for Cd was higher than 1.0, the coefficients in many sites were generally lower than 1.0. The metal concentrations in leaf were invariably higher than that in sediment and ECL was also higher than 1.0. Scientists reported this situation indicated a special ability of the plant to absorb and transport metals from sediment and then stored them in their above-ground part (Baker et al., 1994; Brown et al., 1994; Wei et al., 2002).

3.4. *Enrichment coefficient for the roots of T. latifolia L. (ECR)*

The enrichment coefficients in the roots of *T. latifolia* L. were higher than that in the leaf, except for Mn. This situation means that the roots of *T. latifolia* L. have an important capacity in accumulation of heavy metals. However, the bioaccumulation of chromium by the root of *T. latifolia* L. was low due to ECR lower than 1.0.

4. Conclusion

Kehli Stream has various contaminants such as organic, nitrogen, phosphorus, pathogens, and metals, because it has carried some municipal wastewater. In this study, we considered the effect of heavy metals present in the water environment on sediment and plant.

All metals studied in the water environment accumulated in the sediments and plants contacted with the stream. In *T. latifolia* L., the results indicated that roots were appropriate for metal accumulation. This means that the root of *T. latifolia* L. in contaminated water and sediments or soil by trace metals can be used as biomonitoring for Zn, Ni, Cu, Pb, Co, Mn and Cd. The transfer degree of metals from the down-parts to the up-parts was not very efficient according to TLFs of all heavy metals, except for chromium.

This study demonstrated that the heavy metals accumulated in the area of Kehli Stream and plants. Unfortunately, people in the villages near the stream use its water for irrigation in the agricultural areas and catch fish at the point where the stream enters to Keban Dam Lake. This situation is a threat to public health, and thus a study should be performed on vegetables and fish in the region.

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