Aquatic Botany 140 (2017) 92–95

Contents lists available at ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

Assessment of Trace Metal Contamination and Accumulation in Sediment and Plants of the Suoxu River, China☆

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ARTICLE INFO

Article history:
Received 2 February 2015
Received in revised form 9 November 2016
Accepted 9 November 2016
Available online 10 November 2016

Keywords:
Trace metal elements
Sediment
Plants
Suoxu River
Huaihe river catchments

ABSTRACT

Trace metal contamination in aquatic ecosystems is a major environmental problem since their accumulation along the food chain poses a public health risk. In this study, we tried to find whether, and to what extent, native plant species along the Suoxu River, China, may be useful for phytostabilization. The concentration of several metal elements (Cd, Cr, Cu, Ni, Pb and Zn) in sediment and plant samples collected from different sections of the Suoxu River, China was investigated. Results show that the concentrations of trace metals in the sediment and plants are similar and are found in the order of Zn > Cr > Pb > Cu > Ni > Cd. Standing stock concentration varied between plants groups and metals. The bioconcentration factor (BCF) and translocation factor (TrF) values were <1 for most of the trace metals, suggesting that the investigated species are no strong accumulators of trace metals, and that translocation from roots to shoots is low. Our study shows that native plant species growing on contaminated sites may have the potential for phytostabilization but not for phytoremediation.

1. Introduction

The toxicity of trace metal contamination is a serious environmental problem that not only threatens aquatic ecosystems, but also causes serious health hazards through food-chain magnification. Trace metals are released into the environment by a wide range of natural and anthropogenic sources including industrial, agricultural, and domestic waste (Upadhyay et al., 2014). Some trace metals are persistent in nature and can reside in polluted environments for a longer period, which causes deleterious health effects to humans and aquatic organisms (Rai et al., 2013).

In recent years, with the rapid social and economic development in China, urbanization and industrialization have led to an excessive release of waste that has been increasingly discharged into streams, lakes and rivers (Zhang et al., 2012; Xiao et al., 2013). The persistence and release of toxic chemicals in water bodies cause huge effects on the ecological balance of the aquatic environment and the diversity of aquatic organisms (Rai et al., 2012; Vitória et al., 2015). Numerous efforts have been undertaken to find cost-effective technologies for remediation of metal-contaminated sites. Phytoremediation is one of the environmentally friendly methods of plant-based technology that can be used to restore metal-contaminated sites (Chatterjee et al., 2011).

There has been continuing interest in investigating the scope of native plants for remediation of metal-contaminated sites as they perform well in terms of growth and biomass, and can survive in more extreme environmental conditions than non-native plants (Barbafieri et al., 2011). Native plants have been reported to accumulate significant amounts of metals and can play an important role in metal removal (Sainger et al., 2011; Nawab et al., 2015). Therefore, it is necessary to identify metal-tolerant species from natural areas surrounding sites that are contaminated with trace metals.

The major objectives of our study were to first determine the sediment concentrations of several trace metal elements in different sections of the Suoxu River, China, and then to compare metal concentrations in shoots and roots of various plant species. Thirdly, we evaluated whether these plant species could be useful for phytoremediation purposes based on standing stock, bioconcentration factor (BCF) and translocation factor (TrF) values.

☆ This article is part of a special feature entitled: "Macrophytes in freshwater habitats—Perspectives from Asia. Proceeding of the second International Symposium of Aquatic Plant Biology (MACROPHYTE 2014, Wuhan, China)" published at the journal Aquatic Botany 140C.

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http://dx.doi.org/10.1016/j.aquabot.2016.11.007
0304-3770/

Table 1
Plant samples collected from different sites of Suoxu river, China.

Group	Plant species	Family	Life Cycle	Biomass/Height	No. of samples
1	*Rorippa islandica*	Brassicaceae	Annual herb	Small	4
2	*Scirpus triqueter*	Cyperaceae	Perennial	Small	4
3	*Phragmites australis*	Poaceae	Perennial	High	6
4	*Imperata cylindrica*	Poaceae	Perennial Herb	High	5
5	*Chenopodium album*	Chenopodiaceae	Annual herb	Small	2
	Ranunculus sceleratus	Ranunculaceae	Annual herb	Small	2
6	*Polypogon fugax*	Poaceae	Annual herb	High	3
	Polygonum hydropiper	Polygonaceae	Annual herb	Small	2
7	*Iris tectorum*	Iridaceae	Perennial Herb	Small	2
	Typha orientalis	Typhaceae	Perennial Herb	High	2
	Sagittaria sagittifolia	Alismataceae	Perennial Herb	High	1

2. Materials and methods

2.1. Study area and sample collection

The study area and sampling sites are positioned on the Suoxu River, one of the tributaries of the Huaihe River located in the north of Zhengzhou City (the capital of Henan Province), and adjacent to the sewage drain outlet of a chemical industrial park.

Sediment and plant samples were collected from three sections (34°51′40″N, 113°33′31″E – 34°53′22″N, 113°41′13″E) of the Suoxu River. A total of nine sediment samples and three to four plant samples of eleven species were collected from each section of the river. Due to the paucity of plants at some sample sites, two to three replicates of the same species were mixed together to form a composite of particular species. Thus, we divided the plant species into seven groups with four being single species and another three with mixed species (Table 1).

2.2. Sample analysis

Plant samples were divided into roots and shoots and washed gently with de-ionized distilled water to remove sediment particles, until no solid particles remained adhered to the roots or shoots (Zhang et al., 2010). After washing, plant and sediment samples were air dried at room temperature for two weeks and ground to a powder using a mortar and pestle, then sieved to <2 mm and stored in sterilized sample containers. A precise weight of each sample (0.2 g) was used to prepare the solution for the digestion reaction. A mixture of concentrated HNO_3 (2 ml) at 65% and H_2O_2 (1 ml) at 30% was used for the digestion reaction. After cooling to room temperature, the residue was diluted to 10 ml with de-ionized water and analyzed for metals by inductively coupled plasma mass spectrometry (ICP-MS)(Yoon et al., 2006).

All the metal analyses were conducted in the Geological Survey of Jiangsu Province. Quality assurance and quality control of metal analyses used standard reference material (GSD-11) supplied by the Chinese Academy of Geological Sciences. The analytical error was <5% of the certified values for trace metal elements.

2.3. Data analysis

To estimate a plant's potential for phytoremediation purposes we used standing stock, BCF and TrF. The standing stock is commonly calculated by multiplying metal concentrations in the plant tissue by biomass per unit area and are expressed as mass per unit area (usually g m^{-2} or kg ha^{-1}) (Johnstone, 1991; Vymazal, 2015). The BCF was calculated as the metal concentration ratio of plant roots to sediment given in equation 1 (Mellem et al., 2009). The translocation factor (TrF) is the ratio of shoot to root metals, indicating internal metal transportation, and is given in equation 2 (Zacchini et al., 2008)

$$BCF = C_p/C_s \quad (1)$$

where, C_p and C_s are the metal concentrations in the plant and the sediment respectively.

$$TrF = C_s/C_r \quad (2)$$

where, C_s and C_r are the metal concentrations in the shoots and roots of the plants, respectively.

One-way ANOVA was carried out to compare sediment metal concentration in different sections of river. A non- parametric Kruskal-wallis test was used to determine any significant difference in metal concentration among different plant species and groups. Correlations between metal concentrations in sediment and plant samples at different sites were also evaluated using Pearson correlation coefficients (PC). The correlation coefficient (r) was used to express the relationship between the different quantitative variables.

3. Results and discussion

3.1. Trace metal concentration in sediments

The total concentrations of Cd, Cr, Cu, Ni, Pb, and Zn in the sediment varied from 0.09 ± 0.23, 58.6 ± 98, 9.72 ± 80.5, 15.3 ± 41, 15.2 ± 27.3 and 35 ± 156 mg kg^{-1}, respectively. The concentration of these metals is low compared to values reported in other studies

Table 2
Bioconcentration Factor (BCF), Translocation Factor (TrF) and Standing stock for the metal concentrations in collected plant samples.

Group	BCF						TrF						Standing stock g m^{-2} yr^{-1}					
	Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn	Cd	Cr	Cu	Ni	Pb	Zn
1	**1.6**	0.34	0.74	0.40	0.18	**1.33**	0.66	**1.14**	0.47	0.91	**1.02**	0.70	0.08	15.2	4.97	2.11	1.80	27.2
2	**1.15**	0.26	0.65	0.21	0.19	0.60	0.40	0.26	0.34	0.32	0.49	0.60	0.15	22.5	22.0	6.19	3.27	66.5
3	0.36	0.36	0.28	0.15	0.05	0.64	**1.51**	0.75	0.83	0.86	**2.29**	0.76	0.39	**119**	**69.6**	**21.2**	10.2	**270**
4	**1.39**	**1.0**	**1.06**	0.48	0.32	**1.80**	0.44	0.54	**1.36**	0.52	0.62	0.72	0.24	71.1	11.6	9.71	7.29	80.7
5	**3.29**	0.32	0.82	0.24	0.26	0.96	0.2	**1.23**	0.75	0.49	0.41	0.83	0.16	5.54	10.8	1.89	2.26	54.7
6	**1.8**	0.49	**1.26**	0.50	0.21	**1.14**	**1.15**	0.80	0.53	0.76	0.73	0.74	0.11	18.6	10.8	3.30	3.25	41.5
7	**1.42**	0.3	**1.34**	0.24	0.196	0.79	0.52	0.73	0.49	0.77	**1.2**	0.87	**0.76**	45.0	34.0	10.2	**13.6**	96.9

BCF = metal concentration ratio of plants root to soil, TrF = metal concentration ratio of plants shoot to root >1 in bold font