International Journal of Plant Science and Ecology
Vol. 6, No. 2, 2020, pp. 25-30
http://www.aiscience.org/journal/ijpse
ISSN: 2381-6996 (Print); ISSN: 2381-7003 (Online)

Variation Among Wetland Plants in the Uptake and Translocation of Lead from Wastewater

Yuankang Liu, Yan Zhu, Jianguo Liu*

School of Environmental & Safety Engineering, Changzhou University, Changzhou, China

Abstract

The variations among ten wetland plant species in Pb uptake and translocation were studied under moderate (1.5 mg/L) and heavy (3.0 mg/L) water Pb stress and in artificial wetlands. The results showed that the variations among the wetland plant species were 4.30-4.97 times for Pb concentrations of aboveground parts, 14.58-14.81 times for Pb concentrations of underground parts, 4.96-5.23 times for average Pb concentrations of whole plants, and 8.27-9.01 times for translocation factors (TFs) of Pb from underground parts to aboveground parts. The correlations between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in Pb concentrations of aboveground parts, underground parts, whole plants, and in the TFs of Pb from underground parts to aboveground parts were all positive and highly significant ($P < 0.01$). But the correlations between aboveground parts and underground parts in Pb concentrations were insignificant ($P > 0.05$). From the view of comprehensive consideration on the Pb concentrations in aboveground parts and in whole plants, the plant species *Cyperus iria* and *Monochoria vaginalis* are suitable wetland plants to be used in the treatment of Pb-polluted wastewater with artificial wetlands.

Keywords

Lead (Pb), Water Pollution, Wastewater Treatment, Wetland Plants, Translocation

Received: April 14, 2020 / Accepted: May 11, 2020 / Published online: June 9, 2020

1. Introduction

Heavy metal pollution in water body is a serious environmental problem in China, because it will leads to bio-accumulation and bio-magnification into the food chain in aquatic system [1]. Of the heavy metals, lead (Pb) is one of the most important metal pollutants for its widespread and highly toxic to organism [2]. Pb is highly toxic on human body, for it can poses severe damages on many human systems, such as nervous, skeletal, circulatory, endocrine, enzymatic and immune systems [3]. Therefore, Pb pollution in the environment has attracted great public concerns, and Pb has been listed as a pollutant for priory control in many countries, including China [4]. Excessive exposure to Pb can also damages plant growth, for it interferes with photosynthesis, respiration, nutrient absorption, and the activities of many enzymes [1, 5].

Some current sewage treating technologies have several shortcomings. For instance, the active sludge system is highly cost in construction and complex in operation. However, the wastewater treatment technology with constructed wetland has been proven an appropriate measure for developing countries. It is low in investment and energy dissipation, easy to operate, and can produce high quality effluent [6]. As one of low-cost wastewater treatment technologies, constructed wetlands have been applied in some countries successfully [1].

Wetland plants are the main biological components in wetlands. They can absorb pollutants into their tissues directly, and change the rhizospheric environments also. Therefore, the plants in wetlands can enhance pollutant purification by promoting a variety of chemical and biochemical reactions.

* Corresponding author
E-mail address: liujianguo@cczu.edu.cn (Jianguo Liu)

Some plants are highly tolerable to heavy metal stress and can accumulate high levels of the metals in their tissues, so they have the potential for phytoremediation, such as *Brassica napus* [7, 8]. Researches indicated that the abilities and characteristics of wetland plants in the uptake, transport and accumulation of heavy metals differed greatly with plant species [9]. Great genotypic variations in metal absorption and translocation have been found between and within plant species [10]. Therefore, selection of the plants with the characteristics of tolerable to and high accumulation of target metals, fast growing and high biomass are important for the phytoremediation of the metal-polluted water body.

The purpose of this study was to study the variations among ten wetland plant species in Pb uptake and translocation. The results will be useful in the selection of wetland plant species for the removal of Pb from wastewater.

2. Materials and Methods

2.1. Design of Constructed Wetland

Small-scale plot constructed wetlands were established under open-air conditions. The plots consisted of six chambers, each having 2 m^2 surface area (1 m × 2 m). Each chamber was filled with soil to a depth of 25 cm. The soil was obtained from the top 20 cm of an uncontaminated paddy field, and sieved through a 5 mm sieve. The soil has a neutral pH (6.87) and a moderate level of organic matter (2.95%). Pb concentration of the soil was determined with AAS following H_2O_2 - HF - HNO_3 - $HClO_4$ digestion. Pb concentration of the soil was 33.8 mg/kg (DW). The soil was submerged in water (about 5 cm water layer above the soil surface) for a month before the wetland plant seedlings were transplanted.

2.2. Collection of Wetland Plants and Experimental Design

Ten wetland plant species (totally 7 families) were selected according to our previous studies [11]. The plant seedlings were collected from the suburb of Changzhou, China. Three seedlings of similar size (10-20 cm in height) for each plant species were transplanted into the chambers in an even and randomized order.

The artificial wastewater was spiked with Pb at concentrations of 1.5 and 3 mg/L, respectively, to mimic moderate and heavy Pb-polluted wastewater. The Pb-polluted solutions were prepared using $PbCl_2$. Each level of Pb-treated wastewater was fed into two of the six chambers at three times, i.e. 15th, 22nd and 29th day after the transplanting of the seedlings (160 L for each chamber at each time). The two chambers receiving non-Pb-treated water (tap water) served as controls. All the chambers were submerged with 5-8 cm water layer above the soil surface during the experiment.

2.3. Sample Preparation and Analytical Methods

Fifty days after transplanting of the seedlings, whole wetland plants were harvested, washed thoroughly with tap water, and then rinsed with deionized water. The plant samples were divided into aboveground parts and underground parts, and were dried at 70°C to constant weight. Subsequently, these samples were ground with a stainless steel grinder (FW-100, China), and passed through a 100-mesh sieve. Pb concentrations of the samples were determined with AAS following HNO_3-$HClO_4$ digestion.

3. Results and Discussion

3.1. Variations Among Wetland Plant Species in Pb Concentrations in Different Parts of Plants

The Pb concentrations in aboveground parts of the ten wetland plant species under different water Pb treatments (1.5 and 3.0 mg/L) were shown in Figure 1. The Pb concentrations in some samples of the control were below testing limit, so the data of the control were not shown.

The variations among the ten wetland plant species in Pb concentrations of aboveground parts were large. Pb concentrations in aboveground parts of the plant species ranged from 12.36 to 61.46 mg/kg (4.97-fold variation) for 1.5 mg/L water Pb treatment, and from 23.91 to 102.76 mg/kg (4.30-fold variation) for 3.0 mg/L water Pb treatment. Under 1.5 mg/L water Pb treatment, the top two species in Pb concentrations of aboveground parts were *Cyperus iria* and *Monochoria vaginalis* (code name F and I), with Pb concentrations of higher than 50 mg/kg. Under 3.0 mg/L water Pb treatment, the top three species in Pb concentrations of aboveground parts were *Cyperus iria*, *Monochoria vaginalis* and *Fimbristylis miliacea* (code name F, I and G), with Pb concentrations of higher than 80 mg/kg. For the ten wetland plant species, there was very high correlation between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in Pb concentrations of aboveground parts (r = 0.9934, $P < 0.01$).

There were great variations among the ten wetland plant species in Pb concentrations of underground parts (Figure 2). Pb concentrations in underground parts of the plant species ranged from 17.72 to 262.39 mg/kg (14.81-fold variation) for 1.5 mg/L water Pb treatment, and from 28.91 to 421.58 mg/kg (14.58-fold variation) for 3.0 mg/L water Pb treatment. The top three species in Pb concentrations of underground parts were *Polygonum hydropiper*, *Monochoria vaginalis* and *Alternanthera philoxeroides* (code name D, I and J), with Pb concentrations of higher than 140 mg/kg for 1.5 mg/L water Pb treatment and higher than 210 mg/kg for 3.0 mg/L water Pb treatment. For the ten wetland plant species, the correlation between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in Pb concentrations of underground parts was also highly significant (r = 0.9990, $P < 0.01$).

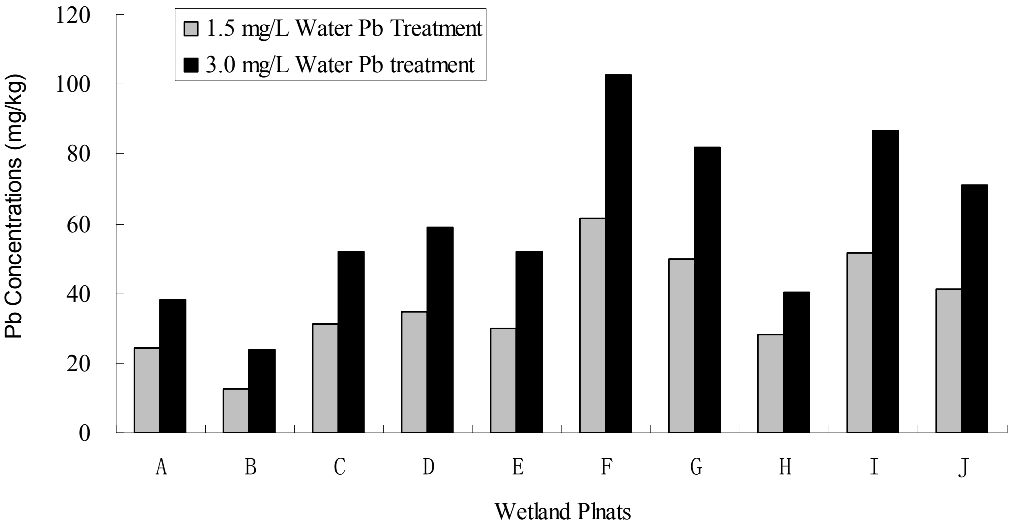

Figure 1. Pb Concentrations in Aboveground Parts of Different Wetland Plants under Different Water Pb Levels

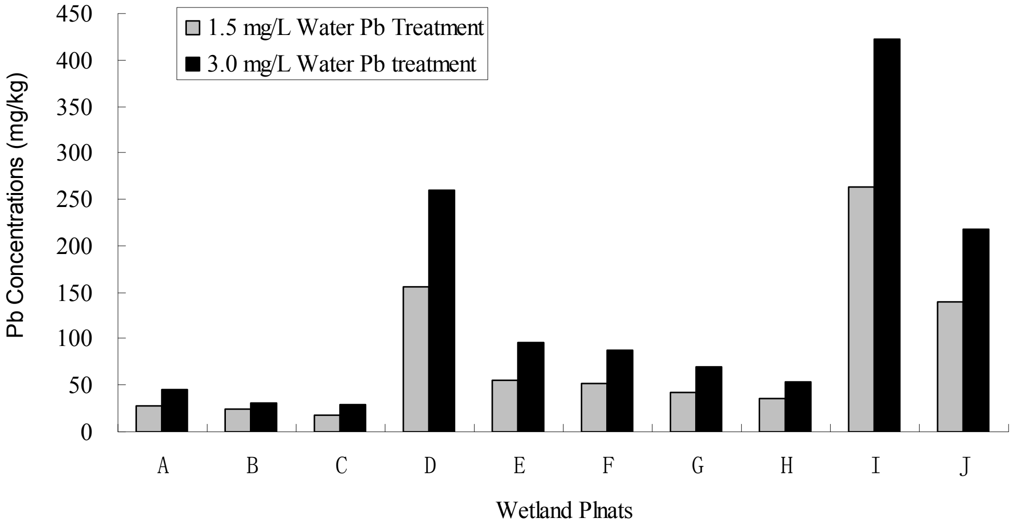

Figure 2. Pb Concentrations in Underground Parts of Different Wetland Plants under Different Water Pb Levels

For the ten wetland plant species, the correlations between aboveground parts and underground parts in Pb concentrations were low and insignificant ($P > 0.05$), irrespectively under 1.5 mg/L water Pb treatment (r = 0.4329) or under 3.0 mg/L water Pb treatment (r = 0.4740).

The variations among the ten wetland plant species in average Pb concentrations of whole plants (total Pb accumulation of plant / total biomass of plant) are presented in Figure 3. The differences of the plant species in average Pb concentrations of whole plants were also very large. Average Pb concentrations of the wetland plant species ranged from 15.04 to 78.62 mg/kg (5.23-fold variation) for 1.5 mg/L water Pb treatment, and from 25.54 to 126.75 mg/kg (4.96-fold variation) for 3.0 mg/L water Pb treatment. The top three species in Pb concentrations of whole plants were *Cyperus iria*, *Monochoria vaginalis* and *Alternanthera philoxeroides* (code name F, I and J), with Pb concentrations of higher than 49 mg/kg for 1.5 mg/L water Pb treatment and higher than 85 mg/kg for 3.0 mg/L water Pb treatment. For the ten wetland plant species, the correlation between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in average Pb concentrations of whole plants was also highly significant (r = 0.9960, $P < 0.01$).

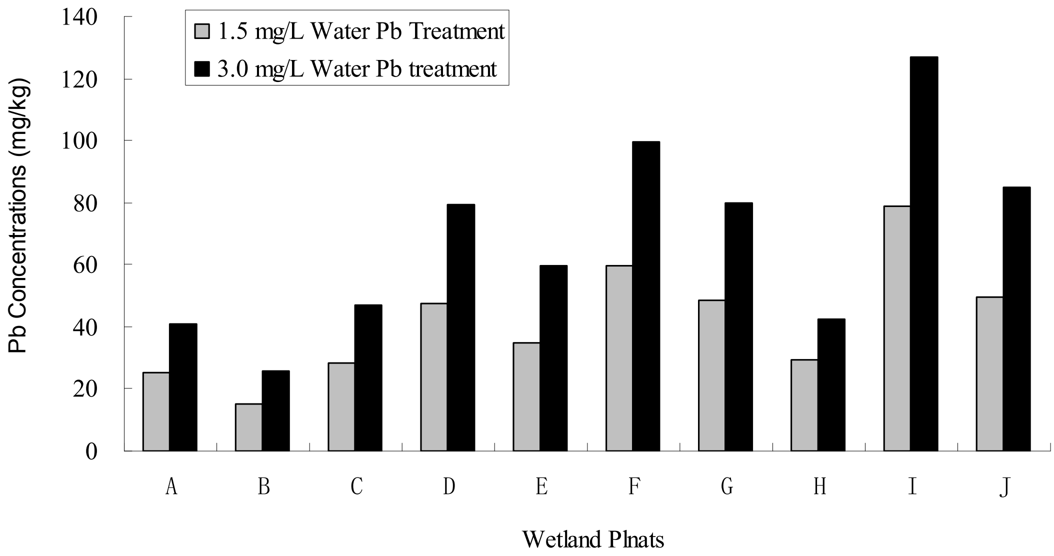

Figure 3. Average Pb Concentrations of Whole Plants under Different Water Pb Levels

3.2. Variations among Wetland Plant Species in Pb Translocation from Underground parts to Aboveground Parts

The ability of Pb transfer from underground parts to aboveground parts in wetland plants can be evaluated with translocation factor (Pb concentration ratio of aboveground parts to underground parts). The translocation factors (TFs) of Pb from underground parts to aboveground parts of the ten wetland plant species are displayed in Figure 4.

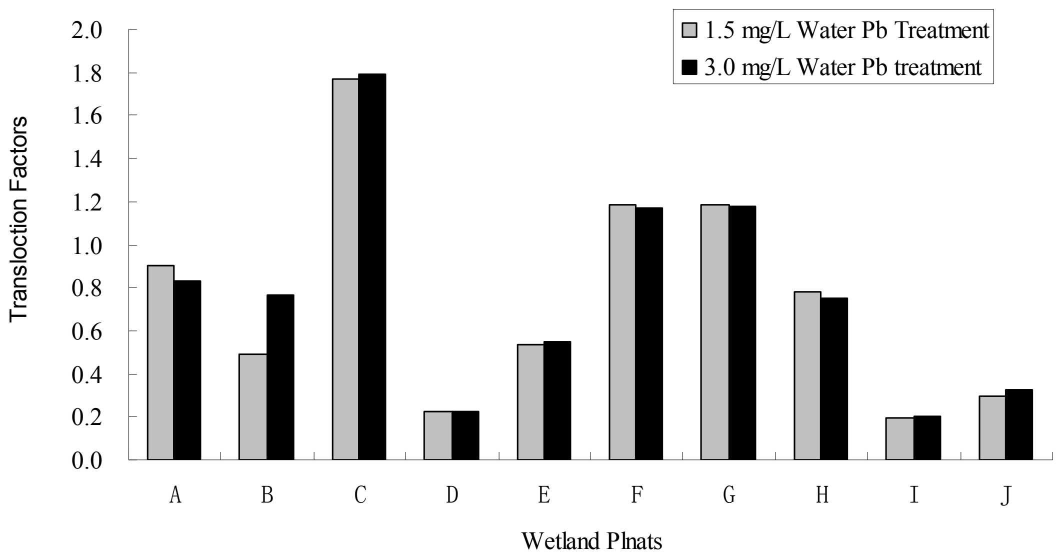

Figure 4. Translocation Factors of Pb from Underground Parts to Aboveground Parts under Different Water Pb Levels

On the average, the TFs were less than 1, because the Pb concentrations of underground parts were higher than the Pb concentrations of aboveground parts for most of the plant species. But the TFs were more than 1 for three plant species, e.g. *Isachne globosa*, *Cyperus iria* and *Fimbristylis miliacea* (code name C, F and G). The TFs of Pb from underground parts to aboveground parts of the ten wetland plant species varied highly. The TFs ranged from 0.1966 to 1.7714 mg/kg (9.01-fold variation) for 1.5 mg/L water Pb treatment, and from 0.2056 to 1.7920 mg/kg (8.72-fold variation) for 3.0 mg/L water Pb treatment. For the ten wetland plant species, the correlation between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in the TFs of Pb from underground parts to aboveground parts was also highly significant ($r = 0.9838$, $P < 0.01$).

Constructed wetland is a kind of engineered system which takes the advantage of natural processes, such as vegetative, soil and microbial activities, in wastewater treatment [12].

Since 1990s, it has been used in the treatment of the wastewaters form acid mine drainage, industrial and agricultural production, urban and highway runoff, food processing, and sludge dewatering [13]. It was reported that constructed wetland removed 87%, 49%, 95%, 85% and 92% of Mn, Co, Cu, As and Pb, respectively, from sewage water [1]. In wetlands, plants can accumulate considerable amounts of heavy metals, which can be removed from the wetlands by harvesting of the plants [14]. It was also reported that the uptake and translocation of heavy metals by wetland plants may be species-dependent and metal-dependent [15, 16].

Our present research showed that several times variations among the wetland plant species in Pb concentrations of aboveground parts, and more than ten times variations in Pb concentrations of underground parts. The differences in Pb translocation factors (TFs) from underground parts to aboveground parts were nearly ten times. The results will provide the possibilities to select proper plant species for the treatment of Pb-polluted wastewaters. The correlations between 1.5 mg/L water Pb treatment and 3.0 mg/L water Pb treatment in Pb concentrations of aboveground parts, underground parts, whole plants, and in the TFs of Pb from underground parts to aboveground parts were all positive and highly significant ($P < 0.01$). The results indicate that the characteristics of wetland plants in Pb uptake and translocation will remain consistent under different water Pb levels. But the correlations between aboveground parts and underground parts in Pb concentrations were insignificant ($P > 0.05$). The wetland plant species with higher Pb concentrations in aboveground parts may accumulate lower Pb concentrations in belowground parts. But the Pb concentrations in aboveground parts are more meaningful, because aboveground parts can be harvested and removed from wetland easily. Therefore, from the view of comprehensive consideration on the Pb concentrations in aboveground parts and in whole plants, the plant species *Cyperus iria* and *Monochoria vaginalis* (code name F and I) are suitable wetland plant species for the treatment of Pb-polluted wastewater.

4. Conclusions

Under moderate (1.5 mg/L) and heavy (3.0 mg/L) water Pb stress, the variations among ten wetland plant species were 4.30-4.97 times in Pb concentrations of aboveground parts, 14.58-14.81 times in Pb concentrations of underground parts, 4.96-5.23 times in average Pb concentrations of whole plants, and 8.27-9.01 times in translocation factors (TFs) of Pb from underground parts to aboveground parts. The characteristics of wetland plants in Pb uptake and translocation remain consistent under different water Pb levels. But the wetland plant species with higher Pb concentrations in aboveground parts may accumulate lower Pb concentrations in belowground parts. From the view of comprehensive consideration on the Pb concentrations in aboveground parts and in whole plants, the plant species *Cyperus iria* and *Monochoria vaginalis* are suitable wetland plant species for the treatment of Pb-polluted wastewater with artificial wetlands.

Acknowledgements

This work was financially supported by “Postgraduate Research & Practice Innovation Program of Jiangsu Province”, China.

References

[1] Rai, U. N., Tripathi, R. D., Singh, N. K., Upadhyay, A. K., Dwivedi, S., Shukla, M. K., et al. (2013). Constructed wetland as an ecotechnological tool for pollution treatment for conservation of Ganga river. *Bioresource Technology*, 148: 535–541.

[2] Chanu, L. B. and Gupta, A. (2016). Phytoremediation of lead using *Ipomoea aquatica* Forsk. in hydroponic solution. *Chemosphere*, 156: 407–411.

[3] Li, Z. Y., Ma, Z. W., Kuijp, T. J., Yuan, Z. W. and Huang, L. (2014). A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. *Science of the Total Environment*, 468–469: 843–853.

[4] Rodrigues, S. M., Cruz, N., Coelho, C., Henriques, B., Carvalho, L., Duarte, A. C., et al. (2013). Risk assessment for Cd, Cu, Pb and Zn in urban soils: chemical availability as the central concept. *Environmental Pollution*, 183: 234–242.

[5] Bharwana, S. A., Ali, S., Farooq, M. A., Ali, B., Iqbal, N., Abbas, F., et al. (2014). Hydrogen sulfide ameliorates lead-induced morphological, photosynthetic, oxidative damages and biochemical changes in cotton. *Environmental Science and Pollution Research*, 21: 717–731.

[6] Tao, W., Sauba, K., Fattah, K. P. and Smith, J. R. (2017). Designing constructed wetlands for reclamation of pretreated wastewater and stormwater. *Reviews in Environmental Science and Biotechnology*, 16: 37–57.

[7] Shakoor, M. B., Ali, S., Hameed, A., Farid, M., Hussain, S., Yasmeen, T., et al. (2014). Citric acid improves lead (Pb) phytoextraction in *brassica napus* L. by mitigating Pb-induced morphological and biochemical damages. *Ecotoxicology and Environmental Safety*, 109: 38–47.

[8] Ehsan, S., Ali, S., Noureen, S., Mahmood, K., Farid, M., Ishaque, W., et al. (2014). Citric acid assisted phytoremediation of cadmium by *Brassica napus* L. *Ecotoxicology and Environmental Safety*, 106: 164–172.

[9] Qian, Y., Gallagher, F. J., Feng, H. and Wu, M. Y. (2012). A geochemical study of toxic metal translocation in an urban brownfield wetland. *Environmental Pollution*, 166: 23–30.

[10] Liu, J. G., Qu, P., Zhang, W., Dong, Y., Li, L. and Wang, M. X. (2014). Variations among rice cultivars in subcellular distribution of Cd: The relationship between translocation and grain accumulation. *Environmental and Experimental Botany*, 107: 25–31.

[11] Liu, Y., Chu, K. and Liu, J. (2020). Differences among ten wetland plant species in the tolerances of lead-polluted water. *Journal of Environment Protection and Sustainable Development*, 6: 1–5.

[12] Liu, J., Dong, B., Cui, Y., Zhou, W. and Liu, F. (2020). An exploration of plant characteristics for plant species selection in wetlands. *Ecological Engineering*, 143: 105674.

[13] Guo, X., Cui, X. and Li, H. (2020). Effects of fillers combined with biosorbents on nutrient and heavy metal removal from biogas slurry in constructed wetlands. *Science of the Total Environment*, 703: 134788.

[14] Vymazal, J. and Březinová, T. (2016). Accumulation of heavy metals in aboveground biomass of *Phragmites australis* in horizontal flow constructed wetlands for wastewater treatment: A review. *Chemical Engineering Journal*, 290: 232–242.

[15] Vymazal, J. (2016). Concentration is not enough to evaluate accumulation of heavy metals and nutrients in plants. *Science of the Total Environment*, 544: 495–498.

[16] Zhang, S., Bai, J., Wang, W., Huang, L., Zhang, G. and Wang, D. (2018). Heavy metal contents and transfer capacities of *Phragmites australis* and *Suaeda salsa* in the Yellow River Delta, China. *Physics and Chemistry of the Earth*, 104: 3–8.