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Heavy Metal Content of Plant Species along Nilüfer Stream in Industrialized Bursa City, Turkey

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Abstract In this study, heavy metal content (Cr, Cu, Mn, Ni, Zn) was determined in sediments and different organs of *Rumex obtusifolius* L. and *Polygonum lapathifolium* L. (Polygonaceae), *Urtica dioica* L. (Urticaceae) and *Xanthium strumarium* L. (Asteraceae) species. These species grow ubiquitously and vigorously on the periodic flooding areas of Nilüfer stream which have been polluted by different local industrial activities. Below and above-ground parts of plant samples and their sediments were analyzed by ICP-MS for their elemental contents. In general, the variations in the heavy metal content in sediments are reflected in heavy metal status of plant organs. However, this variation depends on plant species and heavy metals. *R. obtusifolius*, *U. dioica* and *X. strumarium* species have elevated levels of Cr, Cu, Ni, and Zn whereas Mn was observed only in *P. lapathifolium*. The contribution of different organs to the accumulation capacity of the total phytomass is specific to species.

Keywords Bioaccumulation · Heavy metals · *Polygonum lapathifolium* · *Rumex obtusifolius* · *Urtica dioica* · *Xanthium strumarium*

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1 Introduction

The soil nutrients include essential and non-essential heavy metals such as copper, iron, manganese or nickel and, they have important roles in plant growth (Marschner 1995; Hagemeyer 2004). Heavy metal content of soil is dependent on both natural and anthropogenic sources in the local ecosystems. While natural forms are usually found in relatively low concentrations, in recent decades the number and intensity of anthropogenic sources such as rubbish tips, smelter stacks, waste incineration fertilizers, vehicle emissions, agricultural waste and sewage sludge have increased the local environmental heavy metal concentrations (Bargagli 1998; Koch and

Rotard 2001). Historical pollution of unchecked emissions of heavy metals may persist for decades.

The responses of plants to high heavy metal content of soil, sediment and water vary with species. For instance, some plant species can be injured by the increased heavy metal content in their environment. On the other hand, some plant species called indicators can tolerate heavy metals, reflecting the external heavy metal (Baker 1981), and they can be used as bio-indicators or biomonitors for quality assessment in aquatic and terrestrial ecosystems (Pugh et al. 2002). Also, some plants have the capability to safely accumulate of heavy metals in different ways (Baker 1981; McIntyre 2003; Kim et al. 2003). Many studies have focused on the heavy metal accumulation capacities of terrestrial plants (e.g. Ernst 1996; Aksoy and Öztürk 1997; Aksoy et al. 1999; Freitas et al. 2004; Güleryüz et al. 2002, 2006; Swaileh et al. 2004; Zeidler 2005; González and González-Chávez 2006) and aquatic merged or submerged macrophytes (e.g. Lewander et al. 1996; Biernacki and Lovett-Doust 1997; Ghate and Chaphekar 2000; Samecka-Cymerman and Kempers 2001, 2002; Scott et al. 2002; Kim et al. 2003; Demirezen and Aksoy 2004, 2006) in contaminated sites.

Anthropogenic activities as sources of increased heavy metal content in both terrestrial and aquatic systems are common in Turkey. Bursa is one of the most important industrialized and urbanized cities in Turkey, which is experiencing rapid industrial development. Industrial activities together with agricultural activities, a rapidly increasing population and non-planned urbanization processes have challenged the ecological balance in Bursa City (Karaer and Küçükballı 2006). Nilüfer stream is used for the agricultural irrigation in Bursa plain. However, domestic, industrial and agricultural wastes are discharged into the Nilüfer stream as reported in several studies. For instance, Yılmaz et al. (1998) found that chromium and lead concentrations were above the standard limits given for the heavily polluted class of water. Dere et al. (2006) showed the extent of the pollution by some other environmental pollution parameters (epipelic diatom taxa, fecal coliforms, total coliforms and total bacteria, and also dissolved oxygen, biochemical oxygen demand—BOD_5, electrical conductivity, total dissolved substance).

The aim of this study was to determine the heavy metal (Cr, Cu, Mn, Ni and Zn) content of organs in four plant species [*Rumex obtusifolius* L. subsp *subalpinus* (Schur.) Célak and *Polygonum lapathifolium* L. (Polygonaceae); *Urtica dioica* L. (Urticaceae) and *Xanthium strumarium* L. (Asteraceae)] which naturally grow along the Nilüfer stream. We further relate the plant concentrations to their corresponding sediments. Heavy metal loading of plant organs is compared with the corresponding sediment heavy metal contents.

2 Material and Methods

2.1 Study Area

The Nilüfer basin is located in northwest Anatolia. It includes the Nilüfer Stream (168 km) and the industrialized city of Bursa which lies at the intersection of 40°11′ N latitude and 29°04′ E longitude. The average total precipitation of Bursa city is 696.5 mm and the average temperature is 14.6°C (Güleryüz 1992). The precipitation period is between September and April. The Nilüfer stream passes through the city and supplies drinking water to Bursa city via Doğancı dam which was built on upstream of the city (Fig. 1). Not only does it supply drinking water to Bursa, but Nilüfer stream also it supplies irrigation water for agricultural sites around the city via its tributaries such as Ayvalı, Kaplıkaya, Gökdere, Cilimboz and Deliçay creeks. The Nilüfer stream and its tributaries have been polluted by organic and inorganic pollutants from the industrial and domestic wastes resulting from industrialization and urbanization activities in Bursa. Because there are many industrial zones around Bursa, wastes are discharged into this stream and it's tributaries at seven main points. Industrial activities occur in both main industrial zones (Bursa Organized Industrial Zone, Demirtaş Organized Industrial Zone, and Nilüfer Organized Industrial Zone) and in small industrial zones such as Gürsu, Hasanağa, Kestel Organized Industrial Zones and Yıldırım Industrial Building. Although, there are many industrial zones around Bursa, only two public wastewater facilities were built on this area (Fig. 1), and significant amounts of industrial waste is directly dumped to the Nilüfer stream, without treatment.

2.2 Sample Sites and Sampling

Four sampling sites were selected (Buski, Cilimboz, Buttim, B. Balıklı) along the Nilüfer stream. The

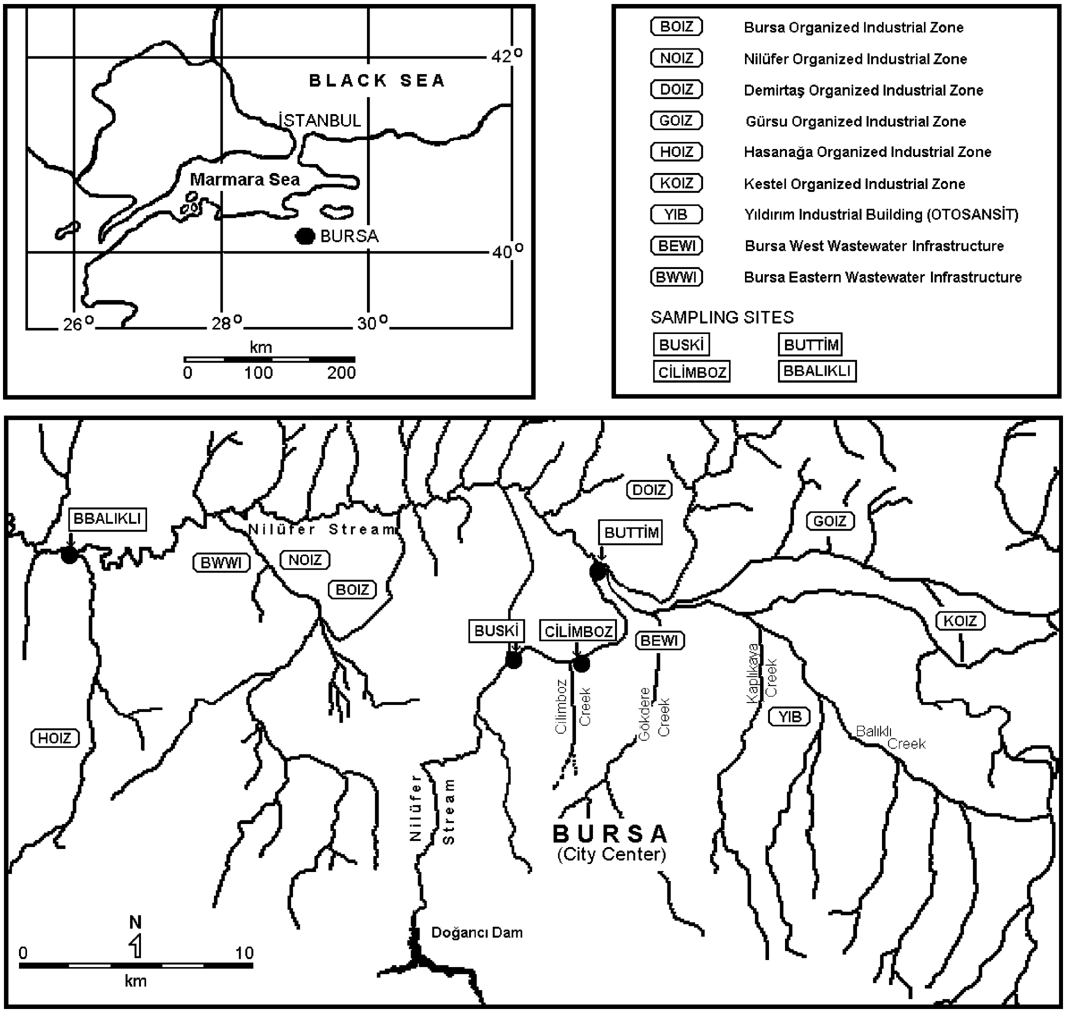

Fig. 1 Location map of the study area and sampling sites along Nilüfer Stream, and central industrial zones in Bursa, Turkey

Buski sampling site is upstream of industrial activities on the upper part of Nilüfer stream which has no industrial activities. Since there is no industrial activity between Buski and the spring points of Nilüfer stream, we propose Buski as unpolluted reference point. The Cilimboz sampling site is the point where the Cilimboz creek mix with the Nilüfer stream. Climboz creek is carries the wastes of the leather tanning industries, and this sampling site is the first polluted area. Buttim is the next site downstream and is affected by the wastes of the automotive and textile industries. B. Balıklı sampling site is located in the downtown of Bursa city. Many creeks transport the wastes of industrial, agricultural and urban activities are mixed to the Nilüfer stream before this site (Fig. 1).

Polygonum lapathifolium L. "Willow Weed, Curly-top Knotweed", *Rumex obtusifolius* L. subsp *subalpinus* (Schur.) Célak. "Sorrel", (Polygonaceae), *Urtica dioica* L. "Stinging Nettle, Common Nettle" (Urticacea) and *Xanthium strumarium* L. "Coklebur, Rough Cocklebur" (Asteracea) are common species on these sites. They grow ubiquitously and vigorously on the periodic flooding areas of the Nilüfer stream. Their basic properties are given in Table 1; the text on the Flora of Turkey and the East Aegean Islands is referred to for the names of taxa cited here (Davis 1965–1985).

Plant and sediment samples were taken from four different places at each sampling site. Sampling was conducted from March to August 2002, and all plant samples were in the flowering phase. After the plant samples were carefully uprooted using a plastic

Table 1 Characteristics of investigated plant species

Species	Family	Common name	Properties
Rumex obtusifolius L. subsp *subalpinus* (Schur.) Célak.	Polygonaceae	Sorrel	Rhizomatous, perennial weed, stems up to 120 cm; habitat banks, shady and damp sites, roadside, silage fields, river banks, waste ground, field margins; flowering time May–October
Polygonum lapathifolium L.	Polygonaceae	Willow Weed Curlytop Knotweed	Rhizomatous, tall annual herb; stem ascending to erect, branched; flowers usually pink; habitat marshes and near streams, disturbed sites, gravel bars, damp clearings, cultivated fields, roadsides, railroads, swampy thickets, shores; flowering time July–October
Urtica dioica L.	Urticaceae	Stinging nettle, common nettle	Rhizomatous, coarse perennial herbaceous with an extensively spreading; matted root system, forming clumps; habitat forests, shaded ravines and rocks, margins of streams, woodland garden, waste places, roadsides, along fences, stockyards, shady edge; overgrazed paddocks, meadow; flowering time June–October
Xanthium strumarium L	Asteraceae	Rough cocklebur	Rhizomatous, annual herb with short, stout; stems unarmed; habitat; disturbed ground, cropland, stream banks, edge riparian flowering time July–September

shovel, a sample of sediment was taken from each plant's habitat. Soil cores, which have 10×15 cm dimensions, were taken using a plastic pipe. They were sifted using with a standard 4-mm stainless steel sieve and then transferred to the laboratory in plastic bags. They were dried in laboratory conditions. Uprooted plant samples were also transferred to the laboratory in plastic bags and they were carefully separated below-ground (roots and below-ground stems) and above-ground (stems and leaves) parts. Plant materials were washed with tap water and then de-ionized water. After they were dried in an oven (105°C) until their weight became constant, samples were ground with a mortar and pestle. Homogenized plant material and soil samples were stored in clear paper bags for analyses.

2.3 Analysis of Sediments and Plant Samples

The pH of air-dried soil samples was measured with a soil/water ratio of 1:2.5 (in saturated mud; Steubing 1965). Exchangeable cations of sediments were analysed in ammonium acetate which was prepared by mixing of 57.5 ml of glacial acetic acid and 60 ml of NH_3 (d=0.91) in water and diluting the resultant mixture to exactly 1 l. The diluting solution was

Table 2 Soil pH and heavy metal contents (exchangeable and acid-soluble) of sediments [mean±standard deviation; different letters represent the difference groups among the sample sites (P<0.05)]

Sampling sites	pH (H_2O)		Elements (mg kg^{-1} dry weight)				
			Cr	Cu	Mn	Ni	Zn
Buski	7.8±0.1a	Exchangeable (ammonium acetate pH 7.3)	0.6±0.0d	0.7±0.1c	108±12bc	0.9±0.1b	1.4±0.4d
Cilimboz	7.6±0.1a		0.9±0.2c	2.1±0.2b	86±12c	1.4±0.2b	6.2±2.8c
Buttim	7.4±0.1a		2.3±0.2a	2.6±1.1ab	152±15a	5.6±1.6a	43.1±2.8a
B. Balıklı	7.4±0.1a		1.7±0.0b	3.6±0.4a	112±8b	2.0±0.1b	11.6±0.4b
Buski		Acid-soluble (HNO_3/HCl)	97±17bc	38±2b	498±38b	87±2a	91±5b
Cilimboz			190±44ab	44±2ab	489±43b	83±3a	120±6ab
Buttim			137±22b	41±4ab	454±44b	54±4b	145±11a
B. Balıklı			231±52a	50±11a	599±15a	89±10a	174±49a

buffered to the mean soil pH value of sediments (pH= 7.3). Air dried sediment samples (10 g) were mechanically shaken in ammonium acetate solution with a vertical shaker for 30 min and then filtered through Whatman blue-band (no. 3) filter paper.

Sediment samples (0.5 g dry weight) were digested with 6 ml HNO_3 and 4 ml HCl in a microwave oven (160°C, 2 h) and digestion samples were diluted to 100 ml volume with de-ionized water for acid-soluble cation analyses. Homogenized plant samples (0.5 g dry weight) were also prepared using the same procedure for metal analyses. All sediments and plant material solutions were anlaysed for Cr, Cu, Mn, Ni and Zn by ICP-MS Agilent® 7500 in Tubitak, Bursa Test and Analysis Laboratory (Tubitak-Butal).

2.4 Statistical Analysis

The differences between the sample sites regarding to heavy metal contents of plant organs and sediments were tested by one-way ANOVA. The difference groups among sample sites were determined by Tukey HSD post hoc test (HSD, honestly significant difference). All statistical analyses were based on significance level of α=0.05 using Statistica Ver 5.0 (StaSoft Inc., 1984–1995, Tulsa, OK, USA) program.

3 Results and Discussion

3.1 Soil pH and Heavy Metal Levels in Sediments

Soil pH and heavy metal contents (exchangeable and acid-soluble) of sediments are given in Table 2. There was no significant difference among sample sites regarding pH levels (P>0.05). The soil pH varied from 7.4 to 7.8 at sample sites.

Heavy metal contents in sediments of all sample sites in were above detectable levels. Significant differences in all examined exchangeable heavy

Table 3 Difference groups among sites regarding to average element contents (mg kg^{-1} dry weight) in above- and below-ground parts of *Polygonum lapathifolium* collected from four different points (Buski, Cilimboz, Buttim, B. Balıklı) along the Nilüfer stream, Bursa, Turkey [mean±standard deviation; different letters represent the difference groups among the sample sites (P<0.05)]

Elements	Sampling Sites	Below-ground phytomass	Above-ground phytomass			Total phytomass
			Stems	Leaves	Total	
Cr	Buski	21±5c	7±2b	10±1a	17±2b	38±4c
	Cilimboz	127±25a	6±1b	13±2a	19±1b	146±25a
	Buttim	69±20b	6±3b	14±2a	20±4b	89±18b
	B. Balıklı	16±1c	20±5a	15±5a	35±6a	51±6c
Cu	Buski	59±15b	57±6a	13±3b	70±7a	129±20b
	Cilimboz	159±43ab	28±4ab	16±2b	44±5a	203±44b
	Buttim	286±140a	63±33a	23±9ab	86±41a	372±142a
	B. Balıklı	15±5b	18±3b	32±10a	50±11a	65±15b
Mn	Buski	127±32a	97±5a	342±41a	439±41a	566±48a
	Cilimboz	136±37a	36±30b	341±91a	377±111ab	513±122a
	Buttim	81±21a	48±25b	215±25b	264±48b	345±53b
	B. Balıklı	105±39a	23±9b	106±23b	129±31bc	234±31b
Ni	Buski	51±5b	52±7a	13±3c	65±7ab	116±5ab
	Cilimboz	146±54a	24±5b	16±2bc	40±7bc	186±59a
	Buttim	123±65ab	48±7a	24±8b	72±14a	195±76a
	B. Balıklı	17±5bc	13±4b	35±4a	48±5b	65±9b
Zn	Buski	38±8bc	46±12b	83±8b	128±12b	166±16b
	Cilimboz	139±19a	118±33ab	133±24ab	250±55a	390±72a
	Buttim	100±39ab	171±57a	164±37a	334±66a	434±49a
	B. Balıklı	61±34b	145±25a	142±20a	287±44a	347±65a

metals were found between samples sites ($P<0.05$). In general, the exchangeable element concentration of sediment increased at the Buttim and B. Balıklı sites (Table 2). For example, the exchangeable Cu content of sediment was 3.6 mg kg^{-1} dry weight at the B. Balıklı sample site where industrial activities are performed heavily. The 0.7 mg kg^{-1} dry weight at the Buski sample site was assumed to have no contamination by industrial activities. Similar variation in element concentration according to sample sites was observed for exchangeable Cr. Cr contents were high at the Buttim and B. Balıklı sites (2.3 and 1.7 mg kg^{-1} dry weight, respectively). Highest Mn, Ni and Zn contents were also measured at the Buttim site which is close to industrial activities (Table 2). Our results indicate that there was an increase in sediment heavy metal content along the Nilüfer stream depending on industrial activities. These results are supported by other authors who previously studied this area (Aydınalp et al. 2005; Dere et al. 2006; Karaer and Küçükballı 2006). Significant difference was found among sample sites regarding to the acid-soluble elements of sediments ($P<0.05$). The acid-soluble Cr, Cu, Mn, Ni and Zn contents increased at the B. Balıklı sample site (Table 2).

3.2 Heavy Metal Levels in Plants

Mean heavy metal contents in different organs of four plant species are presented in Tables 3, 4, 5, 6. According to Markert (1994), the chromium (Cr) level in a plant is 1.5 mg kg^{-1} dry weight but the chromium level above 0.5 mg kg^{-1} dry weight is considered as toxic to plants (Allen 1989). Therefore, it can be accepted that all examined species have Cr accumulation capacity. In this study, the mean Cr content in total phytomass of all species is much higher than the poisonous level (Tables 3, 4, 5, 6).

Table 4 Difference groups among sites regarding to average element contents (mg kg^{-1} dry weight) in above- and below-ground parts of *Rumex obtusifolius* collected from four different points (Buski, Cilimboz, Buttim, B. Balıklı) along the Nilüfer stream, Bursa, Turkey [mean±standard deviation; different letters represent the difference groups among the sample sites ($P<0.05$)]

Elements	Sampling Sites	Below-ground phytomass	Above-ground phytomass			Total phytomass
			Stems	Leaves	Total	
Cr	Buski	16±2b	23±13a	8±1a	32±13a	47±13b
	Cilimboz	30±7a	32±11a	15±6a	47±14a	76±17a
	Buttim	26±4a	23±2a	11±4a	34±4a	61±6ab
	B. Balıklı	28±5a	18±6a	15±4a	33±3a	60±8ab
Cu	Buski	8±3b	8±1b	19±2b	27±2b	34±2b
	Cilimboz	13±4ab	11±1ab	22±7b	33±7b	46±5b
	Buttim	17±4a	9±2b	16±3b	24±4b	41±3b
	B. Balikli	12±4ab	15±3a	63±23a	77±20a	89±21a
Mn	Buski	24±4b	7±3b	59±16a	66±15a	90±14b
	Cilimboz	66±18ab	32±4a	45±12a	77±12a	143±28ab
	Buttim	81±37a	35±20a	81±26a	116±42a	197±77a
	B. Balıklı	33±11b	10±2b	83±27a	93±27a	127±28ab
Ni	Buski	6±1b	8±1a	19±2a	27±2a	32±2a
	Cilimboz	11±3b	11±1a	20±8a	30±9a	42±7a
	Buttim	17±4a	11±5a	14±4a	25±5a	42±3a
	B. Balıklı	10±1b	11±4a	20±6a	30±11a	40±12a
Zn	Buski	17±1b	35±4a	36±3b	71±6a	88±5b
	Cilimboz	47±23ab	48±7a	46±11ab	95±5a	141±25a
	Buttim	77±24a	15±0b	73±21a	88±21a	165±24a
	B. Balıklı	53±8a	38±13a	70±20a	108±31a	161±36a

Table 5 Difference groups among sites regarding to average element contents (mg kg^{-1} dry weight) in above- and below-ground parts of *Urtica dioica* collected from four different points (Buski, Cilimboz, Buttim, B. Balıklı) along the Nilüfer stream, Bursa, Turkey [mean±standard deviation; different letters represent the difference groups among the sample sites ($P<0.05$)]

Elements	Sampling Sites	Below-ground phytomass	Above-ground phytomass			Total phytomass
			Stems	Leaves	Total	
Cr	Buski	12±1b	5±1b	10±3b	14±4c	26±4b
	Cilimboz	24±10b	10±4ab	17±3b	27±6bc	51±13b
	Buttim	64±20a	17±7a	32±10a	48±7a	112±18a
	B. Balıklı	22±9b	18±7a	13±6b	31±12b	52±16b
Cu	Buski	48±5b	34±6ab	71±14bc	104±12b	152±13bc
	Cilimboz	43±22bc	32±7ab	112±12ab	145±10ab	188±32b
	Buttim	146±5a	52±20a	127±28a	179±41a	324±42a
	B. Balıklı	19±0c	15±3b	77±19b	92±22bc	111±23c
Mn	Buski	73±9b	41±6a	51±6a	92±8a	165±13b
	Cilimboz	48±5c	35±7a	101±24a	136±17a	184±21b
	Buttim	143±17a	41±6a	107±49a	148±48a	291±40a
	B. Balıklı	41±5c	18±2b	72±23a	90±24a	131±29b
Ni	Buski	11±1b	15±6b	8±1b	23±5b	34±6c
	Cilimboz	30±11ab	32±8a	20±8ab	52±11a	82±3ab
	Buttim	50±18a	30±10a	24±5ab	54±9a	104±21a
	B. Balıklı	15±5b	15±1b	39±15a	53±16a	69±18b
Zn	Buski	45±13b	26±7b	110±43b	136±43b	181±43b
	Cilimboz	78±12ab	46±7a	280±71a	326±68a	404±78a
	Buttim	80±23a	46±14a	227±38a	273±26a	353±19a
	B. Balıklı	58±12ab	42±9ab	97±56b	139±50b	196±62b

Even the lowest Cr content in total phytomass of *U. dioica* sampled from Buski site was fifty-two fold higher than the 0.5 mg kg^{-1} dry weight level. Also, the high Cr contents in below-ground parts, stems and leaves indicate the Cr accumulation and detoxifying capability of these organs were determined in all species. While the distribution model for Cr was not observed in *P. lapathifolium*, *U. dioica* and *X. strumarium* (Tables 3, 5 and 6), it was accumulated in above-ground parts, especially in stems *of R. obtusifolius* (Table 4). A significant difference was found between the mean Cr content of total phytomass of all species at the different sampling sites ($P<0.05$; Tables 3, 4, 5, 6). The mean Cr contents in total phytomass of *U. dioica* and *X. strumarium* reflect the exchangeable Cr content in their sediments. The highest Cr content was measured in total phytomass of *U. dioica* (112 mg kg^{-1} dry weight; Table 5) and *X. strumarium* (193 mg kg^{-1} dry weight; Table 6) taken from the Buttim site which had the highest Cr content in sediment (Table 2).

The mean Cu content in total phytomass of all species was higher than the copper content in normal plants (4–15 mg kg^{-1} dry weight; Shaw et al. 2004). The mean Cu content ranged between 34–89 mg kg^{-1} dry weight (Table 4) in total phytomass of *R. obtusifolius* L. and this reflects the exchangeable Cu content in sediment (Table 2). The exchangeable Cu content of *R. obtusifolius* (89 mg kg^{-1} dry weight) increased towards the B. Balıklı sampling site which has the highest sediment Cu content (3.6 mg kg^{-1} dry weight). In other examined species, the highest Cu content of total phytomass was measured in plant samples taken from the Buttim site (Tables 3, 4, 5, 6). Although Cu content of above-ground parts of sorrel plants were higher than the Cu content in normal plants, the Cu contents of below-ground parts were at normal levels (8–17 mg kg^{-1} dry weight). Leaves

Table 6 Difference groups among sites regarding to average element contents (mg kg^{-1} dry weight) in above- and below-ground parts of *Xanthium strumarium* L. collected from four different points (Buski, Cilimboz, Buttim, B. Balıklı) along the Nilüfer stream, Bursa, Turkey [mean±standard deviation; different letters represent the difference groups among the sample sites (P<0.05)]

Elements	Sampling Sites	Below-ground phytomass	Above-ground phytomass			Total phytomass
			Stems	Leaves	Total	
Cr	Buski	24±6b	11±3b	7±2b	18±4b	42±8b
	Cilimboz	72±34b	12±3b	17±7a	28±5a	100±33b
	Buttim	160±44a	20±5a	13±3ab	33±3a	193±45a
	B. Balıklı	29±9b	17±3ab	16±3a	32±5a	61±2b
Cu	Buski	57±24b	42±6b	20±3b	61±6bc	119±26c
	Cilimboz	116±16a	40±7b	29±7b	68±7b	184±21b
	Buttim	148±30a	54±4a	43±3a	97±5a	245±28a
	B. Balıklı	23±5b	13±1c	39±6a	52±5c	75±8c
Mn	Buski	37±4b	11±4b	51±33a	62±34b	99±33c
	Cilimboz	70±22b	27±3a	86±6a	112±8a	182±16b
	Buttim	163±46a	19±4ab	53±9a	72±12b	235±48a
	B. Balıklı	66±11b	22±9ab	54±3a	76±8ab	142±6bc
Ni	Buski	39±14c	37±6a	17±4a	55±4b	94±14bc
	Cilimboz	96±23b	50±27a	32±17a	81±30ab	177±18ab
	Buttim	152±41a	52±20a	32±2a	85±20ab	237±58a
	B. Balıklı	17±5c	72±7a	25±17a	97±14a	114±11b
Zn	Buski	67±14a	39±15a	96±16b	135±17b	202±14b
	Cilimboz	131±76a	56±30a	279±14ab	335±34a	466±85a
	Buttim	121±28a	102±57a	256±102ab	358±67a	478±65a
	B. Balıklı	86±20a	39±20a	317±119a	356±168a	442±161a

seem to be the main Cu storage organs in above-ground phytomass of *R. obtusifolius* species (Table 4). The high Cu contents in leaves can be attributed to the function of this element in the basic metabolic activities of these organs. Copper is a co-factor in enzymes, e. g. plastocyanin, superoxide dismutase an amine oxidases (Hagemeyer 2004). Although a significant difference between in mean Cu content of total phytomass of all species (Tables 3, 4, 5, 6; $P<0.05$) between sites, the mean Cu contents of these species do not reflects the exchangeable Cu content in their sediments. These results indicate the Cu accumulation capability of all examined species and agree with previous studies. For instance, another *Polygonum* species, *P. thunbergii*, *P. mite*, accumulated Cu in studies by Samecka-Cymerman and Kempers (2002) and Kim et al. (2003). But the distribution model of Cu in *P. lapathifolium* and *X. strumarium* is not clear and is not similar to Cu distribution model in other examined species.

Among all species, the highest Mn content of total phytomass was found in *P. lapathifolium* and it varied between 234 and 566 mg kg^{-1} dry weight (Table 3). Mn values of this species were higher than that of a normal plant (200 mg kg^{-1} dry weight; Markert 1994) and these values indicate the Mn accumulation capacity of *P. lapathifolium*. But there was no a correlation between mean Mn content of total phytomass in this species and Mn content in sediment. For example: high Mn contents were measured in *P. lapathifolium* plants collected at the Buski and Cilimboz sample sites (566 and 513 mg kg^{-1} dry weight, respectively) which have lower sediment Mn contents than B. Balıklı (Table 2). This may reflect the high Mn accumulation capacity of *P. lapathifolium,* because it was reported that *Polygonum* species are good bioaccumulators (Qian et al. 1999; Samecka-Cymerman and Kempers 2001, 2002). In general, the mean Mn content in total phytomass of *R. obtusifolius, U. dioica* and *X.*

strumarium was lower than that of normal plants (200 mg kg^{-1} dry weight; Markert 1994) and reflected Mn content in sediments. The mean Mn content of these species was highest at site which had the highest exchangeable Mn content. There was significant difference between sample sites regarding to the Mn content in total phytomass of all species ($P<0.05$; Tables 3, 4, 5, 6). With the exception of cocklebur plants taken from the Buttim sample site, the mean Mn contents in above-ground parts of plants were lower than that of below-ground parts. The mean Mn contents of stems were lower than the mean Mn content of leaves in all species and all cases. For example, the mean Mn contents in leaves of *P. lapathifolium* plants taken from Buski are 3.5 fold higher than the Mn content of stems (Table 3). The contribution of leaves in Mn accumulation of plants reflects its function in plant metabolism, particularly its important role in the Hill reaction, where H_2O splits and O_2 releasing process (Hagemeyer 2004).

Ni concentrations in normal plants range from 0.5 to 5 mg kg^{-1} dry weight and the values exceeding these limits are reported as poisonous (Allen 1989). The mean Ni contents in all plant organs and in total phytomass of all examined species in this study were higher than this poisonous Ni level in normal plants (Tables 3 and 6). The mean Ni content was increased in the samples of *P. lapathifolium*, *U. dioica* and *X. strumarium* taken from the Buttim site (Tables 3, 5 and 6). The exchangeable Ni content of sediment was highest at Buttim (5.6 mg kg^{-1} dry weight) and this indicates that the Ni accumulation in these species increases depending on the Ni status of their habitats. Although high Ni contents of these species indicate a Ni detoxifying mechanism, there was no significant Ni distribution between plant parts in all species. Except for *R. obtusifolius*, significant differences were found between sample sites regarding to the mean Ni content in total phytomass of other species (Tables 3, 4, 5, 6).

Normal Zn concentration in plants is 50 mg kg^{-1} dry weight (Markert 1994). Allen (1989) reported that Zn concentrations in plants above 5–20 mg kg^{-1} dry weight are regarded as poisonous. The mean Zn content in total phytomass of all examined species was higher than these Zn levels (Tables 3, 4, 5, 6). This indicates that all species have Zn accumulation capacity in their organs. Our findings on Zn accumulation capacities of *P. lapathifolium* and *U. dioca* agree with the results of previous studies; Kim et al. (2003) concluded that *P. thunbergii* can effectively accumulate Zn. The mean Zn content in total phytomass of all species differed with site ($P<0.05$; Tables 3, 4, 5, 6), and the Zn plant content increased with increasing Zn content (Table 2).

Our findings suggest that *R. obtusifolius*, *P. lapathifolium*, *U. dioica* and *X. strumarium* may be considered bioaccumulation species for Cr, Cu, Ni, and Zn. Therefore, it seems that they can play a substantial role in remediation of polluted sites. But the contribution of different organs to accumulation capacity of total phytomass is specific to species. While *P. lapathifolium* have also Mn accumulation capacity, it was not observed in *R. obtusifolius*, *U. dioica* and *X. strumarium*. Our results demonstrate that the species studied can tolerate high heavy metal sediments and phytomass loadings.

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