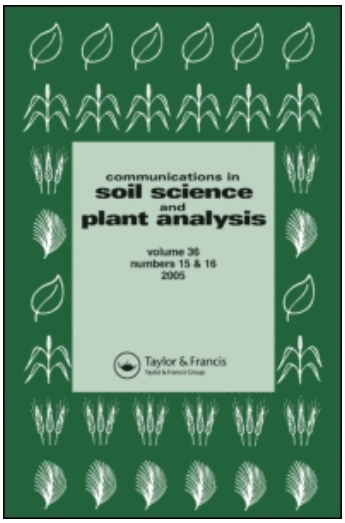

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Determination of Uranium and Thorium in Soil and Plant Parts around Abandoned Lead–Zinc–Copper Mining Area

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Abstract: This study reports distribution of uranium (U) and thorium (Th) in soil samples and the roots and shoots of some plants grown around an abandoned lead (Pb)–zinc (Zn)–copper (Cu) mining area. The plants *Euphorbia macroclada, Verbascum cheiranthifolium Boiss*, and *Astragalus gummifer* were examined. The determinations of U and Th were carried out by inductively coupled plasma-mass spectrometry (ICP-MS). Uranium and Th levels of the studied soil samples were found to be in the range of 1.1–70.3 mg kg^{-1} and 2.1–62.1 mg kg^{-1}, respectively. Some results obtained from this study were higher than the mean U and Th concentrations of soils reported around the world. Uranium and thorium concentrations in studied plant roots were in the range of 0.04–16 and 0.08–14.57 mg kg^{-1}, whereas in plant shoots they were 0.02–2.76 and 0.07–12.3 mg kg^{-1}, respectively. It was concluded that the shoots of *Astragalus* and roots of *Euphorbia* and *Verbascum* can be used as both a biomonitor for environmental pollution and biogeochemical indicator because of their higher U and Th concentrations.

Keywords: Biomonitor, hyperaccumulator, plant and soil contamination, thorium, uptake of toxic metals, uranium

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INTRODUCTION

Uranium (U) and its compounds are carcinogenic and highly toxic, which causes acute kidney failure and death in high concentrations as well as brain, liver, and heart diseases. As related to risk assessment of U compounds, an oral reference dose of $3.0\,\mu g\,kg^{-1}\,d^{-1}$ was recommended by the U.S. Environmental Protection Agency (USEPA). The minimal risk level (MLR) for oral exposure was developed by Agency for Toxic Substances and Disease Registry (ATSDR) as $2.0\,\mu g\,kg^{-1}\,d^{-1}$ for an intermediate duration (Craft et al. 2004). Similarly, thorium (Th) is also highly toxic and accumulates in the lungs and bones of humans and animals (Sarkar 2002). With respect to the degree of their toxicities originating from radioactive properties, U and Th rank alongside lead (Pb), mercury (Hg), and cadmium (Cd). It could be concluded that gamma radiation emitted from naturally occurring radioisotopes including the ^{232}Th and ^{238}U series, which exist at trace levels in all ground formations, represents the main external source of irradiation to the human body (Unscear 2000).

Because the accumulation is roughly a function of the deposited amount of pollutants, many plant species are useful for biomonitoring the environmental deposition of pollutants. On the other hand, the metal composition of vegetation reflects the availability of an element in the vicinity of the root system as well as the ability of the plant to absorb, transport, and accumulate the metal. A hyperaccumulating plant should typically contain at least 10 times more of a metal than plants from unpolluted environments or other plants grown in the same soil. For this purpose, metal analyses are generally carried out in various plant compartments such as roots, wood, bark, twigs, leaves, and flowers (Raju and Raju 1999; Tome, Rodriguez, and Lozano 2002).

The mean concentrations of U and Th in the upper continental crust were reported to be $2.5\,mg\,kg^{-1}$ and $10.3\,mg\,kg^{-1}$, respectively (Wedepohl 1995). These concentrations correspond to an activity concentration of $30.75\,Bq\,kg^{-1}$ for ^{238}U and $40.6\,Bq\,kg^{-1}$ for ^{232}Th. Another report showed that the mean value of radiation in the Earth's crust was calculated to be $39\,Bq\,kg^{-1}$ sourced from Th and $33\,Bq\,kg^{-1}$ from U (Sarkar 2002).

Mean U and Th concentrations of soils around the world are reported in the range of 0.79–11.0 and 3.4–$10.5\,mg\,kg^{-1}$, respectively (Kabata-Pendias and Pendias 2001). In addition, Th concentrations in uncontaminated areas were reported to be relatively high, from 8 to $27\,mg\,kg^{-1}$ for soils in China and from 3.8 to $12.4\,mg\,kg^{-1}$ for soils in the USA. Furthermore, higher U and Th levels were found to be 7.7 ± 1.7 and $60.4 \pm 28.6\,mg\,kg^{-1}$, respectively, in the surface soils taken from high background areas in comparison with the values observed

for an uncontaminated area, 1.7 ± 0.7 and 7.9 ± 3.2 mg kg^{-1} (Sarkar 2002). The contaminated areas include anthropogenic activities, especially those related to mining, industrial emissions, disposal or leakage of industrial wastes, and application of sewage sludge to agricultural soils.

Thorium and U commonly exist in the 4+ and 6+ oxidation states in the most geologic environments. Hydroxide compound of Th^{4+} readily precipitates and also is quickly adsorbed on some weathered deposits. During weathering, organic complexes of U occur, which are easily soluble and in the mobile phase. However, various relatively stable compounds of U including oxides, carbonates, phosphates, and arsenates occur under arid conditions (Kabata-Pendias and Pendias 2001).

Granitic areas may contain high concentrations of U and Th. Sometimes, major U anomalies may be observed after the exploitation of the mineral, and U mines enter a phase of inactivity until its restoration (Tome, Rodriguez, and Lozano 2002). Relatively, however, there are fewer published articles on U and Th determinations in soils and plants with respect to their degree of toxicity.

In the literature, the levels containing <8 to 1300 μg kg^{-1} U and <5 to 20 μg kg^{-1} Th were reported for plant samples (Vargas et al. 1997; Raju and Raju 1999; Tzortzis and Tsertos 2004). Furthermore, higher levels of U and Th in plants grown in industrial areas were reported in some studies (Kabata-Pendias and Pendias 2001; Sarkar 2002). It is known that U and Th contents of soils depend on their geological composition and on contaminants. Tome, Rodriguez, and Lozano (2002) studied the distribution and mobilization of U and Th in the plant–soil compartments that contain mineralized U area. They found that there is a correlation among the U and Th activity concentrations in soils ($r = 0.926$ for affected from mineralized zone and $r = 0.807$ for unaffected zone). In the literature, average daily intake of Th and U in food and water by ingestion and by inhalation were reported to be 5 and 17 mBq for Americans, respectively (Sarkar 2002).

It is known that U and Th elements are revealed during mineralizing of Pb and zinc (Zn) ores (Sagiroglu, Sasmaz, and Sen 2006). Thus, U and Th could be enriched in a mineralized or unmineralized area of the abandoned mining region.

The aim of this study is to examine the distribution of U and Th in the soil samples and the roots and shoots of plants grown around the abandoned mining area. This district has a mining history as long as 6000 years, and the area had been heavily charged with metals by ancient and modern mining activities. The examined plant species are naturally and commonly grown in this area. In addition, the absorption degrees of plant parts including roots and shoots from soil for U and Th were examined.

MATERIALS AND METHODS

Apparatus

A Perkin-Elmer Elan 9000 (Waltham, Mass., USA) inductively coupled plasma mass spectrometer was used for the determination of uranium and thorium. The operation conditions as recommended by the manufacturers (Elan 9000, 2001) are given in Table 1.

Study Area

In this study, the plants and the associated soil samples were collected from the area of the granite-syenites rocks in the Keban mining district of the Elazig province in eastern Turkey (Figure 1). The plant samples together with their roots and soils were taken from 20 sites (nine *Euphorbia*, five *Verbascum* and six *Astragalus*) of Keban mining areas in Elazig, Turkey. ^{14}Carbon absolute age determinations on wooden mining tools were discovered in ancient mining cavities by Seeliger et al. (1985). Copper, iron (Fe), and fluoride (F) ores were mined in this region, only in short periods. The control groups were taken from a basaltic region as far 100 km from the mining area. The plant species in the Keban region are those that can grow in severe climate conditions because of their massive and deep-reaching root systems, which give them ability to live in an organic-matter-deficient area. In this study, *Euphorbia macroclada Boiss* (local name: Sütlegen), *Verbascum cheiranthifolium Boiss* (local name: Sigir Kuyrugu), and *Astragalus gummifer* (local name: Keven) were examined for their U and Th contents.

Table 1. Operation conditions for ICP-MS

Parameter	Value
Inductively coupled plasma instrument	Perkin-Elmer Elan 9000
Nebulizer	Crossflow
Spray chamber	Ryton, double pass
RF power	1000 W
Plasma gas flow rate	15 L min^{-1}
Auxiliary gas flow rate	1.0 L min^{-1}
Carrier gas flow rate	0.9 L min^{-1}
Sample uptake rate	1.0 mL min^{-1}
Detector mode	Auto
Analytical masses	^{238}U, ^{232}Th
Internal standard	Ir

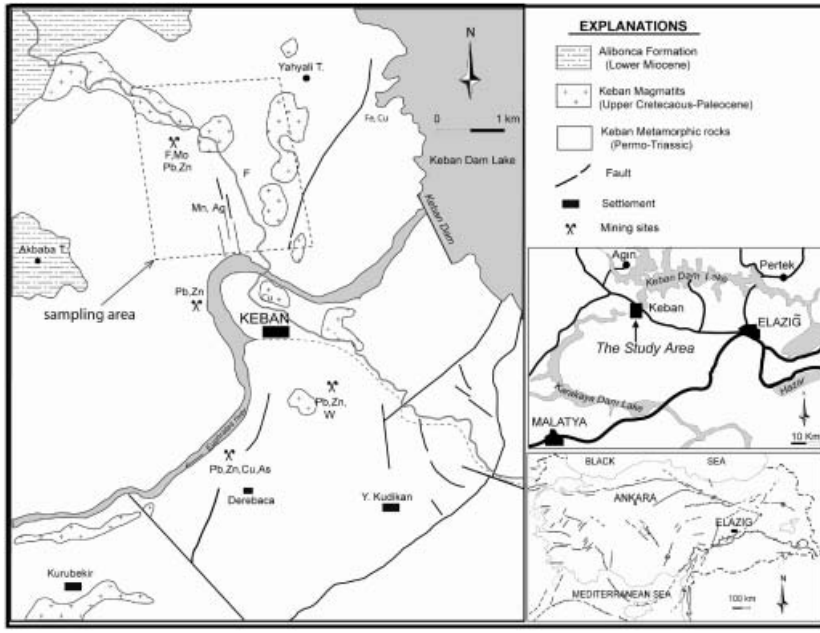

Figure 1. Location and geological map of the study area (Akgul 1987).

Preparation of Samples

Plant Samples

Plant samples were randomly collected and the collection sites were determined in accordance with a pattern that represents the whole of the Keban mining area. Three samples of shoots and roots were taken from each sampling sites. The root samples were taken from a depth of 30–40 cm from the surface. The shoot and root samples of the studied plants were thoroughly washed with tap water, followed by distilled water, and dried at 100 °C in an oven for 30 min and then at 60 °C for 24 h. The chelate ethylenediaminetetraacetic acid (EDTA) washing was applied, and no difference was observed between samples washed with EDTA and washed samples. The dried plant samples (approximately 2.0–3.0 g) 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 nitric acid (HNO_3) for 1 h followed by the mixture of hydrochloric acid (HCl)–HNO_3–H_2O for 1 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.

Soil Samples

Three soil samples (1.0 g) from surrounding roots of the plant samples were collected at 30- to 40-cm depths. After drying in oven at 100 °C for 4 h and removing rocks, the soil samples were ground using hand mortars. For digestion of the soil samples, the mixture of $HCl–HNO_3–H_2O$ (6 mL of the mixture of 1:1:1 was used for 1.0 g) was used for 1 h at 95 °C. Thus, all sample constituents except silicates were digested.

Transfer Factor and Translocation Factor

Transfer factor (TF) were found by calculating the ratios of specific activities in plant parts and soil (concentration in $mg\,kg^{-1}$ of plant compartment divided by concentration in $mg\,kg^{-1}$ of soil) because it can be used as an index for the accumulation of trace elements in plants or the transfer of elements from soil to plants (Yanagisawa, Muramutsu, and Kamada 1992; Whicker et al. 1999; Chen, Zhu, and Hu 2005). Translocation factor was obtained by calculating the ratio of heavy metals in plant shoot to that in plant root. In metal accumulator species, translocation factors greater than 1 were common, whereas in metal excluder species, translocation factors, were typically less than 1 (Baker 1981; Shen and Liu 1998; Zu et al. 2005).

RESULTS AND DISCUSSION

Uranium and Th contents of the studied soil samples were found to be in the range of 1.1–70.3 $mg\,kg^{-1}$ and 2.1–62.1 $mg\,kg^{-1}$, respectively (Table 2, Figures 2 and 3), depending on plant species. Among 20 soil samples, U concentrations in all samples except one were observed to be higher than in those concentrations (1.7 $mg\,kg^{-1}$) of uncontaminated soils, whereas Th concentrations of 11 samples were found to be higher than those concentrations of uncontaminated soils (7.9 $mg\,kg^{-1}$) reported by Sarkar (2002). These results can be attributed to the mineralization of the studied area, which contains sulphide ores of Pb, Zn, silver (Ag), and CaF_2. For example, the soil EU-29 is a Pb–Zn–Cu–molybdenum (Mo) ore, and the highest U concentration was observed in this soil. A significant linear correlation (at least $r = 0.82$) between U and other metals including Mo, Cu, Pb, Zn, Fe, arsenic (As), cobalt (Co), and cadmium (Cd) was observed, whereas insignificant linear correlation between U and Th ($r = 0.16$) was seen (Table 3). Unlike U, no significant linear correlation between Th and other elements was found. There is even negative correlation between Th and some elements including

Table 2. U, Th, and other metal contents in soil with roots and shoots of studied *Euphorbia, Verbascum*, and *Astragalus*

S. no.	U (mg/kg)						Th (mg/kg)					
	Soil	Root	Shoot	TF (root/soil)	TF (shoot/soil)	TLF (shoot/root)	Soil	Root	Shoot	TF (root/soil)	TF (shoot/soil)	TLF (shoot/root)
EU-21	12.7 ± 1.05	3.57 ± 0.38	0.12 ± 0.012	0.28	0.010	0.034	62.1± 7.1	14.57 ± 1.57	0.49 ± 0.06	0.24	0.008	0.340
EU-24	2.5 ± 0.21	0.41 ± 0.05	0.03 ± 0.004	0.16	0.012	0.073	5 ± 0.60	0.85 ± 0.12	0.07 ± 0.01	0.17	0.014	0.082
EU-26	6.4 ± 0.72	0.80 ± 0.11	0.11 ± 0.012	0.13	0.017	0.138	8.5 ± 0.92	1.21 ± 0.18	0.11 ± 0.02	0.14	0.013	0.091
EU-29	70.3 ± 9.93	16.02 ± 1.83	0.42 ± 0.053	0.23	0.006	0.026	13.2 ± 1.40	3.96 ± 0.48	0.16 ± 0.04	0.31	0.012	0.041
EU-31	11.6 ± 1.47	1.68 ± 0.18	0.16 ± 0.012	0.15	0.013	0.095	10.2 ± 0.98	6.30 ± 0.61	0.27 ± 0.04	0.63	0.027	0.043
EU-34	9.6 ± 0.98	2.05 ± 0.22	0.42 ± 0.043	0.21	0.044	0.204	41 ± 4.37	9.24 ± 1.43	1.82 ± 0.22	0.23	0.045	0.197
EU-41	2.3 ± 0.32	0.75 ± 0.08	0.06 ± 0.005	0.32	0.026	0.08	3.1 ± 0.45	0.85 ± 0.09	0.07 ± 0.01	0.27	0.022	0.082
EU-44	3.9 ± 0.45	1.30 ± 0.14	0.07 ± 0.006	0.33	0.018	0.054	2.3 ± 0.31	0.85 ± 0.10	0.09 ± 0.02	0.37	0.039	0.105
EU-45	1.1 ± 0.13	0.57 ± 0.06	0.02 ± 0.003	0.52	0.018	0.035	3.6 ± 0.38	0.97 ± 0.13	0.07 ± 0.01	0.27	0.019	0.072
Mean	13.3	3.02	0.16	0.23	0.018	0.052	16.6	4.31	0.35	0.26	0.021	0.117
SD	21.7	4.97	0.16				20.8	4.88	0.57			
VR-25	3.1 ± 0.41	0.04 ± 0.001	0.87 ± 0.09	0.01	0.28	21.8	4 ± 0.42	0.08 ± 0.11	1.78 ± 0.23	0.20	0.45	21.00
VR -25Y	3.1 ± 0.41	0.26 ± 0.04	0.42 ± 0.05	0.08	0.14	1.62	4 ± 0.42	0.51 ± 0.04	0.84 ± 0.10	0.13	0.21	1.65
VR-27	7.9 ± 0.95	2.44 ± 0.26	2.76 ± 0.35	0.31	0.35	1.13	36.8 ± 1.81	11.61 ± 1.24	12.3 ± 1.40	0.31	0.33	1.06
VR-35	9.6 ±1.08	0.72 ± 0.07	1.65 ± 0.17	0.08	0.18	2.29	41.3 ± 4.28	3.75 ± 0.52	8.6 ± 0.68	0.09	0.21	2.29
VR-47	1.8± 0.21	0.46 ± 0.05	0.43 ± 0.03	0.26	0.24	0.93	2.1 ± 0.32	0.75 ± 0.09	0.78 ± 0.12	0.36	0.37	1.04
Mean	5.1	0.78	1.23	0.16	0.25	5.55	17.64	3.34	4.86	0.19	0.28	5.41
SD	3.4	0.96	0.99				19.62	4.84	5.28			
AS-22	6.9 ± 0.92	n.a.	0.81 ± 0.98	n.a.	0.12		14.4 ± 1.68	n.a.	1.66 ± 0.20	n.a.	0.16	
AS-28	10 ± 1.12	n.a.	2.16 ± 0.18	n.a.	0.22		35.4 ± 5.22	n.a.	8.51 ± 0.99	n.a.	0.24	
AS-32	10.7 ± 1.05	n.a.	2.30 ± 0.26	n.a.	0.21		10.9 ± 1.06	n.a.	2.91 ± 0.35	n.a.	0.26	
AS-36	13.9 ± 1.48	n.a.	2.39 ± 0.27	n.a.	0.17		17.7 ± 2.04	n.a.	3.55 ± 0.34	n.a.	0.20	
AS-40	2.6 ± 0.32	n.a.	0.59 ± 0.08	n.a.	0.23		2.2 ± 0.18	n.a.	0.82 ± 0.07	n.a.	0.38	
AS-42	2.9± 0.27	n.a.	0.82 ± 0.09	n.a.	0.28		2.5 ± 0.31	n.a.	1.03 ± 0.11	n.a.	0.41	
Mean	7.8		1.51		0.19		13.9		3.08		0.27	
SD	4.5		0.85				12.3		2.87			

n.a.: not available.

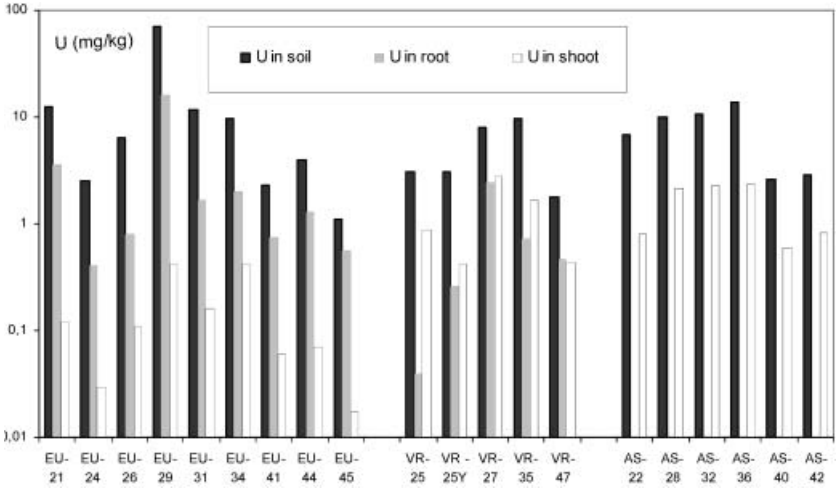

Figure 2. Histogram for U contents of soil, root, and shoot samples (EU: *Euphorbia*, VR: *Verbascum*, AG: *Astragalus*) in Keban mining area (mg per kg of dried sample).

calcium (Ca; r = −0.93), magnesium (Mg; r = −0.59), and potassium (K; r = −0.62). Thus, it can be said that U was transferred to the mining area in its hydrothermal solution (hot and mineralized solution transported the metals in the magma layer) together with other metals including Mo, Cu, Pb, Zn, Ag, Co, Fe, As, Cd, and K (Table 3).

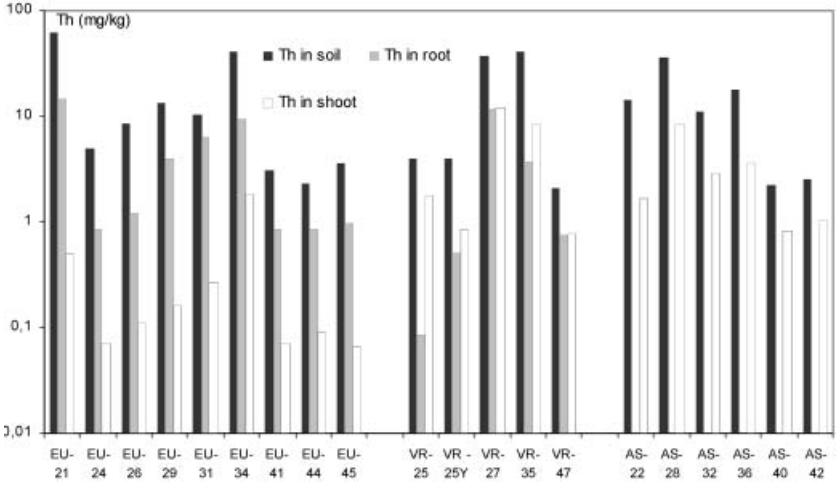

Figure 3. Histogram for Th contents of soil, root, and shoot samples (EU: *Euphorbia*, VR: *Verbascum*, AG: *Astragalus*) in Keban mining area (mg per kg of dried sample).

Table 3. Correlation relationships among U and Th and other elements in soil samples

	U	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	Cd	Ca	Cr	Mg	K
U	—	0.88	0.96	0.82	0.96	0.87	−0.20	0.87	0.12	0.87	0.89	0.96	−0.25	−0.06	0.05	0.46
Th	0.16	−0.16	−0.05	−0.22	−0.06	−0.08	−0.59	−0.27	−0.40	−0.25	−0.17	−0.07	−0.93	−0.83	−0.59	−0.62

The assessment of Th and U uptake by plants from contaminated soils has high importance for environmental studies because of their biomonitoring possibilities. It was reported that the soluble fractions of these elements in soils seem to be readily absorbed by plants, and this is clearly supported by the studies conducted in the U geochemical province (Kabata-Pendias and Pendias 2001). Bowen (l979) reported U concentrations of terrestrial plants were in the ranges of 5 to 60 $\mu g\,kg^{-1}$, and Th concentrations of land plants were in the ranges of <8 to 1300 $\mu g\,kg^{-1}$ on the dried-weight basis. Laul, Weimer, and Rancitelli (1979) reported U concentrations in corn and potatoes were about 0.8 $\mu g\,kg^{-1}$, and Th concentrations in vegetables were in the range of <5 to 20 $\mu g\,kg^{-1}$ on the dried-weight basis. In addition, Rühling et al. (1987) found U concentrations were in ranges of 30 to 120 $\mu g\,kg^{-1}$ on the dried-weight basis. In recent years, it was reported that Th concentration range was between 4 and 5100 $\mu g\,kg^{-1}$ (mean 70 $\mu g\,kg^{-1}$) and U concentration range was between 2.8 and 1300 $\mu g\,kg^{-1}$ (mean 50 $\mu g\,kg^{-1}$) for plant samples (Berg and Steinnes 1997).

Uranium and Th concentrations in soil samples taken from control area were found to be in the ranges of 0.07–0.51 and 0.16–2.22 $mg\,kg^{-1}$, respectively. As it can be seen from the Table 2 and Figures 2 and 3, the obtained U concentrations in all soil samples except one were found to be higher than those in the control area described previously (mean 0.3 $mg\,kg^{-1}$). Similarly, the obtained Th concentrations in 11 soil samples were found to be higher than those in uncontaminated areas described previously (mean 1.2 $mg\,kg^{-1}$). It is seen from Figure 4 that Th levels in soil samples change depending on U levels in the same samples. Similarly,

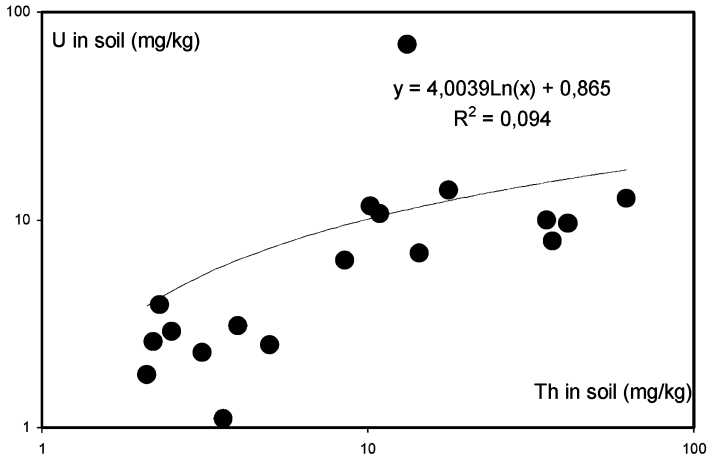

Figure 4. Correlation relationships between U and Th in the soil samples.

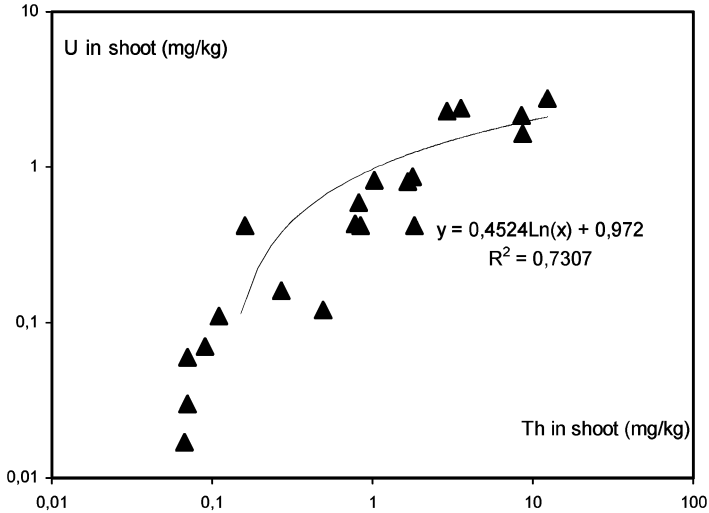

Figure 5. Correlation relationships between U and Th in the shoot samples.

it is also seen that Th concentrations in shoots change depending on U levels in the shoot samples (Figure 5).

Briefly, significant positive correlations were observed between U and Mo, Cu, Pb, Zn, Ag, and As in soil (unpublished data). On the other hand, it was observed that there are not significant positive correlations between Th and the other studied elements (Table 3). The interpretations related to U and Th levels in the studied plant compartments are given later in detail.

Euphorbia (EU)

From Table 2 and Figures 2 and 3, U concentrations in two shoots (EU-29 and EU-34) and two roots of *Euphorbia* plant (EU-21 and EU-29) were found to be significantly higher than in the mean levels of the studied *Euphorbia* samples, whereas Th levels of three roots (EU-21, EU-31, and EU-34) and two shoots (EU-21 and EU-34) were observed to be significantly higher than in the mean level of the studied *Euphorbia* samples. These concentrations are also higher than the normal U and Th concentrations in plants. As can be seen from Figures 2 and 3, both U and Th concentrations in root of *Euphorbia* are correlated to the soil U and Th levels. The similar observations were also found for the shoots of *Euphorbia*. Consequently, it is clearly seen from Table 2 and Figures 2 and 3 that the absorbed U from soil by roots do not transfer to the shoots, and similar results can also be seen for Th. Transfer factors for U

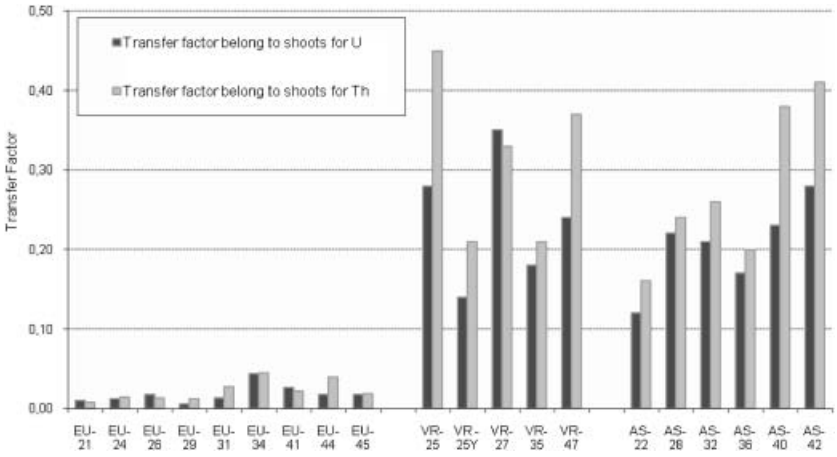

Figure 6. Transfer factors belonging to shoots from soil for uranium and thorium.

and Th belonging to shoots of *Euphorbia* have low values and change between 0.001–0.046 and 0.008–0.045, respectively (Table 2, Figure 6). This also shows that *Euphorbia* shoots could not be used as a hyperaccumulator or biomonitor. However, transfer factors for U and Th belonging to roots of *Euphorbia* change between 0.13–0.52 (mean 0.23) and 0.14–0.63 (mean 0.26), respectively (Figure 7). The mean translocation factor for *Euphorbia* is 0.05 for U and 0.117 for Th. Thus, transfer and translocation factor values for U and Th of *Euphorbia* are low, and *Euphorbia* cannot be suitable for hyperaccumulation and/or

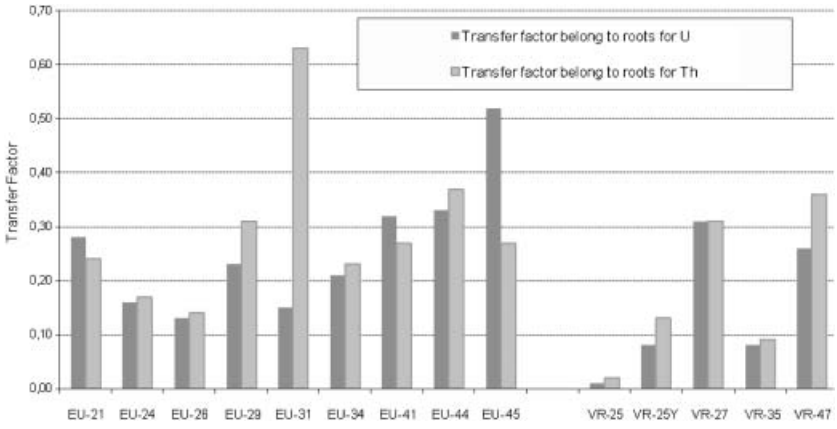

Figure 7. Transfer factors belonging to roots from soil for uranium and thorium.

biomonitoring (Table 2). Furthermore, hyperaccumulating plants should typically contain, at least, equal or more metal than plants from unpolluted environments or the plants grown in the same soil (Zu et al. 2005). Uranium and Th concentrations in *Euphorbia* taken from control area were found to be 0.0015 and 0.006 for shoot and 0.018 and 0.052 for root, respectively.

Verbascum (VR)

From the Table 2 and Figures 2 and 3, U concentrations in two shoots (VR-27 and VR-35) and one root (VR-27) of *Verbascum* and Th levels of two roots (VR-27 and VR-35) and two shoots of *Verbascum* (VR-27 and VR-35) were found to be significantly higher than in the mean levels of the studied samples.

As can be seen from Table 2 and Figures 2 and 3, both U and Th concentrations in *Verbascum* shoots (mean 1.23 for U and 4.86 for Th) are slightly higher than in the *Verbascum* roots (mean 0.78 for U and 3.34 for Th) for all samples except one, unlike *Euphorbia*. This can be attributed to the less absorption of these two elements by the *Verbascum* roots and more transfer of Th and U from roots to shoots (mean transfer factors are 0.16 for U and 0.19 for Th). Therefore, we suggest that *Verbascum* shoots can be used for biomonitoring of environmental pollution and as a biogeochemical indicator for U and Th. In addition, it was observed that there are antagonistic effects among U and Th in VR-27 and VR-35 and other elements including Mo, Pb, Cu, and Zn in *Verbascum*. There are lower U and Th concentrations ($mg\,kg^{-1}$) in roots and shoots of VR-35 (0.72 in root and 1.65 in shoot for U; 3.75 in root and 8.6 in shoot for Th) than those in VR-27 (2.44 in root and 2.76 in shoot for U; 11.61 in root and 12.30 in shoot for Th) in spite of higher U and Th levels in soil of VR-35 (9.6 and 41.3) than in VR-27 (7.9 and 36.8), respectively. Transfer factors of U and Th for shoots/soil of *Verbascum* have very high values and change from 0.14 to 0.35 (mean 0.25) and 0.21 to 0.45 (mean 0.28), respectively (Figure 6, Table 2). Transfer factors from soil to roots of *Verbascum* change from 0.01 to 0.31 (mean 0.16) for U and 0.02 to 0.36 (mean 0.19) for Th. The corresponding factors from soil to shoots are 0.25 for U and 0.28 for Th as mean values. Translocation factor, the indicator of biomonitoring or hyperaccumulating, was described as high translocation of elements from roots to shoots (Shen and Liu 1998). *Verbascum* has quite high translocation factors for U (mean 5.55) and Th (mean 5.41) (Table 2). Furthermore, U and Th concentrations in *Verbascum* taken from the control area were found to be 0.011 and 0.030 for shoot and 0.016 and 0.054 for root, respectively. From this point, it also reveals that *Verbascum* shoots can be a good

biomonitoring plant for U and Th because these elements do not remain in the roots and transfer to shoots of this species. Thus, *Verbascum* shoots may be considered a hyperaccumulator or biomonitoring plant.

Astragalus (AS)

From Table 2 and Figures 2 and 3, both U levels in three shoots (AS-28, AS-32, and AS-36) and Th concentrations in two shoots of *Astragalus* were found to be higher than the mean levels (1.51 for U and 3.08 for Th) of the studied *Astragalus* samples. Although Th concentration in the soil of AS-22 ($14.4\,mg\,kg^{-1}$) is higher than in the soil of AS-32 ($10.9\,mg\,kg^{-1}$), lower Th concentration ($1.66\,mg\,kg^{-1}$) in the shoot of this *Astragalus* sample grown in soil of AS-22 ($14.4\,mg\,kg^{-1}$) than in the shoot of an *Astragalus* sample grown in soil of AS-32 ($2.91\,mg\,kg^{-1}$) was observed. The obtained U concentrations in all studied soil samples represented to *Astragalus* were higher than in the mean U concentration in upper continental crust ($2.5\,mg\,kg^{-1}$) and in the control area (mean $0.3\,mg\,kg^{-1}$). Similarly, the obtained Th levels in all studied soil samples represented to *Astragalus* were higher than in the mean Th concentration in upper continental crust ($10.3\,mg\,kg^{-1}$) and in the control area (mean $1.2\,mg\,kg^{-1}$). Uranium and Th concentrations in *Astragalus* taken from the control area were 0.012 and 0.057 for shoot and 0.010 and 0.014 for root, respectively.

Briefly, distributions of U and Th between the studied soil and plant compartments were given in Figures 2 and 3. From Figures 2 and 3, it is seen that U and Th levels in both roots and shoots of both *Euphorbia* and *Verbascum* linearly change with U and Th concentrations in the represented soil samples. Similarly, U and Th levels in shoots of *Astragalus* linearly vary with U and Th concentrations in soil samples. Transfer factors for U and Th belonging to shoots of *Astragalus* have very high values and change from 0.12 to 0.28 (mean 0.19) and 0.16 to 0.41 (mean 0.27), respectively (Figure 6, Table 2). A hyperaccumulating plant should typically contain, at least, 10 times more of a metal than plants from unpolluted environments or other plants grown in the same soil (Zu et al. 2005). From Table 2, it is seen that the shoots of *Verbascum* and *Astragalus* samples have more than 10 times both U and Th in comparison with *Euphorbia* samples. These results show that *Verbascum* can also be a very good hyperaccumulator and/or biomonitor plant.

CONCLUSIONS

The concentrations of U and Th in shoots and roots of plants change depending on the plant species. Because the increase in U and Th

concentrations of plant compartments depend on the concentrations in soil samples, the shoots of *Astragalus*, the roots of *Euphorbia*, and the roots and shoots of *Verbascum* can be used both as biomonitors for environmental pollution and biogeochemical indicators. In addition, their higher U and Th concentrations as well as higher ratios of these elements in roots/soil, shoot/soil, and shoot/root also support this opinion. Particularly, good translocation of U and Th from roots to shoots in *Verbascum* better reflects this state. Furthermore, *Verbascum* can be classified as a hyperaccumulator because its translocation factor is higher than 1.0. In addition, among the studied plant samples, *Astragalus* can pose a health risk to humans because of its usage for medicinal purposes. Similarly, the plants with high U and Th concentrations may also be harmful for the animals when they feed with these plants.

From the current results, it may be said the soil around the mining area should be kept under observation because of high U and Th concentrations.

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