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The accumulation of strontium by native plants grown on Gumuskoy mining soils

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ABSTRACT

The Gümüsköy mining area is located about 25 km west of Kütahya and the largest silver deposit in Turkey. The present study investigated the translocation and accumulation of Sr from the Gümüşköy mining soils into 11 native plants. Plant and soil samples were collected from the field, and Sr concentrations were analyzed by ICP-MS. The average Sr values in the soil, root, and shoot of the native plants in the study area were 148.55, 163.65, and 163.93 ppm, respectively. The plants were separated to several groups (the best plants, good plant and candidate plants) according to ECS and ECR values of these plants. These groups showed that the best plants; *Carduus nutans*, *Onosma* sp., *Alyssum saxatile*, *Anchusa arvensis* and *Centaurea cyanus*, good plants; *Verbascum thapsus*, *Isatis*, *Phlomis* sp., *Cynoglossum officinale* and *Glaucium flavum* and candidate plants; *Silene compacta* for Sr. The present study revealed that both the best and good plants in the study area had very high potential to remove Sr, Therefore, these plants can be useful for remediation or phytoremediation studies of soils polluted by Sr.

1. Introduction

Strontium (Sr) is one of the common trace elements and varies between 370 and 260 ppm in lithosphere. Sr generally observes in felsic magmatic rocks and carbonate sediments. The biochemical and geochemical characteristics of this element are similar to those of calcium. Sr is mobilized as easily soluble $SrCO_3$ (strontianite) in the formation of sulfuric and calcareous sediments and deposited as $SrSO_4$ (celestite) later. The presence of this mineral in terrestrial areas is an environmental risk (Kabata-Pendias, 2011). Celestite is widely used in making special glass, glass fiber, electro-ceramic sector, fireworks, Zn refining and television monitor (Temur, 2001). Sr content of soils is controlled highly by climate and parent rocks. The highest level of Sr was found in heavy loam soils. The Sr contents in uncontaminated soils range from 20 to 140 ppm in sandstones, 300 to 450 ppm in clays, 20 to 1000 ppm in podzols, 20 to 3100 ppm in cambisols, and 70 to 500 in histosol (Kabata-Pendias, 2011). The toxicity of heavy metals is one of the main problems for the environment because of their persistent and non-biodegradable characters in nature and bioaccumulate in the body of living animals and plants (Khan et al., 2014; Mani et al., 2016; Iqbal, 2016; Iqbal et al., 2016). These heavy metals (Sr, Cd, As, Cu, Ag, Zn, Cr, Pb, Co, Ni, U, Th, Hg, Tl, and Sb) in mining areas contaminate the surface soils and the water (US EPA, 2000; Wong, 2003) and they can be removed through the use of different plants (Iqbal and Khera, 2015; Iqbal et al., 2017). The Sr concentrations of the plants vary depending on the Sr concentration in the soils. Although Sr is not a plant micronutrient, it is absorbed following the plant's metabolic requirements for Ca and related to both mechanism of mass flow and exchange diffusion. Kabata-Pendias (2011) suggested that interactions between P and Sr apparently are related to processes in soil; however, opinions vary as to the effects of P on Sr adsorption by plants. There are no more reports on Sr toxicity and tolerance in plants, but Shacklette et al. (1978) found a toxic Sr value for plants as 30 ppm. Both stable and radioactive strontium use the same way to enter the body. If a person breathes in dust and vapors containing a chemical form of strontium, after that, these will dissolve in the wet surface of the lungs, then, enter the bloodstream quickly. If the chemical forms of Sr do not dissolve easily in water, then the particulates may stay in the lung for a long time. If you eat food that contains Sr, a small portion remains only in the intestines and others enter the bloodstream (ATSDR, 2004). Therefore, it may also cause undesirable physiological and biochemical functions in humans and animals because of various toxic effects on lung, and the reproductive system. Among the various techniques for removal of heavy metals, phytoremediation is the cheapest method to remove them from the soil and water (Ansari et al., 2015; Sasmaz et al., 2015; Sasmaz et al., 2016a, 2016b). Phytoremediation is based on the metal accumulation

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Table 1
Operation conditions for ICP-MS.

Inductively coupled plasma	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	Sr
Internal standard	Ir

capacities of each plant according to their different characters such as the morphologic, physiologic, genetic, and anatomic (Yoon et al., 2006; Liu et al., 2008). There are many reports investigating the accumulation of radioactive Sr in the terrestrial plants but no more reports and information about stable Sr accumulations of native plants. For this reason, the main purpose of this study was (i) to investigate Sr uptake and transport from soil to plant parts by studying the distribution and accumulation of Sr in the roots and shoots of 11 native plant species growing naturally in Sr-contaminated surface soils of the Gumuskoy mining area in Kutahya, Turkey, (ii) eventually to evaluate whether these plants can be used in rehabilitation of soils polluted by Sr or not.

2. Materials and methods

2.1. Apparatus

Both soil and plant samples for Sr concentrations were analyzed with ICP-MS (Perkin-Elmer ELAN 9000) technique. The operation conditions of ICP-MS for Sr are given in Table 1.

2.2. The study area

The study area is situated in the west of Kütahya, Turkey (between 38°96′–39°48′N latitude and 29°48′–29°71′E longitude) about 25 km (Fig. 1) and observed both the continental climate and the mild climate. The summer is dry and hot, while winter is rainy and cold. The average temperature of the region is about 10.5 °C. The forests of Kütahya are spread over a large area surrounding the city and have high economic value because they contain many endemic trees and herbal plants. Gumuskoy mining area is the largest silver deposit of Turkey. The plant and soils were collected from the Gümüsköy's soils. Gümüsköy mining area is situated among the Dulkadir, Sahin and Gümüsköy villages. Arik (2002, 2012) and, Arık and Yaldız (2010) detected that Gümüsköy and its surrounding have been intensely contaminated with both modern and ancient mining activities by the different metals because of long mining period (Kartalkanat, 2008). A number of polymetallic ore deposits represented by Ag, As, Tl, Pb, Zn, and Sb around the Gumuskoy and Sahin villages (Arik, 2002) and B, Fe, Cu, Pb and Au in the western and northern parts of Turkey (Helvacı, 2015; Altun et al., 2015; Tiringa et al., 2016; Cihan et al., 2016; Palutoglu and Sasmaz, 2017) observe. In this region, outcrops metamorphic, volcanic and sedimentary rocks ranging from Permian to present-day eras are present (Fig. 1).

2.3. Plant and soil samples

All samples were randomly taken in July and May of 2013 from the mining district. The soil samples were collected from 39 different points in mining area between 0.10 and 0.40 m depths. The colors of the soils change to dark brown from light brown. The studied plants grown as a native plant in nature and mostly live a few years. Sr concentrations were investigated in 11 dominant and native species growing around and in the study area: *Alyssum saxatile* (AL), *Cynoglossum officinale* (CY), *Anchusa arvensis* (AN), *Onosma* sp. (ON), *Glaucium flavum* (GL), *Phlomis* sp. (PH), *Carduus nutans* (CR), *Silene compacta* (SL), *Verbascum thapsus* (VR), *Isatis* (IS), and *Centaurea cyanus* (CE). After soil samples are dried at 100 °C in an oven. It was digested in a mixture of HNO_3; H_2O; HCl for 1 h at 95 °C. This digest was analyzed in ICP-MS for Sr. In tap water, the root and shoot parts of plants were thoroughly washed and dried at 60 °C, after that, ashed at 300 °C for 24 h. The ashed plants were digested in HNO_3 for 1 h, mixed with H_2O, HCl, HNO_3. The digest was measured in ICP-MS techniques for Sr (it was used Group AQ 200 for soil samples and Group VG104 for ashed plant samples in Acmelab, Canada).

2.4. ECR

The enrichment coefficients (ECR) for root were calculated by dividing to soil concentration of plant root concentration for each plant.

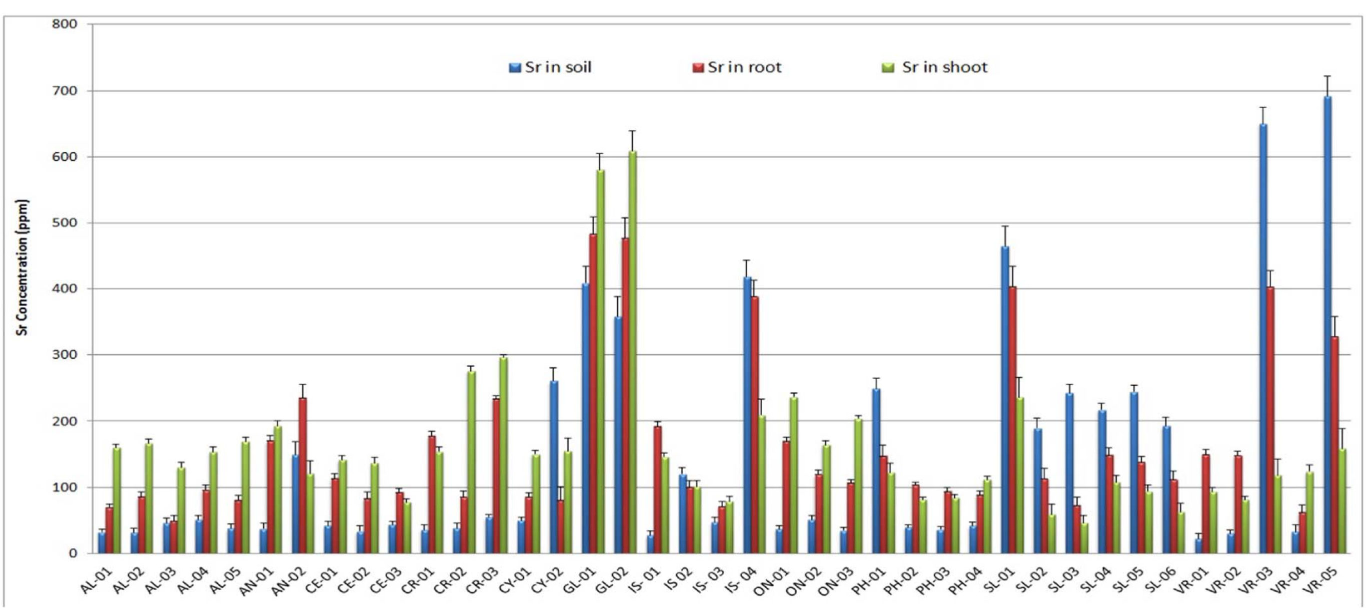

Fig. 1. The Sr concentrations of soils, roots and shoots of 11 plant species.