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Distribution of heavy metals and arsenic in soils and indigenous plants near an iron ore mine in northwest Iran

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ABSTRACT

Heavy metal contaminations in the environment of mining area have become a global problem. The vicinity of an iron ore mine was investigated to estimate the concentrations of As, Pb, Cd, Mn, Ni, Zn, and Cr in the soil and the feasibility of using native plants for phytoremediation. For this, concentrations of elements in soil samples collected and were analyzed by inductivity coupled plasma optical emission spectrometry. The concentrations of heavy metals and arsenic in the roots and aerial parts of *Dactylis glomerata* L. and *Scleranthus orientalis* Rössler were analyzed by inductively coupled plasma mass spectrometer too. As concentrations in the samples surpassed the soil toxicity threshold. Cd concentration in soil samples was considerably high next to mine pit. Neither species was identified as a hyperaccumulator, but both species could be considered as excluder plants for As.

1. Introduction

Heavy-metal pollution is one of the world's most environmental concerns because of the distribution and toxicity of heavy metals [1,2]. The disposal of mine waste in an open mine pit is a serious environmental problem [3]. Toxic mine waste contaminates the surrounding ecosystem [4] and also adversely affects the diversity of vegetal species and can inhibit the development of natural vegetation of the environment [5]. Some vegetal species are able to tolerate waste materials surrounding a mine and even accumulate metals from mine soils [6]. These tolerant species can be used for phytoremediation because of their capacity to uptake and accumulate toxic elements [7]. More than 500 species have been identified as accumulating high contents of trace metals [8].

Iran is one of the world's 15 most mineral-rich countries and one of the world's main mineral producers [9]. There is much metal-contaminated soil and a strong need to investigate metal values in soils and plants throughout Iran [10].

The objectives of the present study were (1) to record the concentrations of heavy metal(loid)s in the soil at selected sites around the Moeil mine and in the roots and aerial parts of *Dactylis glomerata* and *Scleranthus orientalis* (2) to compare metal concentrations in the aerial parts with those in roots and soil, and (3) to assess the feasibility of using the two species of plants for phytoremediation (i.e., phytoextraction and phytostabilization).

2. Materials and methods

2.1. Study area

The Moeil mine, the largest hematite iron ore mine in the province of Ardabil, is located south of the village of Moeil and 16 km south of the city of Meshginshahr in northwest Iran (38° 17′ 19″ N, 47° 42′ 54″ E) (Fig. 1). The major metalliferous minerals are hematite and limonite and minor minerals are goethite and jarosite. The original reserve of the mine was around 2 Mt of ore. Exploitation began in 2003 and lasted until 2013, and annual production was 35,000 tons.

The area has mountainous topography and is mild in summer and cold and snowy in winter. The maximum and minimum temperatures are 17 and −28 °C respectively. The average precipitation is 450 mm. The altitude is approximately 2223 m above sea level. Owing to the harsh climate, there is a low diversity and limited distribution of plant species in the study area. There are no trees or shrubs in the vicinity of the mine, and vegetation is dominated by annual and perennial herbs (e.g., *Agropyron repens* L. and *Cynodon dactylon* L.). Far from the mine center at, for example, sites 2 and 4 shown in Fig. 1, *Ranunculus arvensis* L. can be seen. *Dactylis glomerata* L. and *Scleranthus orientalis* Rössler are the most dominant flora in the metal-polluted area. *Dactylis glomerata* L. from the Poaceae family is highly drought resistant and a summer active species and *Scleranthus orientalis* Rössler from the Caryophyllaceae family is a native plant species in the Middle East and widely distributed in Iran. These two species are tolerant to conditions in the contaminated area.

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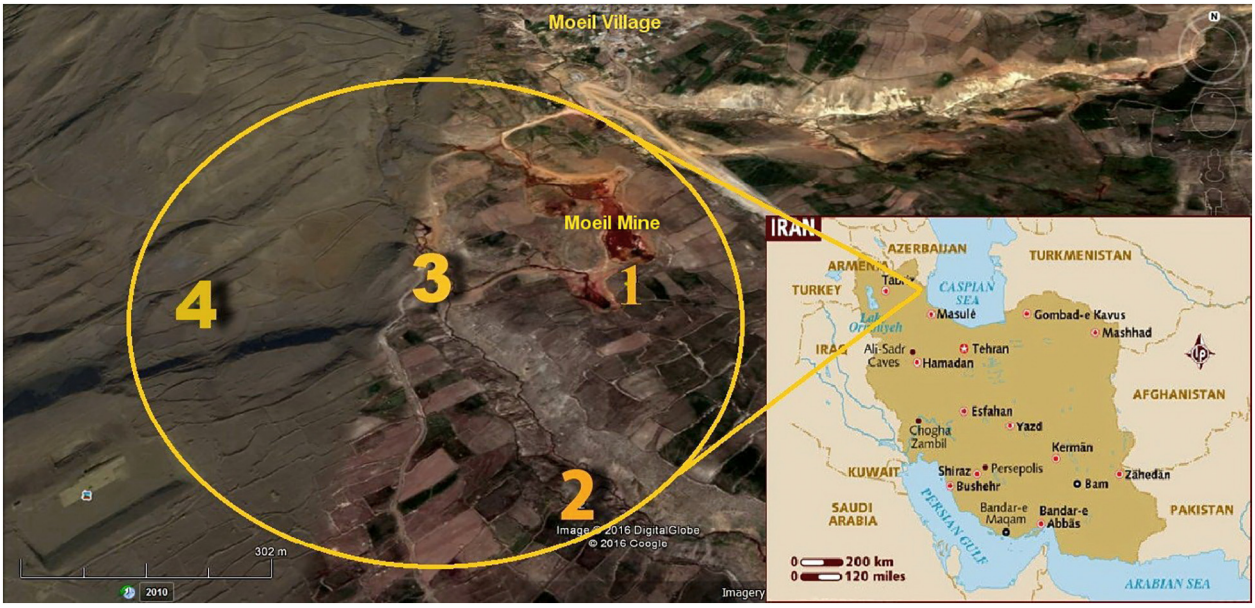

Fig. 1. Map of the area of the Moeil mine and the four sampling points. The map of Iran is taken from lonelyplanet.com

2.2. Sampling

The two species *Dactylis glomerata* and *Scleranthus orientalis* were chosen for study because of their wide distribution in the study area. Soil and plant samples were taken from four sites, denoted sites 1–4 in Fig. 1. Site 1 was south of and next to the mine pit, sites 2 and 3 were about 300 m southward and westward of the mine pit respectively, and site 4 was about 500 m west of the mine pit. Samples were taken in June 2012. Bulk soil samples were collected at a depth of 5–20 cm around each root-plant species. Soil and plant samples were collected in triplicate at each of the indicated sampling sites. Samples were taken of mature plants included roots and above-ground tissue (shoots and leaves). The soil and plant samples were placed in dark polyethylene bags and transported to the laboratory.

2.3. Soil physico-chemical characterization

The soil samples were dried at 50 °C for 48 h. They were then mixed, homogenized, and sieved through a sieve with 2-mm holes. The soil pH and electrical conductivity (EC) were measured electrometrically (Corning pH meter 430; Hanna HI 8333 conductivity meter) after 1 g of soil had been stirred with 10 ml distilled water in a beaker and left for about 1 h. The organic carbon concentration and organic matter (OM) concentration were measured by titration employing the Walkley–Black method [11]. The total N concentration was determined employing the Kjeldahl method [12]. The calcium carbonate concentration was determined using a calcimeter [13]. The distribution of the soil particle size (sand, silt, and clay) was measured using a hydrometer [14].

2.4. Analysis of elements in soils

To determine soil element concentrations, 0.25 g of dried and ground soil sample that passed through the sieve having 2-mm holes was digested in a 10 ml of a mixture of HNO_3, HCl, and $HClO_4$ (6:3:1, v/v/v). The tube was left at room temperature overnight and was then simmered on a hot plate at 120 °C for 2 h. After cooling, the digest was transferred into a 50-ml volumetric flask and diluted with distilled water. After gently stirred, the supernatant solution was transferred into a test tube. The concentrations of major (Fe, Al,) and trace elements (As, Pb, Cd, Mn, Ni, Zn, and Cr) were determined using inductively coupled plasma optical emission spectrometry (ICP-OES, Varian 735-ES) according to the method described by Hseu et al. [15]

2.5. Analysis of elements in plants

The roots of samples were separated from aerial parts. Samples were agitated in a distilled water/methanol solution. This step removed any soil and dust stuck to any surfaces. Samples were rinsed again in distilled water to remove remaining traces. The samples were then dried in an oven at 60 °C until ready for homogenizing. After homogenizing, 0.1 g of sample was digested in a mixture of 5 ml 65% HNO_3 and 3 ml 30% H_2O_2 and then was placed into a sealed high-pressure vessel and was heated in 150 °C an automated microwave digestion machine. After the digestion was completed, the sample was completely decomposed and the solution was made to a final volume of 10 ml. The concentrations of Fe, As, Pb, Cd, Mn, Ni, Zn, and Cr were determined using inductively coupled plasma mass spectrometer (ICP-MS, Agilent 4500, Agilent Technologies, Waldbronn, Germany) according to the method reported by Margesin and Schinner [16].

2.6. Measurement of biological concentration factor (BCF), biological accumulation coefficient (BAC) and transfer factor (TF)

The biological concentration factor (BCF) is the capacity of plant to transfer metals from soil to root and is calculated as the ratio of concentration of metals in plant root to that of soil [17]. The biological accumulation coefficient (BAC) is the capacity of plant to translocate metals from soil to above-ground tissue and is calculated as the ratio of concentration of metals in plant above-ground tissue to that in soil [18]. The transfer factor (TF) measures the ability of plants to translocate metals from the roots to above-ground tissue and is calculated as the ratio of concentration of metals in plant above-ground tissue to that in root [19]. It also was named “translocation factor” [17].

2.7. Statistical analysis

Statistical analysis was performed using IBM SPSS version 21 software. Average results for different soil and vegetal samples were compared using one-way analysis of variance (ANOVA). Prior to ANOVA, homogeneity of variances was tested using Levene's test. Post hoc

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