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Arsenic and heavy metals in native plants at tailings impoundments in Queretaro, Mexico

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ABSTRACT

Ten native plants species that grow in three tailings dams from Ag, Pb, Cu and Zn mine in Queretaro, Mexico were studied. Total concentrations in tailings were 183–14,660 mg/kg As, 45–308 mg/kg Cd, 327–1754 mg/kg Pb, 149–459 mg/kg Cu and 448–505 mg/kg Zn. In the three tailings dams, the solubility of these elements is low. Tailings in dam 1 are acid generating while tailings in dams 2 and 3 are not acid-generating potential. Plants species that accumulate arsenic and heavy metals was identified; *Nicotina glauca* generally presented the highest concentrations (92 mg/kg As, 106 mg/kg Cd, 189 mg/kg Pb, 95 mg/kg Cu and 1985 mg/kg Zn). Other species that accumulate these elements are *Flaveria pubescens*, *Tecoma stans*, *Prosopis* Sp, *Casuarina* Sp and *Maurandia antirrhiniflora*. Two species were found that accumulates a large amount of metals in the root, *Cenchrus ciliaris* and *Opuntia lasiacantha*. Concentrations in soils in which plants grow were 488–5990 mg/kg As, 5–129 mg/kg Cd, 169–3638 mg/kg Pb, 159–1254 mg/kg Cu and 1431–13,488 mg/kg Zn. The Accumulation Factor (AF) determined for plants was less than 1, with exception of *N. glauca* for Cd. The correlation between arsenic and heavy metals found in soils and plants was low. Knowledge of plant characteristics allows it use in planning the reforestation of tailings dams in controlled manner. This will reduce the risk of potentially toxic elements are integrated into the food chain of animal species.

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1. Introduction

The mining activity in Mexico has been of great importance for the country's economy for over 500 years (Coll et al., 2002). Currently, they continue to exploit mineral deposits of various metals such as gold, silver, copper, molybdenum, zinc, lead, manganese and iron, among others. The processes of concentration used for the recovery of metals have evolved considerably and now apply cyanidation process for recovering gold and silver, leaching for copper oxide, flotation for sulfide minerals and magnetic concentration for iron ore.

Waste generated in these processes are primarily tailings and are characterized by the contents of a large variety of minerals among which are mainly silicates, oxides, hydroxides, sulfides and sulfates, as well as low concentrations of some metals and metalloids that may represent a risk to the environment (Sengupa, 1993; Lottermoser, 2007).

In Mexico has been studied the damage to the environment caused by the mining wastes in regions such as Zimapan, Hidalgo (Ongley et al., 2007; Romero et al., 2006) Taxco, Guerrero (Armienta et al., 2003; Romero et al., 2007), Santa Maria de la Paz at San Luis Potosi (Castro et al., 1997; Razo et al., 2004) and Guanajuato, Guanajuato (García et al., 2004; Mendoza et al., 2006). These studies have generally focused on investigating the physical and chemical processes that occur in tailing impoundments after they are out of operation, to define the mechanisms of dispersion and release of metals and metalloids and determine the magnitude and extent of impact produced. Oxidation processes and acid generation have been studied in great detail in tailings, as these processes allow the release of potentially toxic elements such as arsenic, lead, cadmium, nickel, selenium, copper and zinc, and represent a risk to the environment and health of local populations.

Due to environmental problems that can lead mining waste, it is necessary to study and evaluation of alternatives to control erosion and reduce the impact to soils, surface waters, aquifers and the health of the population.

An alternative that can be widely used in Mexico is the use of plants to stabilize the tailings dams, as some plants have the ability to remove or transform pollutants in soils, through processes as

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adsorption, microbial degradation and stabilization by phase change, mainly (Reddi and Inyang, 2000).

In several countries the use of plants has been successfully applied in the extraction and stabilization of metals such as copper, zinc, cadmium, nickel, cobalt, manganese and lead in contaminated soils (Baker et al., 2000; Chaney et al., 2000). Some species studied have the ability to accumulate high concentrations of metals and are used in soil bioremediation processes. These are called hyperaccumulating species and among them include *Pteris vittata* and *Pityrogramma calomelanos* that concentrates high amounts of arsenic (Zhang et al., 2002; Visoottiviseth et al., 2002; Jankong et al., 2007) or *Thlaspi caerulescens* to accumulate cadmium and zinc (Yanai et al., 2006; Liu et al., 2008).

Mining areas are observed in plants that grow even in the same deposits of waste spontaneously.

Usually these species are endemic or native and fail to adapt to the presence of metals and metalloids contained in waste. The interest for this type of species lies in the possibility that they may be used in a controlled manner at the closure of waste dumps, to avoid the release of potentially toxic elements.

Studies in tailings dumps have been found plants with capacity to accumulate metals and metalloids. Chang et al. (2005) report species such as poplar trees (*Populus davidiana*) with potential for waste reforest a gold mine in South Korea and found ferns (*Pteridium aquilinum*) that accumulate arsenic. Carrillo and González (2006), report two species found in mine waste in Zacatecas, Mexico that accumulate high concentrations of zinc, *Polygonum aviculare* and *Jatropha dioica*. Li et al. (2007) found that species *Castanea henry* and *Phytolacca acinosa* accumulate high concentrations of cadmium and manganese in a mine of Guangxi, China. Visoottiviseth et al. (2002) identified two hyperaccumulating species of arsenic in the vicinity of a mining area in Thailand, *P. calomelanos* and *P. vittata*. Marguí et al. (2007) identified the species *Betula pendula* in waste of lead and zinc mine in northern Spain.

In Mexico Díaz et al. (2005), Carrillo (2005), González et al. (2005) have studied plants in mining areas of Zacatecas and the State of Mexico and determined its ability to retain certain metals such as cadmium and zinc. Puga et al. (2006) studied accumulation of arsenic and zinc in plant near of tailings dams in Chihuahua (*Acacia farnesiana, Juniperus deppeana, Baccharis glutinosa, Prosopis julifora* and *Cynodon dactylon*). Juárez et al. (2010) studied waste, soil and plants in a mining area of manganese in Hidalgo and identified accumulating species (*Cnidoscolus multilobus, Platanus mexicana*, *Solanum diversifolium, Asclepius curassavica* and *Pluchea sympitifolia*).

The study of native plant species growing in tailing dumps is important for application in the closure of these deposits. Understanding the mechanisms that plants use to adapt to metals and metalloids, allows proper planning of reforestation deposits and reduce erosion of the waste and the risk that accumulating species pose to animal diet.

The purpose of this work is to study the native plants that grow naturally in the tailings dumps of Pb, Cu and Zn mine in Queretaro, Mexico, and determine their ability to accumulate or fix metals and metalloids contained in the tailings, so they can use in the reforestation of the deposits.

2. Materials and methods

2.1. The study site

La Negra mine is located in the town of Maconi, in the municipality of Cadereyta de Montes, Queretaro, Mexico at UTM coordinates 2,304,026 m N and 445 660 mE, and at an elevation of 1805 m above sea level (Fig. 1).

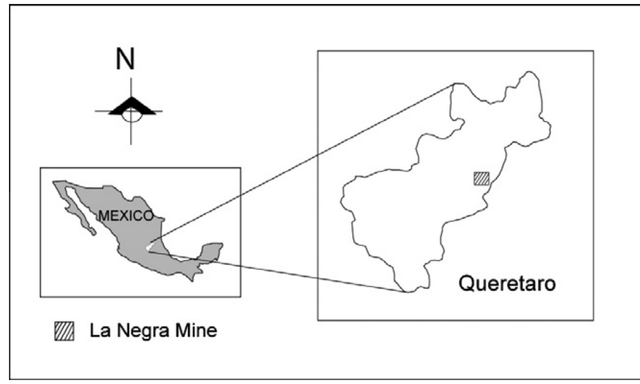

Fig. 1. Location of La Negra mine.

Physiographically mining is in the province of the Sierra Madre Occidental in the western portion and part of the Subprovince of Sierras Altas. Locally, the mine is located in the Sierra Gorda of Querétaro. The terrain is mountainous and extremely rugged. The Maconi river sits up to 4 km southeast of the mine and is a tributary of Moctezuma river. The climate prevailing in the place is dry steppe with summer rains. The average annual temperature is 20 °C. The vegetation varies with elevation; in the highlands dominated by conifers such as pine, juniper, oak and cedar; in the lowlands, there are higher temperatures and lower humidity, the terrain is arid and the soil is poor; the predominant vegetation consists of organs, cardenche, ocotillo, lettuce, maguey and nopal.

Mineral deposits are in the form of low-angle sheets with thicknesses ranging from 3 m to 25 m. These sheets are housed in laminar limestone interbedded with dark gray bands of black flint, which belongs to Doctor formation. The elements of economic interest are copper, lead, zinc and silver. The mineralogy consists of: pyrite, pyrrhotite, arsenopyrite, sphalerite (marmatite), chalcopyrite and galena, silver is contained in galena as hessita and in some cases associated with chalcopyrite. The ore is mined by underground methods and ore processing is done by the flotation method. The installed capacity is 1500 tons per day. As products of the flotation process, three concentrates are obtained, lead, copper and zinc, and a waste called tails.

Tailings generated in the mine contain significant amounts of copper, lead and zinc, and other such as arsenic, cadmium and iron. Waste has accumulated in five impoundments (Fig. 2), three of them are closed (impoundments 1, 2 and 3) and two in operation (impoundments 4 and 5). In the older deposits, were seeded vegetation to prevent erosion of the waste and after, spontaneously native vegetation of the region grew over deposits.

2.2. Sampling and analysis

2.2.1. Tailings

A sampling of waste was made in dams identified as 1, 2 and 3. Samples were taken at the surface, we first removed the soil on which vegetation grows and then took the sample of tailings with a thickness of 10 cm (Fig. 2). We used a hand shovel to remove soil and a sampler type “auger” to take the sample of waste. Single samples were stored in plastic bags. In the laboratory, samples were air dried, homogenized and then composite samples were formed for each dam. Three single samples (1.5 kg) were taken from each dam and then formed three composite samples of dam 1 (J1), dam 2 (J2) and dam 3 (J3), one sample for each dam.

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