Role of private sector and national policy for rehabilitation of abandoned mines in Portugal

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Abstract

Historical mining activities in the São Domingos mine, one of the Portuguese massive sulphide deposits, located in the northern sector of the Iberian Pyrite Belt (IPB) since pre-Roman times to 1960's, have produced thousands of tons of mine waste, and acid mine drainage (AMD) leachates rich in sulphates, iron and toxic heavy metals. Results of this study showed that the concentrations of As and Sb ranged from 2098 to 9120 mg/kg and 388 to 1250 mg/kg in mining waste, contaminated soils and sediments in nearby streams, 10.5 to 832.40 and 7.60 to 245.8 mg/kg for plants, respectively, and were much higher than the regional background levels. Higher concentrations were also found for Pb, Zn, Fe, Br, La, and Cr. São Domingos is now a residential area suffering from the considerable consequences of poorly regulated mining activities. Nowadays mining-contaminated sites and the affected communities at risk are important issues on the agenda of both researchers and policy makers, particularly in the European Union. However, very few countries had government mine regulation and reclamation policies until the latter part of the century. Most of the mining operations closed without adequately addressing their clean-up and reclamation responsibilities, leaving millions of dollars of clean-up costs to the government. Both the private sectors and the governments are playing poor role for rehabilitation of abandoned mines. Therefore, this study suggested public private partnership initiative that can perform the rehabilitation of historic abandoned mining sites in Portugal and other parts of the world following the sustainable reclamation options. For this purpose, phytoremediation and constructed wetland techniques can be the best option to remove, contain, or render harmless environmental contaminants by the use of green plants and their associated microbiota, soil amendments, and agronomic techniques. Plant species, e.g. *Erica andevaleris, Erica australis*, *Juncus acutus, Eucalyptus comaldulensis*, *Pinus pinaster, Pteridium aquilinum*, *Quercus ilex, Rumex santalus*, *Genista hirsutus* and *Daphnia gnidium,* that grow abundantly in the São Domingos area, were identified as the potential candidates for the rehabilitation of abandoned mining sites.

Keywords: private sector, government regulation policy, phytoremediation, rehabilitation, abandoned mines

Introduction

Historic abandoned mines are still important sources of environmental contamination. Mining activities discarded huge piles of waste, rock, tailings and leaching residues, and caused high concentrations of toxic elements in adjacent soils, crops, plants, aquatic organisms, water and river systems (Pirrie et al. 2003). Mine tailings contain variable trace element concentrations due to variations in the methods used for ore extraction, different types of ore bodies and their

associated sulfide minerals and oxide (Ashley et al. 2003; Bhattacharya et al. 2006). Different metal and non-metal mining activities have released As, Sb, Pb, Cu, Zn, Fe, Al, Mn, Mo, Cd, Ag, Sn, W, Bi, Hg, U, Co, Ni, V, U, Cr, ^{222}Rn, U, Th, ^{226}Ra, Ba, F, and Ti. Out of these, the potentially toxic metal and metalloids e.g., As, Ag, Cd, Cr, Cu, Hg, Ni, Pb, Sb, U, and Zn are most commonly found in elevated concentrations in the mine tailings and contaminated environments, compared to the maximum permissible or tolerant limits set by international regulatory agencies (Bhattacharya et al. 2006).

The historic metal mines of Portugal have left a legacy of contamination in the south-east and northern regions of the country. As a consequence of this historical mining activity, since pre-Roman times to the 1960's, different type of materials, such as metallurgical slags, sub-grade ore, pyrite ash, weathered host rock, and materials from gossan waste, were deposited in the surrounding area of the open pit, and to downstream rivers and streams. Toxic elements from these mining waste heaps are transported downstream to the rivers, surface water and streams (e.g., Telheiro river) as dissolved species or as suspended particles. Subsequently, suspended sediments will settle in the stream, river or estuary, leading to a gradual accumulation of metals in sediments by different dynamic geochemical systems depending on physico-chemical conditions and the aquatic environment over time. Diffusion of these toxic elements causes toxicological effects to the living organisms and biodiversity in the environment.

Limiting the fluvial transport of mine waste particles requires a remediation method which increases the stability of each mine spoil heap as an integral structure. This could be achieved by traditional methods such as solidification, but such an approach is not sustainable in the long-term. An alternative and more acceptable natural approach would be phytoremediation, or more specifically, phytostabilisation using metal-tolerant vegetation. Many mine spoil heaps are bare of vegetation indicating the harsh environments for plants and re-colonisation after cessation of mining operations. Revegetating the metal tolerant plants on the mine spoils can reduce the erosion and dispersion of contaminants. Therefore, remediating historic mining areas might be achieved by novel forms of remediation like phytoremediation and constructed wetlands.

Environmental laws and regulations were promulgated as recently as 1987 in Portugal. Before that time, the industries did not practice any environmental pollution control and reclamation of contaminated sites. Most of the mining operations ceased in Portugal before the 1970s, while there were no effective environmental laws and regulations for mine closure and reclamation. Therefore, mining companies left the mining sites unreclaimed and since then the mines remain abandoned. The decreasing environmental quality and increasing public pressure for rehabilitation promoted the research in these affected areas. To understand the relevance of landscape reclamation in São Domingos mine and other mines of Portugal, it is necessary to analyse the strengths, weaknesses, opportunities and threats present in this landscape, considering cultural, economic and environmental aspects. The main problems to achieve the above goals are insufficient private and government investments, lack of sound private and government roles and policy, isolated town, and lack of public transportation.

The objectives of this study were to address (1) the problems associated with post-mining landscape reclamation and the sustainable rehabilitation strategies, and (2) the role of private and national policy for rehabilitation of abandoned mines in the São Domingos and other Portuguese abandoned mining sites. Furthermore, the study conducted field survey and systematic questionnaire study with the mine villagers, community, water and agriculture researchers, private and public stakeholders for sharing their views, opinions and knowledge.

Materials and methods

São Domingos copper mine is a volcanogenic massive sulfide deposit within the Iberian Pyrite Belt (IPB), which extends from Spain along the southern region of Portugal, in Baixo Alentejo Province. The São Domingos pyrite orebody has a 537-m-long and 45–70-m-thick lense shape with mineral assemblage composed by pyrite, sphalerite, chalcopyrite, galena, arsenopyrite, and sulfosalts; and the products were pyrite, roasted pyrite, sulfur, and copper. The open pit covers 6.2 ha and is 120 m deep; it is now partially filled with acid, brown to reddish colored water. The mine exploration began in 1858 under the supervision of the English company Manson & Barry and ceased in 1966. The mining activities promoted the development of a railway and harbor for ore transportation, two pyrite roasting factories, water reservoirs, cementation tanks, network channels for acid water evaporation, dam and lake creation in the surrounding area; the topographic alteration caused by the extraction of the ore and the mine structures and mining village that occupy most of the degraded area (acidic lake, galleries, miners houses, warehouses, etc.) (Alves 1997; Anawar et al. 2011). There are some remnants of the old industrial activities and landscape developed during mining operations (Figure 1).

Mine tailings and soil samples with different composition and river bank sediments were collected (0–15 cm depth). The samples were dried at room temperature, mixed, homogenized, and sieved through a 2-mm screen. Three replicates of every homogeneous sample were analysed by neutron activation analysis.

Figure 1 *São Domingos mine dumps and ruins*

The plant samples were collected from the different sites of the mine e.g., mining waste, and colluvial mine tailings at inner sites of the mine, and organic rich good soil cover mixed with mine tailings around the mine. The shoots (stems, leaves,

and flowers) of plant species were washed with tap water followed by several rinses with de-ionized water to remove completely particulate material attached to stem, leaves, and flowers (shoots). The well-cleaned and washed plant materials were freeze-dried, ground in Teflon (balls and capsule) mills, thoroughly homogenized, and made into 250-mg pellets for neutron activation analysis, following the k0-standardized procedure.

Results and discussion

Portuguese environmental legislation and government and private roles

Portuguese legislation on environmental issues is very recent, being the Law n. 11/87 - "The Environmental Main Law"("EML") the starting point for all further legislation (despite an "right to the environment" previewed on the Portuguese Constitution of 1976 - article 66). In fact, since 1987 more than 200 statutes were published. Furthermore, only in 1991 a Ministry of the Environment was created. The public authorities are not yet well prepared to deal with environmental issues. The GTL (Local Technical Office) developed the rehabilitation proposal for the São Domingos mine the late nineties. The proposal was constituted by reclamation and redevelopment project, with main purpose to preserve and valorise the existing mining structures, in order to emphasise their historic and socio-economic significance. To achieve these objectives little progress was made since then. The mining sites are privately owned. They have poor capabilities for reclamation of the contaminated lands. The government is also reluctant to take responsibility of enormous cost for reclamation of these mining sites. Both the private sectors and the government want to avoid the economic liability necessary for reclamation of the mining sites. The citizens are also not yet well prepared to deal with environmental issues. However, they realize that mining waste is contaminating the land, water and their habitats, and exerting threat to quality of life.

Present problems

The total concentration of trace elements, especially As and Sb in the tailings and soil samples were very high. The concentrations of As and Sb ranged from 2098 to 9120 mg/kg and 388 to 1250 mg/kg, respectively, in mining waste, tailings, contaminated soils and sediments in streams, 10.5 to 832.40 and 7.60 to 245.8 mg/kg for plants, respectively, and were much higher than the regional background levels. Elevated levels of concentration were also found for Pb, Zn, Fe, Br, and Cr. Some previous studies also identified the mining sites in Portugal as the probable sources of contaminants for the surrounding environments and emphasized the need of reclamation (Alves 1997; Dias et al. 2008; Alvarenga et al. 2009; Anawar et al. 2011). The attitude of people has been changing given the need to protect the environment. Currently the recovery and redevelopment of those spaces is necessary to achieve sustainable development (Dias et al. 2008).

Sustainable strategy for rehabilitation of mining areas

In the present study, plant species, e.g. *Erica andevaleris, Erica australis*, *Juncus acutus, Eucalyptus comaldulensis*, *Pinus pinaster, Pteridium aquilinum*, *Quercus ilex, Rumex santalus*, *Genista hirsutus* and *Daphnia gnidium* that grow abundantly in the São Domingos area, were identified as potential candidates for phytostabilization

and rehabilitation of the mining waste, contaminated sulfide mine soil, sediment and AMD water. They have a massive, finely structured, and deep root system capable of reaching 3–4 m, effective at reducing soil erosion and highly tolerant to extreme soil conditions, including soil acidity, Al, Mn, and heavy metal toxicities in the soils. The proportion of vegetation covers of the above plant species varied widely depending on the characteristics of mining waste and soil quality at different sampling sites of the mine. Based on the above results this study suggested that rehabilitation of the degraded mine sites can be achieved by selective planting of drought resistant, fast-growing, and metal-tolerant plant species in combination with various soil amendments such as organic compost, industrial organic rich wastes, good soil, zeolites, beringite, steel shot, and hydroxyapatite that immobilize metals and help to develop soil cover on waste (Alvarenga et al. 2009; Rieuwerts et al. 2009). Mining contaminated areas can be progressively reclaimed by transporting soil, and covering the exposed mining waste, bedrock or inert materials for soil erosion control. Soil amendment will help soil development process on mining waste, growth of planting species and vegetation cover in and around the mining area.

Public private partnership business

Public private partnership (PPP) initiative can solve the reclamation problems of historic abandoned mining sites in Portugal and other parts of the world following the sustainable reclamation options. Sustainable development practices have the potential to leave a legacy of positive impact long after the life cycle of a mine has ended. It is important to design and deliver the most cost effective risk management program to address the operational exposures, including known, unknown, legacy or future environmental issues. Government should invest money for reclamation of these abandoned mines to protect the land, water, public and animal health, biodiversity, climate change (by carbon sequestration and afforestation) and the environment. This investment will improve the quality of life for the citizens, a holy duty of the democratic governments. The owners of the mining land will partially invest for this PPP business. The investments from the private and government sectors will be used for reclamation of the mining sites. The mining sites will be revegetated and afforested using tree-type taller plants like *Eucalyptus comaldulensis*, *Pinus pinaster, Quercus ilex etc.* by addition of amendments on the mining waste and tailings to increase the soil development and soil fertility. This plantation will generate income for the mine land owners by producing fuel, wood, furniture and other forest ecosystem services.

Conclusion

The remediation strategies conducted in this study will contribute effectively to protect the environment, to improve the abandoned mining landscape, boost economic activity and enhance life quality helping in fact to accomplish the objective of sustainable development.

Acknowledgement

This research work was supported by the Fundação para Ciência e Tecnologia (FCT, Portugal) through research contract PTDC/AMB/65462/2006 – HYPERAS.

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