Improving Resource Efficiency and Minimize Environmental Footprint – a case study preliminary results

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Abstract Panasqueira Mine (Portugal) has been mainly exploited for wolframite, cassiterite and chalcopyrite (W, Sn, Cu). Through the detailed and careful characterization of tailings with different mineralogy, new invaluable insights into the weathering characteristics of many different minerals will be received, making possible proper risk assessments, and predict which type of tailings might pose severe future environmental risk namely to the Zêzere river. The Zêzere River is an important river and is under the Cabeço do Pião tailings influence. The knowledge and methods acquired will lead to a conceptual model working as guidance to a more sustainable mining in the hereafter.

Key words Panasqueira mine; Cabeço do Pião; Risk assessment; guidance

Introduction

The worldwide demand for metals and minerals is rapidly rising, driven by economic growth. Europe delivers a huge trade deficit for metallic minerals, and thus needs to evoke more of its own resources to reduce this dependence. Mining is still the primary method of metals extraction so it is of crucial importance to identify new processing methods and process design, as well as risk assessment for the remaining residuals.

Since 1898, Panasqueira Mine in Portugal was exploited for wolframite, cassiterite and chalcopyrite (W, Sn Cu), the latter two as by-products. Until 1912 the mining scale was minor, but increased by 1928 and ultimately got a large development. One, of seven areas is the Cabeço do Pião (Fig.1) where tailings have been displaced from 1927 and 90 years ahead. The tailings deposit has an average height between 30 and 40 m and slopes around 35º. The estimated volume of the tailings is 731 034 m3. An ore processing plant was constructed at that site using gravity, electromagnetic separations, and flotation. The grain size of the material is variable. The tailings have average grades around 4000 ppm of W, 6800 ppm of Zn, 2494 ppm of Cu, but also contain 76350 ppm of As. The geochemistry and mineralogy of the tailings have been thoroughly studied as well as the acid mine drainage impact. The tailings are nowadays property of the municipality of Fundão and they are not included in the National Program for Mine Rehabilitation.

Material and Methods

Sampling of the tailings was performed in two different dates: in December 2016 and January 2017. It was used an excavator (Fig.2) to gather 33 superficial (50 to 60 cm of depth) mineral waste samples. The sampling was performed on a rectangular grid of 40 x 20 m and a Global Position System (GPS) allowed to georeferenced all with UTM system.

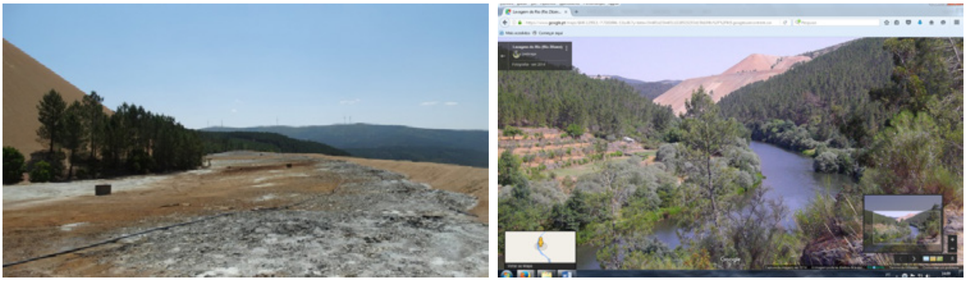
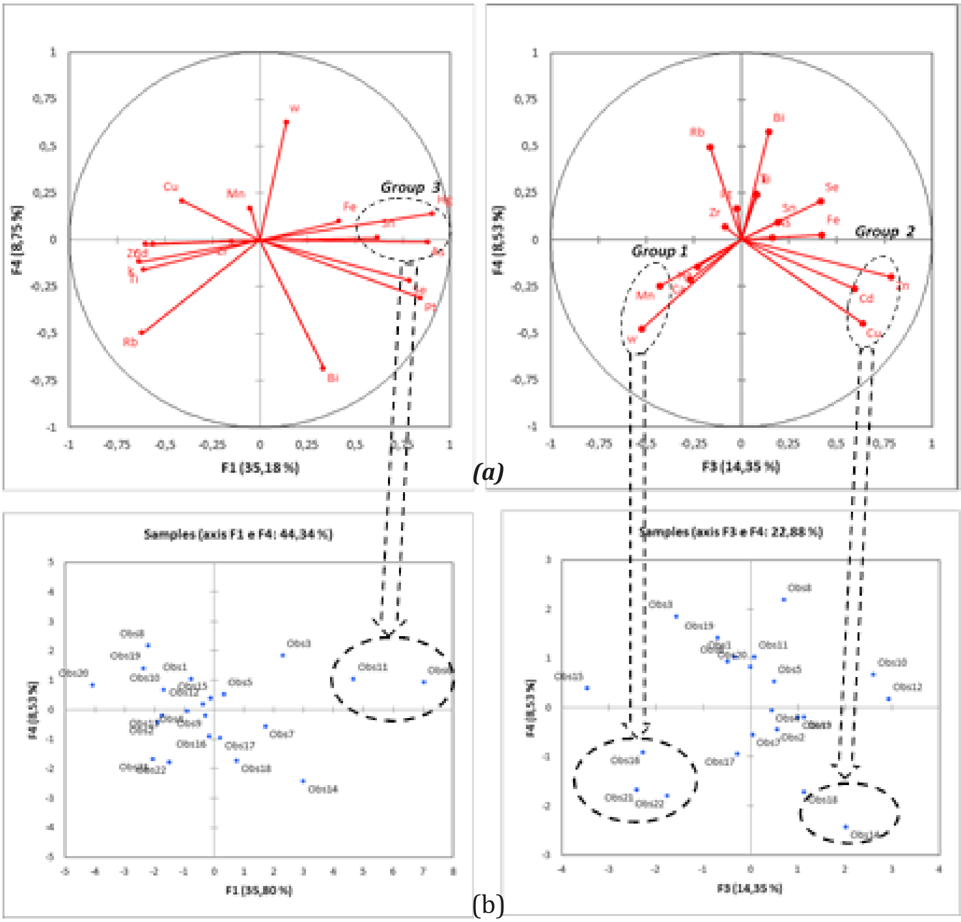


Figure 1 *Cabeço do Pião tailings deposit (Joel Braga, Sept 2014)*

Figure 2 *Sampling procedure – Cabeço do Pião tailings deposit*

The samples were then dried at a temperature of 50 °C during 24 h. The potentially toxic metals and semi-metals were analyzed by Energy Dispersive X-Ray Fluorescence (XRF) method using an X-MET8000 instrument (Oxford Instrument). The equipment was used in Mining Mode, allowing fast and accurate analysis with low limits of detection. After, the geochemical dataset composed by 16 elements (Bi; Cu; Zn; Se; Hg; As; Pt; Rb; K; Mn; Sn; Ti; W; Zr; Fe and Cd only determined in 22 samples) went through a multivariate statistic analysis (Principal Components Analysis – PCA Spearman technique) to evaluate the relationships among the trace elements and the presence of outliers. The first four factors retain 78% of the total variability and hence providing an accurate image for the geochemical association s definition. Three important associations emerged: Group 1: W and Mn Group 2: Cd; Zn; Cu and Group 3: Sn; As; Hg (Fig. 3).

Figure 3 *Principal Component Analysis (PCA) – Factorial planes F1/F4 and F3/F4; a) Correlation circle and attributes' projection; b) individual's projection*



Thus, in a first step the missing Cd values were estimated using multi-linear regression where Cu and Zn were used as independent attributes for Cd prediction (Tab. 1; Fig. 4):

$$Cd = -2.53\times10^{-4} - 2.36\times10^{-3}Cu + 1.49\times10^{-2}Zn \qquad (1)$$

Table 1 *Correlation matrix and Multiple Correlation Index for Cu; Zn and Cd*

	Cu	Zn	Cd
Cu	**1**	0,839	0,699
Zn	0,839	**1**	0,871
Cd	0,699	0,871	**1**
Multiple Correlation index: Cd Cu Zn		0,84	

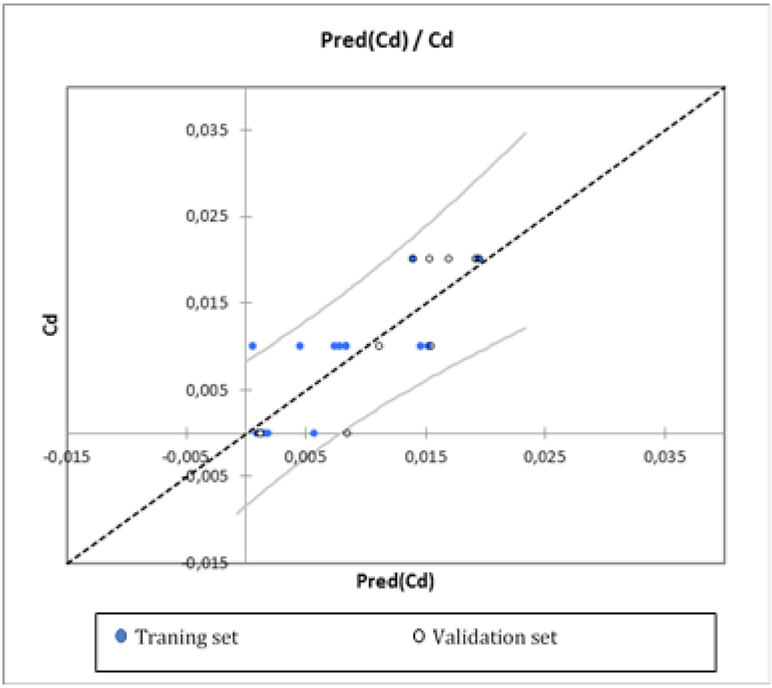


Figure 4 *Linear regression: training and validation sets*

In a second step a geostatistical approach was used to accomplish the construction of elements' concentration patterns.

Geostatistical techniques are founded along the theory of regionalized variables (Matheron, 1971) which says that variables within an area show both random and spatially structured properties (Journel and Huijbregts, 1978). Experimental variograms must be estimated and modelled to quantify the spatial variability of random variables as a function of their separation lag (Antunes et al. 2013). When forecasting the risk of contamination (e.g. months ahead), it is mandatory to stress the importance of the future estimated values to exceed the maximum admissible values. The delineation of enriched zones requires the interpolation of content values to the nodes of a regular grid where a prediction model will work as guidance to a more sustainable mining management.

The new variables (F1 and F3) obtained by PCA are defined as regionalized variables and are additive by construction. Therefore, a two-step geostatistical modelling methodology was used as follows:

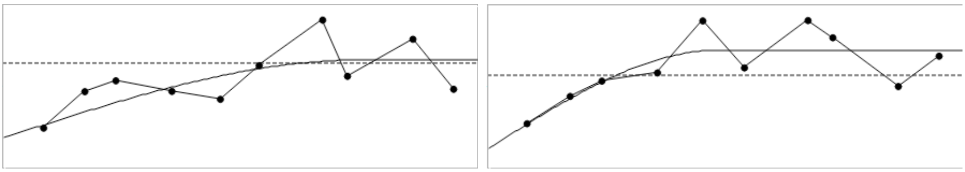
1) Selected attributes (F1 and F3) went through structural analysis, and experimental variograms were computed (Fig. 5);

2) The factors (F1 and F3) coordinates were transformed into normal scores to attenuate the impact of extreme values on the computation of the variogram. Multi-Gaussian kriging was then used aiming interpolation and proceeded: 1) normal score transforms of the F1 and F3 data, 2) interpolation of normal scores using ordinary kriging, and 3) back-transform of the results using the empirical procedure developed by Saito and Goovaerts (2000) (Fig.5). For computation, the Space-Stat Software V. 4.0.18, Biomedware, was used.

Results and Discussion

Isotropic experimental variograms, for F1 and F3, were computed for structural characterization and spherical models fitted. Cross-validation results were considered satisfactory for the selected models, showing consistency between the calculated and the observed values. The graphic behavior of the variogram function provides an overview of the spatial variation structure of the variable (Chica, 2005). One of the parameters that provide such information is the nugget effect, which shows the behavior at the origin (Pereira et al. 1993). The other two parameters are the sill and the range which defines, correspondingly, the inertia used in the interpolation process and the variable structure influence zone. For the considered new synthesis variables, 79% of the total inertia was used for F1 estimation and 72% for F3 estimation (Fig.5).

The spatial patterns shown allow to identify two enriched clusters: 1- Sn; Cu; As; Zn and Cd and 2- W and Mn (Fig. 6).



(a) (b)

Figure 5 *Experimental variograms and fitted models: a) F1 normal scores and b) F3 normal scores*

It is important to stress that the central area of the tailings dam is where it is observed the higher concentration in Sn and Cu and it is in its margins where W is mainly concentrated (Fig.5).

Conclusions

In the herein study a set of 16 chemical elements, gathered in Cabeço do Pião have been used for characterization of the tailings dam's enrichment characterization. In a first step a Principal Components Analysis (PCA) was directed to find the trace elements' associations. In a second step a multilinear regression allowed to complete Cadmium missing values, using as independent variables Zn and Cu. A stochastic approach was performed through Multi-Gaussian kriging algorithm, and back-transform of the results. The central area of the tailings dam shows notable enrichment in Sn; Cu; As; Zn and Cd whereas it is in its margins where W and Mn content is more relevant.

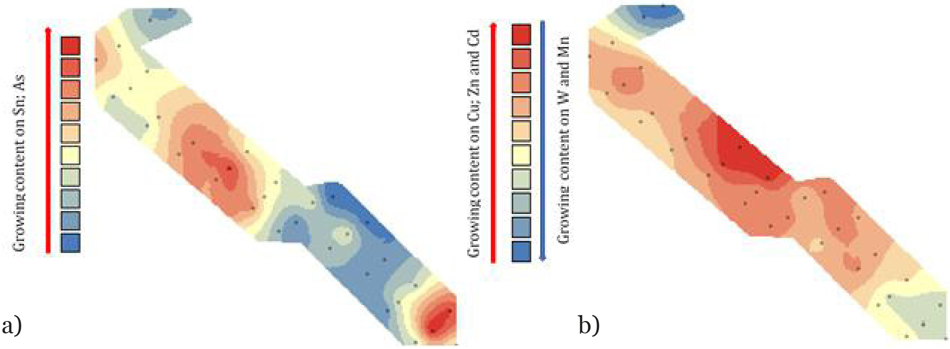


Figure 6 *a) F1 map created by multi-Gaussian kriging and b) F3 map created by multi-Gaussian kriging*

Future work must be extended out to explore new possibilities for the Cabeço do Pião tailing re-mining.

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