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Geostatistical estimation of chemical contamination in stream sediments: The case study of Vale das Gatas mine (northern Portugal)

A.R. Salgueiro [a,*], P. Freire Ávila [b], H. Garcia Pereira [a], J.M. Santos Oliveira [b]

[a] CERENA, Natural Resources and Environment Centre, IST, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[b] INETI – National Institute of Engineer, Technology and Innovation, Laboratory, 4465-956 S. Mamede de Infesta, Portugal

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Abstract

Based on an environmental geochemistry case study carried out in the neighbourhood of a W–Sn abandoned mine, the pollution in stream sediments was modelled through a Global Contamination Index. Such an index permits one to summarize the combination of deleterious elements in a single variable, obtained by the projection of samples onto the first axis of a PCASD (Principal Components Analysis of Standardized Data) applied to the entire $n \times p$ matrix containing the available concentrations of $p=16$ elements in the set of $n=220$ collected samples.

In order to provide a sound basis for a coherent planning of the remediation process which will be put in operation in the affected area, it is necessary to balance the costs of reclaiming with the probabilities of exceeding the upper limits accepted for concentrations of environmentally harmful elements in sediments. Given these limits, they are back-transformed in the index values, providing a practical threshold between 'clean' and 'contaminated' samples. On the other hand, the minimum dimension of the cell to be reclaimed is restrained by the selected remediation process to be applied in the affected area. Hence, to meet the constraints of such a remediation process, it is required to estimate the probabilities of exceeding the index threshold in technologically meaningful sub-areas. For this end, the Indicator Block Kriging technique was applied, producing a series of maps where sub-areas to be reclaimed can be spotted for different probability levels. These maps, on which the decision making remediation agency can rely for its cost-benefit analysis, take into account both the spatial structure of 'clean' *vs.* 'contaminated' samples and the constraints of the reclaiming process.

Keywords: Abandoned mines; Environmental remediation; Global Contamination Index; Indicator Block Kriging

1. Introduction and methodological overview

When assessing the impact of abandoned mines on the environment, an important issue is to map the concentration of deleterious elements in stream sediments affected by the spread of old tailings and wastes. Instead of mapping these elements individually, giving rise to unmanageable plots, the global contamination of a given area can be easily visualized by summarizing such elements in a global index, which may be provided by the PCASD (Principal Components Analysis of Standardized Data) of the entire data set, under the approach given in Barradas et al. (1992). In contrast with usual PCA, this approach (described in detail in Vairinho et al. 1990, p. 384), allows the n samples to be projected onto the same axes that are interpreted in terms of the p variables, linking R^p and R^n factorial spaces through transition relationships. The projection of samples onto the particular axis interpreted on the grounds of deleterious elements concentrations give the values of the required Global Contamination Index.

But, in addition to summarize the set of harmful elements into a single contamination index, it is also necessary, for remediation purposes, to locate in space significant areas where the index exceeds a certain threshold, derived from upper limits in the concentrations allowed for dangerous elements in sediments. Such areas, which must conform to technological constraints stemming from the selected remediation process (minimum dimension of a cell to be reclaimed and maximum contiguity between cells), can not be spotted from the sample map, which refers to index values in point supports.

* Corresponding author.
E-mail address: rita.salgueiro@ist.utl.pt (A.R. Salgueiro).

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For decision making in remediation planning, costs of reclaiming must be related to the probability of exceeding the maximum limits in dangerous elements. In order to approach this problem, providing a sound basis for cost-benefit reclaiming studies, an Indicator Block Kriging based methodology was developed, aimed at associating the probabilities of exceeding a given threshold with the correspondent sub-areas to be reclaimed, and producing a series of maps where these sub-areas are located in space. This methodology relies on the following assumptions:

(i) An indicator variable can be found to account for the probability of surpassing, in each sample point, a certain threshold derived from international regulations for upper limits in deleterious elements concentration.

(ii) The estimation of such a variable in technologically significant cells can provide a set of different sub-areas, formed by contiguous cells and associated with a range of estimated probabilities of exceeding the threshold.

The Indicator Kriging technique was used along the lines put forward by Journel (1983), and fully developed in environmental applications by Goovaerts (1997) and Mohammad et al. (1997).

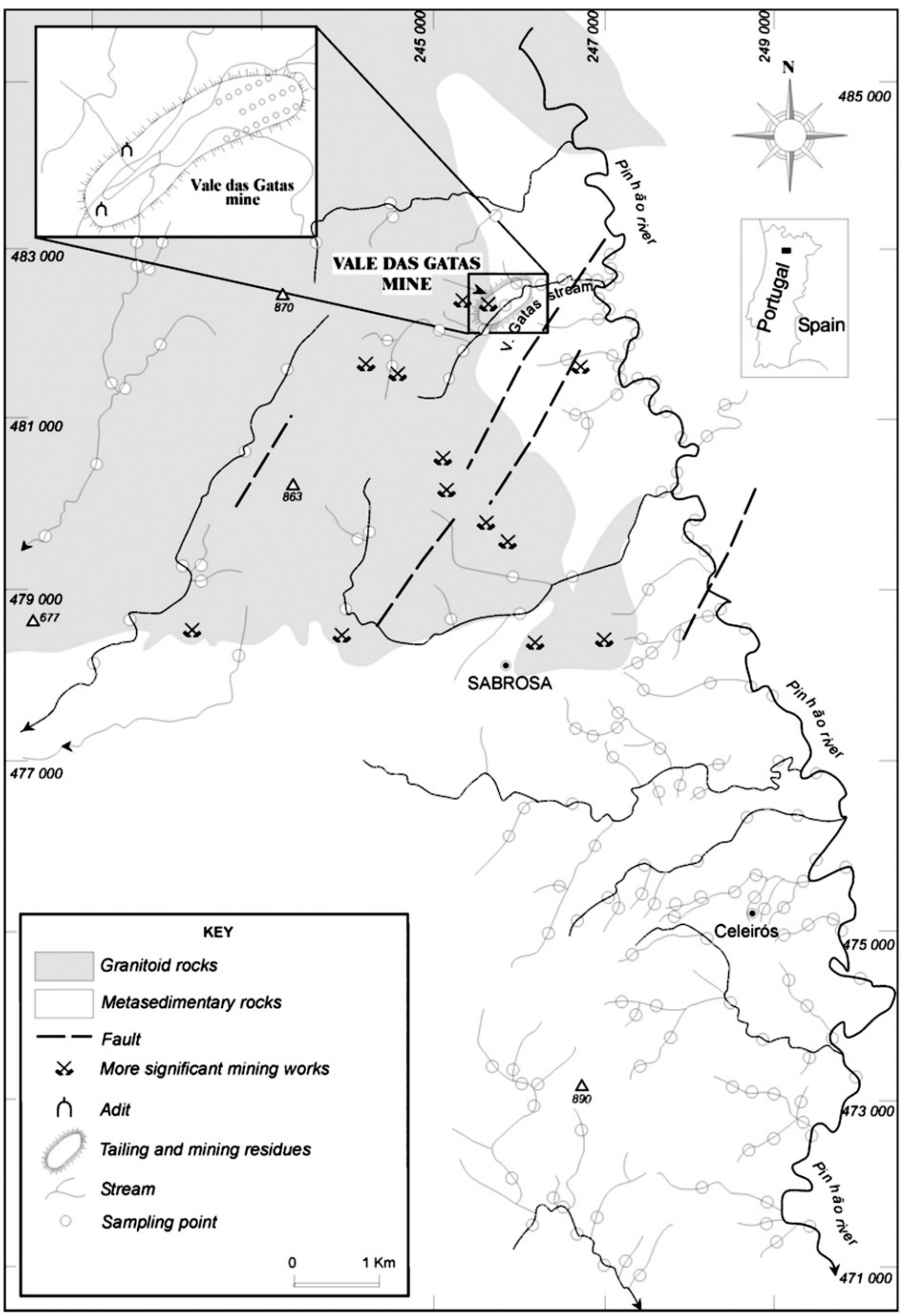

Fig. 1. General geological map of the Vale das Gatas area showing the sampling sites.