Environmental Geostatistics with Isatis

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C. Roth (Geovariances)

Geostatistical methods were initially developed in the 1960's for the specific problem of estimating resources in the mining industry. However the very idea on which they are founded means that they are equally applicable in other earth science industries like the environment. The correlation between sample grades used in mining geostatistics to estimate ore resources is equivalent to using the correlation between soil pollutant concentrations in the environment to obtain the best pollutant map from which to evaluate remediation costs.

The Isatis geostatistical software package includes the entire range of geostatistical estimation and simulation algorithms. It thus provides all the tools needed to obtain an accurate image of the state of the environment from which the most appropriate strategy can be adopted. Typical problems to be solved include:

- defining optimal sampling strategies based on 2 or 3D variographic analysis
- mapping pollutants using linear kriging
- estimating volumes of material exceeding a critical threshold using non-linear techniques
- performing risk analysis/assessment studies, based on conditional simulations.

Consider the following case study, performed by Geovariances consulting team, using non-linear geostatistical methods to predict the volume of contaminated soil to be removed from a given area. Soil is deemed as contaminated if the pollutant concentration exceeds a critical threshold. Linear methods like ordinary kriging cannot be used here. Applying the threshold to the smooth kriged estimate of the pollutant concentration will lead to a biased estimate of the volume of contaminated soil. Non-linear geostatistical methods provide the answer to this problem by directly estimating the required volume of contaminated soil, without any bias-inducing post-processing to apply the threshold.

The data, collected by the Swiss Federal Institute of Technology, are composed of 259 Pb concentration values (ppm) from the Swiss Jura. The critical threshold of 65ppm applies to 10x10m units. So a unit will be remediated if its average Pb concentration is above 65ppm, NOT if the Pb concentration at its centre is above 65ppm. Figure 1 shows the sample histogram and their location within the area to be remediated (in orange). For illustrative purposes those samples exceeding the unit threshold are marked by a dot and the others by a cross. The sampling density means that a good local estimate cannot be obtained for grid cells of less than 100x100m. So we will estimate the proportion of units within each grid cell that must be remediated.

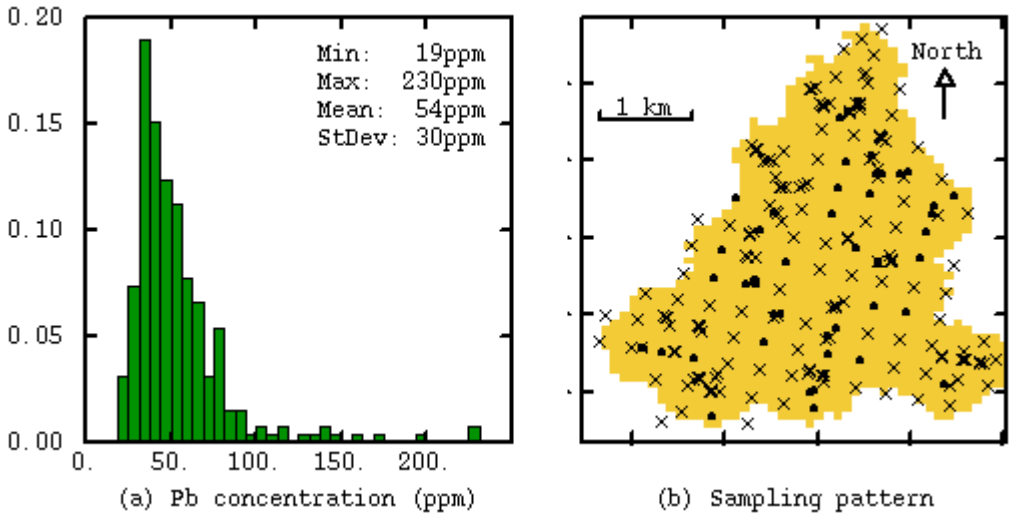

Fig. 1: Sample histogram and sampling pattern within the area to be remediated

The variogram map in Isatis allows us to quickly isolate the main directions of continuity for the Pb concentrations, as seen in Figure 2. The pollutant grade is most continuous along N15 W and least continuous along N75 E. This map facilitates the calculation and modelling of the directional variograms that define the spatial continuity of the Pb concentration in 2D space.

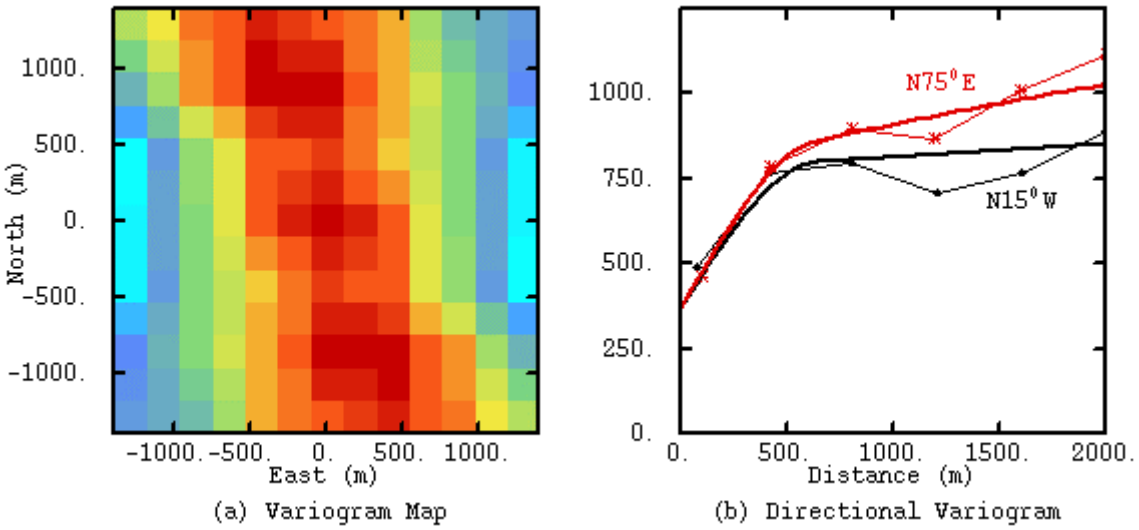

Fig. 2: Variographic analysis: experimental variogram (thin line) and the fitted model (thick line)

Of the non-linear methods available in Isatis (indicator kriging, disjunctive kriging or uniform conditioning), uniform conditioning was chosen as it best respects the physical properties of the samples themselves. The resulting estimate is given in Figure 3(a) in terms of the proportion of each grid cell that must be remediated. Figure 3(b) shows the unrealistic result that what would have been obtained had ordinary kriging been used to estimate the Pb concentrations of individual 10x10m units, and then the critical threshold applied to them.

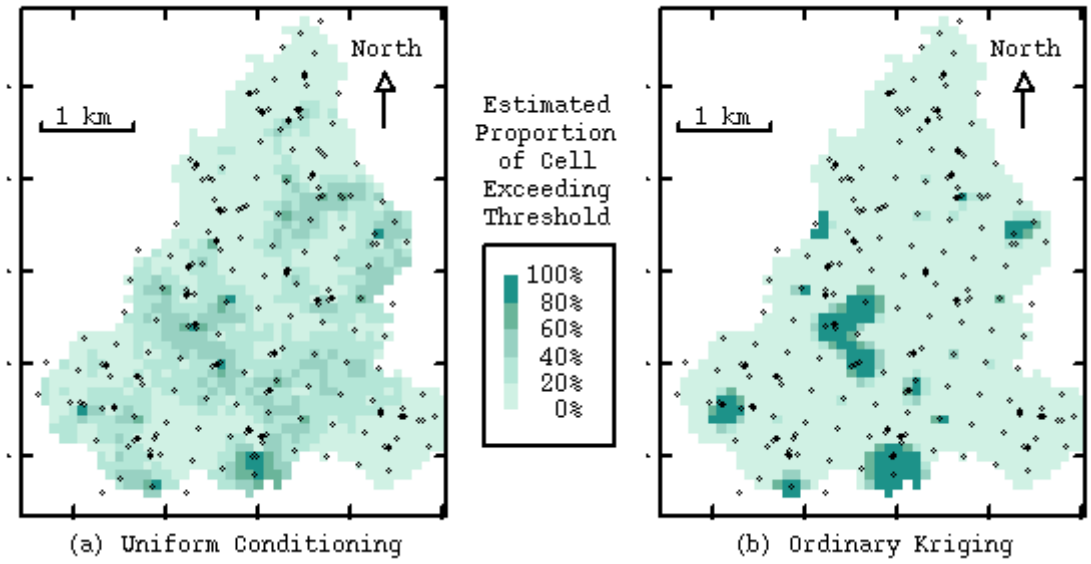

Fig. 3: Estimation results by uniform conditioning and ordinary kriging

We cannot simply apply the threshold to the ordinary kriging estimate to get a map from which a any strategy can be planned. There will be severe financial consequences if the remediation of 1.14 of land as predicted by ordinary kriging has been budgeted for, when the real figure will be much closer to the 2.89 given by uniform conditioning.

The above study shows that geostatistics can be used as an important aid when defining the environmental management strategy for a mine site. Applying the most appropriate technique, from those available in Isatis (linear kriging, non-linear techniques and conditional simulations in 2 or 3D), provides the most accurate solution from the available data to real practical environmental problems.