Geostatistics Perspectives for Sampling Optimization During Radiological Characterization

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Introduction

Dismantling and decommissioning of nuclear facilities or remediation of contaminated sites are industrial projects with huge challenges. Precise knowledge of the contamination state is required [1]. Radiological evaluations have multiple objectives to be considered: determination of average activity levels, to allow the categorization of surfaces or volumes (sorted into different radioactive waste categories); location of hot spots (small areas with significant activity levels); and estimation of the source term (total activity) contained in soils or building structures. In addition, there are radiation protection and other logistics considerations.

This paper deals with feedback experience over years in the use of geostatistics and sampling optimization for the radiological characterization of various media (soils, concrete structures, process equipment, groundwater…), various activity levels (clearance, low and intermediate, high), and various sizes from very small areas (a few m2 or a few m3) to very large sites (at a country scale in post-accidental context).

Spatial structure and variography

Geostatistics assumes spatial continuity for radioactive contamination [2]. Variability behavior over distance between data points is the spatial signature of the phenomenon being studied. This spatial structure is analyzed and interpreted through the variogram, which plots the average variation between pairs of points. Typically for a structured phenomenon, this variability increases gradually and stabilizes at a certain sill for a characteristic distance called ‘range’.

Figure 1 illustrates three phenomena with the same statistical characteristics (in terms of a histogram). However, they have very different spatial organization (variograms) that requires dedicated sampling strategies.

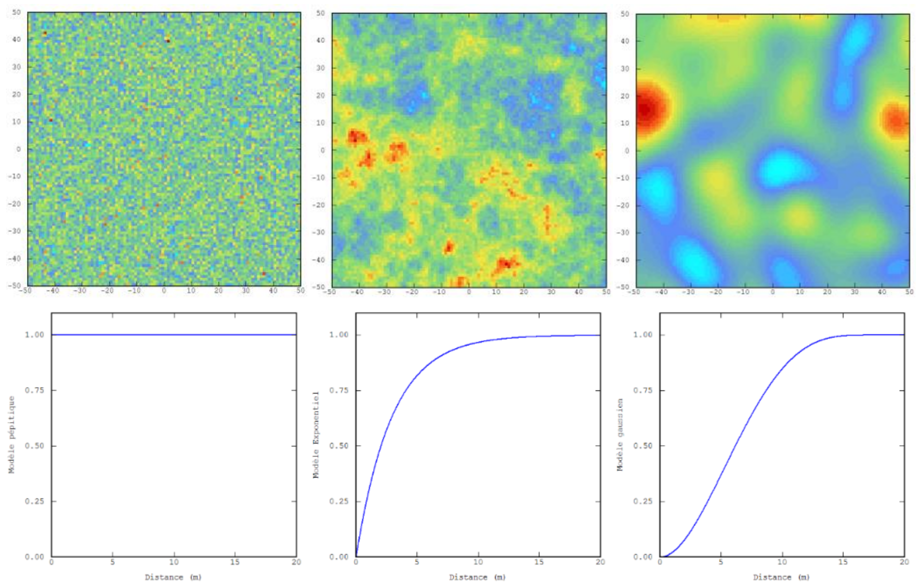

Figure 1: Three phenomena with the same statistical distribution (on the top) but with significantly different spatial structures (corresponding variograms on the bottom part)

Sampling optimization

Within the geostatistics framework, the spatial structure of radioactive contamination makes the optimization of sampling (number and position of data points) particularly relevant. Geostatistics methodology can help determine the initial mesh size and reduce estimation uncertainties (both global and local). Combining the three levels of information, namely historical context, radiation maps and destructive sampling, is also an issue geostatistics can provide useful recommendations about the total investigation effort.

With radiation mapping, prior information about spatial structures of radioactive contamination is used to determine the initial sampling mesh. By default for soils, 200 data points per hectare (corresponding to a 7 m mesh size) allows a first analysis of the phenomenon spatial structure for contaminated soils around nuclear facilities. This initial mesh may range from 5 m to 10 m according to the available information (historical and functional analyses, prior measurements…).

More generally, with larger size for example, the tenth or the twentieth of the site size is a good candidate for the initial mesh size of the regular grid. For building structures (mainly concrete) a 1 m mesh size may be relevant to conduct a first geostatistical analysis. Similarly, this size has to be adapted to the size of the building, the stakes and the expected spatial structure.

Adding extra data points is a then good way to reduce estimation uncertainty. This is quickly obtained by analyzing early mapping results. For geometric uncertainties, the kriging error variance easily identifies areas with a lower sampling density. For high variability areas, the confidence interval around the estimated value is used to detect, for instance, the boundaries of contaminated areas. For probability results, the risk of exceeding a given threshold allows surfaces or volumes to be categorized in order to optimize radioactive waste management and sampling optimization to reduce misclassification risk [3].

As presented on Figure 2, sensitivity to sampling density can be quantified as regards local or global uncertainties. This feedback experience is then advantageously used for the sampling optimization.

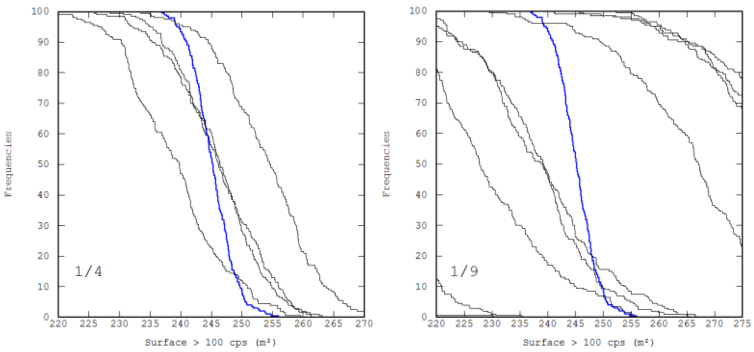

Figure 2: Impact of sampling density on local risk curves (probability of exceeding a threshold).

Conclusion

The objective of radiological characterization is to find a suitable balance between gathering data (constrained by cost, deadlines, accessibility or radiation) and managing the issues (waste volumes, levels of activity or exposure). Geostatistics quantifications of local and global uncertainties are powerful decision-making tools for better management of remediation projects at contaminated sites, and for decontamination and dismantling projects at nuclear facilities.

The spatial structure of radioactive contamination then makes the optimization of sampling (number and position of data points) particularly important. Geostatistical data can soundly help determine the initial mesh size and advantageously reduce estimation uncertainties.

References

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