Prediction reliability of chemically contaminated volumes of soils. Feedback on 23 former industrial sites (RECORD study) and lessons learnt for radioactively contaminated sites

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Abstract

A feedback on remediation of chemically contaminated sites was carried out for the French cooperative research network on waste and environment (RECORD). For 23 former industrial sites that were already cleaned up, volumes of contaminated soils predicted at the characterization stage were compared to those really extracted at the remediation stage. Reasons explaining the discrepancy between predictions and real remediated volumes were systematically studied, computing statistics on a list of criteria. The study shows that sampling plans and interpolation methods are two key factors for reducing the difference between estimation and real volumes. Major benefits are gained with geostatistical interpolation methods, provided that they are rigorously applied. General advice for characterization could be provided at the end of the study to increase the reliability of predictions.

The opportunity of transferring these results to the assessment of volumes of soils in radioactively contaminated sites was studied based on the experience of the authors on these kinds of sites. Due to large similarities, most of recommendations for characterizing chemical contaminations are found to be relevant for radioactive contaminations. Adaptations are nevertheless required to account for the specificities of radiological characterization, with the use of non-intrusive sub-surface measurements for a 2D mapping as a first step before soil sampling in boreholes to investigate depth migration.

In this paper, the methodology and the results of the feedback study on chemically contaminated sites are presented and followed by a discussion of the lessons learnt for radioactively contaminated sites, to increase reliability of the contaminated volumes predictions.

KEYWORDS: feedback, characterization, prediction, geostatistics, chemically contaminated sites, radioactively contaminated sites

Introduction

Assessing the volumes of soil that require remediation plays a major role in the global economy of chemically contaminated sites rehabilitation. Significant differences between predictions defined at the characterization stage and real volumes cleaned up at the rehabilitation stage have severe consequences in terms of budget overspending, deadlines exceeding, or health risks linked to the remaining contaminations. Professionals of radioactively contaminated sites may experience the same challenges, with the difference that materials of buildings have also to be cleaned up and not only the soil, and unit prices are much higher for cleaning radioactive materials than chemical ones.

Despite a more than 20 years-experience of chemical depollution in France, important differences may be observed in certain operations, with some pending issues: what is the size of the differences? Do significant differences impact only a few cases or a large number of the contaminated sites? What are the causes of the discrepancies and how could they be reduced? The study performed by eOde and Geovariances for the RECORD association aims at addressing these questions, by conducting a feedback on 23 already remediated sites provided by industrial companies, consulting offices and remediation companies (RECORD 2016). The main results of the study are presented in the first chapter of

the paper.

But even if similarities can be found between chemical and radioactive contaminated sites, it may be questioned if the guidelines deduced from the RECORD study may be valid for radioactive contaminations. The applicability and the benefits of the recommendations deduced from the RECORD study were then studied, based on the experience of the authors of the characterization and predictions conducted in radiological contaminated sites. Results are presented in the second chapter of the paper.

Feedback RECORD study on chemically contaminated sites

Data from both the characterization stage and the remediation stage were available on the 23 contaminated sites, so that it was possible to compare the volumes predicted at the end of the characterization stage to those really excavated and cleaned up at the rehabilitation stage. Exhaustive information about the sampling conditions at the characterization stage and the conditions for classifying the contaminated soils at the rehabilitation stage were also provided by the stakeholders.

The 23 case studies cover a large range of situations of chemical contaminations. Contaminations may be due either to distribution or production of petroleum and gas products, wood treatment, metal processing or dry cleaning. Contaminations in soil were either mixtures of organic and inorganic compounds, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) or volatile organic compounds. Contaminated areas extended from 1 000 to 10 000 m^2. Soils were cleaned up after excavation for most of the sites (83%), while 17% of them were treated in situ. Volumes of remediated soils amounted from 300 to 80 000 m^3.

For every site, the difference between the predicted volume and the really excavated volume was computed and divided by the real volume considered as the reference[1] (relative difference). It was found that under-estimation at the characterization stage occurs in 57% of the sites, whereas volumes are over-estimated in 43% of the situations.

The relative difference is equal to 25% on average. Professionals of depollution were consulted to know their point of view on this order of magnitude: they consider that an error of 25% is usual and acceptable, accounting for the state of the art in remediation technologies and the usual level of information available at the end of the characterization stage.

The relative difference exceeds 30% for one third of the 23 sites. Such an error has significant consequences on the cost and the duration of remediation operations, which may lead to customer dissatisfaction and deterioration of brand image of depollution companies. A maximal error of 84% was found in this study.

Different factors may produce significant errors. One of them is linked to the complexity of the situations of contamination. Volumes are more difficult to predict when soil is highly heterogeneous and impacted by a complex mixture of compounds. Among the 23 contaminated sites of the RECORD study, the relative difference is indeed 10% higher on average in the most complex situations. The highest differences are found with the sites contaminated with heavy hydrocarbons, in particular PAHs. Since it is obviously not possible to change the site complexity, this observation is at least useful to anticipate the situation and inform the customers so that they can integrate the management of these hazards in the operation planning.

But other factors influence the magnitude of the differences between estimations and really remediated volumes (**Figure 1**). The 23 contaminated sites of the RECORD study show that the conditions of sampling the soil at the characterization stage play a major role for reducing the errors. The errors are in average equal to 18% when investigation conditions are favorable, in contrast with the 32% average errors found in the other situations. Favorable sampling conditions at the characterization stage are : 1) homogeneous sampling protocol, 2) homogeneous spatial distribution of boreholes over the contaminated area, 3) systematic sampling of soil along the boreholes with a minimal density of boreholes

[1] With in situ depollution, the difference between the mass of pollutant to be extracted predicted at the end of the characterization stage and the mass actually extracted was computed and divided by the actual mass taken as reference.

and samples (with 4) 1 borehole per 100 m^2 of site surface, 5) 1 sample per meter of borehole). It should be noted that 3 of these 5 recommendations are enough to reduce of 15% in average the prediction errors observed in the 23 contaminated sites.

Geostatistical methods lead also to improved predictions of the volumes of soils requiring remediation, as a complement of the expert judgement of the professionals of contaminated sites. It was found indeed that among the 23 sites, the sole expert judgement for estimating the volumes leads to a higher dispersion of the differences between characterization predictions and real remediated volumes. Conversely, geostatistical methods lead to both lower and less dispersed differences, especially with state-of-the-art geostatistics, following a few objective methodological recommendations. Geostatistics have been applied to chemical contaminated sites for more than 15 years in France, with the development of pragmatic methods and tools by geostatisticians from both the academic and private sectors (Chilès et al. 2005; RECORD 2013).

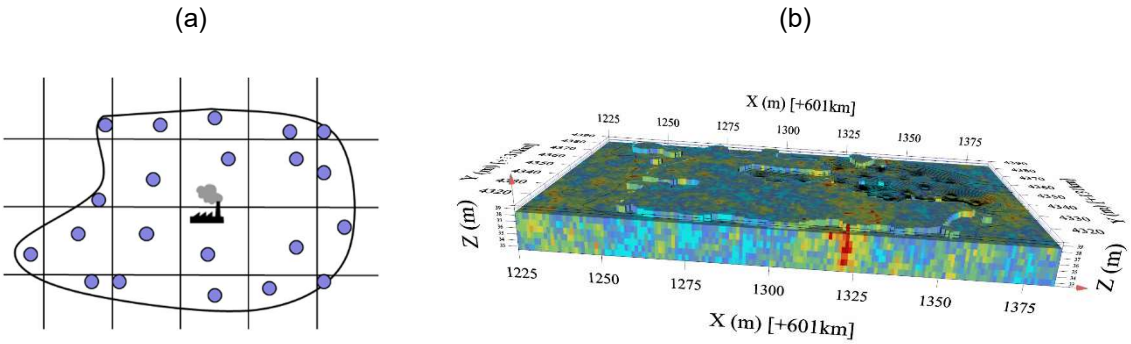

Figure 1: **Design of the sampling plan (a) and Use of geostatistical methods (b) are 2 key factors for reducing errors on contaminated volumes predictions at the characterization stage.**

Lessons learnt for radioactively contaminated sites

Contaminated sites with radiological materials also benefit from a sound data processing with geostatistics to assess contamination spatial extent and volume estimates. Experience is gathered for more than 10 years on various types of sites and nuclides: from few cubic meters to country scale (Fukushima) and for NORM (Naturally Occurring Radiological Materials) as well as Cs-137, Sr-90, Pu-241, etc…

In comparison to chemical pollution, radiological characterization takes advantages of non-destructive investigations as an initial 2D mapping of the contamination. For soils, artificial nuclides are generally measured at sub-surface level (first tens of centimeters) that make this kind of measurement particularly relevant. Mesh size of this initial mapping can integrate prior knowledge on similar sites as well as target sampling objectives and historical environment of the site. As a second step, spatial positioning of boreholes to investigate depth migration are decided on this 2D map. 3D spatial structure (continuity) present similar spatial characteristics as chemical pollutions (anisotropies, typical ranges…).

As in France there are no free-release or clearance levels, each site is analyzed thanks to volume risk curves. They enable the decision of relevant thresholds on a cost-benefit analysis. These thresholds can be discussed with the safety authority on this basis (so integrating uncertainties).

Conclusion

The RECORD study making a feedback on chemically contaminated sites highlights 2 key factors for reducing the prediction errors of volumes of contaminated soils: the sampling plan design and the use of geostatistics. These criteria may be applied to the radioactively contaminated sites, provided small adjustments, accounting for their specific characterization protocol.
Lastly, the same kind of feedback conducted on the radioactively contaminated sites could be very informative for the professionals of dismantling of nuclear industry.

References

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