Methodological Approach for Ground Contamination Assessment and Remediation of Brownfields

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Abstract: A methodology is presented for ground contamination assessment and remediation of brownfields, through the application of geostatistical models in sequential stages of site investigation. The methodology is applied to a former industrial area in Barreiro (Portugal), in the left margin of Tagus River, 7km south of Lisbon. The area, where several heavy industries (chemical, metallurgical, etc.) operated during the last hundred years, is presently submitted to environmental requalification planning for urban redevelopment.

Key-words: ground contamination, site assessment, remediation, geostatistics, brownfields, heavy metals

1 Introduction

Soil is a high value natural resource, hardly renewable at the human scale, whose chemical contamination leads to its economical loss.

The growing need to promote the redevelopment of *brownfields* instead of the systematic use of *greenfields*, calls for the standardization of contaminated site assessment procedures.

A methodology for ground contamination assessment and remediation of brownfields, through the application of geostatistical models in different stages of site investigation is presented.

2 Methodology

The methodology integrates the application of geostatistical mathematical models as key tools for the reduction of site investigation costs associated to land contamination evaluation and site remediation plan. It encloses 3 site investigation phases:

1st phase – Preliminary investigation phase

- collection of relevant historical data, such as, site activity and industrial processing, existing field survey data, technical reports, maps, etc., evaluation of ground characteristics, namely, geological and hydrogeological maps and topography;
- Spatial identification of “hot spots” using low cost data screening methods (as photo ionizer detectors (PID), X-ray fluorescence spectrometers (XRF)), including geophysical survey (electromagnetic, georadar and resistivity surveys).

Geostatistical modelling, together with GIS, is used to produce surface pollution maps and to define the geometry of soil sampling campaign and identification of operational site constraints. Figure 1 illustrates main steps used for preliminary investigation phase.

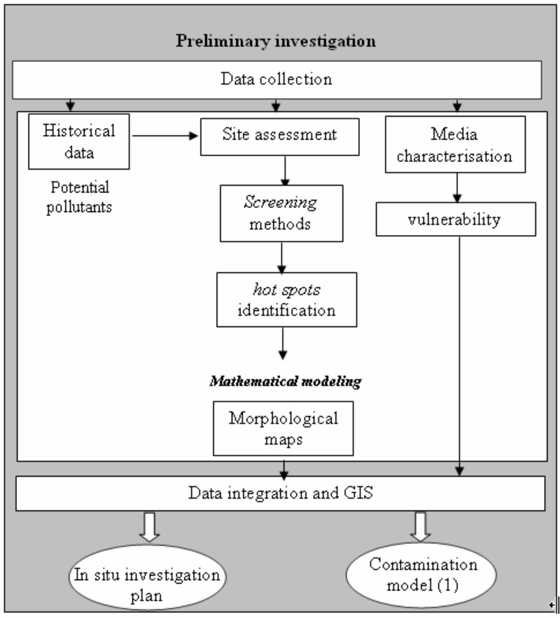

Fig.1 – Main steps for preliminary investigation phase (in [2])

2nd phase – Exploratory investigation phase

This phase aims at the evaluation of ground contamination (soil and groundwater) and the definition of the contamination model.

- Site investigation for soil and groundwater, including sampling,
- identification of chemical contaminants,
- Identification of physical media characteristics (such as soil type, permeability, pH, groundwater electrical conductivity, etc.),
- Characterization of terrain morphology.

Geostatistical modelling is used for the identification of contamination plumes. Estimated maps resulting from this phase define the type and extension of contaminated areas, quantification of contaminated media and uncertainty areas.

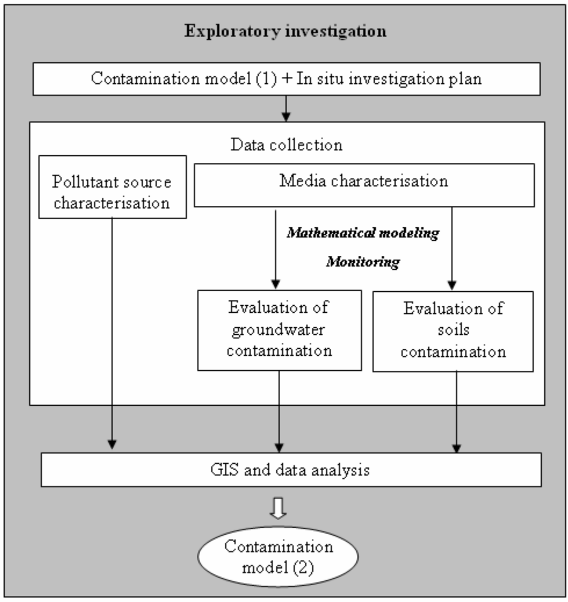

Fig.2 – Main steps for exploratory investigation phase (in [2])

If necessary, a second sampling campaign is planned in order to clarify uncertainty areas.

3rd phase – Detailed investigation phase

During this phase a 2^{nd} field sampling campaign is performed to refine contaminated areas boundaries. Indicator kriging geostatistical modelling is used to calculate volume of contaminated soils for distinct scenarios, depending on required reference values.

Generally, surface soil and groundwater remediation criteria are based on “Guidelines for use at contaminated sites in Ontario” [1].

Geostatistical modelling is also used to quantify contaminated media and create scenarios for the remediation plan, based on estimated risk maps and uncertainty areas.

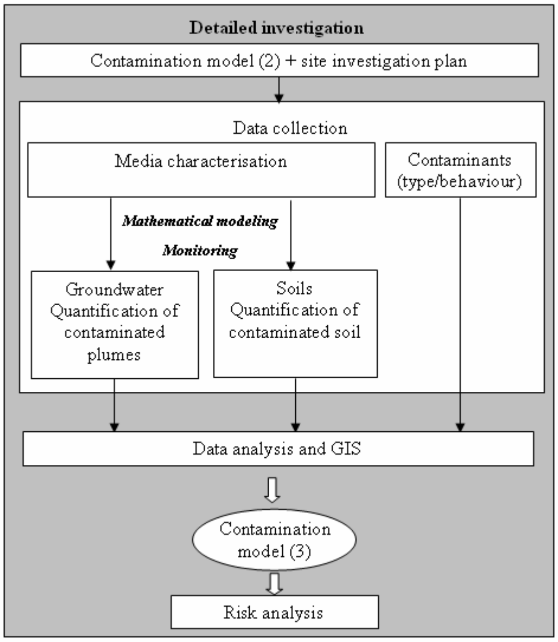

Fig.3– Main steps for detailed investigation phase (in [2])

2 Barreiro Case Study

The methodology was applied to a former industrial area in Barreiro (Portugal), located in Tagus river estuary, 7km south of Lisbon [2, 3], presently under the process of environmental requalification for urban redevelopment (Fig. 4).

The priority area, of about 30 hectares was, during the last century, scenario for heavy chemical industries: production of sulphuric acid, phosphate acid, copper and sodium sulphates, copper, lead, gold and silver metallurgies and others, resulting in a widespread of industrial waste containing heavy metals in soil and groundwater.

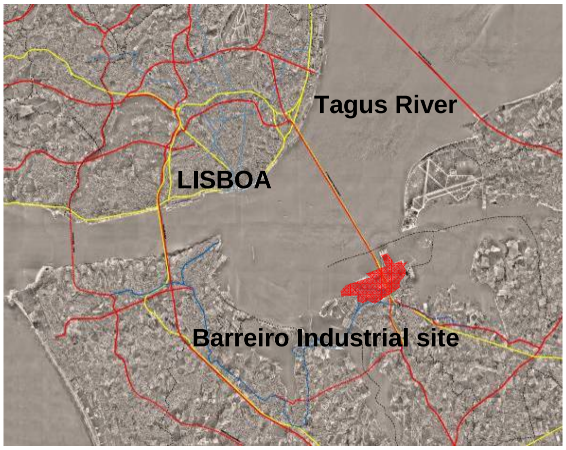

Fig. 4 – Location of Barreiro Industrial site

2.1 Site assessment

During the preliminary investigation phase a set of screening methods were performed:

- XRF *Niton* analyzer survey, for heavy metals screening (83 measurements and 4 soil sampling for calibration);
- PID *Photovac* 2020, for VOC analysis in soils and infrastructures;
- Electrical resistivity survey (12 profiles up to 13.5m depth), for identifying ground anomalous concentrations in dissolved salts and metals
- Electromagnetic conductivity survey with *Geonix* EM31 method (19 profiles) for identifying anomalous concentrations in dissolved salts and metals, in saturated terrain (3 and 6 m depth)
- Georadar survey with *Ramac GPR* equipment, for detection of buried infrastructures.

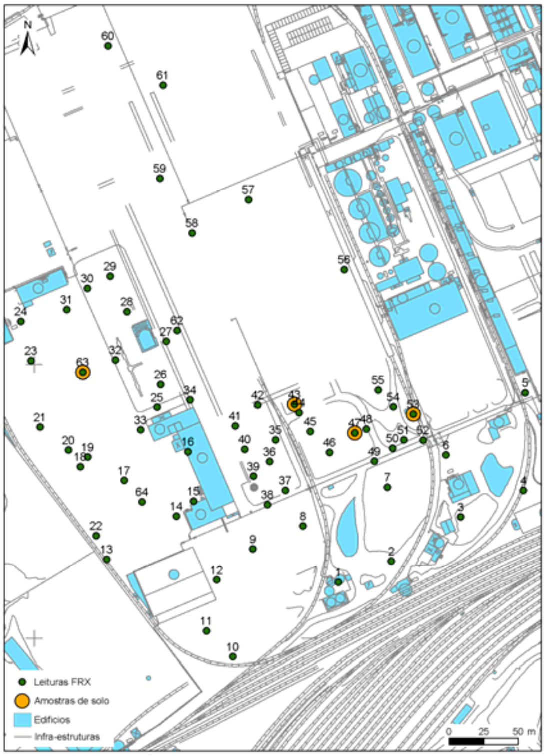

Fig.5 – Location of XRF measurements (in [2])

The XRF screening campaign allowed the identification of several chemical elements at the surface, mainly in the south area of the site which could be related to the location of the old metallurgical plants (Fig.5).

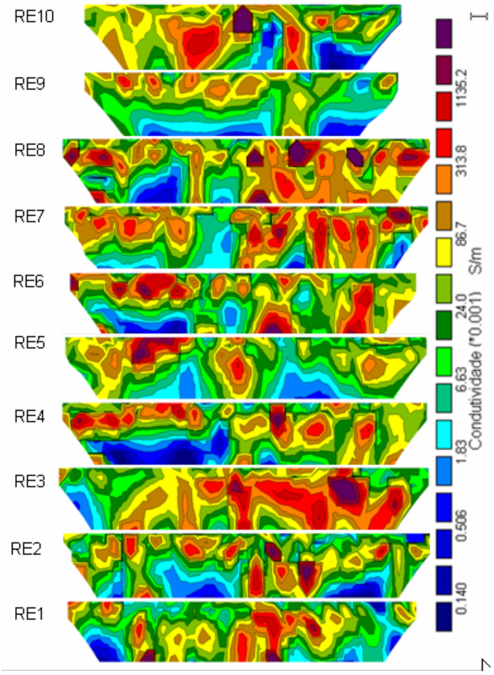

Fig.6 – Illustration of a resistivity profiles (values in electrical conductivity (x10^{-3} S/m)) (in [2])

The high conductivity values could be related with infrastructures (cables) and dissolved salts or metallic elements concentrated in soil (Fig. 6); electromagnetic maps showed higher conductivity values at 6m depth (Fig. 7).

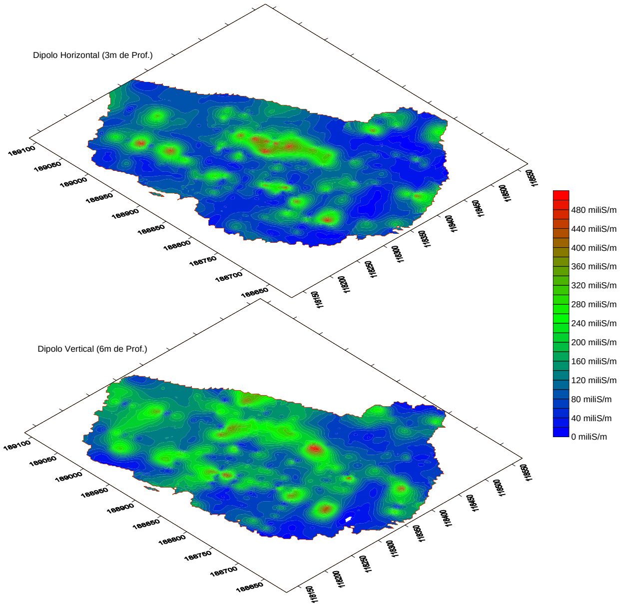

Fig.7 – Electromagnetic conductivity maps; 3m and 6m depth, respectively (in [2])

Georadar survey identified buried infrastructures (Fig. 8).

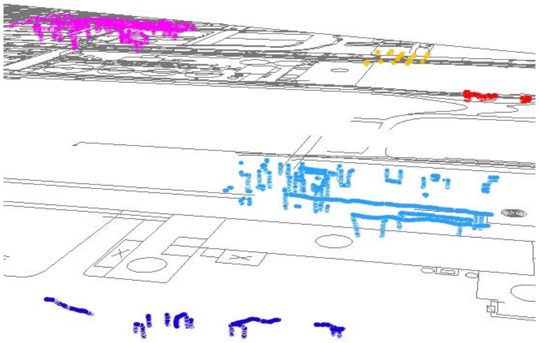

Fig.8 – Identification of buried infrastructures through georadar survey (in [2])

Preliminary investigation data helped in defining hotspots location and the extension of contamination plumes.

Exploratory investigation phase comprised:

- 41 trial pits (maximum 4m depth) and collection of 62 soil samples at 3 levels;
- 8 drilling boreholes (maximum 10 m depth) for soil and groundwater sampling.

Collected samples where submitted to basic geotechnical and chemical laboratory tests. Interpretation of borehole logs enabled the execution of geological profiles (fig. 9).

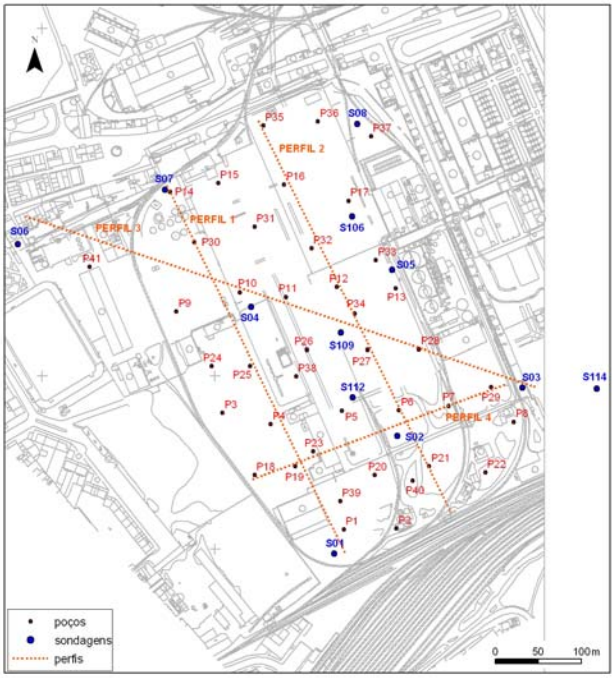

Fig.9 – Exploratory site investigation plan: trial pits (P), boreholes (S) geological profiles location (in [2]).

Detailed investigation phase aimed at the refinement of the boundaries of contaminated areas. The following works were performed:

- 11 additional trail pits, with the collection of 23 soil samples
- 14 boreholes, up to 14m depth, for soil and groundwater sampling.

Collected data gathered in all site investigation phases allowed the definition of local conceptual contamination models and the characterization of contaminated areas.

2.2 Site modelling

During each site investigation phase, geostatistical models, using the indicator kriging method [4] and software *geoMS* [5], were applied in order to estimate morphology of contaminated areas. Fig. 10 illustrates a probability map located in a sub-sector of the industrial zone, for the occurrence of arsenic in soil, in concentrations higher than 20 mg/kg, modelled during the exploratory site investigation phase.

Studies showed that contamination is closely related with the presence of the wastes dumped by the old industrial units, such as those from the pyrite *ustulation* (a incineration process), and metallurgical processes rich in heavy metals, namely Cu, Zn, Pb, and also in As. Consequently, the higher concentration values were identified in the southern part of the industrial area, in an extension of about 30% f the studied area.

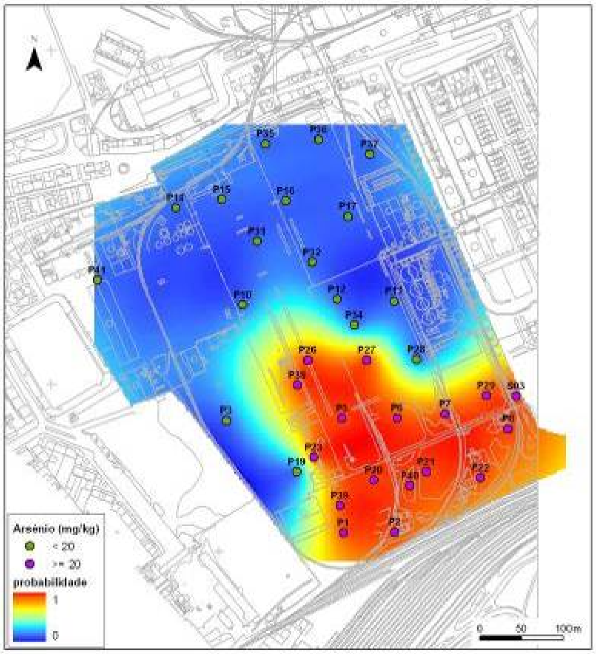

Fig.10 – Probability map for As higher than 20mg/kg (in [2])

The contamination model was built using GIS to integrate estimated contaminated maps for two depths, with lithological properties of the ground, such as clay content, as shown in fig. 11.

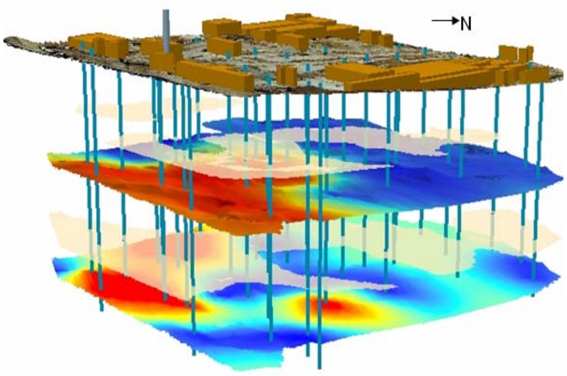

Fig.11 – 3D contamination model (in [2])

Groundwater site model was built with *Visual Modflow* software [6], based on estimated hydrogeological units (figures 12 and 13).

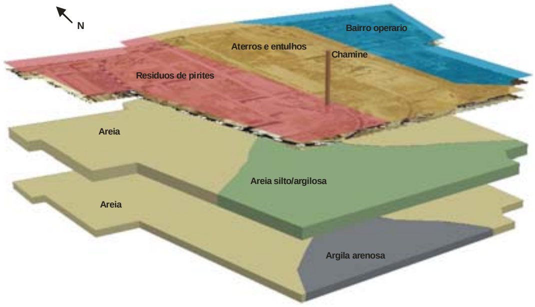

Fig.12 – Hydrogeological units estimated by indicator kriging. Top layer: industrial waste (in [2])

Fig.13 – Dynamics of local groundwater flow and path of a contaminated plume (in [2])

Figure 13 shows the simulation of local groundwater flow as well as particle pathways, based on local aquifer characteristics. As it can be seen, the groundwater flow is rather low, weakening the spread of the contaminated plume towards the Tagus estuary, due to the low gradient values and tide influence.

3 Conclusions

The application of a three phased methodology for site investigation and the integration of geostatistical models in each phase allowed: (i) the rationalisation of site investigation works at different stages; (ii) the characterisation of pollutants in the environment; (iii) the estimation of contamination plumes in soils and groundwater and respective volumes for treatment; (iv) the definition of the local contamination model in order to develop a risk analysis approach for urban occupation.

Environmental requalification of the polluted industrial sub-sector encloses the need of a risk analysis evaluation approach in order to define the best remediation actions for minimizing potential contamination risks facing to a future urban occupation [7].

4 Acknowledgments

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