Risk assessment for redevelopment of contaminated land at an old industrial site

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Abstract: - This paper presents an integrated two phased methodology for the evaluation and mapping of potential human health risk areas at contaminated sites. In a first step, a human health risk index is calculated for each sample location based on exposure pathways and land use scenarios. In a second step, human health risk maps are obtained by the estimation of local index values using geostatistical models. Spatial estimation of human health risk allowed, on one hand, the identification of most dangerous areas inside the contaminated site and, on the other hand, the quantification of respective polluted media, subject to further remediation.
The methodology was applied to an old industrial site, located near Lisbon, on the left margin of the Tagus River (Barreiro - Portugal). The priority area, with an extension of about 30 ha, has been scenario of several chemical industries over the last one hundred years. Nowadays, the area is almost deactivated and designated for urban redevelopment.

Key-Words: Ground contamination, risk assessment, remediation, geostatistics, indicator kriging, heavy metals

1 Introduction

Human Health Risk Assessment is a methodology used to describe and estimate adverse effects on human health due to exposure to certain chemical substances, for a certain period of time [1].
Commonly, contaminated sites are classified based on an index risk value calculated for the most polluted collected sample. This approach gives rise to the overestimation of risk areas, especially in cases where sites enclose non contaminated sub-areas. To avoid this situation and obtain spatial mapping of human health risk grade, geostatistical modelling is used as a tool for estimating distribution of risk indexes based on values calculated for the whole set of sampled locals. Spatial zoning of site risk index contributes for optimization of future remediation actions and, additionally helps planning extra site investigation works, when necessary.

2 Methodology

The methodology consists on the integration of geostatistical models with Human Health Risk Assessment procedures [1] to estimate the spatial distribution of human health risk grade of a site, based on local contamination. Considering that the generalization of the risk calculated based only on the highest value of a sample cannot identify its spatial variability, in this study it was decided to adopt a specific methodology for risk assessment, composed of two sequential stages described as following:
Stage 1 – Risk Assessment - Calculates, on each sample location, the carcinogenic effects (cancer risk) on human health and non-carcinogenic effects (hazard quotient) of chemical pollutants taking into account different exposure pathways and scenarios;
Stage 2 – Risk Mapping - Spatial mapping of risk areas using indicator kriging geostatistical techniques.

2.1 Stage 1 - Risk assessment

Developed by the United States Environmental Protection Agency the first stage of risk assessment approach consists on the following sequential procedures: (i) data compilation and evaluation; (ii) exposure assessment; (iii) toxicity assessment; (iv) risk characterization and; (v) risk monitoring [1].

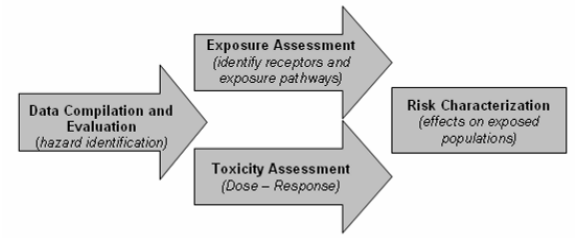

Fig.1 – Human health risk assessment steps [1]

Data compilation and evaluation – consists on the acquisition of relevant data for the human health risk assessment and the identification/selection of contaminants present in the study area [1].

Exposure assessment (*I*) – estimation of the type, frequency, magnitude and the routes of exposure *n* to the chemical substance of concern *i*.
Includes the characterisation of exposure setting (physical environment and potentially exposed populations), identification of exposure pathways (chemical sources and releases, transport media, exposure points and routes) and quantification of exposure, that can be described as (equation 1) [1].

$$I_{ni} = C_i * \frac{CR_n * EF * ED}{BW} * \frac{1}{AT} \quad \text{(Equation 1)}$$

Where:
I_n – Contaminant (i) intake for the exposure n (mg/kg body weight/day)
C_i – Contaminant (i) concentration (mg)
CR_n – Contact rate for the exposure pathway n (mg/kg)
EF – Exposure Frequency (days/year)
ED – Exposure Duration (years)
BW – Body Weight (kg)
AT – Average Time (days)

Toxicity assessment – gathering toxicity information for non-carcinogenic effects (target organs or critical effects) and carcinogenic effects (carcinogen class). Consists in identifying important toxicity values such as:
(i) *chronic oral reference doses* (*RfDs*) for non-carcinogenic effects; (ii) *oral cancer slope factors* (*SF*) for carcinogenic effects [1].

Risk characterisation - summarises and combines outputs of the exposure and toxicity assessments into a quantitative and qualitative expression of risk**.**
The *carcinogenic risk* is the probability of an individual to develop cancer over a lifetime, and is estimated from calculated intakes (I_{ni}) and chemical-specific *Slope Factor* (*SF*) (equation 2) [1].

$$CR = I_{ni} * SF \quad \text{(Equation 2)}$$

Where:
CR – Carcinogenic Risk
SF - Slope Factor

The *Hazard Quotient* (*non-carcinogenic risk*) is the probability of an individual to develop a non cancer disease over a lifetime and is estimated from calculated *Intakes* (I_{ni}) and the *Reference-Dose* (*RfD*) (equation 3) [1].

$$HQ = \frac{I_{ni}}{RfD} \quad \text{(Equation 3)}$$

Where:
HQ – Hazard Quotient (non-carcinogenic risk)
RfD – Reference Dose

2.2 Stage 2 – Risk mapping

After the estimation of *carcinogenic risk* (*CR*) and *hazard quotient* (*HQ*) values for each local sample, it is necessary to estimate the morphology and extension of the risk areas to identify the priority areas to remediate. For the characterization of priority risk areas the indicator kriging [2] geostatistical approach is used considering the following cut-off for risk values [1]:

- If $CR \geqq 1E^{-4}$; carcinogenic risk is assumed for industrial/commercial use (probability of 1 individual in 10 thousand, to have cancer);
- If $CR \geqq 1E^{-6}$; carcinogenic risk is assumed for residential use (probability of 1 individual in 1 million, to have cancer);
- If $HQ \geqq 1$; non-carcinogenic risk is assumed.

Risk values are transformed into indicator variables represented by 0 (zero) and 1 (one), respectively if the risk values are below or above the respective cut-offs. Probability risk maps are obtained by kriging the indicator variables, considering each scenario and exposure pathway.

3 The Case Study

The study area is an old industrial site located near Lisbon, on the left margin of Tagus River (Barreiro - Portugal) (Fig. 2). The priority area, with an extension of about 30 ha, has been scenario of several chemical industries over the last one hundred years. Nowadays, the area is almost deactivated and designated for urban redevelopment [3].

Selection of relevant data was based on soil samples where chemical content exceed the reference values for residential use, in accordance with Ontario guidelines [4]. In conformity, the selected contaminants are: arsenic (As), copper (Cu) and lead (Pb). Figure 2 presents a map locating all the 59 pit/boreholes used as data source for the risk evaluation.

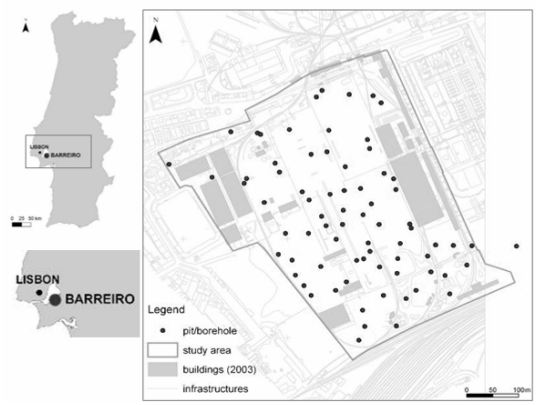

Fig.2 – Location of the 59 soil data samples

The evaluation was developed considering different scenarios for present and future use of the area: residential child, residential adult, industrial or commercial worker and construction worker.
The contact between the receptor and the contaminant may occur through the following exposure pathways (figure 3): ingestion of soil, dermal contact with soil and ingestion of vegetables.

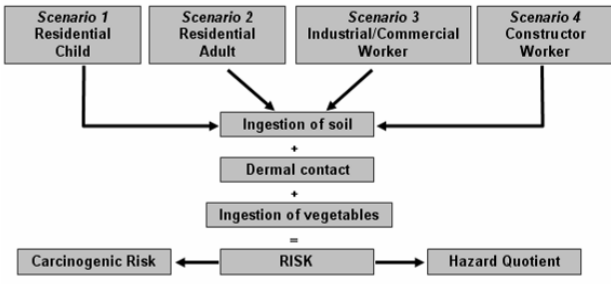

Fig.3 – Land use scenarios for risk assessment

To calculate the risk values the *RISCWorkbench* software was used [5] based on the Manual "Risk Assessment Guidance for Superfund (RAGS)" of the U. S. Environmental Protection Agency [1], and the GIS software ArcGIS from ESRI [6].
Estimation of probability maps and respective risk maps where built using *Geoms* software [7].
Figures 4 and 5 illustrate the risk maps estimated for scenario 1 (residential child) and scenario 2 (residential-adult) for the related exposure pathways.

The estimation of risk maps allowed not only the quantification of risk areas but also the weighting of exposure pathways.
As illustrated in maps presented in figures 4 to 11. It can be said that:

- In terms of total carcinogenic risk (sum of the 3 exposure pathways), it can be concluded that almost the entire area should have some kind of intervention in terms of soil remediation or use restriction for residential use (figure 4).

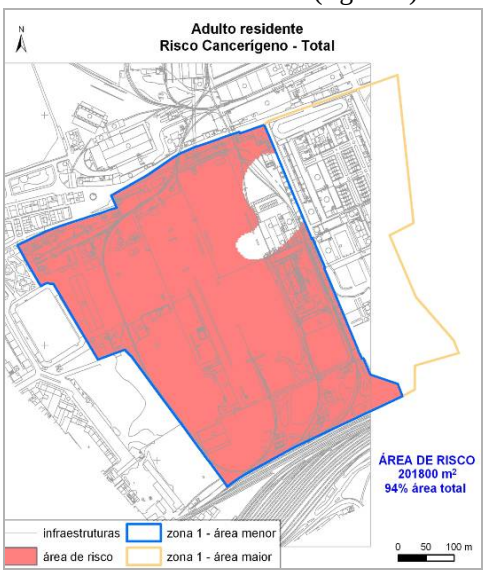

Fig. 4 – Total carcinogenic risk map (residential - adult) – (in [3])

- concerning residential receptor - the carcinogenic risk for the *ingestion of vegetables* is higher than the risk caused by *the ingestion of soil* (figures 5 and 6);

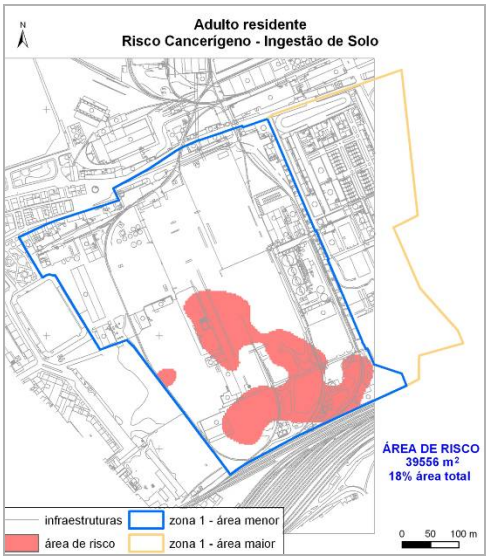

Fig. 5 – Carcinogenic risk map for soil ingestion (residential - adult) – (in [3])

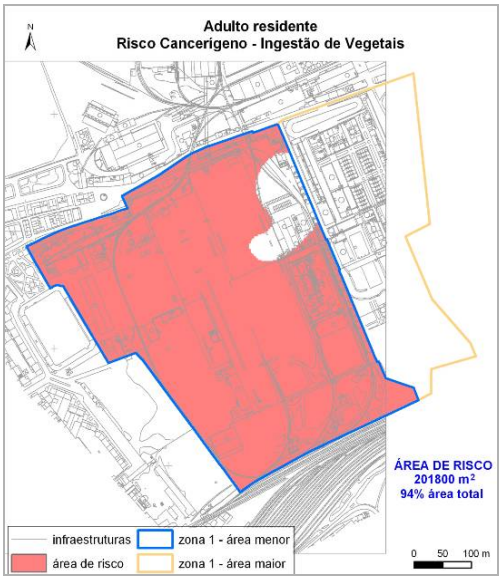

Fig. 6 – Carcinogenic risk map for vegetables ingestion (residential - adult) (in [3])

- The risk for *dermal contact* is reduced, compared with the other exposure pathways, (figure 7);

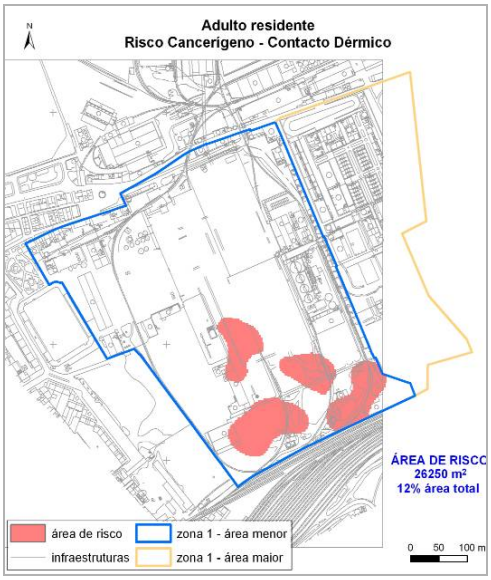

Fig. 7 – Carcinogenic risk map for dermal contact (residential - adult) (in [3])

- The study concluded that, in the hypothesis of eliminating the risk for *ingestion of vegetables* (through a mere restrictive measure of use), the *carcinogenic risk* of the study area is reduced to about 2/3 of the total risk in the case of a child and to about 5% in the case of the adult;
- Concerning scenarios 3 and 4 (*commercial worker* and *construction worker*), the results show that they are subject to a total *carcinogenic risk* in approximately 1/3 of the area. For these scenarios the exposure pathway for *ingestion of vegetables* is not considered.
- The *commercial worker* has a risk of *ingestion of soil* higher than the risk of dermal contact (figures 8 and 9);

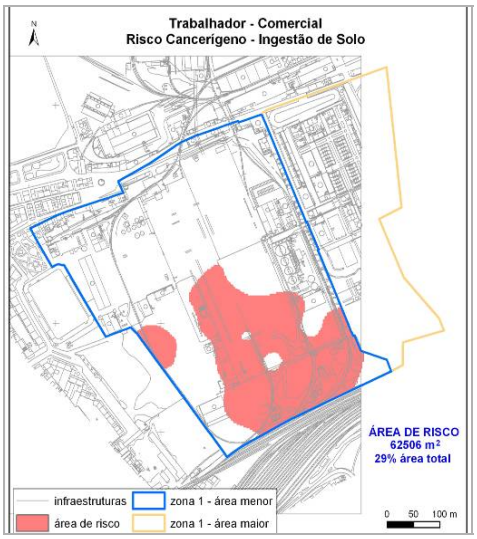

Fig. 8 – Carcinogenic risk map for soil ingestion (commercial worker) (in [3])

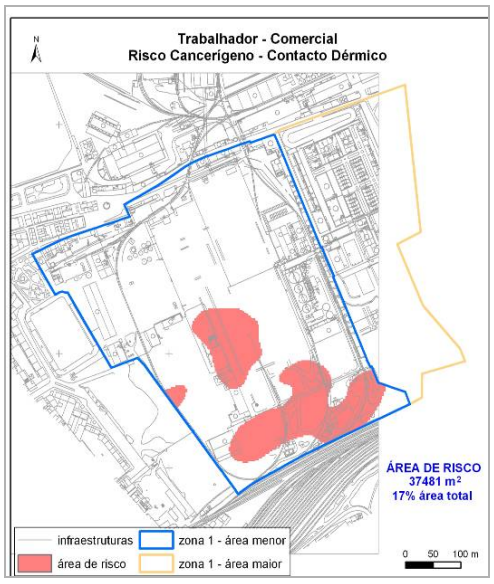

Fig. 9 – Carcinogenic risk map for dermal contact (commercial worker) (in [3])

- The *construction worker* has a similar risk for both ways of exposure, as a consequence of direct manipulation of materials (figures 10 and 11).

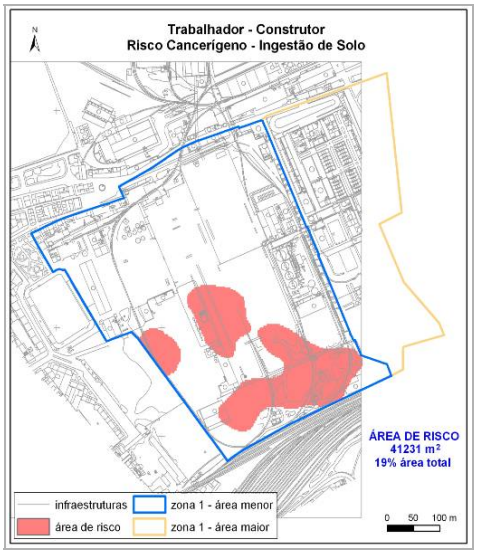

Fig. 10 – Carcinogenic risk map for soil ingestion (construction worker) (in [3])

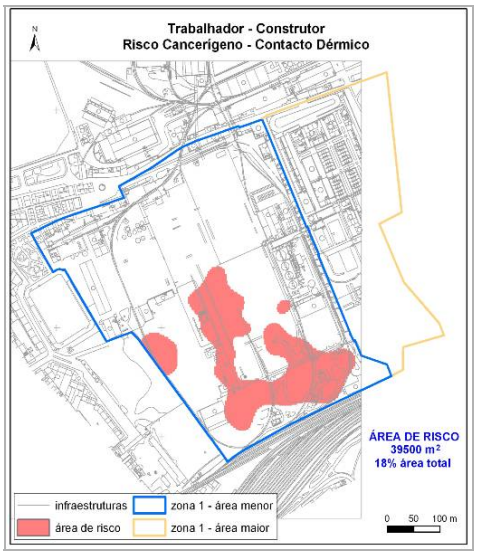

Fig. 11– Carcinogenic risk map for dermal contact (construction worker) (in [3])

Concerning the non carcinogenic risk it can be said that the contribution of the factors of exposure is very similar to those of the total carcinogenic risk.

4 Conclusions

The integration of geostatistical techniques as a second stage for site risk assessment allowed the characterization and quantification of the priority areas to be remediated and, consequently, minimized the respective environmental costs.

The methodology contributes to the planning of human occupation and identifies potential restrictive actions to implement in order to minimize the identified risks.

This methodology allows the comparison of risk areas resulting from the different exposure pathways related to human occupation. In the particular case of this study, it was possible to reduce the total risk area to about 2/3 by the application of restrictive landuse rules (restriction of agriculture practices) to the site.

5 Acknowledgments

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References:

[1] US EPA, *Risk Assessment Guidence for Superfund Volume I Human Health Evaluation Manual (Part A). Report no. EPA/540/1-89/002*, United States Environmental Protection Agency, Washington D.C., 1989.

[2] Soares, A., *Geoestatística Aplicada às Ciências da Terra e do Ambiente*. *IST Press*, 2000 (in portuguese).

[3] Brito, M.G., *Metodologia para a avaliação e remediação da contaminação por metais pesados em áreas industriais degradadas*, *PhD Thesis* from the New University of Lisbon, Faculty for Sciences and Technology, 2005 (in portuguese).

[4] Ontario Ministry of Environment and Energy (OMEE), *Guidelines for Use at Contaminated Sites in Ontario (Revised February 1997)* - Queen´s Printer Ontario, 1997.

[5] Waterloo Hydrogeologic, *RiscWorkbench User's Manual, Human Health Risk Assessment Software for Contaminated Sites*, 2001.

[6] ArcGIS Desktop 9.2 Software. ESRI.

[7] CMRP-IST, *Manual de utilização do geoMS* – Geostatistical Modelling Software, (v.1.0). IST, 1999 (in portuguese).