APPLICATION OF GEOSTATISTICAL METHODS TO SOIL DATA FROM AN OLD GOLD AND SILVER MINE (VILA VERDE-NORTHERN PORTUGAL)

REIS, A. P.[1], SOUSA, A. J.[2], FERREIRA DA SILVA, E.[3], CARDOSO FONSECA, E.[3]

[1] BPD of Fundação para a Ciência e a Tecnologia, Portugal; [2] CVRM / Centro de Geo-Sistemas, IST, Technical University of Lisbon, Lisbon, Portugal; [3] Departamento de Geociências, Aveiro University, Aveiro, Portugal

PURPOSES

- This is a preliminary environmental study about soil contamination by heavy metals in Marrancos area.

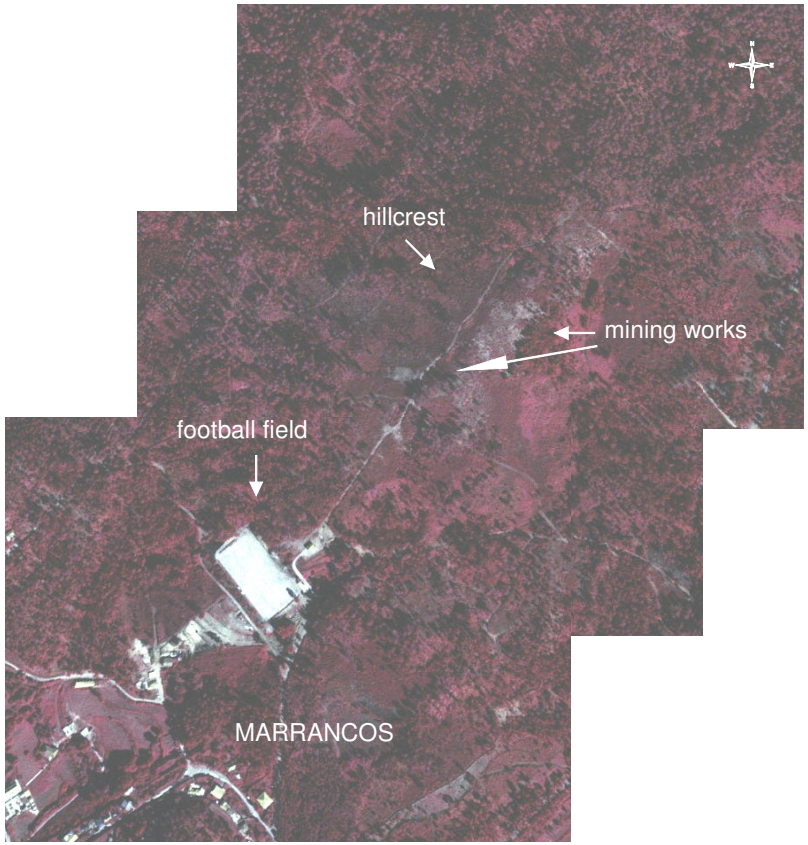
- The purpose of this work is to assess the negative impact on soil caused by several mining episodes that occurred in Cova dos Mouros mine, a old gold and silver mine;

i. using geostatistical methods of spatial data interpolation (Indicator Kriging) to assess potential risks of contamination in unsampled areas and,

ii. creating risk maps of contamination probabilities for the soil. The potential risks mapping can be important information for decision-making regarding the evaluation of contaminated locations, such as old mining areas.

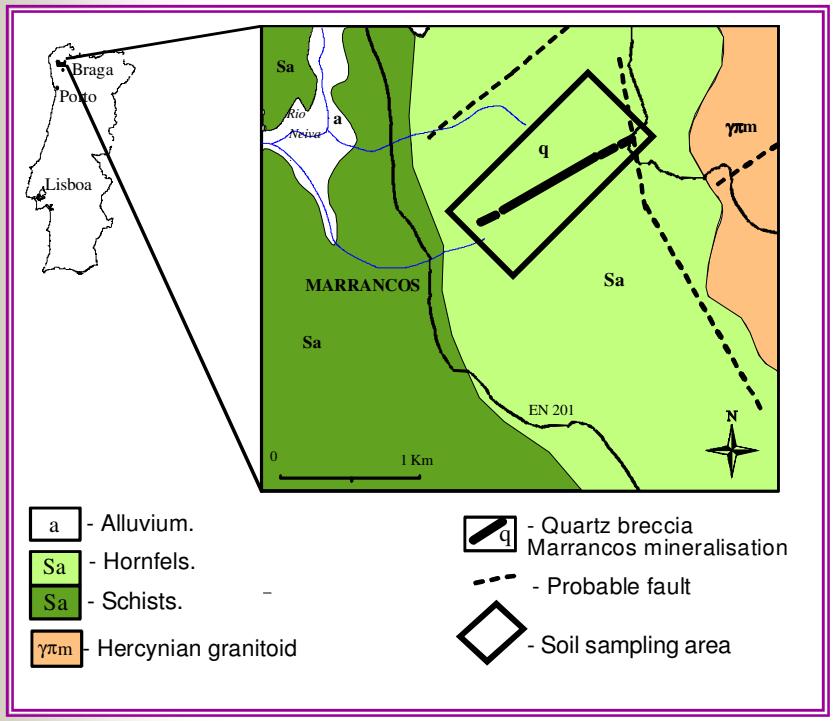
COVA DOS MOUROS MINE

- **Gold** with the Roman Empire, resulting in large "holes" at surface.
- First half of the 20th Century for **tin** and **tungsten**, resulting in a number of wells and galleries. At present, these old mining works are used for water exploitation systems.
- **Gold** and **silver** in the early sixties but was later abandoned.
- Recent geochemical, geophysical and geological surveys to establish the economic interest of the buried **gold** deposit (IGM 1989).



SURVEY AREA

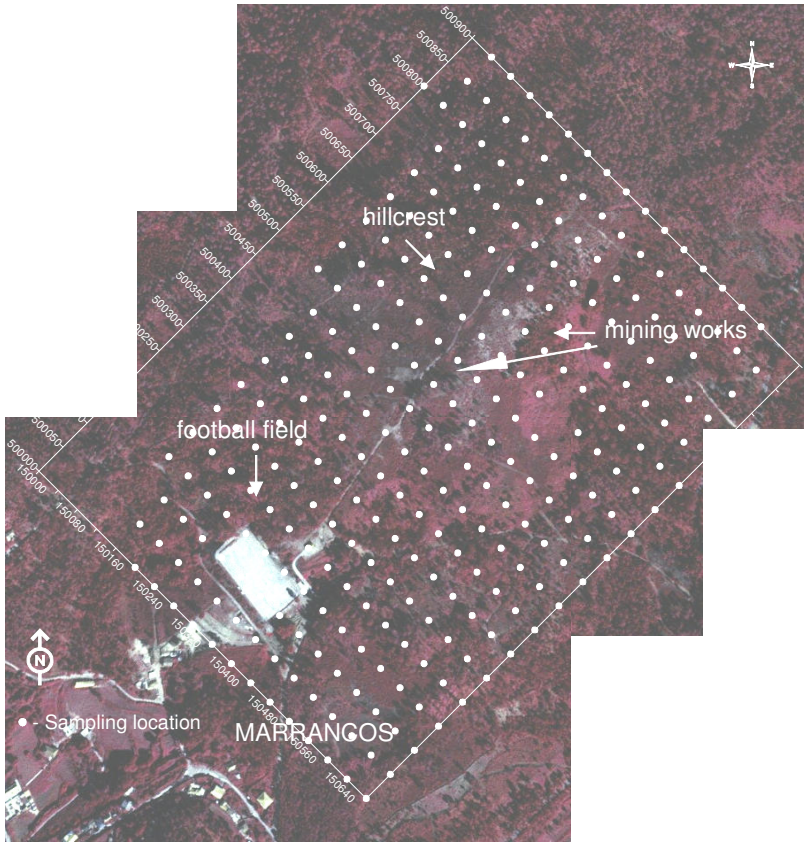
- GEOLOGY: the soil sampling area is at a hornfels zone developed at the schist/granitoid contact.



- SOIL: a brown soil type, with a low content in organic matter and a medium to coarse grain size, varying in depth from 10 to 30 cm.
- CILMATE: a maritime temperate climate; mean annual rainfall of above 1500 mm; average temperature of 15-16ºC.
- TOPOGRAPHY: a small hill with a gentle slope.
- LAND-USE: essentially to agriculture, it is a heavily inhabited region.
- VEGETATION: pines, eucalyptos, *agrostis cutisii* and *castellana*, *halimiun*, *lasianthum*, *alyssoides*, *erica umbellata*, *hypochoeris radicata*.

SAMPLING AND ANALYSIS

- 286 soil samples were collected in a rectilinear grid at equal distances (40×50 m).
- The lines have an N45°W orientation that is perpendicular to the NE-SW trend of the hillcrest.
- The samples, collected at 10-30 cm depth, were dried at a temperature of 50°C for 24 hours and dry sieved into the <200 mesh size fraction.
- The soil samples were analysed for arsenic by atomic absorption spectrometry - hydride generation after an HClO4-HF attack, with a 5 ppb detection limit.



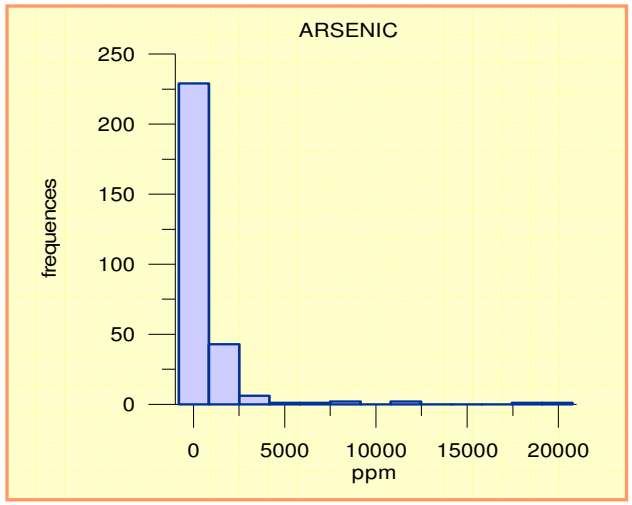
RESULTS

Arsenic Raw Data

Summary Statistics

	N	Mean	Median	Min.	Max.	1st Q	3rd Q	Variance	Std. Dev.	Skewness
As	286	768	142	18	19950	69	665	4315979	2077	6.41

Histogram



Intervention Values (Swartjes, 1999)

Soil standards to assess soil quality based on potential risks

Ecotoxicological Serious Soil Contamination
(EIV)
40 ppm

Human Toxicological Serious Soil Contamination
(HTIV)
678 ppm

Intervention Value for Soil
(SIV)
55 ppm

RESULTS

Methodologies

- Given a data set for the variable Z at n locations x_i, $Z(x_i)$, i= 1, 2,..., n, the simple variogram $\gamma^*(h)$ measures the average dissimilarity between data separated by a vector h .

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \quad (1)$$

N(h) is the number of data pairs at a distance of h.

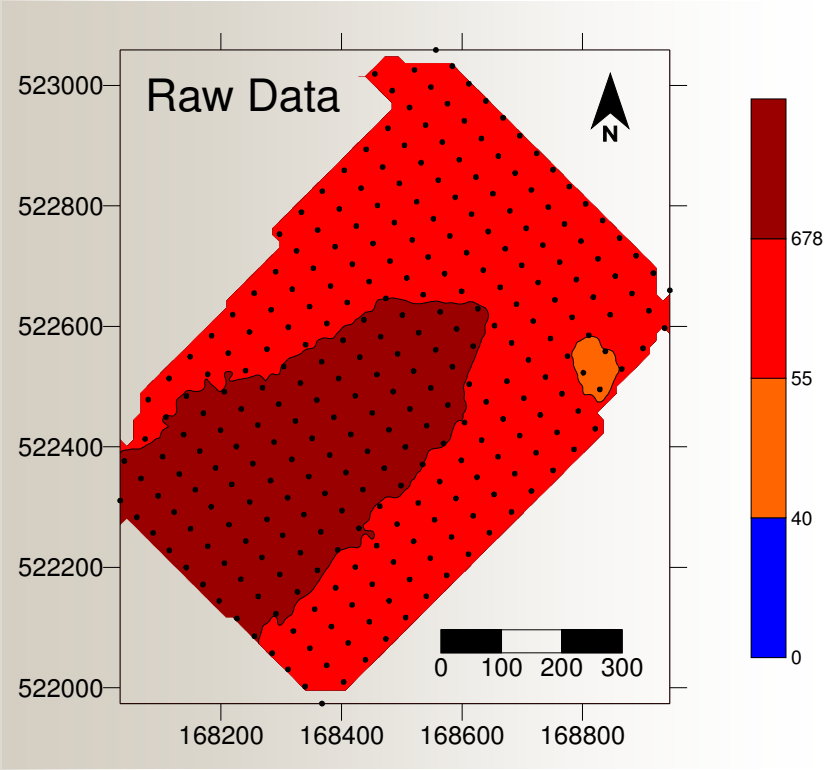
- For the estimation of the variable Z at n locations x_i, $\{Z(x_i)$, i= 1, 2,..., n$\}$, the estimator $Z^*(x_i)$ is defined as:

$$Z^*(x) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad (2)$$

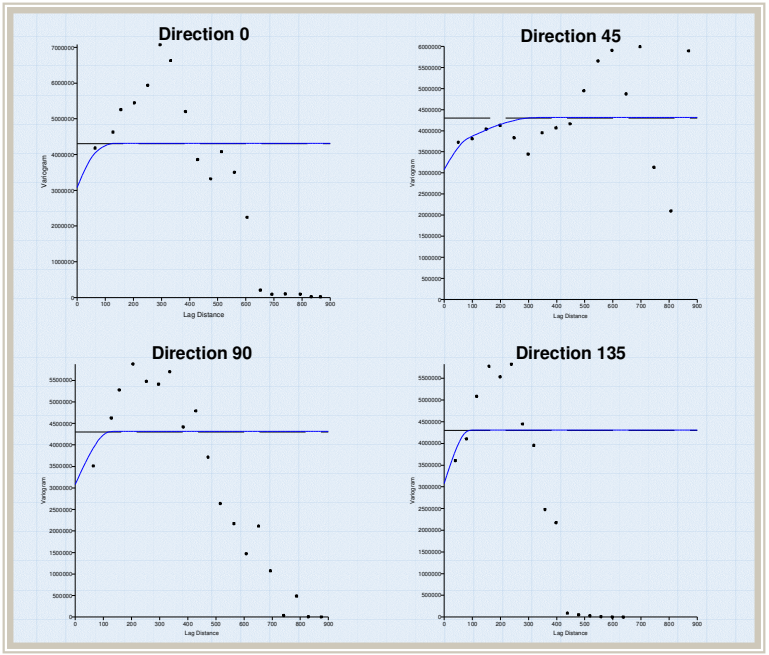
$$(3) \quad \begin{cases} \sum_j^n \lambda_j \bar{\gamma}(x_i, x_j) + \mu = \bar{\gamma}(x_i, x) \ , \ i = 1, \ldots, n \\ \sum_j^n \lambda_j = 1 \end{cases}$$

RESULTS

Raw Data Mapping



VARIOGRAMS



Spherical Model parameters

	C0 (ppm)	C1 (ppm)	A1 (m)	Dir.1	Anis.1 (m/M)	C2 (ppm)	A2 (m)	Dir.2	Anis.2 (m/M)
As	3079853	439833	120	90º	0.55	791853	330	45º	0.29

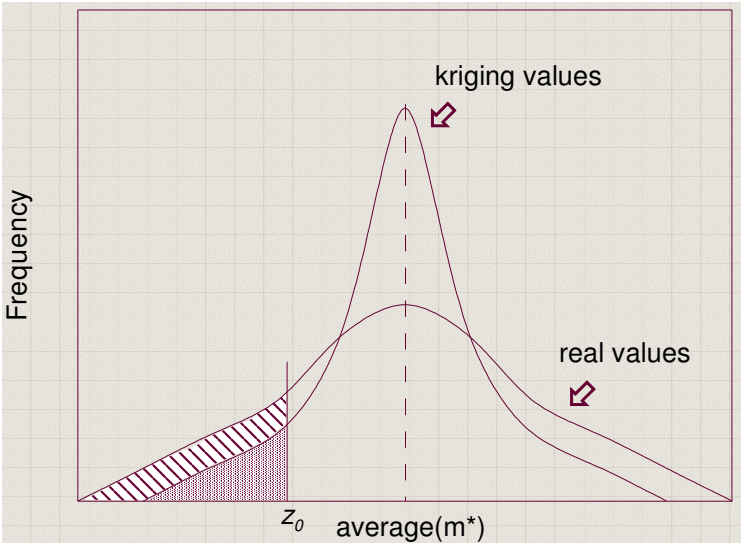
RESULTS

KRIGING

- Kriging, as an estimation method, has a smoothing effect over the true values. Therefore, the contaminated areas obtained using estimated values (kriging values) are biased:

  - ✓ if the **threshold is lower than average** the obtained contaminated area is **over estimated**;
  - ✓ if the **threshold is higher than average** the obtained area is **under estimated**;

- Solution: a data transformation (indicator variables).



RESULTS

Methodologies

- Any variable Z(x) can be transformed into an indicator variable $I_z(x)$ based on a given threshold z,

(4) $$I_z(x) = \begin{cases} 1 \cdot if \cdot Z(x) < z \\ 0 \cdot if \cdot Z(x) \geq z \end{cases}$$

- The indicator variable can be understood as the probability of exceeding the established threshold.

Like the variogram (1),

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{j=1}^{N(h)} \left[I(x_j) - I(x_j + h) \right]^2 \quad (5)$$

The estimator $I^*(x_j)$ is defined as:

$$I^*(x) = \sum_{j=1}^{n} \lambda_j(x) I(x_j) \quad (6)$$

(7) $$\begin{cases} \sum_j^n \lambda_j \bar{\gamma}(x_i, x_j) + \mu = \bar{\gamma}(x_i, x) \ , \ i = 1, \ldots, n \\ \sum_j^n \lambda_j = 1 \end{cases}$$

RESULTS

INDICATOR KRIGING

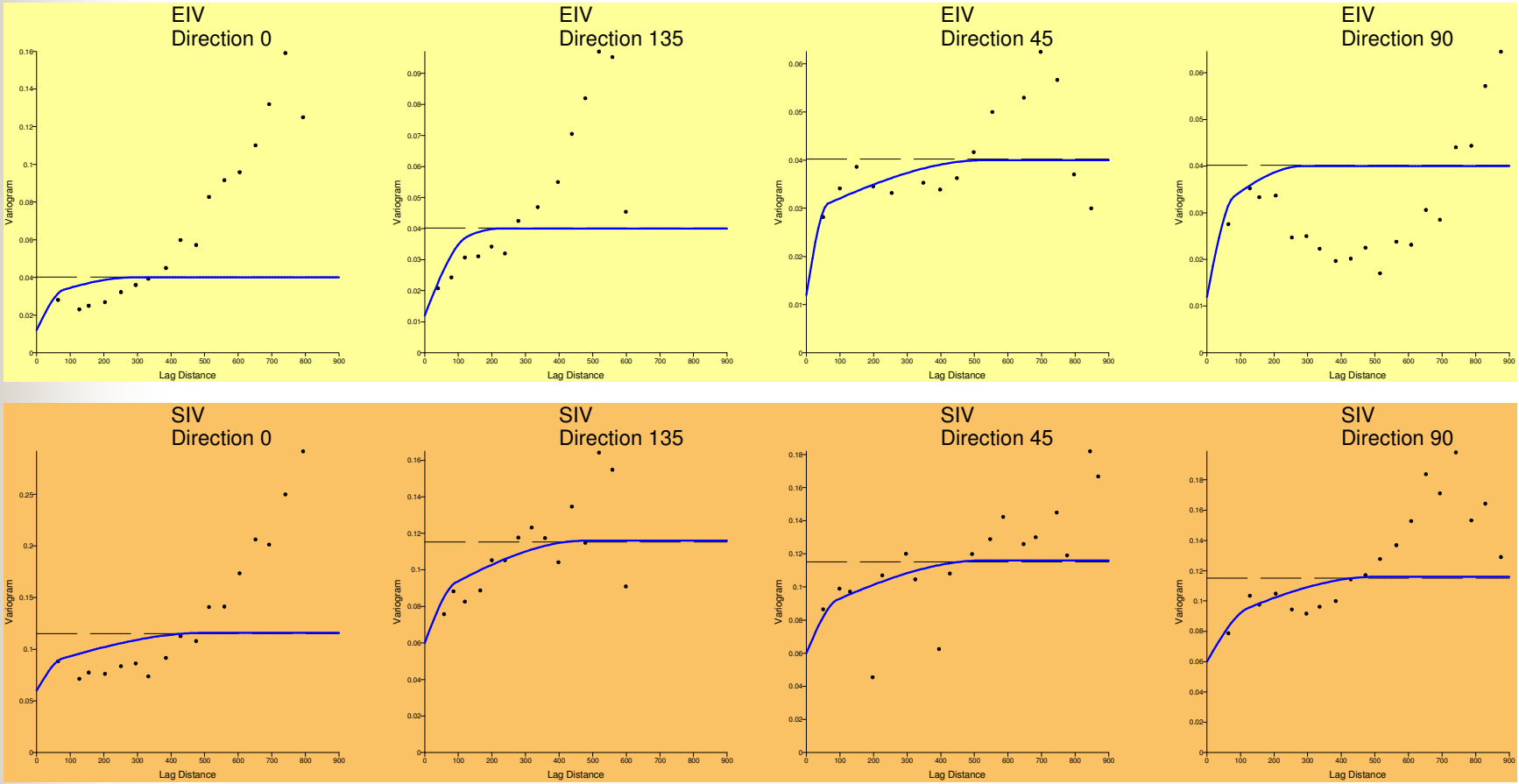
The thresholds used were the Intervention Values for Soil (Swarjtes,1999):

- Ecotoxicological Intervention Value (EIV) of 40 ppm,
- Intervention Value for Soil (SIV) of 55 ppm,
- Human Toxicological Intervention Value (HTIV) of 678 ppm.

RESULTS

INDICATOR KRIGING

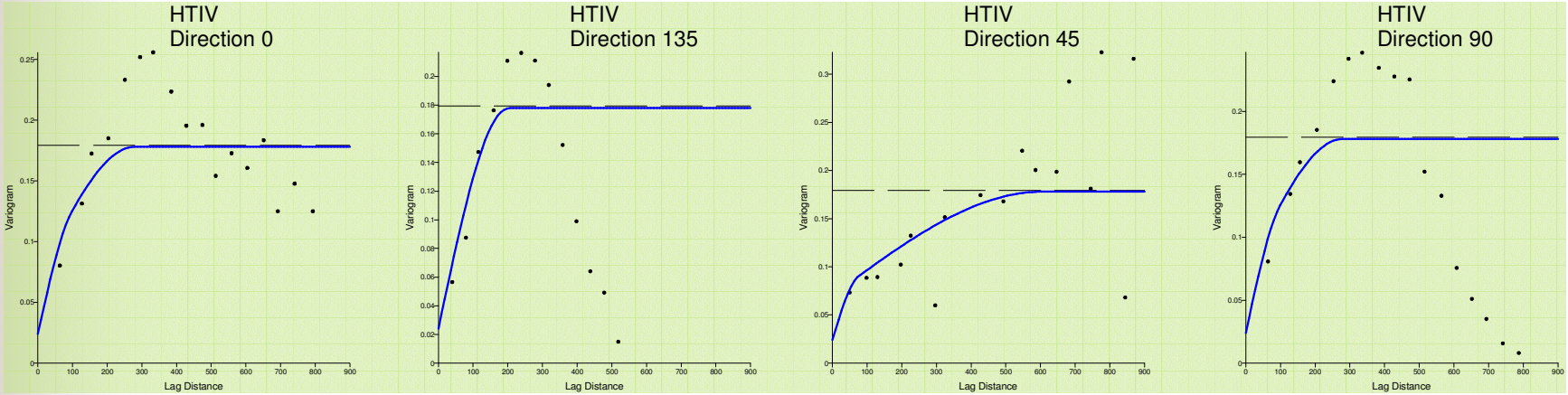
variograms



RESULTS

INDICATOR KRIGING

VARIOGRAMS



RESULTS

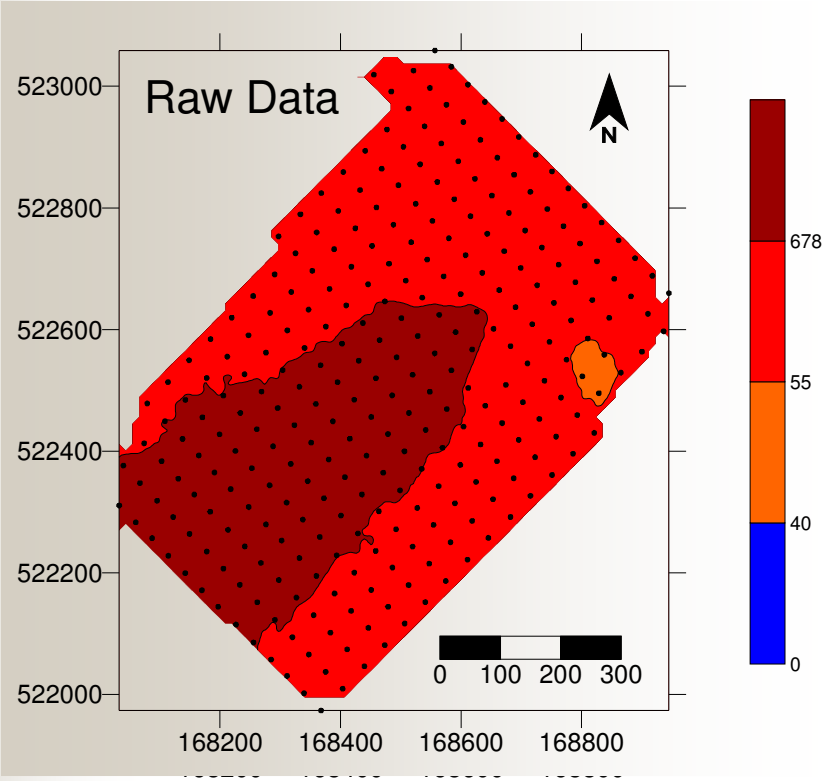
INDICATOR KRIGING

Spherical Model parameters

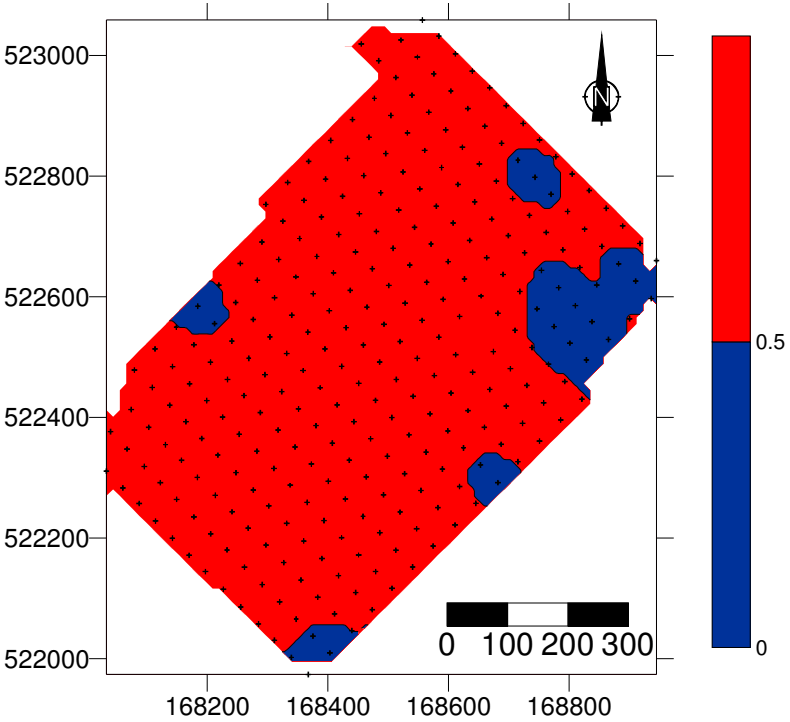
Parameters	EIV	SIV	HTIV
C0	0.012	0.06	0.024
C1	0.017	0.024	0.046
A1	128	125	187
Dir.(1)	135°	90°	135°
Anis.(1)	0.49	0.63	0.4
C2	0.011	0.032	0.108
A2	530	530	604
Dir.(2)	45°	45°	45°
Anis.(2)	0.42	0.89	0.35

RESULTS

Mapping

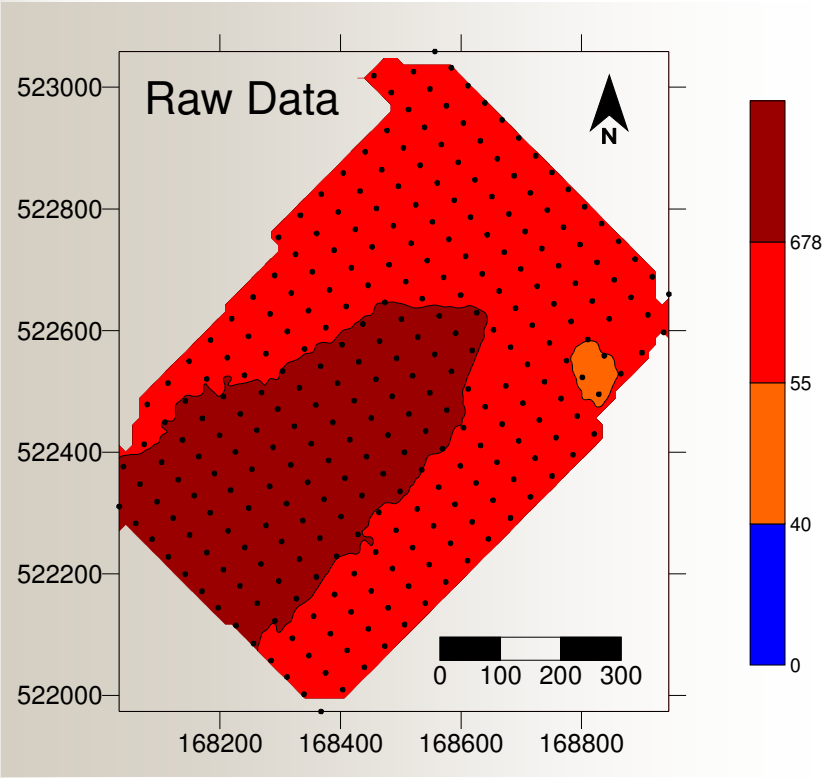


EIV Binary Map

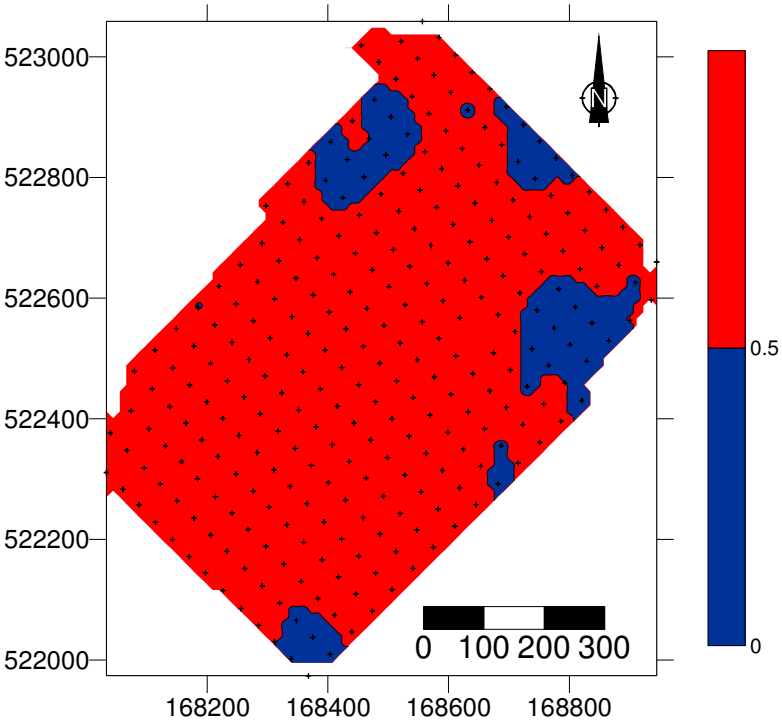


RESULTS

Mapping

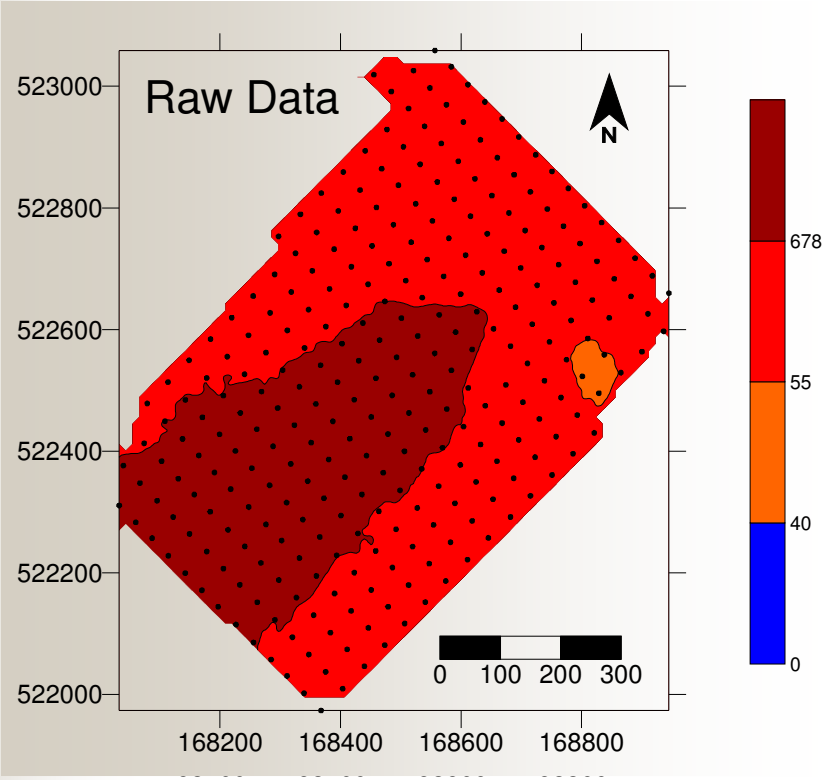


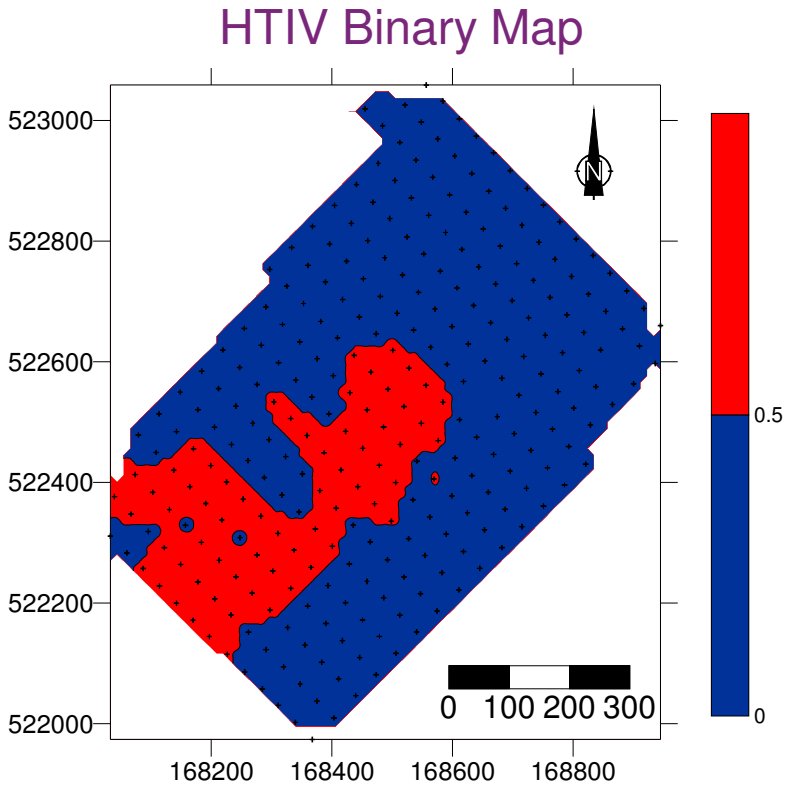
SIV Binary Map



RESULTS

Mapping





conclusions

Raw data from soil samples of cova dos mouros mine shows that:

- ✓ Soils have high contents in arsenic; 75% of data values (concentrations) is above the lowest intervention value proposed by Swartjes (1999),
- ✓ Kriging smoths the extreme values of the database; average value of arsenic contents in Marrancos soils is higher than the given thresholds, which means that the contaminated area is over estimated,

Indicator variable shows that:

- ✓ The indicator kriging produces estimated values that are **not biased** and allows the estimation of the **real** contaminated area.
- ✓ **SIV mapping** allowed the assessement of Marrancos **soil quality** (soils seriously contaminated).

developments

Phase 1: Intervention values are based on potencial risks to humans and ecosystems; total arsenic concentrations used in this study gave an indication of potential problems.

Phase 2: Consider metal associations and bioavailability; some chemical thecniques such as sequencial extractions will be applied to the soil samples from Cova dos Mouros mine.

Phase 3: Determination of the urgency of remediation and the suitable process of remediation.

Thank you so much!