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MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR Portugal



Environmental Hazards and Risk Assessment and Management

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# Assessing landslide susceptibility for spatial planning in Portugal

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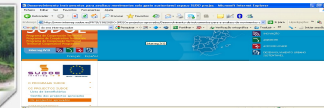
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Methodologies for assessing landslide hazard and risk applied to municipal planning



- Context and study area
- Objectives
- Methods (4 slides)
- Results and discussion (7 slides)
- Conclusion and applications

# Context and study area



Avaliação e Gestão de Perigosidades e Risco Ambiental  
CEG-IGOT III

- **Context:**

The National Ecological Reserve (NER) decree that requires the consideration of the areas which natural hazards at the municipal level.

- Contiguous to Lisbon, where are living
- **Study area:** ~~With 205,000 inhabitants~~ (169 km<sup>2</sup>) (National Institute of Statistics, 2011);
- Prone to various natural hazards, in particular landslides, most of them being triggered by rainfall.

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# Objectives



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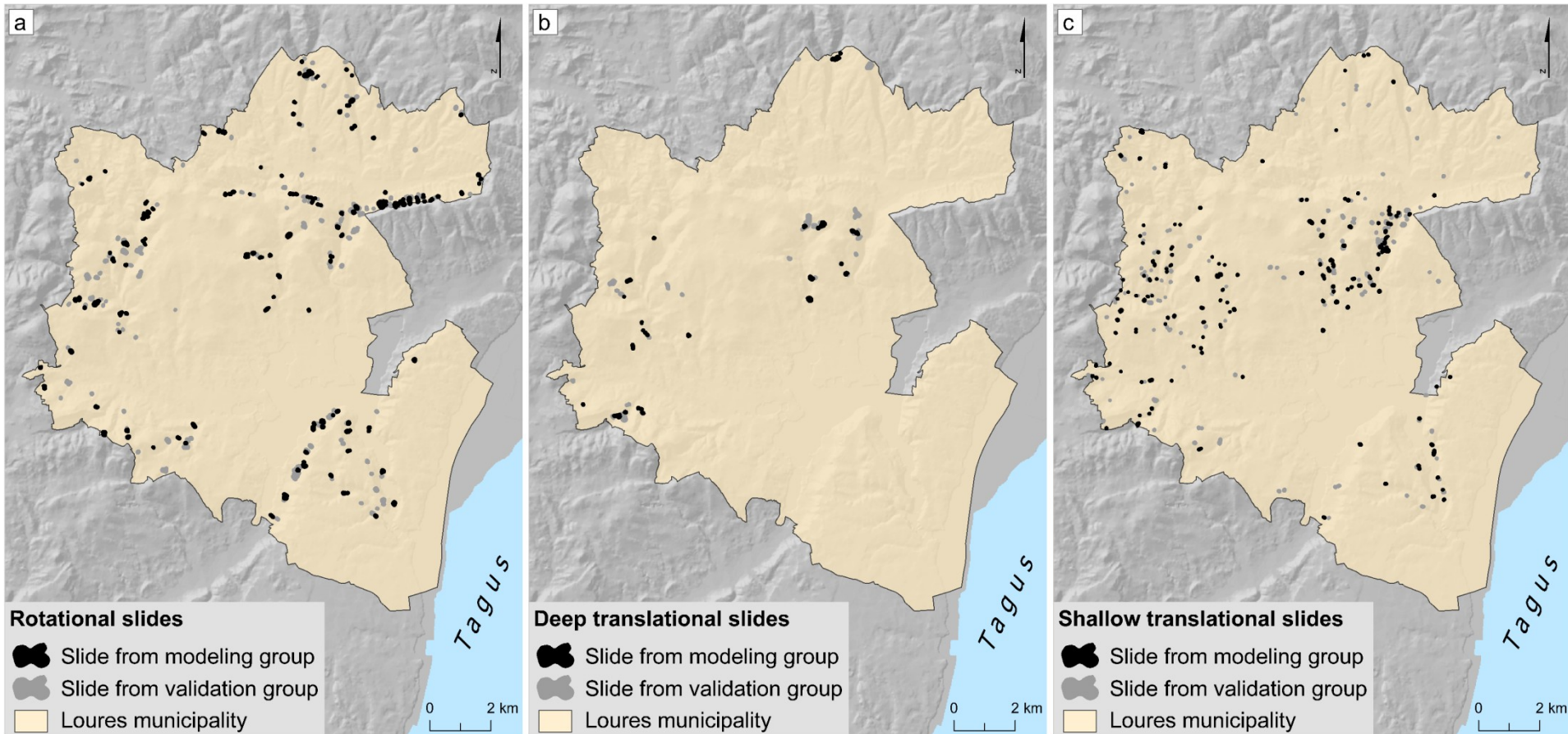
- Assessment and mapping of the landslide susceptibility of the Loures municipality by using a bi-variate statistical method;
- Creation of three landslide prediction models for three different types of landslides, and independent validation of these models;
- Selection of the potentially unstable slopes that must integrate National Ecological Reserve and should be restricted for development purposes according to the Portuguese law;
- Identification of the main exposed elements (roads and buildings) which are within the NER.

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## • Landslide sets

- A landslide inventory was

# Methods (1)



# inventory was

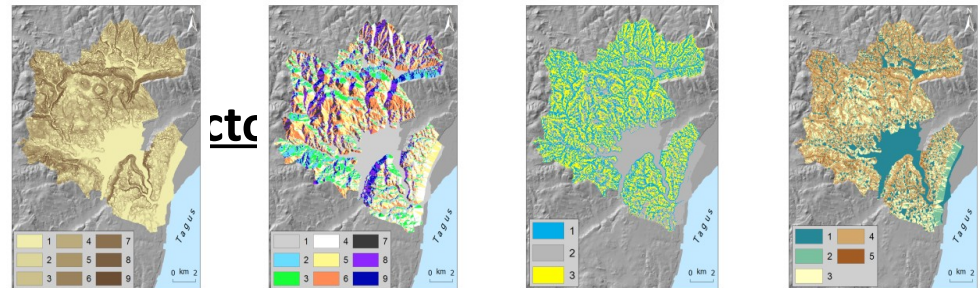
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# Methods (2)

- **Probability of landslide area:**

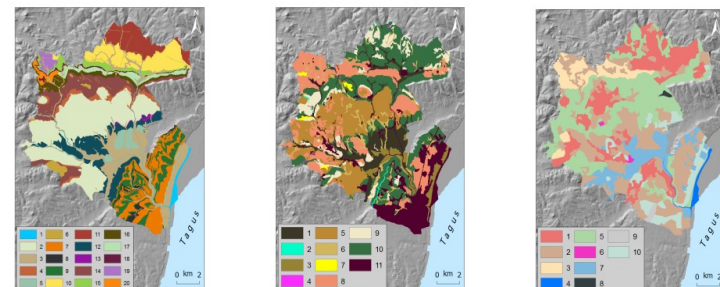
- Use of the probability density function proposed by Malamud and other (2004), considering two landslide groups: shallow and deep landslides
- Assessment of the probability of landslide size, which is a proxy for landslide magnitude (Guzzetti et al. 2005)

- **Identification of 7 landslide predis**



- Slope angle
- Slope aspect
- Slope curvature

Pixel: 5 m



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- Topographic wetness index

# Methods (3)



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- **Modeling strategy:**
  - Modeling with depletion areas or with total (i.e. depletion + accumulation) areas of the landslides? Chung and Fabbri (2005) recommend to model with the total landslide areas when their spatial signatures are not significantly different from the ones of the depletion areas.
  - Split each landslide set into two roughly equivalent groups (a modeling group and a validation group) using a random criterion
  - Application of the Information Value Method (a bi-variate statistical method) to the modeling groups of each set of landslides => 3 susceptibility models



# Methods (4)



## NER delimitation and identification of the elements at risk:

- According to the National Commission of the National Ecological Reserve (CNREN 2010), the slopes classified as being most susceptible by the Information Value Method must integrate the NER.
- The area to be included in the NER should guarantee the inclusion of at least 70% of the landslides identified in the landslide inventory. This criterion was applied to the three landslide susceptibility models and the union of the obtained areas is selected to integrate the NER.
- The exposed elements of the Loures municipality are crossed with the obtained NER in order to identify buildings and roads that would not be allowed according to the NER law.

# Results and discussion (1)

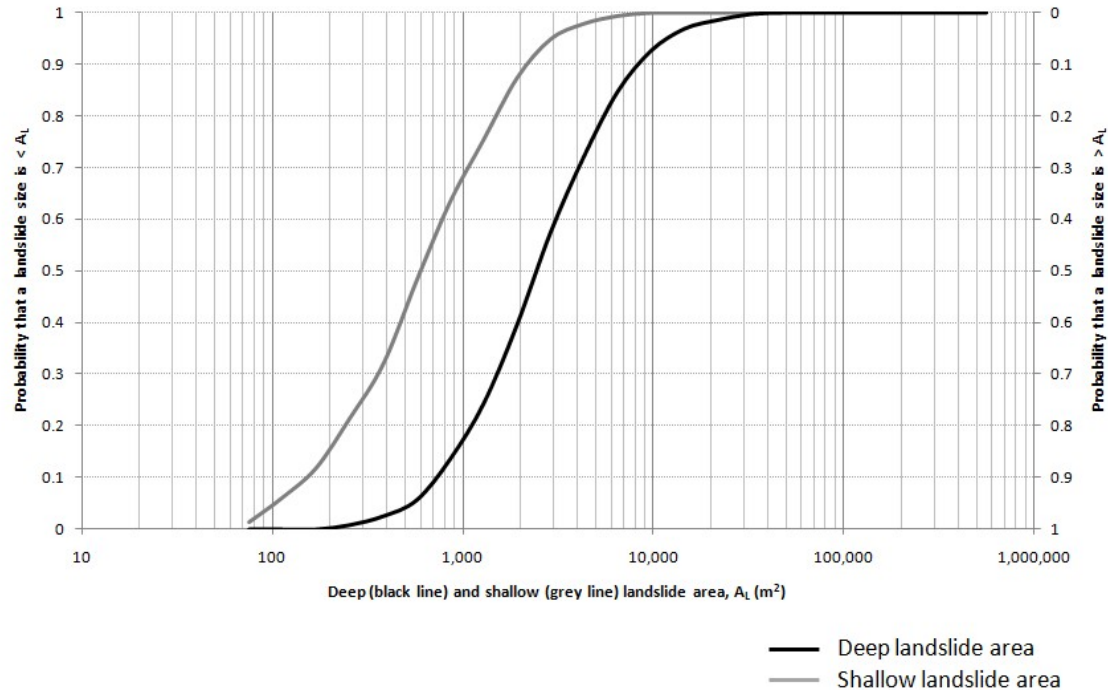


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## Probability of landslide size

### Results and discussion (1)

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The complete landslide inventory was divided into two groups according to depth of slip surface (335 shallow slope movements and 353 deep slope movements) in order to assess probability of landslide areas in the Loures municipality. Curves represented correspond to the expected probability for a deep or a shallow landslide according to its size. The left axis represents the probability that a slide will have an area smaller than a given size, and the right axis shows the probability that its area will exceed this given size. The size of

# Results and discussion (1)



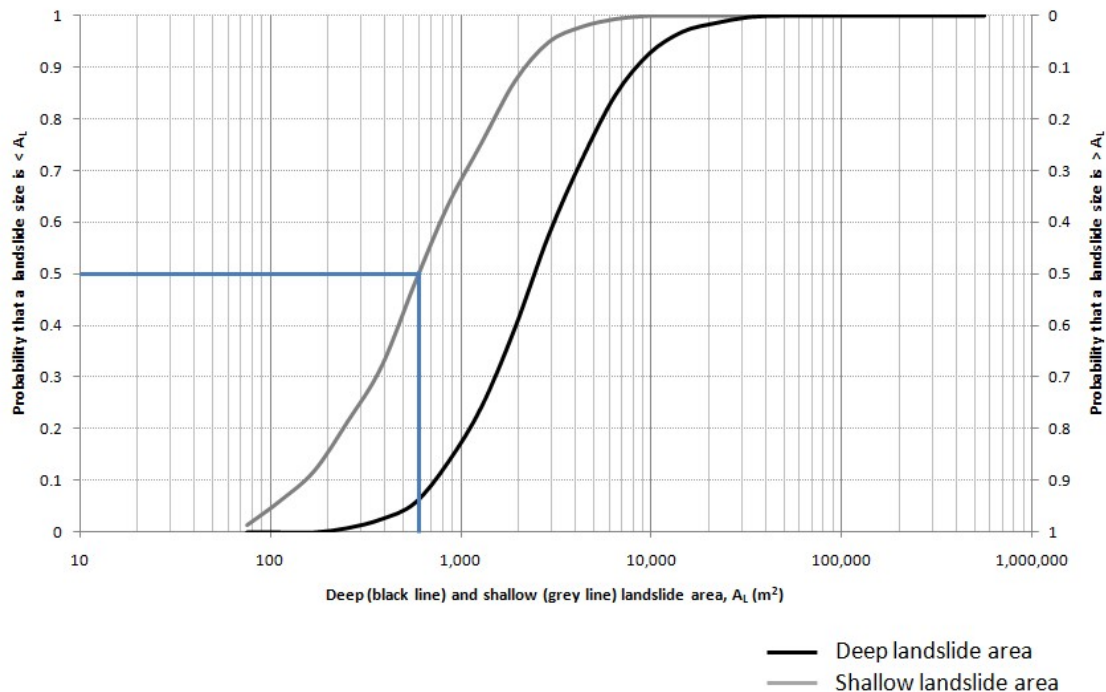
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### Results and discussion (1)

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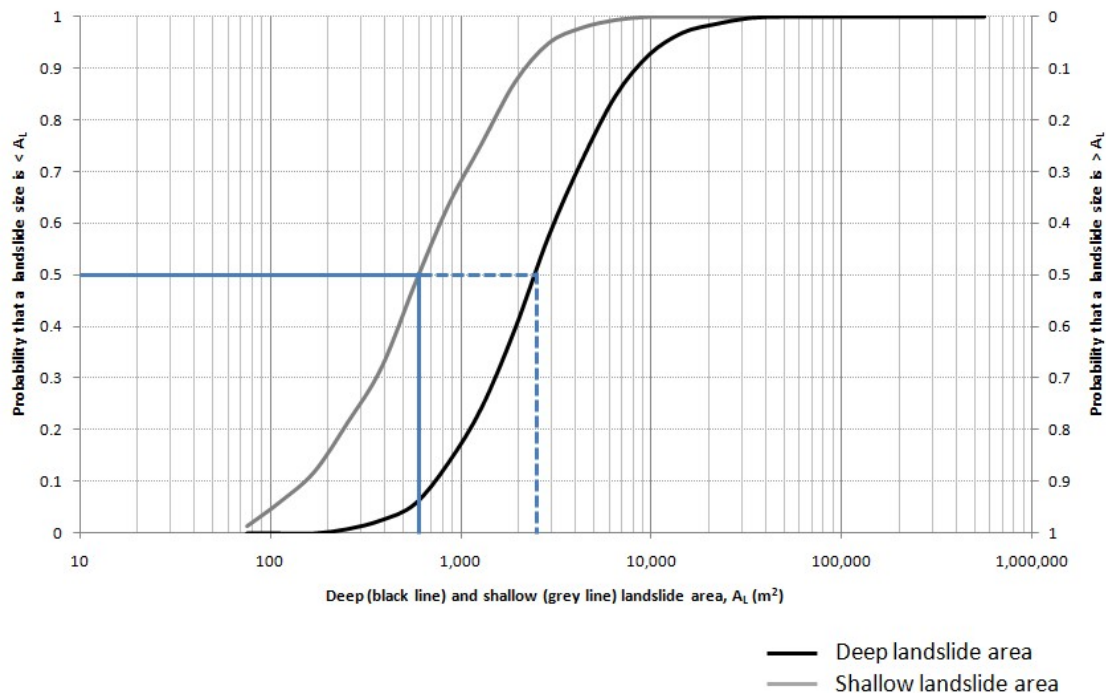
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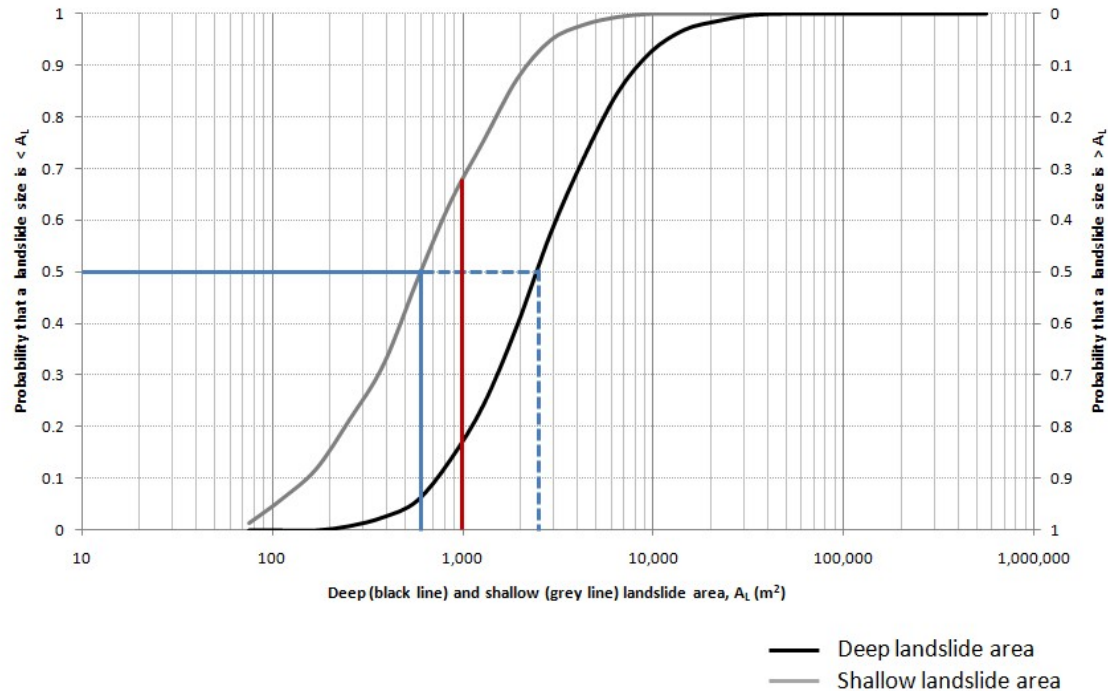
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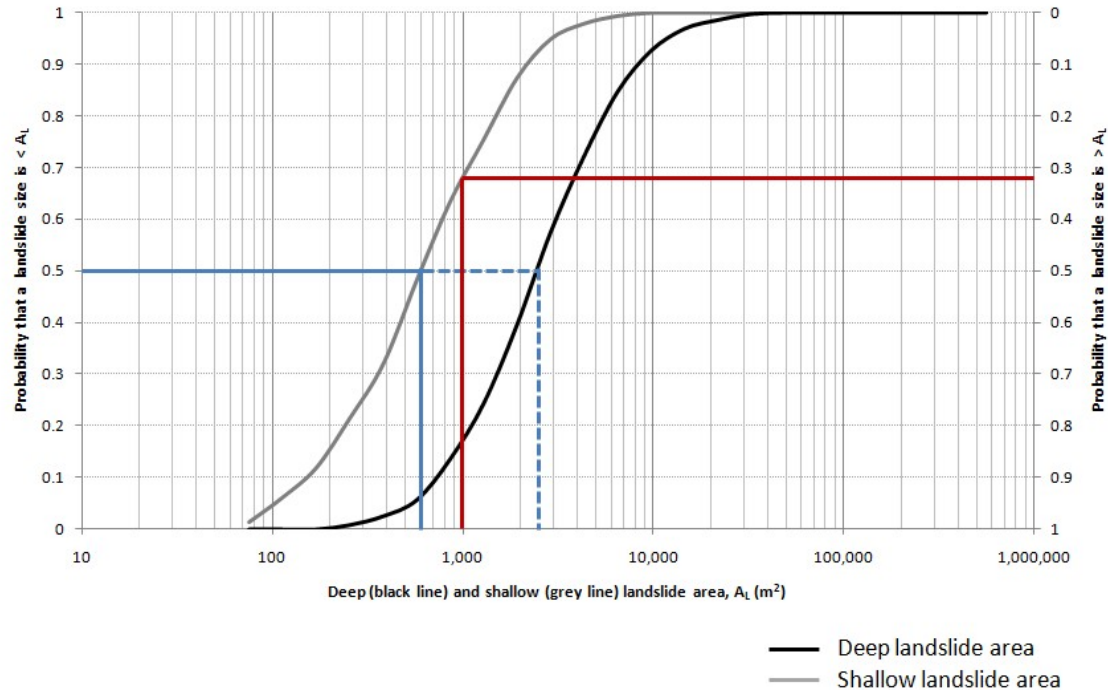
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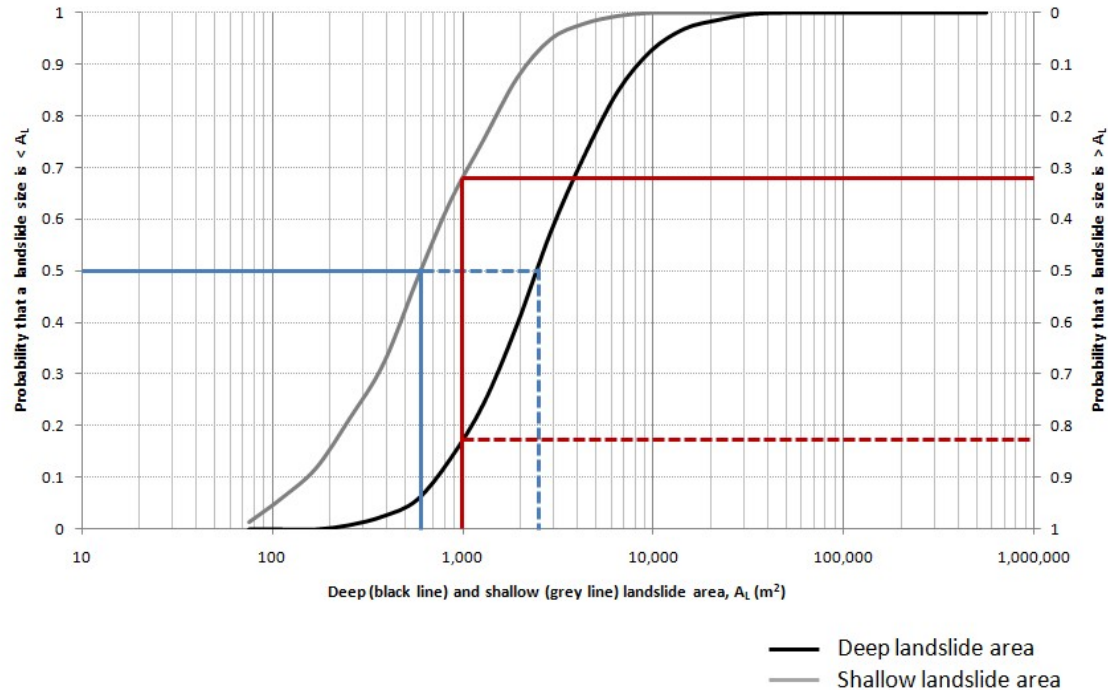
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## Probability of landslide size

### Results and discussion (1)

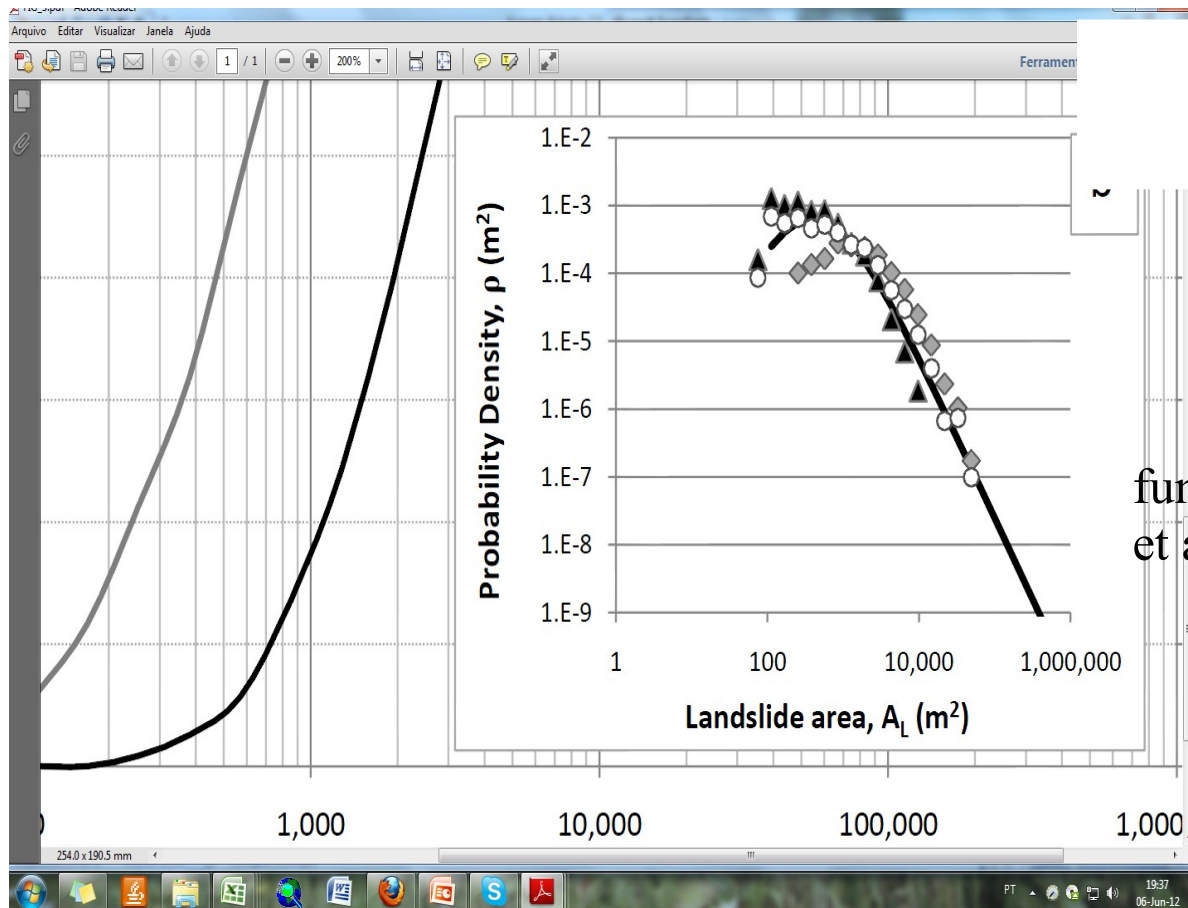
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# Results and discussion (2)

## Probability density function



◆ Deep landslides areas

▲ Shallow landslides areas

○ Total landslides areas

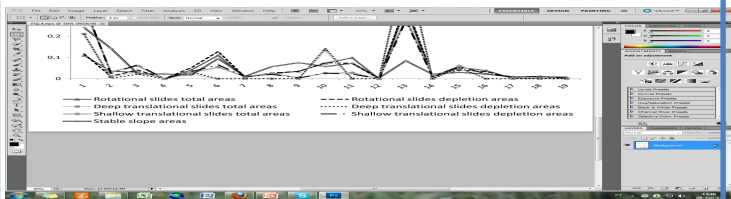
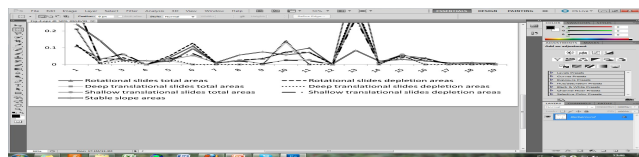
Probability density  
function described by Malamud  
et al. (2004)



# Results and discussion (3)

## Spatial signatures of depletion areas and total areas of landslides

### Legend:



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Fig.a: Slope angle factor

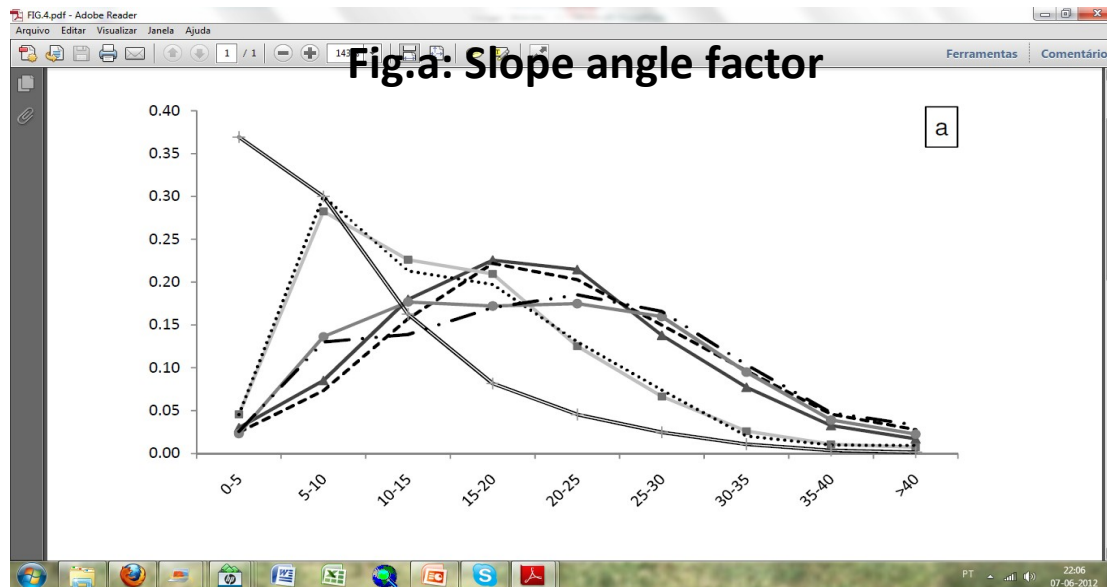
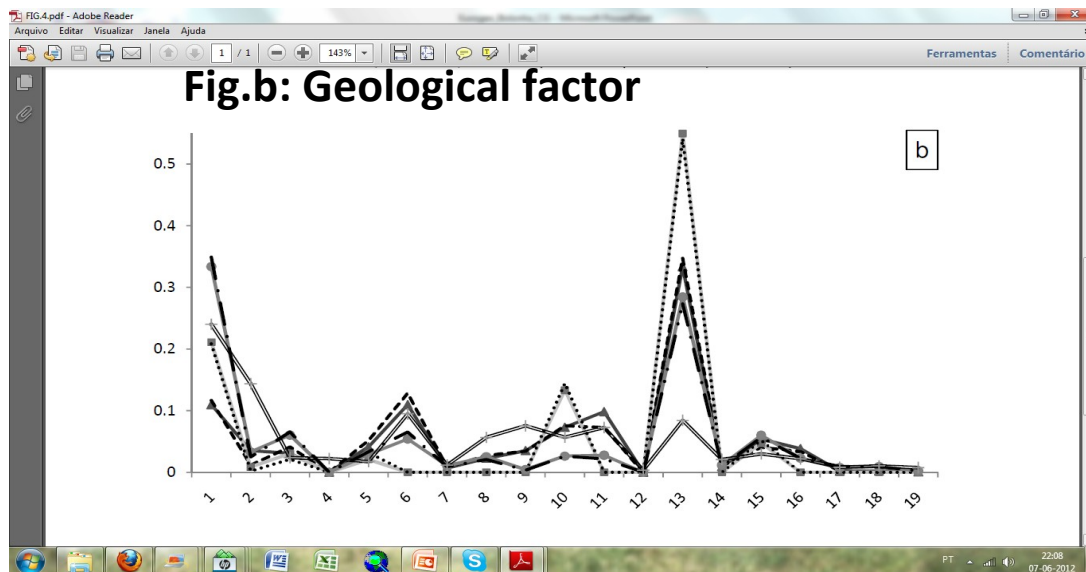


Fig.b: Geological factor



# Results and discussion (4)



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## Application of the Information Value

### Method

Ideal conditions for landslide occurrence in the study area are:

- A concave slope (or convex in the case of deep translational slides);
- Oriented to North, West or Northwest (for rotational and shallow translational slides), and South or Southwest (for deep translational slides);
- With a gradient above 15°;
- An inverse of the wetness index;
- A geology containing marl and rhyolite;
- Soils being brown vertisols or kaolinitic oxisols;
- Covered by dense shrubs.

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Table 1 and Table 2 - Microsoft Word

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Table 1 Thematic layers and Information Value scores of variables considering the modeling groups of inventories landslides. More significant results are highlighted in bold.

Thematic layer	Class	Number of pixels	Rotational slides IV	Deep translational slides IV	Shallow translational slides IV
Slope angle					
[0-5[	1	2469554	-2.934	-1.940	-2.682
[5-10[	2	2014058	-1.130	-0.142	-0.666
[10-15[	3	1099793	0.154	0.516	0.041
[15-20[	4	559885	1.035	<b>0.938</b>	0.782
[20-25[	5	317099	1.493	0.839	1.365
[25-30[	6	173792	1.643	0.756	1.681
[30-35[	7	77930	<b>1.853</b>	0.783	<b>2.032</b>

# Results and discussion (5)

## Validation of the susceptibility models

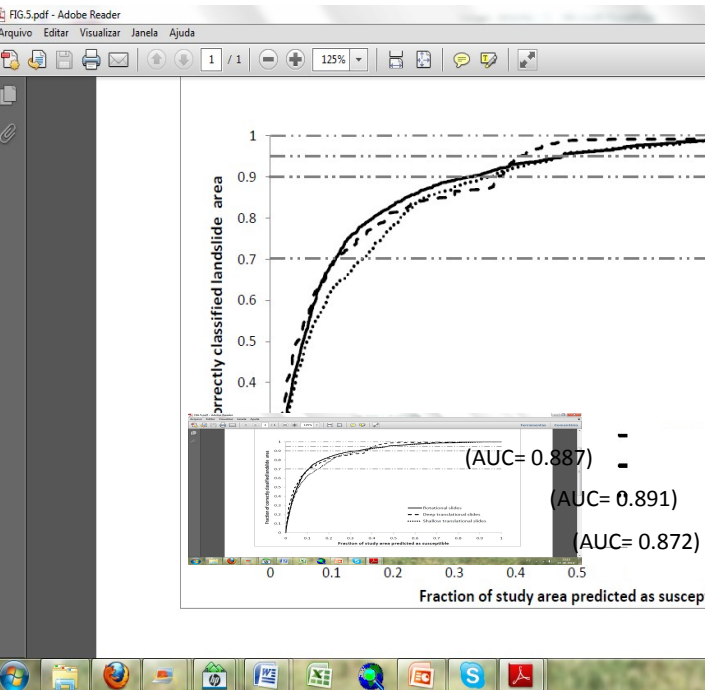


Table 3 - Microsoft Word

Susceptibility class of rotational slides model	Area (pixels)	% of study area	Predictive capacity (%)	Predictive capacity / % of study area
I	716877	10.7	70	6.567
II	1443910	21.5	20	0.932
III	1023718	15.2	5	0.328
IV	3540552	52.6	5	0.095

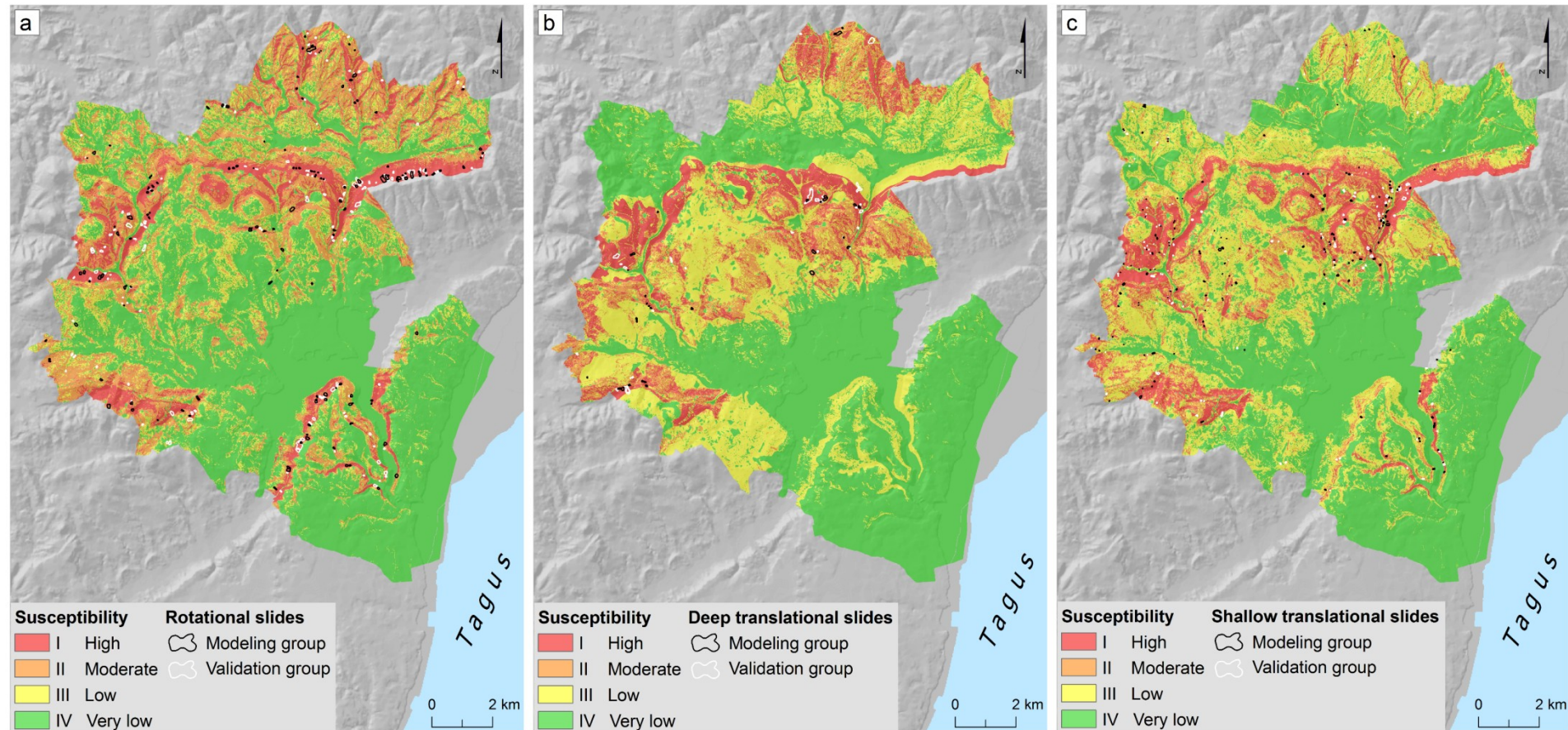
Susceptibility class of deep translational slides model	Area (pixels)	% of study area	Predictive capacity (%)	Predictive capacity / % of study area
I	706345	10.5	70	6.665
II	1785980	26.6	20	0.753
III	213940	3.20	5	1.572
IV	4018792	59.8	5	0.084

Susceptibility class of shallow translational slides model	Area (pixels)	% of study area	Predictive capacity (%)	Predictive capacity / % of study area
I	1001759	14.9	70	4.699
II	1385835	20.6	20	0.971
III	814009	12.1	5	0.413
IV	3523454	52.4	5	0.095

# Results and discussion (6)

## Landslide susceptibility maps

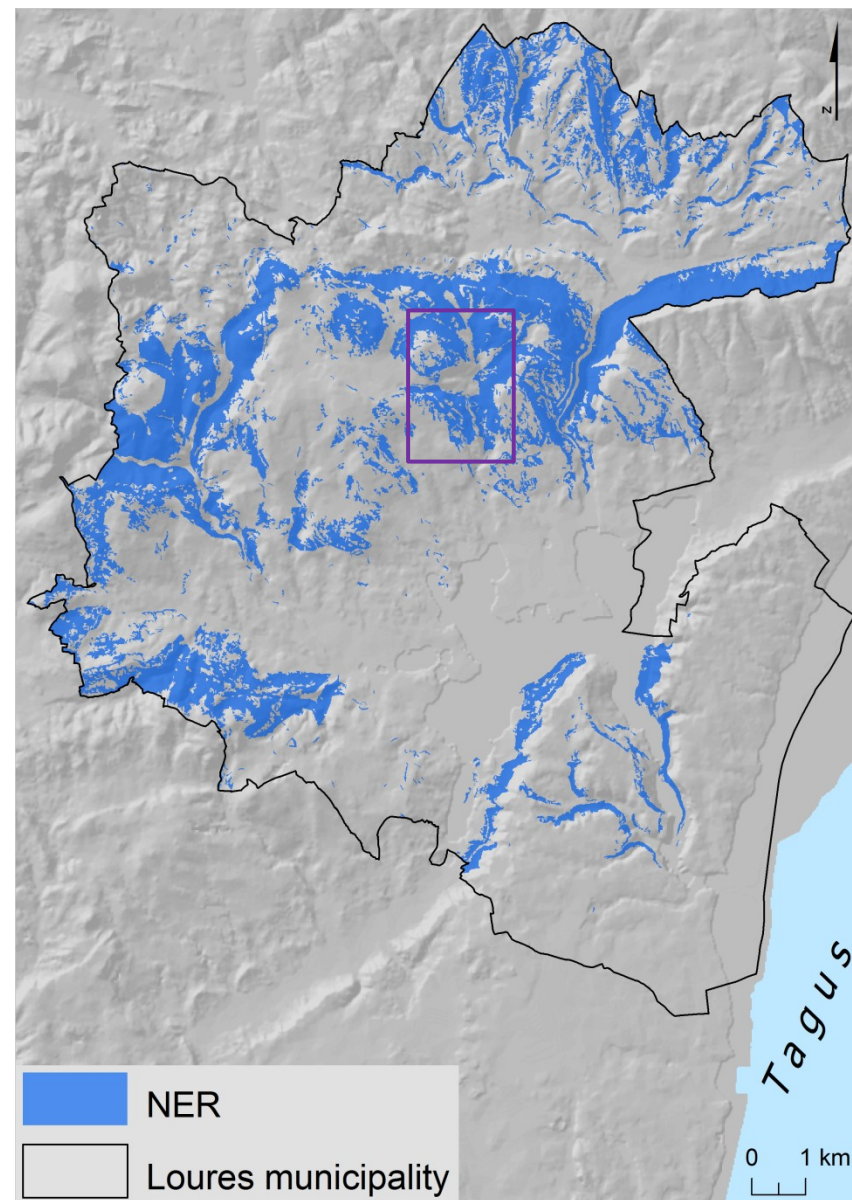
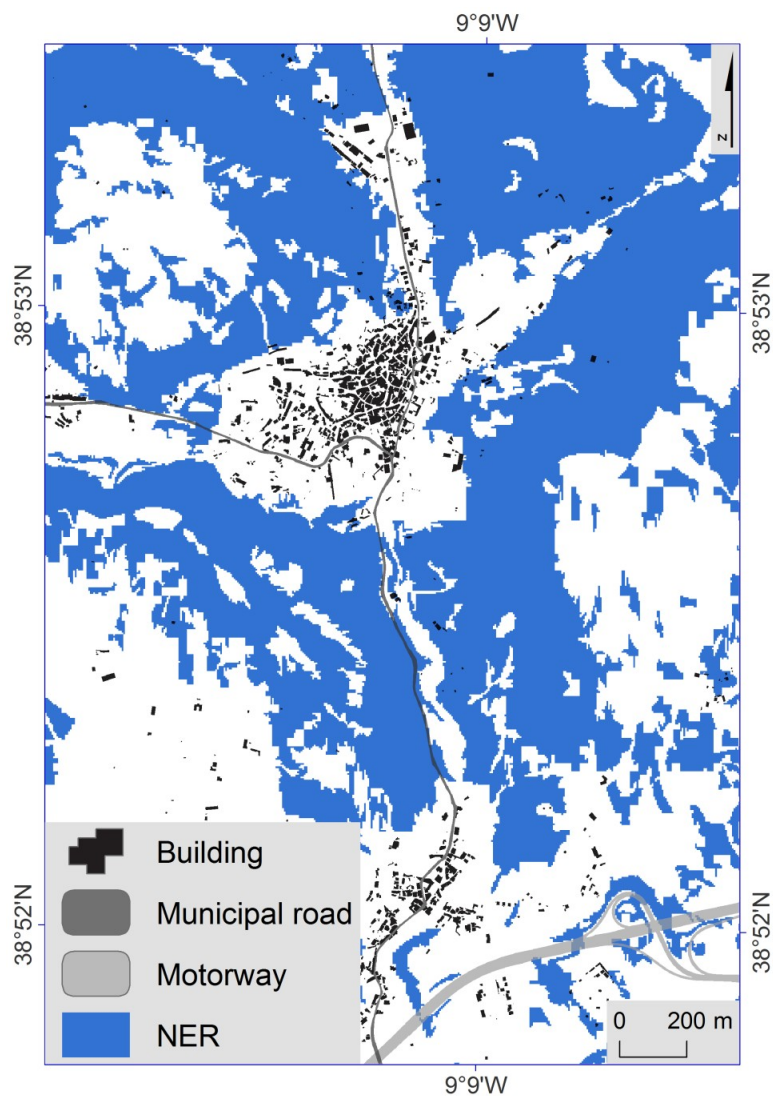


Class I: 10.7% of the total area    Class I: 10.5% of the total area    Class I: 14.9% of the total area

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The union of those three areas represents 34.3 km<sup>2</sup> (20.3% of the Loures municipality area) and is the base of the NEP elaboration

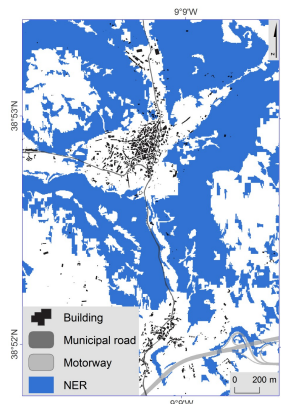
# Results and discussion (7)

## National Ecological Reserve

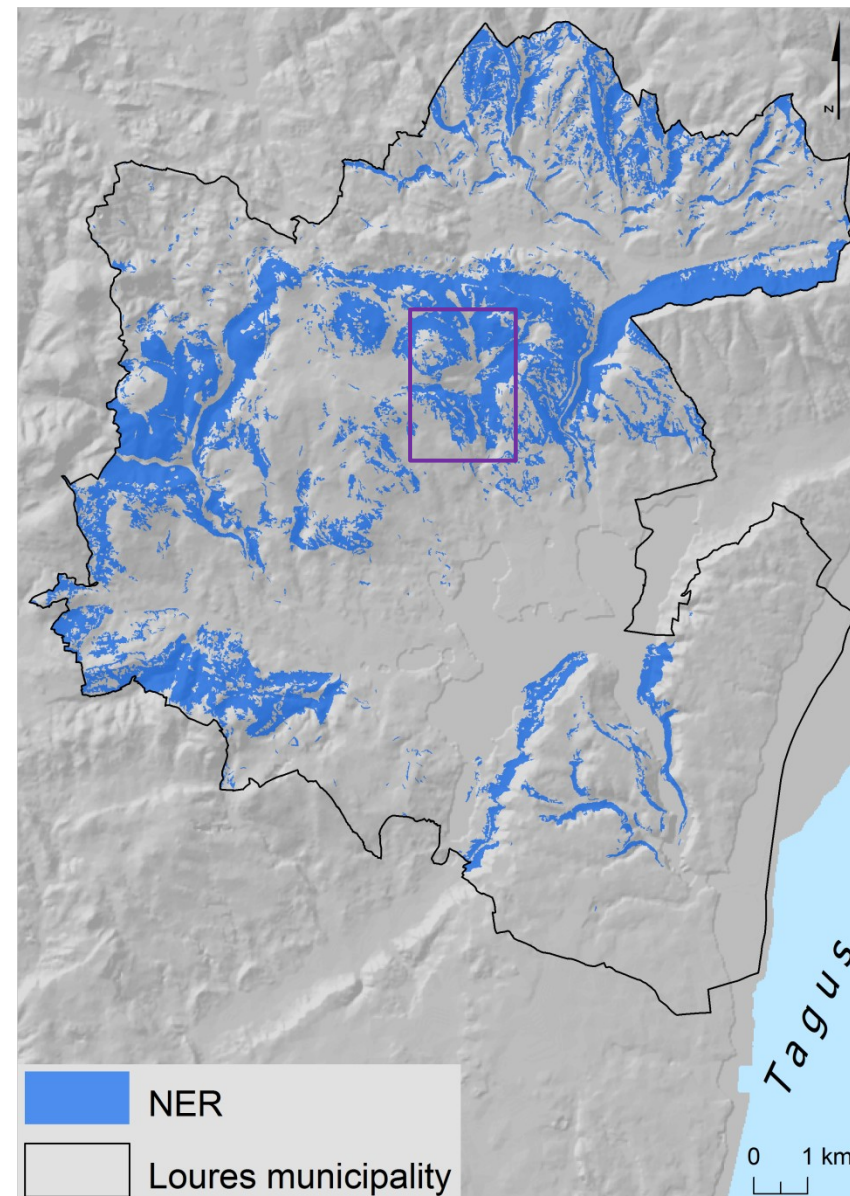


# Results and discussion (7)

## National Ecological Reserve



	Exposed element within the NER	% of total exposed element of Loures
Buildings	114 040 m <sup>2</sup> (i.e. 2 638 buildings)	2.1%
Motorways	124 590 m <sup>2</sup>	5.7%
National roads	56 050 m <sup>2</sup>	6.6%
Municipal roads	55 260 m <sup>2</sup>	10.4%



# Conclusion and applications



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- Production of three susceptibility models, one for each landslide type, validated by prediction-rate curves;
- Production of National Ecological Reserve (NER) obtained using a union procedure of Class I (high susceptibility) of the three susceptibility models;
- Intersection of the NER with exposed roads and buildings;

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**Thank you for your attention !**

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