Dear Editor Thomas Glade,

We thank the revision and we send point-by-point reply to the reviewer's comments and a marked–up manuscript version showing all the changes made in the manuscript.

Best regards

Bruno Meneses

Susana Pereira

Eusébio Reis

Comments to Reviewer 1,

The authors thank the comments. These are very relevant and well prepared and most of them were considered in the reviewing process. We believe that your contribution helped to improve the manuscript.

The manuscript addresses the effect of using land cover data of different spatial and thematic resolution in landslide susceptibility modeling, particularly for susceptibility zonation of a road network. The topic is interesting and significant. Land cover data is used in susceptibility mapping, often without questioning its quality and suitability for such an analysis. The authors provide us with an overview of what we might be missing in case we use unsuitable data (or data which is too coarse for example).

The authors first introduce us to landslides in general, and their effect on human lives, activities, infrastructure, etc. They proceed with describing the usefulness of landslide susceptibility assessments. Afterwards, we are introduced to the role of land cover and how the choice of geoinformation details of land cover is usually not studied – despite being a significant factor. The authors demonstrate their approach in a watershed in Portugal (with a detailed focus on three smaller areas within the watershed boundaries).

They use two different land use and land cover data to demonstrate the effect of using different data on landslide susceptibility: the Portuguese land cover map (COS), and the European Corine Land Cover (CLC). The landslide susceptibility mapping itself is straightforward and is based on acknowledged and commonly used methods (information value). Although, there are other approaches, where similar data could be used (logistic regression, weights of evidence), the authors chose this method, as it has been applied at a similar scale, also in Portugal. Generally, it is a nice study, however with some major flaws - most of them related to the fact that some topics were not addressed. This means, that my revision recommendation is mostly based on rewriting the main body of the text, adding additional clarifications, or expanding the discussion.

Aditional analyses are not needed.

First, while the authors investigated the role of land cover data on modeling landslide susceptibility, they did not compare different methods. I do not expect the authors to perform additional analyses with other modeling approaches – however, I would like them to discuss the method used a bit more extensively. For example, could other methods lead to larger (or smaller) differences between different land cover data?

Authors: We believe that the use of different landslide susceptibility methods culminated in different results, many studies highlight some differences in results obtained by different methods, specially between IV, logistic regression and weights of evidence. This fact is well developed scientifically, and the manuscript goal is not to compare results with different methods, but LUC with different properties. If the conditions are the same in the modeling process (predisposing factors, method, software, …), the differences in results can be derived from the change the LUC data, and its properties justify these differences. However, we introduced a reference about this point in discussion.

"*the differences observed in the landslide susceptibility models are a consequence of using different LUC data inputs (different properties), because the other predisposing factor maps are the same in two models*."

Second, I have seen many landslide susceptibility studies, where data with relatively coarse data has been used. Also here, the data on soil and lithology is on a (much) coarser resolution than other data (slope characteristics, and land cover). We can see, that while all other data has a fine and detailed pattern, the lithology and soil maps have clear boundaries, with relatively large mapping units. This is of course not the authors fault – this are probably still the most detailed soil and lithology maps available for the study area. Nevertheless, I would like to see a more detailed section in the discussion, reflecting on the discrepancy of such differences (e.g. scale and mapping unit) and the effects on susceptibility modeling. The authors already did this for the land cover maps, and wrote a few sentences in the discussion.

Authors: The data of soil and lithology used is the only free data available for the study area. Nevertheless, the soil data is incomplete in study area at scales ≥1:50 000 and this is also very expensive. The geological data is not available to the study area at the 1:50 000 scale (please check in http://www.lneg.pt/servicos/215/).

The predisposing maps (soil, lithology, slope, …) are statics in the landslide modelling process, except the LUC data, then the results change derived from the LUC data properties that integrated each landslide model. The IV can change if the scales of factor maps are different, is a fact, but we do not have the possibility to use more detailed geoinformation, specially information with high costs.

About this topic, a new sentence was introduced in discussion.

"*the data of soil and lithology was constrained to very generalized (1:1000000 and 1:50000 scales, respectively) and this factor can influence the IV results if more detailed data was considered in the modeling process. The performance of the* *landslide susceptibility mapping and assessment is controlled by the quality of the available data and it depends not only on the method.*"

Third, I have two comments regarding the landslide inventory (page 9, lines 5-10). To be clear, the authors mapped landslides using orthophotos and google earth themselves? And the authors went on the field themselves as well? Currently, it is not clear if they received the data that was developed by photointerpretation, or if they performed it themselves. Moreover, it seems that the most landslides are outside forested areas – I compared the two land cover maps with the landslide distribution map visually.

This is of course possible, as evidence shows that forests have a positive role on slope stability (e.g. due to roots). Nevertheless, it is also difficult to map landslides in forests, using photointerpretation only. This can have significant effects on the results.

For example, if we look at Figure 4, the areas where the differences between the two susceptibility maps are the lowest are indeed areas covered by forests (or seem to be, the authors did not provide additional information that would lead to other conclusions). Also, studies have shown that landslide unit definition have a significant effect on landslide susceptibility modeling. It makes a difference if a landslide is mapped as a point, as the whole landslide area, or only the scar of the landslide. What did the authors map? From the text, I cannot see if a landslide is presented by a (centroid) point, by the whole area, or something else. Please clarify how you mapped landslides.

Authors: The landslides were inventoried and validated only by authors. In fact, the photointerpretation of landslides in forest areas is very complex, and possibly some landslides cannot be inventoried or validated in the field because are covered by vegetation. Some landslides in burned areas were also considered.

The landslides are not represented with points, but polygons (areas) that represent the unstable area (scarp, body and toe), see the table 3 (Statistics description of the landslides inventory). Additional information was introduced in the Data section.

"*The landslide inventory was obtained by photointerpretation (orthophotos of the year 2005 and Google Earth images), a process supported by ancillary topographic data and further field work validation only performed in the sample areas (Fig. 1) due to the extension of the study area. A total of 128 landslides (predominantly shallow translational slides), with a total area of 74042 m2, was validated during field work in sample areas (49.4% of the total inventoried landslide cases). Among the landslides initially inventoried by photointerpretation in sample areas more than 90% of cases were confirmed. In these sample areas roads disruptions were also validated.*"

Specific comments

Title

In my opinion, geoinformation properties is too vague. What about simply "effects of different land cover data on: : :"

Authors: We accept your suggestion and the title was changed accordingly.

Data

Effect of the different land cover data used – what I would be interested in, is also the extent of the influence of any land cover data at all. The difference between the results of the two LUC data used suggests, that land cover does play a role – we do not fully know how significant it is (in this study area). I would be interested in seeing the difference between the two land cover data, and a susceptibility map without a land cover map. It would also be a sort of sensitivity analysis.

I would like to see the distribution of landslides (so, the points) on the data figure (Figure 2) as well (so, where are landslides located on a land cover map, soil map...)

Authors: We present a new table in supplementary data with the importance of each LUC type to landslide occurrences inventoried and also the distribution this LUC classes by slope classes, because this is also an important variable to landslides occurrence.

LUC data was tabulated (COS and CLC) and represented in table 2. The results show a distinction of the LUC types with principal differences between CLC Vs COS. The importance of this LUC variables is presented in table 4 and it is not necessary a new map to assess their importance in modeling. The construction of a new susceptibility landslide map without LUC data will be developed in a further study.

The landslides areas are represented in Figures 2 and 5.

Figure 4. I would like to see a different color map for the difference map. First of all, it would make sense, that there is a more logical center class. Currently, there are classes between 0.1 – 1 and -0.9 -0 (I assume, 0 is completely within this class). It would make more sense, to have a class -0.5 - +0.5 (or something similar).

Authors: we acknowledge the reviewer comments. The colors and classes of this map were corrected in order to be represented with a more logical center and constant interval.

Results

The authors compared the two maps visually, by map overlay, and by performing an overall accuracy and kappa coefficient. There is something I do not understand: what exactly is the overall accuracy? You compared the two maps, so this cannot be overall accuracy, is it maybe overall agreement? The same goes for commission and omission errors. These are not errors, but differences between two maps (so, two models). Also, I do not fully understand Table 4. From what I see in the table, most of the area is modelled as very high susceptibility in the study area – this however cannot be true. Or is the table presenting something else – maybe the susceptibility of the road network only? Please explain or modify the table.

Table 4 is one of the main results in my opinion, however, now you present it in % of total area. This is fine, but then you really need to replace the term accuracy with agreement, because 66.7% of accuracy (LSRN2/LSRN1) for the class high does not mean accuracy, but agreement.

Authors: The overall "accuracy" was changed to overall agreement and "errors" by differences. The table presents errors in the column headers due to a mistake in the copy process. The classes will be corrected. The class "very low" can never have 86.11% of total study area! Thank you for reporting us this error.

Discussion

I already mentioned above what needs to be expanded in the discussion. Besides that, I would like to see the following in the discussion: - Any recommendations based on the results? (in terms of using land cover data) - Comparison with other, similar studies, and what did they find out? - The influence of the method used (maybe information value results to fewer differences between using different land cover maps) - Discussion on other data, particularly landslide inventory (potentially missed landslides in forests, or type of mapping).

Authors: We introduced some recommendations based on results, and discussion the problem of landslide inventory (potentially missed landslides in forests, or type of mapping).

"*More detailed LUC data (COS) allows better landslide susceptibility results, while LUC data is more generalized than CLC data, resulted in the IV reduction, not allowing identify some places where landslides occurred effectively*."

"*The assignment of landslide susceptibility results to the road network allowed to identify the locations with the highest spatial probability to the landslide occurrence*"

Technical corrections

In the abstract, the authors use the term "very good" when describing their models – please either replace it with a different term, or add justification for it being very good (e.g. both have an AUC over 0.9). Also, the AUC is not the only measure to address the model success, so I would refrain myself by using very good – you can state that the models have a high accuracy in terms of AUC or something similar.

Authors: We agree with your comment and changes were made accordingly.

The last sentence – landslide susceptibility maps are exactly what their name implies, maps providing information on how susceptible an area is to landslides. They are not maps, where landslides will probably occur. Please change this.

Authors: Thank you for the comment. Changes were made accordingly.

Generally, the level of English is high. Nevertheless, a spell check or rewriting of some parts of the manuscript is necessary: - The authors tend to use the word "the" too much in my opinion (the landslides, the total or partial, the landslide susceptibility assessment: : :).

Authors: The English was reviewed by English editor services. (https://www.scribendi.com/service/academic_proofreading)

- Study area description, first sentence: simplify and write "We performed this study in Zezere: : :).

Authors: OK.

Also, what does “high slopes” mean? Steep slopes?

Authors: high slopes will be changed by “steep slopes”.

Same goes for low slopes.

Authors: low slopes will be changed by “gentle slopes”

The authors use a lot of abbreviations – while some are presented in the main body, some are presented only in the abstract (e.g. LUC, COS, CLC). I recommend that you again define the abbreviations in the main text, when you use them for the first time.

Authors: Some abbreviations were decoded and eliminated (e.g. MMU, AUR, SRC, PFM). Other were defined in the text when used for the first time.

Comments to reviewer 2,

The authors thank the comments. These are very relevant and well prepared and most of them were considered in the reviewing process. We believe that your contribution helped to improve the manuscript.

This paper analyses landslide susceptibility for an area in Portugal using standard input data and also conventional bivariate statistical analysis. From a methodological point of view, the paper doesn’t provide new approaches or insights. The aim was to see what would be the effect of different land use/land cover maps on the overall prediction of landslides. For that two land use maps were used with a different level of detail. Although the authors acknowledge the importance of land use/land cover changes for the occurrence of landslides, they do not make an attempt to use a map of land cover changes as input for their analysis. While this could have been done with the use of multi-temporal satellite images, and also correlate this with the changes in landslides that occurred after these changes.

Now the relationship between land use/land cover remains vague throughout the paper. It is also not clear when the two land cover maps were made and how these relate to the landslides mapped from images of 2005. Parts of this study area have been affected seriously by forest fires in the past years, and this must have also resulted in higher landslide activity. Nothing of that is mentioned in the paper, and a multi-temporal analysis is also lacking.

Authors: the relationship between land use/land cover (LUC) is referred in introduction, and this case study, is evaluated its importance in landslide susceptibility zonation (now table 4). The LUCC was not evaluated in the present research, because the main goal of this work is the comparison between the landslide susceptibility results obtained with different LUC datasets (same predisposing factor, but with different properties). The guidelines of drawing up LUC maps are presented in the text, but we consider important to resume the properties of this LUC geoinformation to the reader in a Table.

The wildfires were evaluated by us in other research’s (e.g. see Meneses *et al.*, 2018a), but the LUC maps (COS or CLC) do not represent the total burned areas, because if there is a potential to vegetation regeneration, the technical guidelines refer that the LUC type with this potential correspond to forest or scrubs, not the burned area observed in photointerpretation. By other side, this wildfires information does not interfere in the research goal, because burned areas were indirectly represented in the classes “Open spaces with little or no vegetation” and “Scrub and/or herbaceous vegetation associations”. However, we also observed that burned areas do not match the principal location of the landslide inventory.

The landslide inventory was obtained by photointerpretation (orthophotos of the year 2005 and Google Earth images - 2004, 2005 and 2006), so these dates of information support the inventorying process selected according to LUC dates available (2006 and 2007). If these landslides were old slope movements, it would be more difficult to be identified through this information because of the regeneration of the vegetation.

The relation between the two land use maps should also be presented more in detail: how do the classes overlap? And are differences caused by errors or by temporal changes? Are landslide more frequent in zones where the classification do not match?

Authors: The relation between two land use maps was made and results are presented in Table 2. The main discrepancies were observed in forest areas and scrub and/or herbaceous vegetation associations, especially in central sector of watershed (surround of Cabril dam). By the landslides inventoried GIS analysis, we do not observed landslides in the areas with main discrepancies between COS and CLC (for the LUC types before mentioned). Some explanations were made in the text.

Table 2. LUC data agreement (area ha) between CLC and COS classes.

Data	COS												
CLC	Urban fabric (UF)	Industrial, commercial and transport units (ICT)	Mine, dump and construction sites (MDC)	Artificial, non-agricultural vegetated areas (ANA)	Arable land (AL)	Permanent crops (PC)	Pastures (P)	Heterogeneous agricultural areas (HAA)	Forests (F)	Scrub and/or herbaceous vegetation associations (SHV)	Open spaces with little or no vegetation (OSV)	Inland waters (IW)	Total
UF	3160.2	439.8	77.3	100.8	207.7	502.0	15.7	929.2	337.7	251.5	0.1	18.7	6040.7
ICT	134.1	650.4	83.0	9.5	33.4	27.4	9.0	62.5	130.8	207.7	0.3	8.1	1356.1
MDC	6.1	58.3	283.0	0	3.6	3.6	6.8	6.5	48.2	53.5	0.2	5.4	475.0
ANA	29.3	2.9	0	22.5	0	0	0	0	1.7	9.1	0	0	65.6
AL	245.3	171.7	25.0	12.2	9166.1	1304.4	2225.0	1317.1	1133.2	1435.9	51.0	190.7	17277.5
PC	1271.4	93.3	37.3	21.2	1357.9	7948.5	315.4	2930.0	2004.5	2300.2	7.9	38.1	18325.7
P	4.4	2.4	0	0	61.3	0.9	36.1	58.4	41.2	188.6	0	0	393.2
HAA	7791.6	736.5	271.4	73.7	11773.1	15553.2	2341.0	23762.4	16514.4	12935.5	143.3	243.9	92140.0
F	745.3	392.9	173.1	29.3	741.9	1715.5	238.1	4058.7	100486.5	26805.7	42.0	735.8	136164.8
SHV	826.5	510.0	259.3	38.0	1353.1	2543.2	958.3	5832.8	50509.8	149644.0	4052.8	846.7	217374.5
OSV	29.4	13.8	5.3	1.4	18.3	10.3	10.7	140.4	860.0	6367.1	4206.6	30.3	11693.7
IW	5.6	12.0	0	0.2	1.3	7.5	0	15.2	278.5	180.7	2.4	4589.5	5093.0
Total	14249.1	3084.1	1214.7	308.8	24717.7	29616.3	6156.0	39113.2	172346.6	200379.5	8506.6	6707.1	506399.7

The relationship between the factor maps is considered as a bivariate relation only, whereas it is a multivariate problem. It matters to know what the slope steepness is in order to assess the importance of different land cover classes for landslide susceptibility.

Authors: The importance of each class of explanatory variables to landslides occurrence was evaluated by conditional probabilities that integrated the Eq. 1. We also present new information about the slopes and LUC relation (supplementary data - tables) and more information about this point was introduced in the text.

"*In general terms, slope angle increasing promotes the landslide occurrence and is a very good proxy of the shear stress (Zêzere et al., 2017). Slope instability is more frequent in higher slope angles of the Estrela Mountain and throughout Zêzere valley. Also, in these areas, convex slope curvature is predominantly related with slope instability. The slope aspect is important in the spatial distribution of the different LUC types of the study area (Fig. 2) and on slope instability, especially in northwest-facing slopes (more exposed to the rain and with higher humidity levels).*"

Extract of supplementary data - Conditional and priori probabilities (CP and PP, respectively) of landslides occurrence in Zêzere watershed.

PFM	Classe	Area watershed (%)	Landslides test area (%)	CP	PP	IV
Slope angle	0 - 5	28,17	1,69	0,000098	0,001652844	-2,824
	06-10	18,22	2,07	0,000206	0,001652844	-2,083
	11v-15	17,93	5,73	0,000617	0,001652844	-0,986
	16 - 20	15,30	12,97	0,001433	0,001652844	-0,143
	21 - 25	10,94	17,48	0,002798	0,001652844	0,526
	26 - 30	6,03	17,95	0,005499	0,001652844	1,202
	31 - 35	2,47	17,76	0,01118	0,001652844	1,912
	36- 40	0,73	10,71	0,020153	0,001652844	2,501
	41- 45	0,16	10,90	0,090941	0,001652844	4,008
	46 - 50	0,03	2,54	0,159236	0,001652844	4,568
	51 -55	0,01	0,19	0,042391	0,001652844	3,244
	> 55	0,01	0	0	0,001652844	-2,824

Landslide susceptibility maps are not validated using independent data sets that were not used for making the model. This is not how it should be done.

Authors: we acknowledge the reviewer comment. The research was reformulated, and independent dataset were used in order to perform an independent validation of the landslide susceptibility. The landslide inventory was randomly divided in two subsets (Fig. 1): the landslide training group and the landslide test group. The first group integrated the modeling an the second the validation process. More explanations about this procedure were introduced in the text.

"*The landslide inventory was obtained by photointerpretation (orthophotos of the year 2005 and Google Earth images), a process supported by ancillary topographic data and further field work validation only performed in the sample areas (Fig. 1) due to the extension of the study area. A total of 128 landslides (predominantly shallow translational slides), with a total area of 74042 m2, was validated during field work in sample areas (49.4% of the total inventoried landslide cases). Among the landslides initially inventoried by photointerpretation in sample areas more than 90% of cases were confirmed. In these sample areas roads disruptions were also validated.*

For complete Zêzere watershed 259 landslides have been identified, predominantly of shallow type. On the total, 32 landslides affected directly the road network (total or partial blockages by the material and 7 cases with partial loss of infrastructure). The landslide inventory was randomly divided in two subsets (Fig. 1) (Chung and Fabbri, 2003): the landslide training group and the landslide test group (81.5% and 18.5% of the total landslide affected area, respectively). The statistical description of each landslide group is presented in Table 3."

Table 3. *Statistics description of the training group and test group landslide inventories.*

	Training group		**Test group**		**Total inventory**
	Non affected roads	Affected roads	Non affected roads	Affected roads	
Total landslides	185	26	42	6	259
Total area (m^2)	44604	369404	10444	12089	104077
Minimum (m^2)	134	7	18	82	7
Maximum (m^2)	27364	12507	1911	5881	12507
Mean (m^2)	2414	1421	249	2015	402
Std. deviation (m^2)	3284	2647	304	2627	1069

The authors do not develop a specific method for landslide susceptibility along the road, but basically, overlay the susceptibility maps of the two landcover maps with the road network.

The assessment of landslide susceptibility along road requires a different approach where engineered slopes and natural slopes are evaluated separately, and where homogeneous road section is outlined with the upslope areas that could influence it. The method presented here is too simple for practical use along roads.

Authors: We don't simply overlay the susceptibility maps of the two landcover maps! The LUC maps integrated only the susceptibility modeling and the results was integrated in the road network (different datasets), allowing these results the representation of the landslide susceptibility obtained in context more widely, not point by point and assessed in isolation by each segment of roads.

The paper does not address the issue of landslide runout, which in the case of roads might be one of the most important hazards: debris (flows) or rock falls from the upslope areas are likely to affect the road. Only addressing land- slide initiation is not considered appropriate in such a case.

Authors: We present some examples of landslides validated in study area (Fig. 1). In the landslide susceptibility model only landslides were considered (predominantly shallow translational slides of small area and length).

The level of English is problematic, and the text needs to be thoroughly reviewed by an English editor.

Authors: The text was reviewed by an English editor. (https://www.scribendi.com/service/academic_proofreading)

The paper also uses too many abbreviations which makes it very difficult to read. For ex- ample GI, MMU, LUC, COS, CLC, PFM, IV, Ai, Ri, LSM, LSRN. . .

Authors: Some abbreviations were decoded and eliminated (e.g. MMU, AUR, SRC, PFM). Other were defined in the text when used for the first time.

The paper refers to other publications of the authors which seem to have a substantial overlap with this manuscript.

Authors: The manuscript is an original research and the other publications do not focus on the same goals of this work. The study area is very important in Portugal, because have important supply water bodies and this fact justify the many publications of authors in this watershed, although not overlapping in the goals and results of the presented work. None of the published work addresses the issue of landslides or uses the presented methodology.

Some detailed comments:

- 1/23: locals should be locations Authors: OK
- 2/1: The landslides.. should be Landslides. The entire sentence should be rewritten Authors: OK
- 2/9: same Authors: ok
- 2/10: landslide occurrence Authors: OK
- 2/16-19: The entire sentence is not clear should be rewritten. I would not use the abbreviation GI throughout the paper. Just mention factor maps. Authors: OK
- 2/23: of landslides Authors: ok
- 2/23- : you indicate the importance of land use dynamics but do not analyse it yourselves in this paper.
  Authors: Yes, this is an introduction, and the main goal isn't the dynamics of LUC assessment.
- 3/8-9: avoid GI. Improve the sentence Authors: OK
- 3/10-13: is this not the same topic as this paper?
  Authors: The references present two different researches: 1 – LUCC in Portugal: multi-scale and multi-temporal differences obtained by LUC of different years; 2 – The paper assess the effects LUC geoinformation raster generalization in the analysis of LUCC in Portugal using different LUC datasets. None of the published work addresses the issue of landslides or uses the presented methodology.
- 3/16: improve description between brackets. Authors: OK
- 3/21-22: I don't think you achieved this goal
  Authors: This goal was achieved, because we present different results about the landslide susceptibility zonation of road network derived of integration LUC GI with different properties in the models, and we explain why in manuscript.
- 3/24: what does MMU mean? It is another abbreviation one has to remember.
  Authors: This abbreviation was decodified in the text.
- 4/6: high slope: steep slopes Authors: OK

- 4/10: rankers? Authors: OK
- 4/15: artificial land? Authors: OK
- 4/17-18: Improve the sentence Authors: OK
- 5/15- : there is no need to explain why you use slope steepness as a factor in landslide susceptibility assessment
  Authors: this is a complementary information for the readers and explain part of landslides, for example in Estrela mountain.
- Table 1: include the date of production. Authors: OK
- 7/8: why such a coarse scale? 1:500000 for roads is too general.
  Authors: This is the data validated available to research (free data). Other information is available, but with considerable costs. However, at the scale of research, the GI used represent the main road network and serve the purposes of this research.
- Figure 2: Are all these maps needed? Where is the landslide inventory map?
  this is the predisposing factor maps used in many researches of landslide susceptibility in Portugal and we explain why in the introduction and, also, in characterization of study area. The landslide inventory is represented in Figure 1 and the characteristics in Table 3.
- 9/9 and table 2: round off values. Authors: OK
- What is the size frequency distribution?
  Authors: the frequency is represented in fig 3.
- 10: is it needed to describe this method again? Authors: recast text.
- 12/11-12: explain why this is done? Shouldn't this be based on the final score? Why 10 classes? What is the use of this for the end user of the susceptibility map?
  Authors: Landslide susceptibility maps were built and classified in 10 classes (deciles) because allow the visual comparison between results of different models. We performed some tests to represent IV by classes and the deciles method present good results allowing the comparison above mentioned.
- 13/15-16: if these are landslide scars then the landslides are not caused by it, but they result in bare areas.
  Authors: this is an assumption generalized, but the forest also includes landslides. Please, see the extract table with the landslide area by LUC type in supplementary data.

Extract of supplementary data.

PFM	Classe	Area watershed (%)	Landslides test area (%)
COS	Urban fabric	2,81	0,72
	Industrial, commercial and transport units	0,61	0
	Mine, dump and construction sites	0,24	0
	Artificial, non-agricultural vegetated areas	0,06	0
	Arable land	4,88	0
	Permanent crops	5,85	0,84
	Pastures	1,22	0
	Heterogeneous agricultural areas	7,72	0,96
	Forests	34,03	14,34
	Scrub and/or herbaceous vegetation associations	39,57	81,96
	Open spaces with little or no vegetation	1,68	1,19
	Inland waters	1,32	0
CLC	Urban fabric	1,19	0
	Industrial, commercial and transport units	0,27	0
	Mine, dump and construction sites	0,09	0
	Artificial, non-agricultural vegetated areas	0,01	0
	Arable land	3,41	0

PFM	Classe	Area watershed (%)	Landslides test area (%)
	Permanent crops	3,62	0
	Pastures	0,08	0
	Heterogeneous agricultural areas	18,20	1,91
	Forests	26,89	22,10
	Scrub and/or herbaceous vegetation associations	42,93	71,57
	Open spaces with little or no vegetation	2,31	4,42
	Inland waters	1,01	0

- 14/15: success rate curves: validation should be done with independent data. What would be the result if you don't use any land-use map?

  Authors: the landslide susceptibility validation was made with landslide test group (1), and we also assessed the performance of models with a part of the landslide inventory (training group), and now prediction and success rate curves will be presented. The partition inventory increases the performance of models (see AUC), comparatively to the results presented in first version.

  By other side, the importance of each variable in model's is presented in table 4 and LUC is important in the analysis, i.e., the determined classes of this predisposition factor are relevant because they contain landslide area.

- 15/6-9: I don't understand what you are saying here. Explain it better. We made an effort to clarify this idea in the text.
- 15/11-14: not clear. Authors: ok
- Figure 6: the land use classes should be combined with slope. It is difficult to find out what the codes mean. There is not much description of it in the text.

  Authors: we introduced the decoding after figure. 16-17: I got lost in reading these pages with so many abbreviations and English language issues.

  Authors: the abbreviations were reduced.

- Table 4: Not clear what the values indicate? Percentage of the area? Then the combinations are very strange: 86% in very high, and only 0.23 in very low?

  Authors: table 4 (now table 5) represent the area (%) of watershed area by each susceptibility class, and when tabulation is performed between LSRN1 and LSRN2 the coincident area between the same classes and the area distributed by other classes is obtained. In final, it is possible to represent the agreement value between two maps.

- Figure 10 could be skipped. Authors: Ok

~~Land~~ Effects of different land use and land cover ~~geoinformation properties and its influence~~data on the landslide susceptibility zonation of road ~~network~~networks

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Abstract. This ~~paper~~work evaluates the influence of land use and land cover (LUC) ~~geoinformation~~data with different properties on the landslide susceptibility zonation of the road network in the Zêzere watershed (Portugal). The Information Value ~~method~~Method was used to assess the landslide susceptibility using two models: one including detailed LUC ~~geoinformation (~~data (the Portuguese Land Cover Map - COS) and the other including more generalized LUC ~~geoinformation (~~data (the Corine Land Cover - CLC). A set of six fixed independent layers were considered as landslide predisposing factors (slope angle, slope aspect, slope curvature, slope over area ratio, soil, and lithology), while the COS and CLC were used to find the differences in the landslide susceptibility zonation. A landslide inventory was used as a dependent layer, including 259 shallow landslides obtained from ~~photo-interpretation~~the photointerpretation of orthophotos ~~of~~from 2005, and further validated in three sample areas ~~(128 landslides).~~. The landslide susceptibility maps were ~~merged into~~assigned to the road network ~~geoinformation,~~data and resulted in two landslide susceptibility road network maps. The models' performance was evaluated with prediction and success rate curves and the area under the curve (AUC). The landslide susceptibility results obtained in the two models present a high accuracy in terms of the AUC (>90%), but the model with more detailed LUC data (COS) produces better results in the landslide susceptibility zonation on the road network with the highest landslide susceptibility.

~~Models performance was evaluated with success rate curves and area under the curve. Landslide susceptibility results obtained in the two models are very good, but in comparison the model obtained with more detailed LUC geoinformation (COS) produces better results in the landslide susceptibility zonation and on the road network detection with the highest landslide susceptibility. This last map also~~

~~provides more detailed information about the locals where the next landslides will probably occur with possible road network disturbances.~~

Keywords LUC; ~~geoinformation~~LUC data properties; landslide susceptibility; road networks disruption, Information Value ~~method~~Method.

1 Introduction

~~The landslides are natural processes that can cause constraints on the free movement of people and goods, when directly or indirectly affect the road network (Bíl et al., 2014, 2015; Hilker et al., 2009; Winter et al., 2013). The total or partial blockages of road network have economic and societal impacts, particularly direct damages in the infrastructure (material damages) and cause injuries and deaths of people when driving on the affected infrastructures (Guillard and Zêzere, 2012; Pereira et al., 2014, 2017) or causing indirect damages as delays, detours, material damage and raw material rising prices (Zêzere et al., 2008; Bíl et al., 2014, 2015; Jenelius and Mattsson, 2012; Winter et al., 2016).~~

~~The landslide susceptibility assessment is crucial to identify locations with higher probability of landslides occurrence (Conforti et al., 2014; Guillard and Zêzere, 2012; Guzzetti et al., 2006; Pereira et al., 2014; van Westen et al., 2008). Landslide susceptibility is the likelihood of a landslide occurring in an determined area controlled by local terrain condition, may also include a description of the velocity and intensity of the existing or potential landslide (Fell et al., 2008; Günther et al., 2013; Guzzetti et al., 1999). Landslide susceptibility reflects the degree to which terrain unit can be affected by slope movements in the future (Günther et al., 2013).~~

~~In general, the choice of geoinformation (GI) details for the landslide predisposing factors are not often explained in the landslide susceptibility assessment based on statistical methods; or some criteria defined in the literature is used for this selection, since these variables explain the occurrence of slope movements in the study area (Blahut et al., 2010; Carrara et al., 1991; Castella et al., 2007; Castellanos Abella, 2008; Guzzetti et al., 1999, 2006; Soeters and van Westen, 1996; van Westen et al., 2008; Zêzere et al., 2008, 2017).~~

Beyond the influence of different environmental factors (e.g. lithology, slope angle, slope morphology, topography, soils, hydrology) on spatial distribution landslides, the LUC dynamics is also an important factor on landslide susceptibility assessment (Guillard and Zêzere, 2012). Certain land use and land cover changes (LUCC) increase the number of unstable slopes (Reichenbach et al., 2014), i.e., promoting the propensity to landslide occurrence (e.g. deforestation, slope ruptures to roads construction, steep slopes), and can have an important impact on landslide activity (Beguería, 2006; Glade, 2003; Mugagga et al., 2012; Persichillo et al., 2017; van Westen et al., 2008). In short, the LUC, while proxy variable, is very dynamic over time influenced by climate-driven changes and direct anthropogenic impacts (Promper et al., 2014).

Landslides are natural processes that can constrain the free movement of people and goods when they directly or indirectly affect road networks (Bíl et al., 2014, 2015; Hilker et al., 2009; Winter et al., 2013). The total or partial blockages of road networks have economic and societal impacts, particularly on the direct damage to the infrastructure (material damages), on the population (injuries and deaths) when driving on the affected infrastructures (Guillard and Zêzere, 2012; Pereira et al., 2014, 2017), or by causing indirect damages, such as delays, detours, material damage, and the rising prices of raw materials (Zêzere et al., 2008; Bíl et al., 2014, 2015; Jenelius and Mattsson, 2012; Winter et al., 2016).

Landslide susceptibility assessment is crucial to identifying locations with higher probabilities of landslide occurrence (Conforti et al., 2014; Guillard and Zêzere, 2012; Guzzetti et al., 2006; Pereira et al., 2014; van Westen et al., 2008). Landslide susceptibility is the likelihood of a landslide occurring in an determined area controlled by local terrain conditions; it may also include a description of the velocity and intensity of an existing or potential landslide (Fell et al., 2008; Günther et al., 2013; Guzzetti et al., 1999). Landslide susceptibility reflects the degree to which a terrain unit can be affected by future slope movements (Günther et al., 2013).

In general, the choice of landslide predisposing factors and the main details of the geographical information are not explained in a landslide susceptibility assessment based on statistical methods; rather, criteria defined in the literature (e.g., slope angle, slope aspect, slope curvature, soil, lithology, LUC) are used for this selection because it can explain the occurrence of slope movements in the study area (Blahut et al., 2010; Carrara et al., 1991; Castella et al., 2007; Castellanos Abella, 2008; Guzzetti et al., 1999, 2006; Soeters and van Westen, 1996; van Westen et al., 2008; Zêzere et al., 2008, 2017).

Beyond the influence of different environmental factors (e.g., lithology, slope angle, slope morphology, topography, soils, and hydrology) on the spatial distribution of landslides, land use and land cover (LUC) dynamics are also an important factor on landslide susceptibility assessment (Guillard and Zêzere, 2012). Certain land use and land cover changes (LUCC) (e.g., deforestation, slope ruptures to road construction, steep slopes) increase the number of unstable slopes (Reichenbach et al., 2014), i.e., promoting the propensity for landslide occurrence, and can have an important impact on landslide activity (Beguería, 2006; Glade, 2003; Mugagga et al., 2012; Persichillo et al., 2017; van Westen et al., 2008).

The LUC, while a proxy variable, is very dynamic over time and is influenced by climate-driven changes and direct anthropogenic impacts (Promper et al., 2014). In this regard, it is an important predisposing factor to landslide susceptibility assessment, and Dymond et al. (2006) mention that importance: "*the quality of the input land-cover map is important because the main purpose of the landslide susceptibility model is to identify where land cover needs to be changed*."

For instance, performing a landslide susceptibility analysis with ~~an~~a historical inventory ~~for~~over long periods (e.g~~.~~., decades) demands the use of a permanent set of predisposing factors along the landslide inventory ~~time~~timeline. LUC can ~~be changeable~~change over time; due to this reason, it will be more accurate to use the LUC for different periods~~, not~~ than using ~~an available and~~the most recent LUC map, ~~in order~~ to avoid spatial relations between past slope instability and ~~wrong~~incorrect LUC classes.

~~Selection of the GI scale influences the map elements representation and detail, as well as the choice of the scale of analysis of final results (Leitner, 2004; Stoter et al., 2014). The choice of the GI level of detail will constrain the modeling final results. For example, Meneses et al. (2018) obtained different LUCC results in the Portuguese territory due to the use of different LUCC datasets, namely Corine Land Cover (CLC) and official Land Cover Map of Portugal (Portuguese designation and acronym: Carta de Ocupação do Solo, COS), with different properties concerning scale (1:100000 and 1:25000, respectively), minimum mapping unit – MMU (25 and 1 ha, respectively) and generalization level (Table 1).~~

~~Due to the variation of the road network morphology (length versus width of the roads typologies), the selection of appropriate GI which integrates the analysis of ruptures of the roads caused by landslides requires a systematic assessment of more detailed properties of the landslide predisposing factors (Drobnjak et al., 2016; Imprialou and Quddus, 2017; Kazemi and Lim, 2005; Orongo, 2011) in order to obtain detailed landslide susceptibility results at the local scale (roads).~~

The scale of the predisposing factors directly influences the map elements' representation and detail, as well as the choice of the scale of analysis of the final results (Leitner, 2004; Stoter et al., 2014). The choice in the level of detail will also constrain the modeling results. For example, Meneses et al. (2018b, 2018c) obtained different LUCC results in the Portuguese territory due to the use of different LUCC datasets, namely the Corine Land Cover (CLC) and the official Land Cover Map of Portugal (Portuguese designation and acronym: Carta de Ocupação do Solo, COS), with different properties concerning the scale (1:100000 and 1:25000, respectively), minimum mapping unit (25 and 1 ha, respectively), and generalization level (Table 1).

Due to the variation of the road network morphology (the length vs. width of the roads), the selection of appropriate data that integrates the analysis of road blockages caused by landslides requires a systematic assessment of the more detailed properties of the landslide predisposing factors (Drobnjak et al., 2016; Imprialou and Quddus, 2017; Kazemi and Lim, 2005; Orongo, 2011) to obtain detailed landslide susceptibility results at the local scale (roads).

In this context, the main goal of this work is to evaluate the ~~assessment~~influence of ~~land use and land cover GI~~the LUC data properties ~~influence~~ on the landslide susceptibility zonation of road ~~network. Other two~~networks. Two specific goals ~~was~~were defined: ~~in the first one, we want~~(i) to evaluate and quantify the landslide susceptibility results using two LUC datasets (CLC 2006 and COS 2007) with different properties (scale and ~~MMU~~minimum mapping unit) in two landslide susceptibility models; ~~in~~(ii) to use the ~~second goal, we want~~output results of the two landslide susceptibility models to identify ~~road~~the sections of the main road network with the highest landslide susceptibility that will suffer future road blockages ~~using the output results of the two landslide susceptibility models~~.

2 Material and methods

2.1 Study area

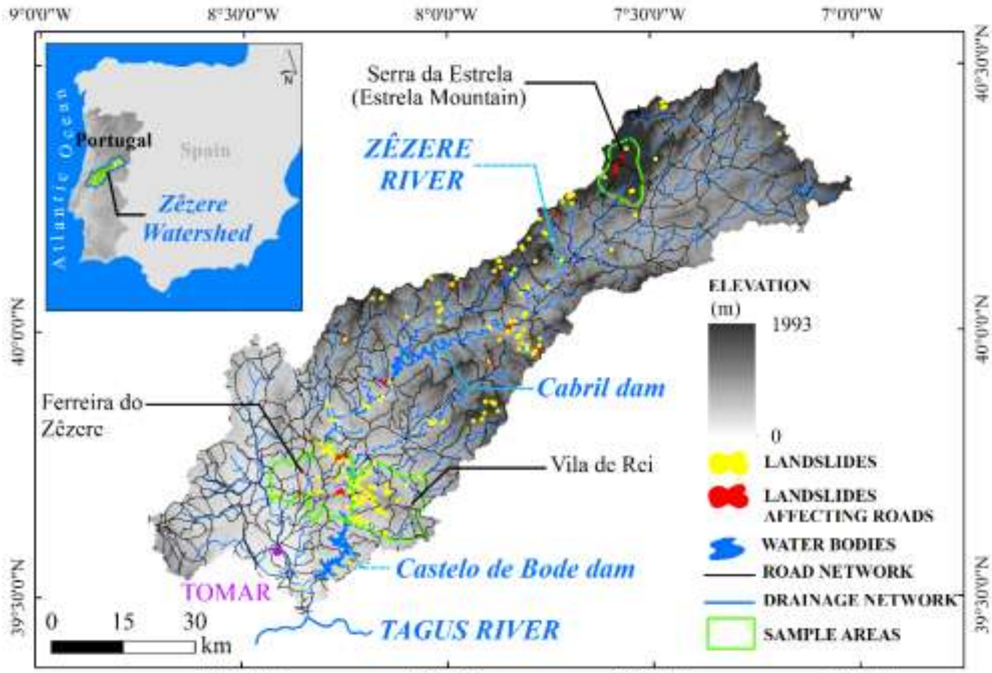
This researchstudy was developedperformed in the Zêzere watershed (5063.9 km^2) located in the Center region of mainland Portugal (Fig. 1). The North-Northwest sector of this watershed is occupied by the Estrela mountainMountain, reaching thea maximum elevation of 1993 m and, where highsteep slopes can be found; in the Central sector, the relief is less irregular when compared to the previous sector, but it still has highsteep slope areas (e.g.., the vicinity of the Castelo de Bode and Cabril reservoirs and Cabril); in the South-Southwest sector low, gentle slopes and flat areas are predominant.

The soils of the Zêzere watershed are very variable between the North-Northwest, Center, and Southwest sectors. In the Northwest sector, cambisols predominate, with small areas of fluvisols and rankerseutric lithosol along the Zêzere River. The centralIn the Central area of the watershed is characterized by the predominance of, lithosols are dominant, with some areas of cambisols. In the South-Southwest sector, there are areas of lithosols intercalated with cambisols and luvisols.

According to the CLC 2006, the predominant LUC in the study area are forest and semi-natural areas representing 72% of the total area, agricultural land (25.5%), artificial land (1.5%) and water bodies (1%), including an important reservoir of fresh water, such as Castelo de Bode dam (Meneses et al., 2015a). The LUC of this watershed is very dynamic, especially the LUCC in forest and agricultural areas derived from multiple socio-economic driving forces and forest fires (Meneses et al., 2017).

According to the CLC 2006, the predominant LUC in the study area are forest and seminatural areas, which represent 72% of the watershed area. Other LUC types are less representative, for example, agricultural land (25.5%), artificialized land/urban areas (1.5%), and water bodies (1%), including an important fresh water reservoir, the Castelo de Bode dam (Meneses et al., 2015a). The LUC of this watershed is very dynamic, highlighting the LUCC in forest and agricultural areas derived from multiple socioeconomic driving forces (Meneses et al., 2017) and the degradation of vast forest areas by wildfires (Meneses et al., 2018a).

Due to the large extension of this watershed, three sample areas were selected –according to the high density of landslides observed in these locations: the Estrela Mountain, Vila de Rei, and Ferreira do Zêzere municipalities (areas of 86.7, 191.5, and 190.4 km^2, respectively), where field workfieldwork was developed to validate the landslide inventory and the disruption of roads caused by landslides. ~~The selection of these areas was based on the criteria of higher density of landslides observed in these locations.~~



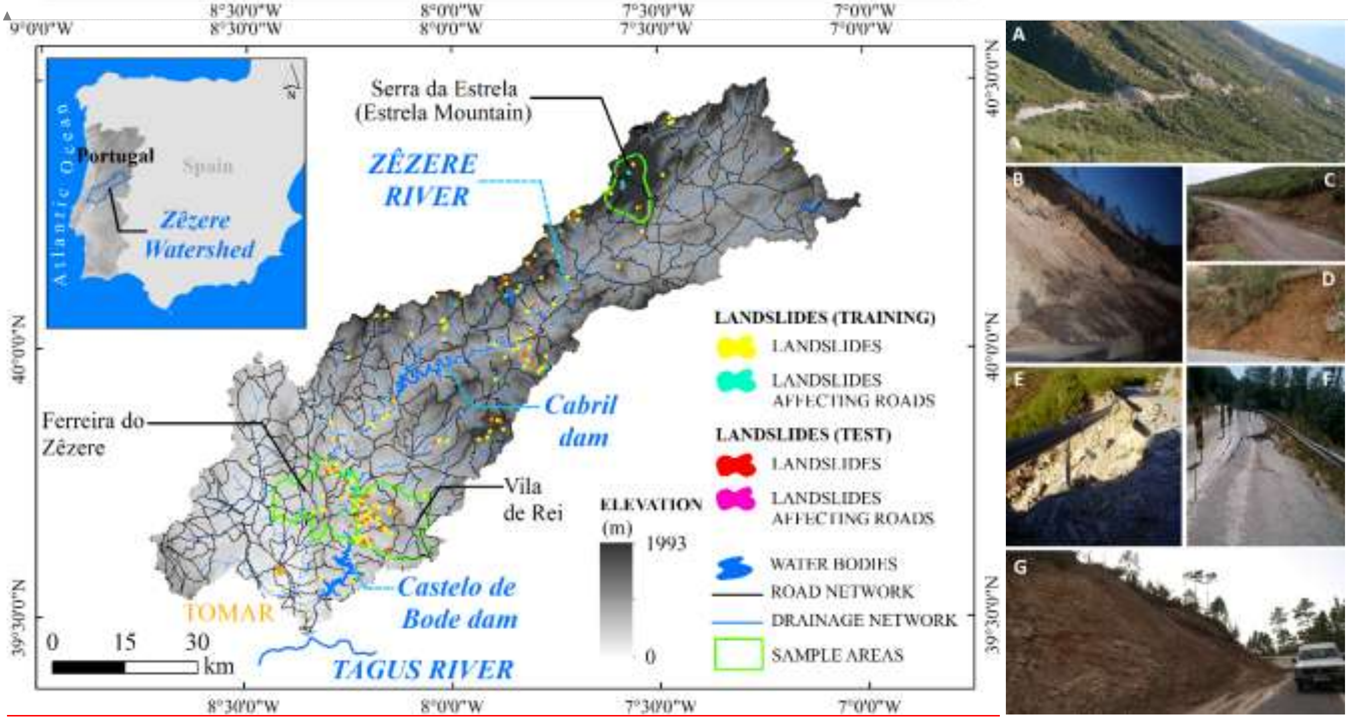


Figure 1. Zêzere watershed ~~study area~~ and landslide ~~spatial distribution~~inventory. The pictures represent landslides that affected roads: A, B, C, D and E - municipality roads of Estrela mountain; F – Ferreira do Zêzere; G – Vila de Rei.

2.2 Data

~~The predisposing factor maps (PFM) were selected after literature reviewing about the causal factors of landslides occurrence (Blahut et al., 2010; Carrara et al., 1991; Castella et al., 2007; Castellanos Abella, 2008; Guzzetti et al., 1999; Soeters and van Westen, 1996; van Westen et al., 2008; Zêzere et al., 2008, 2017). The PFM selected to the landslide susceptibility modeling in Zêzere watershed are presented in Figure 2.~~The landslide predisposing factors used to model the landslide susceptibility in the Zêzere watershed were selected after reviewing the literature about the causal factors of landslides occurrence (Blahut et al., 2010; Carrara et al., 1991; Castella et al., 2007; Castellanos Abella, 2008; Guzzetti et al., 1999; Reichenbach et al., 2018; Soeters and van Westen, 1996; van Westen et al., 2008; Zêzere et al., 2008, 2017) (Figure 2).

Six fixed landslide predisposing factors were considered: slope angle, slope aspect, slope curvature, slope over area ratio~~,~~ (SOAR), soil, and lithology. The LUC of the COS and CLC were used to find the differences in the landslide susceptibility zonation. The set of landslides predisposing factors and the corresponding classes (Fig. 2) were the same in all models, only changing the LUC data.

~~In general terms, slope angle increasing promotes the landslide occurrence and is a very good proxy of the shear stress (Zêzere et al., 2017). Higher slope instability was identified in higher slope angles of the Estrela Mountain and throughout Zêzere valley. Also in these areas, convex slope curvature is predominantly related with slope instability. The slope aspect is important in the spatial distribution of the different LUC types of the study area (Fig. 2) and also on slope instability, especially in northwest-facing slopes (more exposed to the rain and with higher humidity levels).~~

~~The slope over area ratio is a proxy variable that reflects the moisture retention, the soil water content, and the surface saturation zones (Zêzere et al., 2017), highlight in Zêzere watershed the upstream (very close of Zêzere river) and SW areas with higher ratio.~~

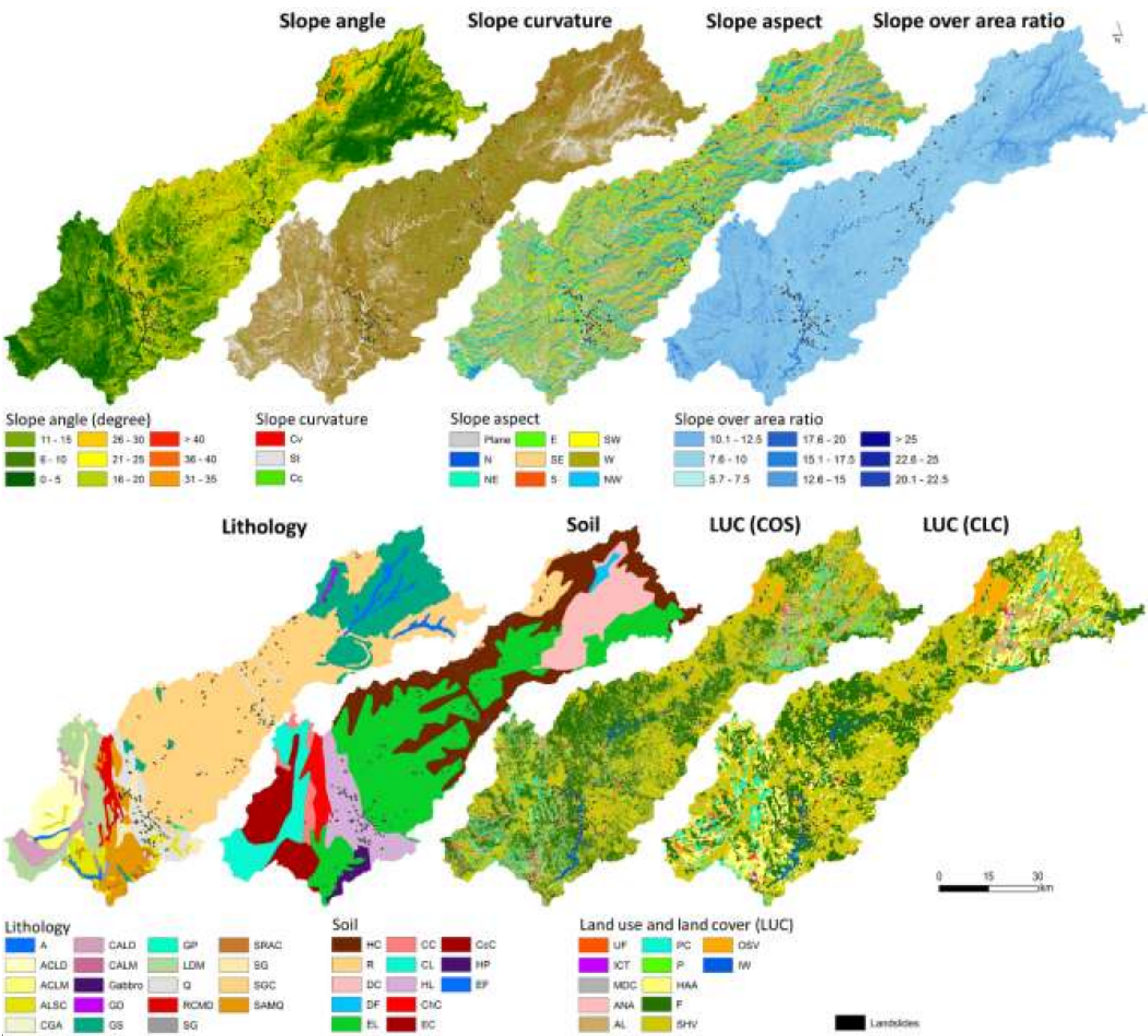
~~In sample areas (Vila de Rei and Ferreira do Zêzere) where high landslide density was observed, schist and metasedimentary lithology are predominant. Also slope instability in the study area is higher in the hortic luvisols and in LUC classes of forest and shrubland or herbaceous vegetation associations (Fig. 1).~~

~~The official LUC GI available for the study area are the CLC, available in European Environment Agency (EEA), and the COS, available in General Directorate for Territorial Development (DGT), Portugal. This GI has different properties and has been used in several studies about landslides in Portuguese territory (e.g. Guillard and Zêzere, 2012; Meneses et al., 2015b; Piedade et al., 2011; Reis et al., 2003; Zêzere et al., 2017).~~

~~Table 1 describes the main properties of this LUC GI (DGT, 2013; EEA, 2007; IGP, 2010). Among the differences of the two LUC datasets, the scale is highlighted because COS is the most detailed relatively to CLC (proportion 1/4). However, the properties are not proportional between the two LUC datasets, while the COS features have 1 ha of MMU the CLC has 25 ha; and the minimum distance between lines is 20 m in COS and 100 m in CLC.~~

~~To reduce possible discrepancies in the field, LUC data was collected for near periods: CLC 2006 and COS 2007. The LUC GI was developed with base information that matches in temporal terms, for example the satellite images, orthophotos and agricultural and forestry inventories used as auxiliary information. The nomenclature of this LUC GI has correspondence to the third level (see official CLC~~

nomenclature on EEA website). In this study the second level of the CLC nomenclature was opted



because it has a lower number of classes for the study area (12 of 31 classes, respectively).

Table 1. Properties of LUC geoinformation.

Properties	**Land Cover Maps of Portugal**	**Corine Land Cover**
Acronym	COS	CLC
Scale	1:25000	1:100000
Minimum mapping unit	1 ha	25 ha

Data structure	Vector	Vector
Geometry	Polygons	Polygons
Minimum distance between lines	20 m	100 m
Base data	Orthophotos	Satellite images
Spatial resolution	0.5 m	20 m
Nomenclature	Hierarchical (5 levels)	Hierarchical (3 levels)
	225 classes	44 classes
Production method	Visual interpretation	Semi-automated production and visual interpretation

The soil and lithology GI were obtained on the web platform of the Environment Atlas, published by the Portuguese Environment Agency (APA) at 1:1000000 scale. Digital elevation model (DEM) was built using digital topographic maps at 1:25000 scale (IGEOE), containing contour lines with 10 m equidistance. Slope angle, slope aspect, slope curvature and slope over area ratio - SOAR (topographic wetness index) layers were extracted from the DEM. Road network GI (vector lines) was extracted from the military cartography of Portugal (itinerary maps, 1:500000), available on website of the Portuguese Army Geospatial Information Center. The road network was classified according to the road network hierarchy and their width. Considering the road center line, a buffer of 5 m distance was defined for municipal roads, 10 m for complementary roads and 20 m for motorways. These distances were measured in roads of study area with Geographic Information Systems (GIS) (directly on the orthophotos).

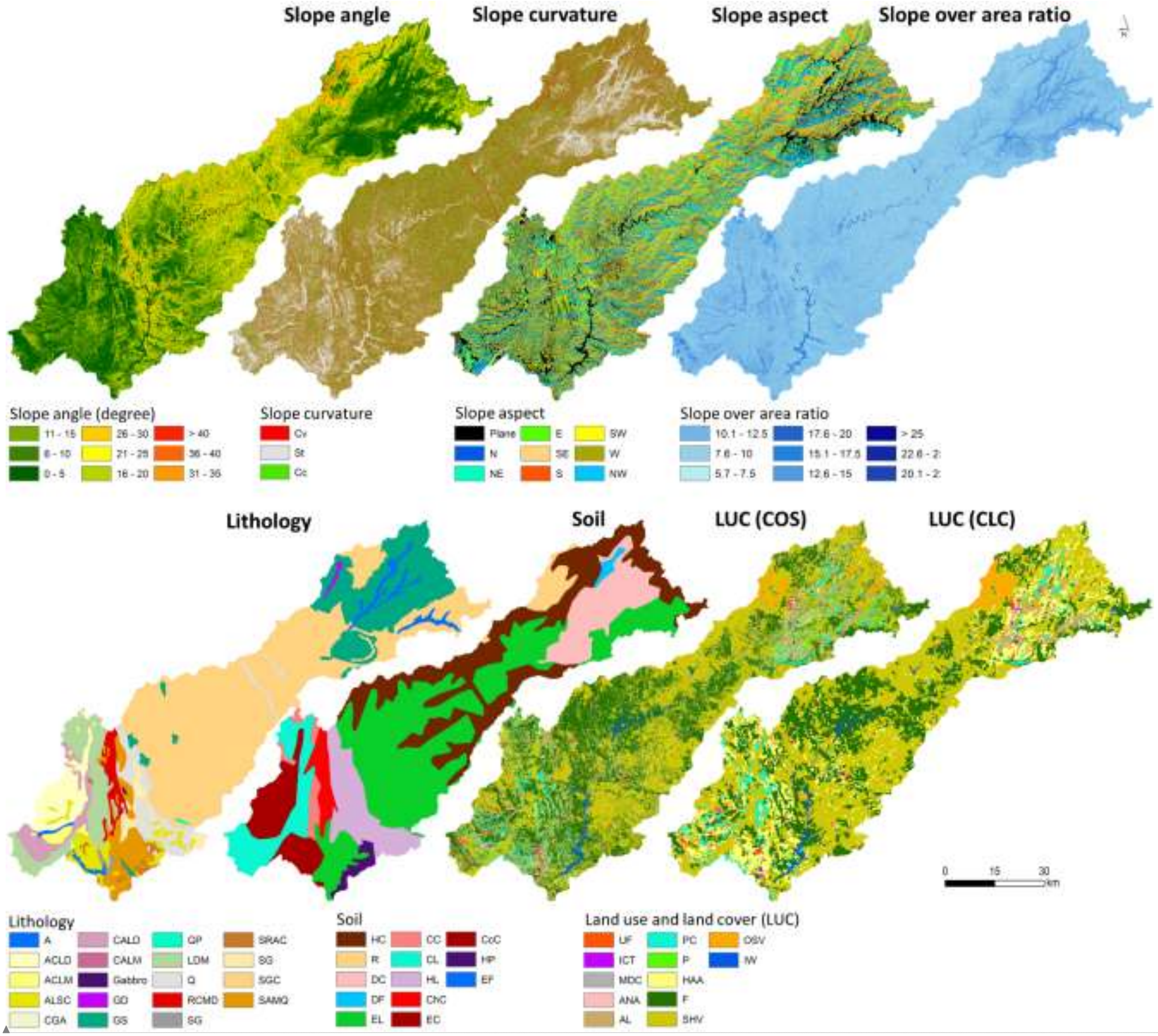


Figure 2. Predisposing factors used in the landslide susceptibility assessment (See legend on Table 3).

Predisposing factor maps ~~(PFM) used in the landslide susceptibility analysis.~~

~~**PFM**~~ **legend**: **Curvature** - Cv: Convex, St: straight, Cc: concave; **Lithology** - A: Alluvium, ACLD: Arenites, conglomerates, limestones, dolomitic limestone, ACLM: Arenites, conglomerates, limestones, dolomitic limestone and marl, ALSC: Arenites, limestone, sand, stony banks and clay, CGA: Clayey schist, grauwackes and arenites, CALD: Conglomerates, arenites, limestone, dolomitic limestone, marly limestone and marl, CALM: Conglomerates, arenites, white limestone and red marl, G: Gabbro, GD: Glacial deposits, GS: Granite and other stones, GP: Granite porphyritic, LDM: Limestones, dolomitic limestone, marly limestone and marl, Q: Quartzite, RCMD: Red sandstone, conglomerates, marl and dolomitic limestones, SG: Sands and gravel, SRAC: Sands, rocky, arenites and clay, SG: Schists and grauwackes, SGC: Schists and grauwackes complex, SAMQ: Schists, amphibolite, mica schists, quartzite grauwackes, carboned stones and gneisses; **Soil** - HC: Humic Cambisols, R: Rankers, DC: Dystric Cambisols, DF: Dystric Fluvisols, EL: Eutric Lithosol, CC: Calcic Cambisols, CL: Calcic Luvisols, HL: Hortic Luvisols, ChC: Chromic Cambisols, EC: Eutric Cambisols, CcC: Calcic-chromic Cambisols, HP: Hortic Podzols, EF: Eutric Fluvisols; **LUC** - UF: Urban fabric, ICT: Industrial, commercial and transport units, MDC: Mine, dump and construction sites, ANA: Artificial, non-agricultural vegetated areas, AL: Arable land, PC: Permanent crops, P: Pastures, HAA: Heterogeneous agricultural areas, F: Forests, SHV: Scrub and/or herbaceous vegetation associations, OSV: Open spaces with little or no vegetation, IW: Inland waters.

The landslide inventory was obtained by photointerpretation (orthophotos of the year 2005 and Google Earth images), a process supported by ancillary topographic data and further field work validation onlyIn general terms, an increasing slope angle promotes landslide occurrence and is a very good proxy of the shear stress (Zêzere et al., 2017). Slope instability is more frequent in the higher slope angles of the Estrela Mountain and throughout the Zêzere Valley. Also, in these areas, convex slope curvature is predominantly related to slope instability. The slope aspect is important in the spatial distribution of the different LUC types of the study area (Fig. 2) and on slope instability, especially in northwest-facing slopes (more exposed to rain and with higher humidity levels).

The SOAR is a proxy variable of the moisture retention, the soil water content, and the surface saturation zones (Zêzere et al., 2017), highlighting, in the Zêzere watershed, the upstream (very close to the Zêzere River) and SW areas with a higher SOAR.

In the sample areas of the Vila de Rei and Ferreira do Zêzere municipalities, where a high landslide density was observed, schist and metasedimentary lithology are predominant. Further, slope instability in the watershed is higher in the hortic luvisols and in the LUC classes of forest and shrubland or herbaceous vegetation associations (Fig. 1).

The official LUC data available for the study area is the CLC produced by the European Environment Agency (EEA) and the COS produced by the General Directorate for Territorial Development (DGT) in Portugal. This LUC data (CLC and COS) has different properties and has been used in several studies about landslides in the Portuguese territory (e.g., Guillard and Zêzere, 2012; Meneses et al., 2015b; Piedade et al., 2011; Reis et al., 2003; Zêzere et al., 2017).

Table 1 describes the main properties of this LUC data (DGT, 2013; EEA, 2007; IGP, 2010). Among the differences between the two LUC datasets, the scale is highlighted because the COS is the most detailed relative to the CLC (proportion 1/4). However, the properties are not proportional between the two LUC datasets; while the COS features have a minimum mapping unit of 1 ha, the CLC has a minimum mapping unit of 25 ha; and the minimum distance between lines is 20 m in the COS, while in the CLC, it is 100 m.

To reduce possible discrepancies in the field, the LUC data was collected for near dates: CLC 2006 and COS 2007. The LUC data was developed with base information that matches in temporal terms, for example, the satellite images, orthophotos, and agricultural and forestry inventories used as auxiliary information. The nomenclature of this LUC data corresponds to the third level (see the official CLC nomenclature on the EEA website). In this study, the second level of the CLC nomenclature was used because it has a lower number of classes for the study area (12 of 31 classes, respectively).

Table 1. Properties of LUC data.

Properties	**Land Cover Maps of Portugal**	**Corine Land Cover**
Acronym	COS	CLC
Scale	1:25000	1:100000
Minimum mapping unit	1 ha	25 ha
Data structure	Vector	Vector
Geometry	Polygons	Polygons
Minimum distance between lines	20 m	100 m
Base data	Orthophotos	Satellite images
Spatial resolution	0.5 m	20 m
Nomenclature	Hierarchical (5 levels)	Hierarchical (3 levels)
	225 classes	44 classes
Production method	Visual interpretation	Semi-automated production and visual interpretation
Date of production	2007	2006

The agreement between the LUC data is presented in Table 2. The forest class shows great differences between the two LUC datasets. For example, the COS represents more forest area relative to the CLC (34 and 26.9% of the study area, respectively), because a part of the COS (approximately 10% of the study area) is classified as scrub and/or herbaceous vegetation associations in CLC. The reverse was also verified; approximately 5% of the study area is classified as scrub and/or herbaceous vegetation associations in the COS, and this same area is represented by forest class in the CLC. These discrepancies are derived from the LUC data properties because the COS is more detailed and represents more degraded forest areas, especially where wildfires occurred. These events affected a large percentage of the watershed (Meneses et al., 2018a), especially the Central sector, as a vast burned area culminated in a large transition of forest area to shrubland.

The forest, scrub and/or herbaceous vegetation associations and open spaces with little or no vegetation are the LUC types predominant in the hillsides with steep slopes (see Tables 1 and 2 in the supplementary data). The remaining LUC classes present more area in the lower slopes (> 10 degrees).

The soil and lithology data were obtained from the Environment Atlas web platform, published by the Portuguese Environment Agency (APA) at 1:1000000 scale. A digital elevation model (DEM) was built using digital topographic maps at 1:25000 scale (IGEOE), containing contour lines with 10 m equidistance.

Table 2. LUC data agreement (area ha) between CLC and COS classes.

Data	**COS**												
CLC	**Urban fabric (UF)**	**Industrial, commercial and transport units (ICT)**	**Mine, dump and construction sites (MDC)**	**Artificial, non-agricultural vegetated areas (ANA)**	**Arable land (AL)**	**Permanent crops (PC)**	**Pastures (P)**	**Heterogeneous agricultural areas (HAA)**	**Forests (F)**	**Scrub and/or herbaceous vegetation associations (SHV)**	**Open spaces with little or no vegetation (OSV)**	**Inland waters (IW)**	**Total**
UF	3160.2	439.8	77.3	100.8	207.7	502.0	15.7	929.2	337.7	251.5	0.1	18.7	6040.7
ICT	134.1	650.4	83.0	9.5	33.4	27.4	9.0	62.5	130.8	207.7	0.3	8.1	1356.1
MDC	6.1	58.3	283.0	0	3.6	3.6	6.8	6.5	48.2	53.5	0.2	5.4	475.0
ANA	29.3	2.9	0	22.5	0	0	0	0	1.7	9.1	0	0	65.6
AL	245.3	171.7	25.0	12.2	9166.1	1304.4	2225.0	1317.1	1133.2	1435.9	51.0	190.7	17277.5
PC	1271.4	93.3	37.3	21.2	1357.9	7948.5	315.4	2930.0	2004.5	2300.2	7.9	38.1	18325.7
P	4.4	2.4	0	0	61.3	0.9	36.1	58.4	41.2	188.6	0	0	393.2
HAA	7791.6	736.5	271.4	73.7	11773.1	15553.2	2341.0	23762.4	16514.4	12935.5	143.3	243.9	92140.0
F	745.3	392.9	173.1	29.3	741.9	1715.5	238.1	4058.7	100486.5	26805.7	42.0	735.8	136164.8
SHV	826.5	510.0	259.3	38.0	1353.1	2543.2	958.3	5832.8	50509.8	149644.0	4052.8	846.7	217374.5
OSV	29.4	13.8	5.3	1.4	18.3	10.3	10.7	140.4	860.0	6367.1	4206.6	30.3	11693.7
IW	5.6	12.0	0	0.2	1.3	7.5	0	15.2	278.5	180.7	2.4	4589.5	5093.0
Total	14249.1	3084.1	1214.7	308.8	24717.7	29616.3	6156.0	39113.2	172346.6	200379.5	8506.6	6707.1	506399.7

Slope angle, slope aspect, slope curvature, and SOAR (topographic wetness index) layers were extracted from the DEM. Road network data (vector lines) were extracted from Portugal's military cartography (itinerary maps, 1:500000 scale), available on the Portuguese Army Geospatial Information Center's website. The road network was classified according to the roads' width and their network hierarchy. Considering the road center line, a buffer of 5 m was defined for municipal roads, 10 m for complementary roads, and 20 m for motorways. These distances were measured with geographic information systems (GIS) (directly on the orthophotos) on the study area roads.

The landslide inventory was obtained using photointerpretation (orthophotos from 2005 and Google Earth images), a process supported by the ancillary topographic data and further fieldwork validation only performed in the sample areas (Fig. 1) due to the extension of the study area. A total of 128 landslides (predominantly shallow translational slides~~)~~), with a total area of 74042 m^2, was validated during ~~field work~~fieldwork in the sample areas (49.4% of the total inventoried landslide cases~~), with a total area of 74042 m^2.~~). Among the landslides initially inventoried by photointerpretation in the sample areas, more than 90% of cases were confirmed. In these sample areas ~~roads~~, road disruptions were also validated. ~~In~~

For the complete Zêzere watershed, 259 landslides ~~have been~~were identified ~~(Table 2),~~, predominantly of shallow type. ~~On~~Of the total, 32 landslides ~~affected~~ directly affected the road network (total or partial blockages by the material and 7 cases with partial loss of infrastructure). The landslide inventory was randomly divided into two subsets (Fig. 1) (Chung and Fabbri, 2003): the landslide training group and the landslide test group (81.5% and 18.5% of the total landslide affected area, respectively). The statistical description of each landslide group is presented in Table 3.

~~GIS were used to convert the predisposing factors to raster (10×10 m) and to compute the landslide susceptibility zonation. Selection of cell size of the predisposing factors was based on several GI conversion tests in the Zêzere watershed previously performed by Meneses et al. (2016).~~

Table ~~2.~~3. Statistics description of the ~~landslides inventory~~training group and test group landslide inventories.

	Training group		**Test group**		**Total inventory**	
	~~**Total inventory**~~Non affected roads	~~**Landslides affecting**~~Affected roads	Non affected roads	Affected roads		
Total landslides	185	26	42	6	259	~~32~~
Total area (m^2)	44604	369404	10444	12089	104077~~.4~~	~~49029.7~~
Minimum (m^2)	134	7~~.4~~	18	82	7~~.4~~	
Maximum (m^2)	27364	12507~~.2~~	1911	5881	12507~~.2~~	
Mean (m^2)	~~398.8~~ 2414	~~1532.2~~ 1421	249	2015	402	
Standard deviation (m^2)	~~1065.2~~ 3284	~~2653.5~~ 2647	304	2627	1069	

The landslide size frequency distribution is different between the landslides that affected the road network and those that did not (Fig. 3). The area of the majority of landslides ranges between 101 and 200 m^2, while most of the landslides that affected the road network present a larger area (>1000 m^2).

All the predisposing factors and landslide inventory were converted to raster (resolution 10 m) to assess the landslide susceptibility. The selection of the predisposing factors' cell size was based on several geoinformation conversion tests in the Zêzere watershed previously performed by Meneses et al. (2016, 2018b).

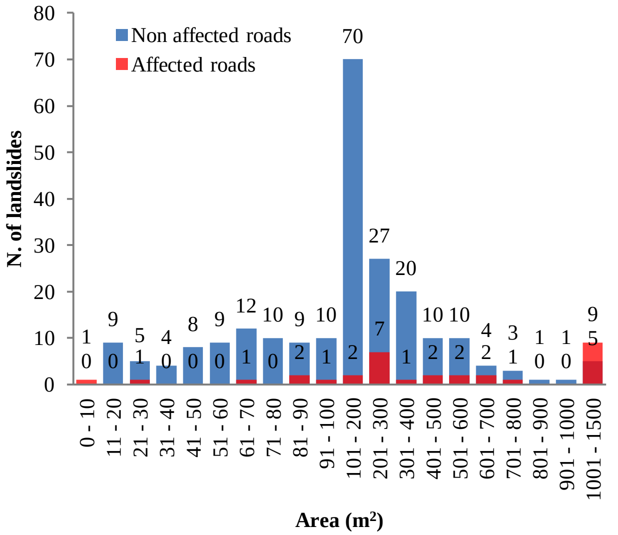


Figure 3. Landslide size frequency distribution.

2.3 Methods

The landslide susceptibility modeling was carried out using the Information Value (IV) method (Yan, 1988; Yin and Yan, 1988). The IV is a bivariate statistical method that has been used in several studies and different areas with good results for landslide susceptibility assessment (e.g., (Guillard and Zêzere, 2012; Oliveira et al., 2015a; Zêzere et al., 2017). The IV of each class within each explanatory variable is given by Eq. (1) (Yan, 1988; Yin and Yan, 1988):

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$$IVX_i = \ln \frac{S_i / N_i}{S / N} \tag{1}$$

where IVX_i is the ~~Information Value~~IV of the variable X_i; S_i is the number of terrain units with landslides and the presence of variable X_i; N_i is the number of terrain units with variable X_i; S is the total number of terrain units with landslides~~;~~, and N is the total number of terrain units.

~~The IV method was applied in several landslide susceptibility zonation studies, providing good results (e.g., Che et al., 2012; Chen et al., 2016; Conforti et al., 2012) at the regional scale. This method was also applied in several studies conducted in Portuguese territory with good performance in the susceptibility assessment (e.g., Guillard and Zêzere, 2012; Oliveira et al., 2015b; Pereira et al., 2014; Zêzere et al., 2017).~~

~~Priori~~The IV method was applied in several landslide susceptibility zonation studies, providing good results (e.g., Che et al., 2012; Chen et al., 2016; Conforti et al., 2012) at the regional scale. This method was also applied in several studies conducted in the Portuguese territory, with good performance in susceptibility assessment (e.g., Guillard and Zêzere, 2012; Oliveira et al., 2015b; Pereira et al., 2014; Zêzere et al., 2017).

The *a priori* probability of finding a landslide unit in the study area (S/N) and conditional probabilities for each class of the independent variables (S_i/N_i) were calculated, ~~allowing to obtain~~obtaining the IV for ~~this~~these classes. However, the IV method presents constraints on obtaining the natural logarithm for negative results; in this case, the lower value calculated for each variable was assigned to classes ~~where it has not been possible~~when S_i is equal to ~~make the calculation of IV.~~ zero.

The IV of all the variables were combined ~~and obtained~~to obtain the landslide susceptibility map (LSM). For the final landslide susceptibility assessment, i.e., the integration of the ~~information values~~IVs of all the independent variables, the following equation was considered:

$$IV_j = \sum_{i=0}^{n} X_{ij} I_i \qquad (2)$$

where IV_j is the total ~~information value~~IV of the cell j, I_i is the information value of each cell of each independent variable, n is the number of variables, X_{ij} assumes the value 1 or 0, depending on the presence or ~~not~~absence of the variable in the field unit.

Success rate curves (SRC) were produced for each final susceptibility maps (Chung and Fabbri, 1999, 2003) and the area under the curve (AUC) was computed.

The importance of each independent variable in the assessment landslide susceptibility was also determined, so that the spatial influence of each predisposition factor in the models can be understood. The accountability (A_I) and reliability (R_I) indexes have been used in different contexts to assess the importance of each independent variable in bivariate statistical methods (e.g. Blahut et al., 2010; Meneses et al., 2016).

Landslide susceptibility model performance was assessed using training landslides. Landslide areas in the test group were only used to perform an independent validation of the landslide susceptibility. Prediction rate curves (PRC) were computed for each final LSM (Chung and Fabbri, 1999, 2003) and also the AUC. Success rate curves (SRC) were obtained for the landslide susceptibility road network maps using only the landslides that affected roads.

The importance of each independent variable in the landslide susceptibility assessment was also determined, so that the spatial influence of each predisposition factor in the models can be understood. The accountability (A_I) and reliability (R_I) indexes have been used in different contexts to assess the importance of each independent variable in the bivariate statistical methods (e.g., Blahut et al., 2010; Meneses et al., 2016).

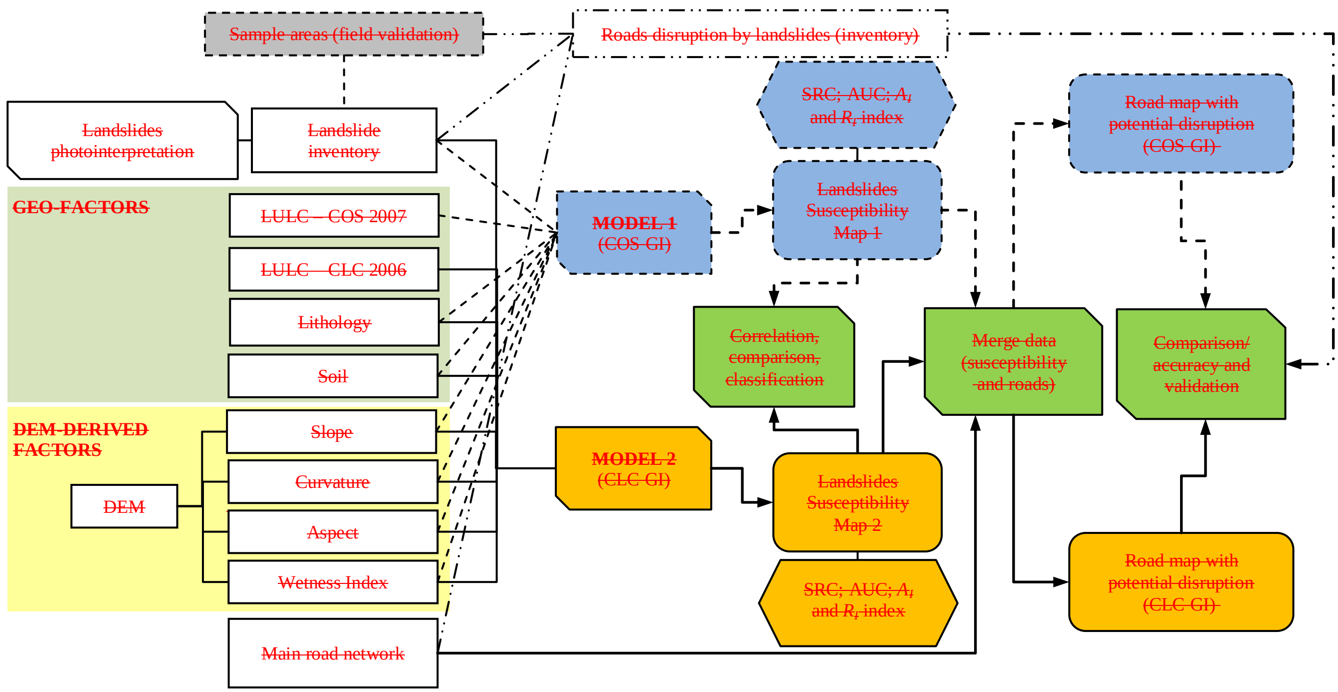
A_I explains how different classes of predisposition factors are relevant in the analysis because they contain the landslide area, while R_I depends on the average density of the landslide area in the predisposing factors classes that are more relevant to the development of this process. In this procedure, the A_I and R_I were determined using Eq. (3) and (4) (Blahut et al., 2010)(3) and (4), respectively (Blahut et al., 2010).

$$A_I = \frac{\sum_{i=1}^{n} k}{N} 100 \tag{3}$$

$$R_I = \frac{\sum_{i=1}^{n} k}{\sum_{i=1}^{n} y} 100 \tag{4}$$

where k is the landslides area in classes with the conditional probability values ~~of conditioned probabilities superior to~~higher than a priori probability; N is the total landslides area; y the area of each class of independent variable with ~~conditioned~~a conditional probability above the a priori probability.

Two landslide susceptibility models were built using the IV ~~method,~~Method (see results in Table 3 in the supplementary data), using the same set of predisposing factors, except the ~~types of~~ LUC ~~GI~~data (Fig. ~~3~~4): model 1 (M1) ~~modelled~~was modeled with the COS 2007 and resulted in the LSM1; ~~the~~ model 2 (M2) ~~modelled~~was modeled with the CLC 2006 and resulted in the LSM2. The LSM1 and LSM2 results were correlated, and the corresponding spatial ~~concordance~~agreement was analyzed.



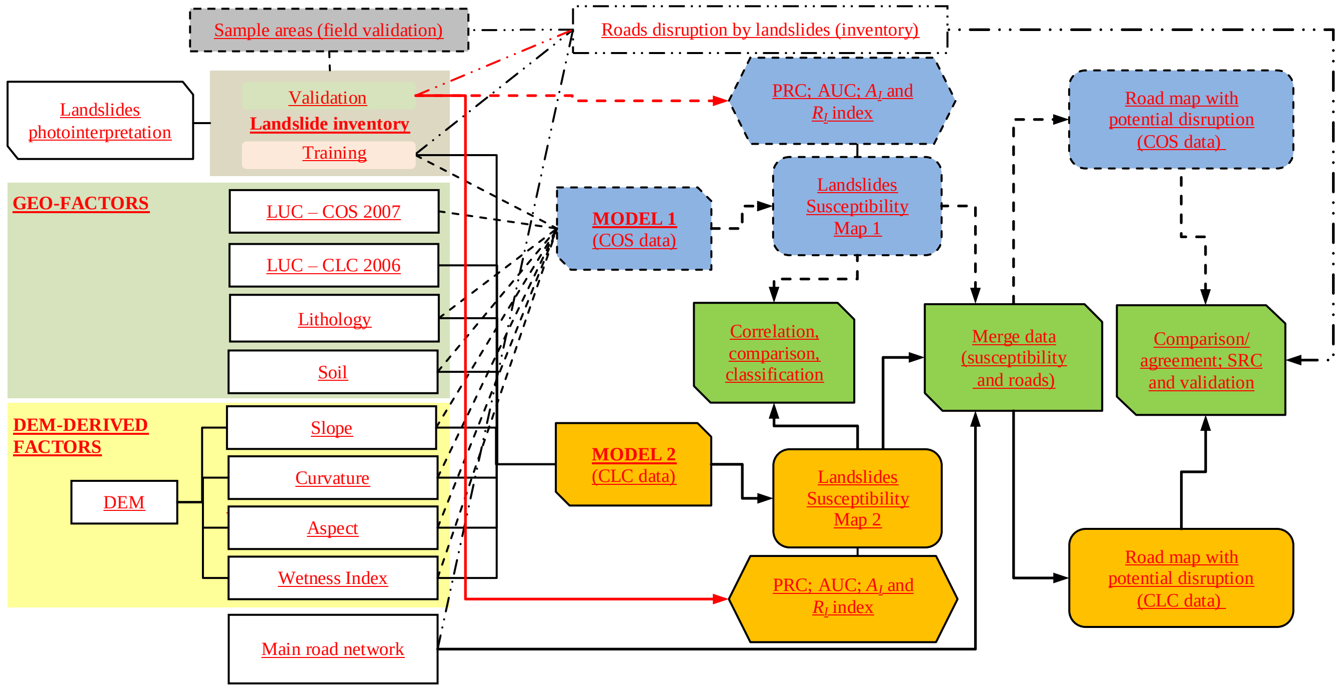


Figure 4. Workflow of landslide susceptibility assessment (using different LUC datasets) and the roads susceptibility data integration.

The information values of LSM1 and LSM2 ~~was extracted for~~were assigned to the road network (using GIS), resulting in a road network map with the landslide susceptibility location (the LSM of the roads network - LSRN1 and LSRN2), where there is ~~greater~~a higher spatial probability of road interruption or road interference caused by landslides. ~~Then different~~Different outputs of the two models (road network) were compared~~, i.e.,~~ using the overall ~~accuracy~~agreement and Kappa coefficient ~~(Congalton and Green, 2009) was performed,~~(Congalton and Green, 2009), allowing ~~to assess~~the assessment of the consistency and agreement of the obtained results with different LUC datasets. ~~Road~~The information of road disruptions caused by landslides were used to validate these results~~ in the sample areas~~.

~~Landslide susceptibility maps~~LSMs were built and classified in 10 classes (deciles) containing an equal number of terrain units to allow ~~the~~ visual comparison of the results.

3 Results

3.1 ~~Landslides~~Landslide susceptibility

The landslide susceptibility results show spatial contrasts in the study area. Some areas in ~~centre~~the center of the watershed (highlighting the vicinity of the Castelo de Bode reservoir) and the north (Estrela Mountain) sectors present the highest landslide density and ~~landslide~~ susceptibility (Fig. ~~4~~5).

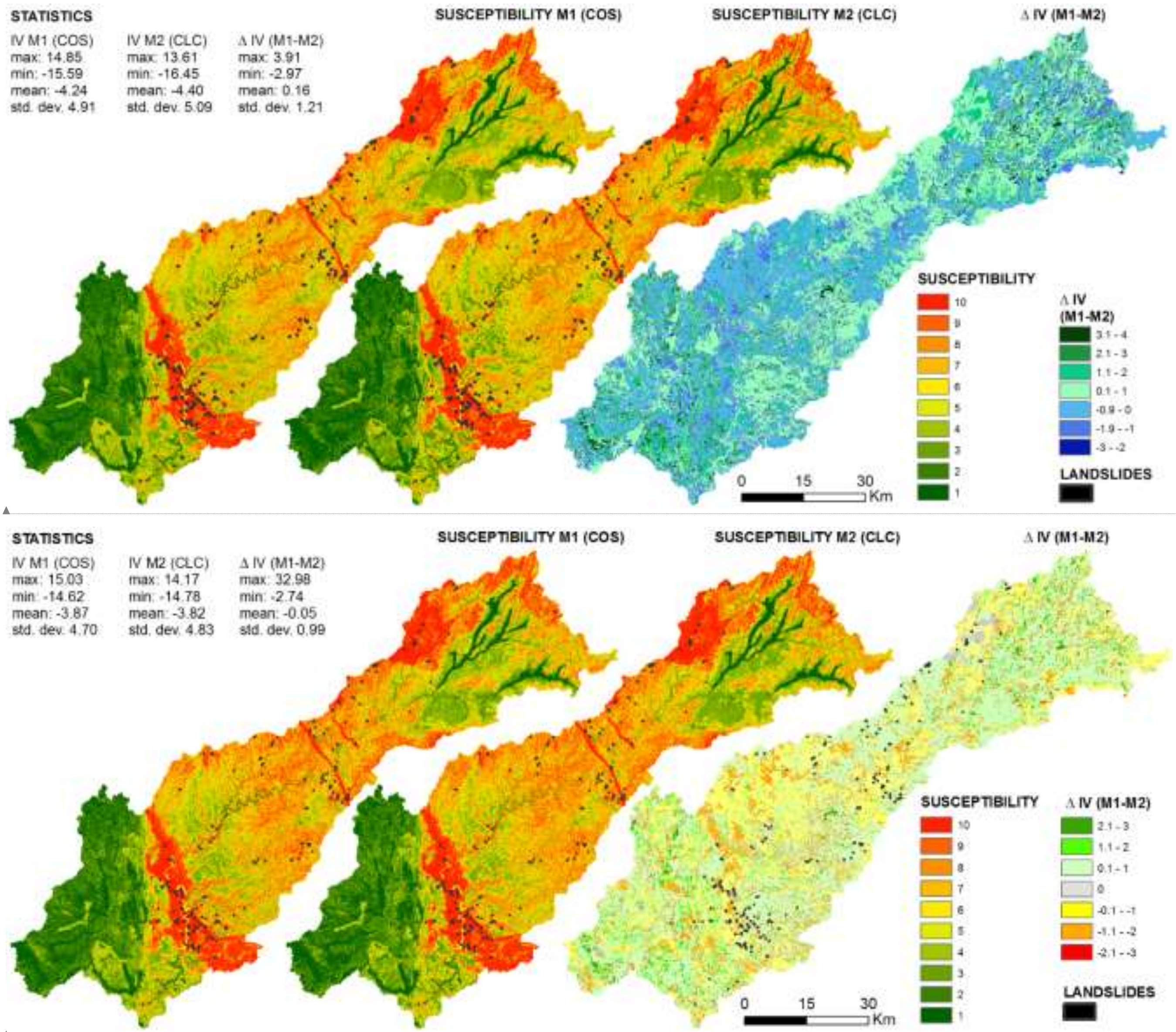


Figure 5. Spatial landslideLandslide susceptibility (IV represented in deciles):from the highest (red) to the lowest susceptibility (green)): susceptibility M1 represent the results obtained with model 1 (performed with COS GIdata) and susceptibility M2 represent the results obtained with model 2 (performed with CLC GIdata). The map in the right is the variation between M1 and M2.

The results of the A_I and R_I indexes show important differences between the predisposing factors that have integrated the landslide susceptibility models (Table 3), except A_I of the LUC (COS and CLC4). The LUC predisposing factors (the COS and CLC) registered the highest A_I results, highlighting the COS's LUC with a higher A_I. These results show the relevance of certain classes of the COS in the predisposing factors dataset, by the number of landslide areas covered (emphasis on the forests, scrubland, and/or herbaceous vegetation associations and open spaces with a scarcity or absence of vegetation).

The LUC predisposing factors (COS and CLC) registered the highest A_I results (81.1,

Table 3), showing the relevance of certain classes of this predisposition factors by the number of landslide area covered (emphasis on the forests, scrubland and/or herbaceous vegetation associations and open spaces with scarcity or absence of vegetation).

In the case of R_I, soil SOAR and slope angle present the highest values which shows that landslide density is concentrated in a reduced number of classes of each of these predisposing factors area (e.g. Hortic Luvisols, SOAR [22.5-25] and slope [between 25 and 45 degrees]).

Table 3.4. Results of the accountability (A_I) and reliability (R_I) indexes.

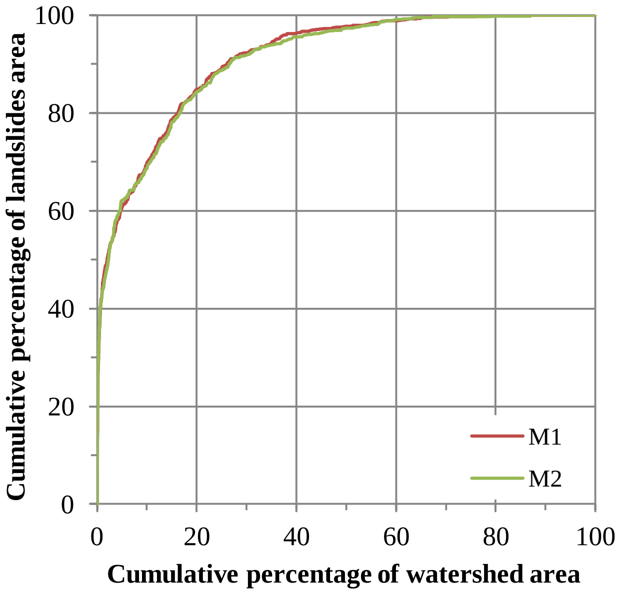
Factors	A_I	R_I
Aspect	71.179.5	0.3224
Slope	77.576.1	0.8062
SOAR	15.813.5	1.040.70
Soil	6662.4	1.300.96
Lithology	67.260.6	0.5544
Curvature	60.061.1	0.3931
LUC (COS)	81.182.0	0.4334
LUC (CLC)	81.176.0	0.4028

In the case of R_I, soil, SOAR, and slope angle present the highest values, which shows that landslide density is concentrated in a reduced number of classes of each of the predisposing factors areas (e.g., Hortic Luvisols, SOAR [22.5-25], and slope [between 25 and 45 degrees]).

The landslide susceptibility model's accuracyagreement test was performed using the landslide training inventory andused to perform the final outputs of each model (M1 and M2).), and these results were validated using the landslides test group. The SRCPRC of each final susceptibility mapsmap (obtained from the results of GI mentioned abovethe landslide training group) show slight variations (Fig. 56), but, in general terms, the curves are very identical, demonstrating the high and similar performance of the models in the determination of landslides susceptibilitysusceptible areas.

The area under the curve (AUC) of LSM1M1 and LSM2M2 that includes the same landslide information used to train the models is 91.4 e 9194.1% and 93.9%, respectively. However, the landslide susceptibility results obtained in the two models are spatially differentThese results (landslide prediction) were considered to integrate the LSRN1 and LSRN2 and the next analyses presented. Additionally, spatial differences were observed in the LSMs (Fig. 45), reflecting the differences in the influence of LUC properties.

When the two LSMLSMs are reclassified ininto two classes (not susceptible IV≤0 and susceptible IV>0), the susceptible area in LSM1 correspondcorresponds to 17.319.7% and in LSM2 to 16.9%. With input the20.8%. The CLC GI, thedata provide IV results are mostly lower in comparison to than the IV obtained with COS GI.the COS data, but the CLC is more generalized and justifies that the most susceptible area is observed in LSM2 compared to LSM1. The variation between the most positive and negative IVs (4 and -3 of ΔIV (4 and -3) (in Fig. 4) shows5) show that different IV are obtained in the LUC classes of the two LUC datasets. The highest variations between LSM1 and LSM2 results are found in places with reduced IVIVs (low and moderate susceptibility), marking the Southwest and North sectors (Zêzere valley)central sector of the study area. In theThe areas with the highest IVIVs in LSM1 and LSM2 thepresent a lower variation is lower, with IV differences between 0.1 and 2.



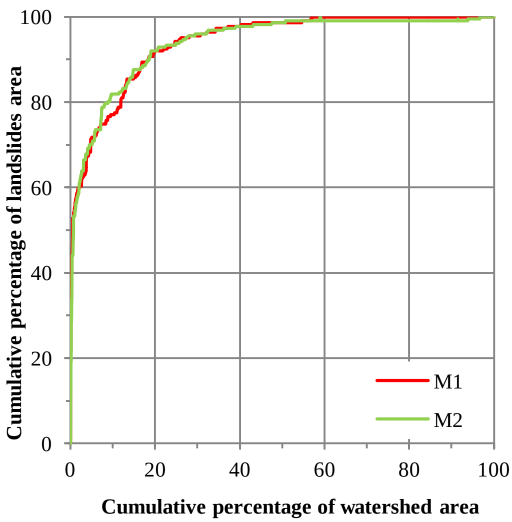


Figure 6. ~~Success~~Prediction rate ~~curve (SRC~~curves (PRC) of the landslide susceptibility models M1 and M2.

3.2 Landslides susceptibility in the road network

Due to the width of the road network, in most cases, these infrastructures are not identified in the LUC ~~GI~~data due to the properties or specifications (Table 1), namely, the minimum distance between lines considered in theeach LUC cartography scale (Table 1).data in the research. The class “road and rail networks and associated land” (LUC nomenclature:, level III) is inserted inintegrates the main class "industrial, commercial, and transport units” (level II),); however, different when a tabulation of the area of the roads network and the LUC datasets are crossed with the main roads it shows that mostwas performed, the density of the roads are mostly intersected by other types of LUC was different in COS and CLC mapseach LUC class between datasets (Fig. 67).

When the IV

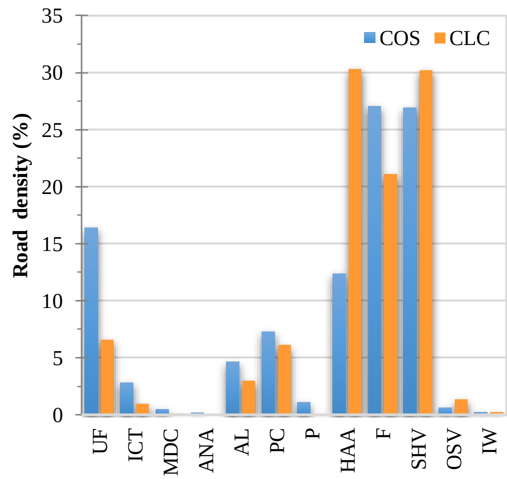
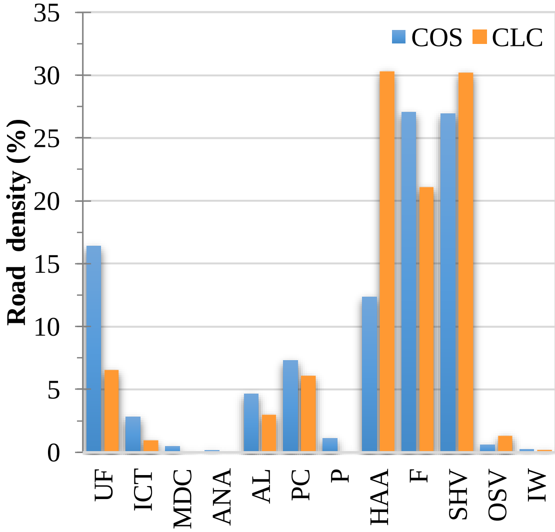


Figure 7. Density of roads by LUC class of CLC and COS data.

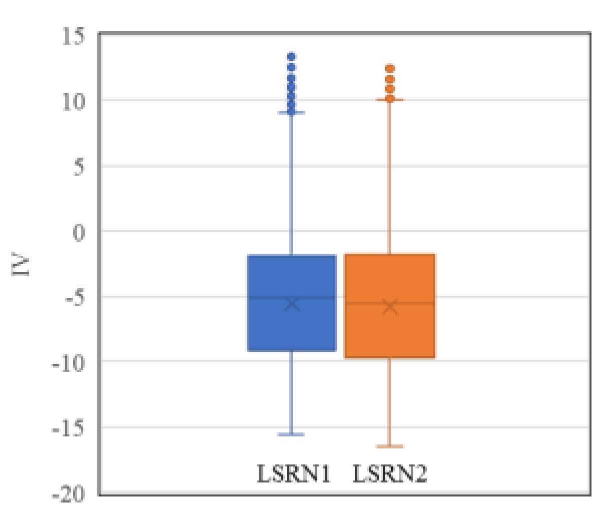
LUC legend: UF: Urban fabric, ICT: Industrial, commercial and transport units, MDC: Mine, dump and construction sites, ANA: Artificial, non-agricultural vegetated areas, AL: Arable land, PC: Permanent crops, P: Pastures, HAA: Heterogeneous agricultural areas, F: Forests, SHV: Scrub and/or herbaceous vegetation associations, OSV: Open spaces with little or no vegetation, IW: Inland waters.

The IVs of LSM1 and LSM2 was associatedassigned to the road network it was possible to differentiatedifferentiated the roads dueaccording to the landslide susceptibility, representing the highest IV where probably will occur the nextfuture landslides will occur and possibly causingrupture of the road network or cause socioeconomic constrains, due to total or partial blockages or rupture of the road network. . In this case, the differences of the roads landslide susceptibility were also analyzed.



~~**Figure 6.** Density of roads by LUC class of CLC and COS GI (see LUC legend Fig. 2).~~

The ~~IV~~IVs assigned to the road network ~~does~~do not have spatial agreement between the two models. The difference between the maximum and minimum ~~IV~~IVs of the LSRN1 and LSRN2 variations is notorious, with approximately 1 value of IV variation. The interquartile range of the IV is greater in LSRN2 than in LSRN1 (Fig. ~~7~~8). However, the IV average is ~~smaller~~similar in LSRN2 in comparison to LSRN1.



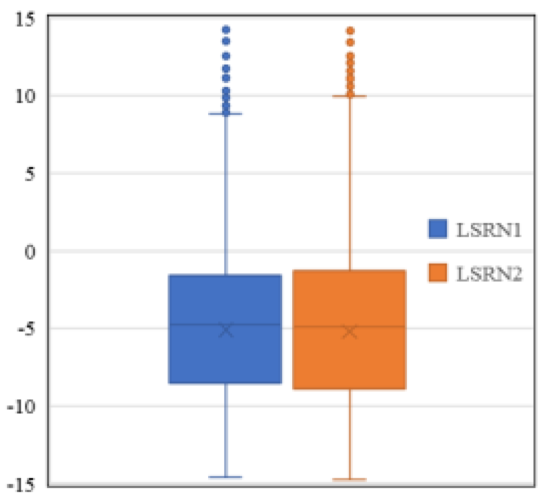


Figure 8. Landslide susceptibility of the road network. LSRN1 – IV ~~extracted of~~assigned for the LSM1; LSRN2 – IV ~~extracted of~~assigned for the LSM2.

The ~~landslide susceptibility map~~LSM of the ~~roads~~road network obtained by LSM1 (resulting in LSRN1) (Fig. ~~8), i.e., IV extracted of the LSM1, the landslide susceptibility~~9) shows that it is spatially contrasted along the road network, highlighting the places where ~~is most likely to occur the~~ future landslides that may cause disturbances on the roads~~.~~

are most likely to occur. On the other hand, in the ~~landslide susceptibility map~~LSM of the roads network obtained by LSM2 (resulting in LSRN2), the IV assigned to the road network is generally lower when compared to LSRN1, ~~which is~~ a result derived from the LUC ~~(CLC)~~ generalization (CLC) used in the input of M2.

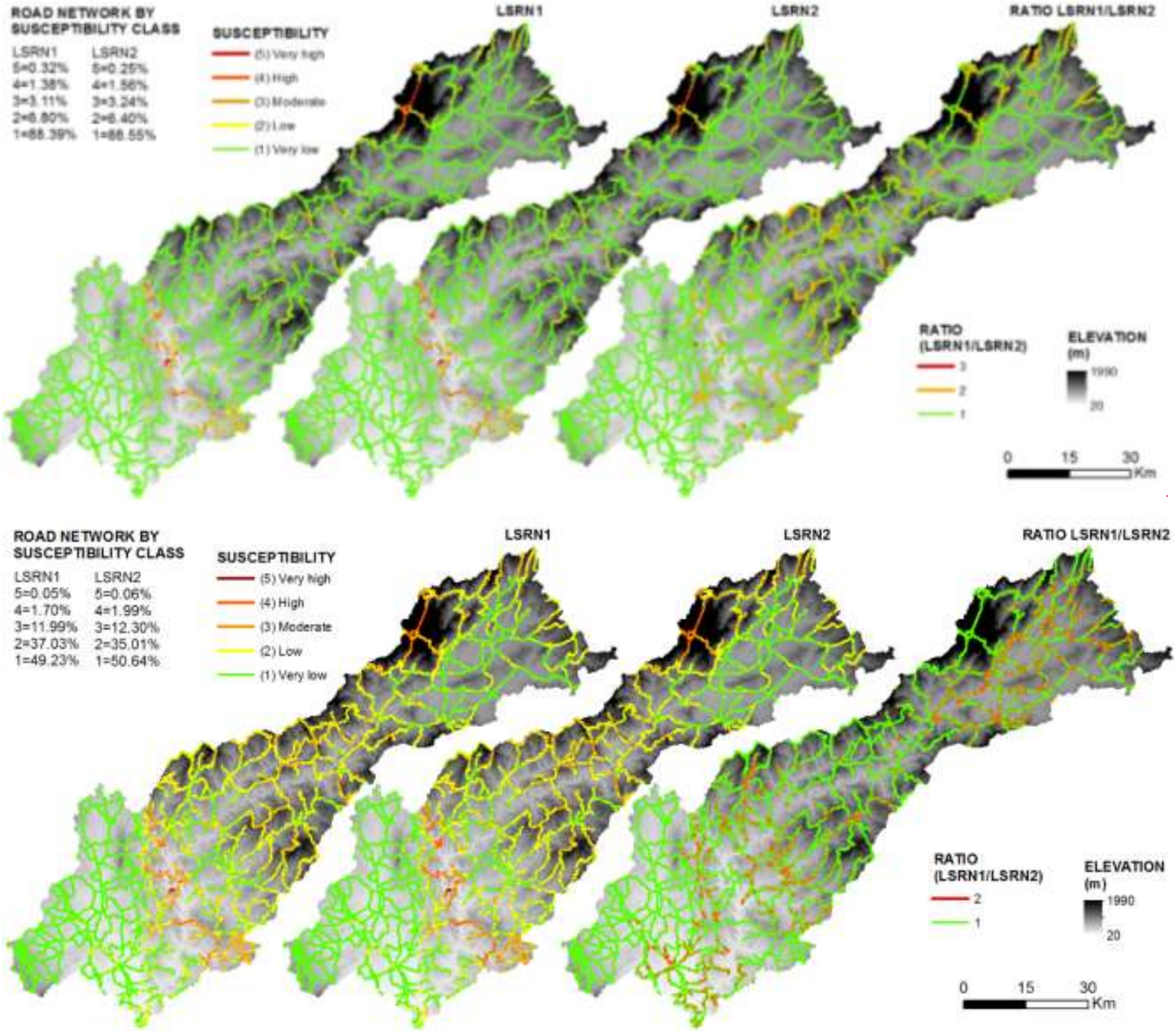


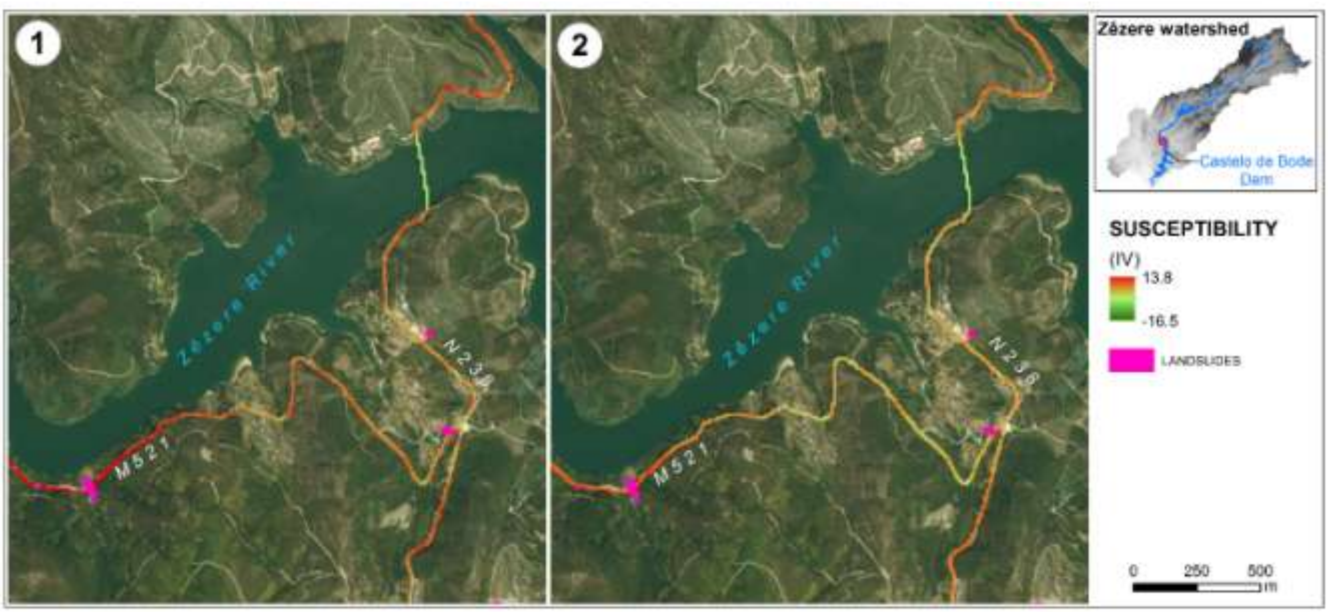
Figure 9. Landslide susceptibility of the road network (LSRN1 and LSRN2) and the ratio between landslide susceptibility class of the roads. LSRN1 – IV ~~extracted of~~assigned to the LSM1; LSRN2 – IV ~~extracted of~~assigned to the LSM2.

LSRN1 includes ~~11.6~~14.05% of the roads with a positive landslide susceptibility (IV ≥ 0), and the roads with high landslides susceptibility (IV~~ > 7.5~~≥10) represent only 0.~~32~~06% of the total road network (Fig. ~~8); while in the~~9). In LSRN2~~ case~~, the positive landslide susceptibility (IV~~ ≥ ~~≥0) ~~reduces to 11.5% in~~

the increases (compared with LSRN1) and comprises 14.67% of the total road network, where 0.305% of this network corresponds to a high landslide susceptibility (IV > 7.5>10).

Landslide susceptibility in LSRN2 dodoes not show a high variation in short roads distances of roads, i.e., the IV tends to be extended within each polygon of the same class of the CLC's LUC of CLC ((larger polygons larger in comparison with the COS GI)data), reducing the IV variation along the roads. The variation of the IV within each polygon of the LUC GIdata is only explained only by the remaining predisposing factors included in the model.

OnIn the output of LSRN2, the places with a high landslide susceptibility are not always identified as those where landslides effectively landslides occurred (Fig. 910). The landslide susceptibility of the road network enhances the results obtained with the COS (LSRN1) in very high landslide susceptibility identificationareas, precisely where landslides were validated in the fieldwork. These results show the importance of LUC GIdata properties in the spatial differentiation of the landslide susceptibility.



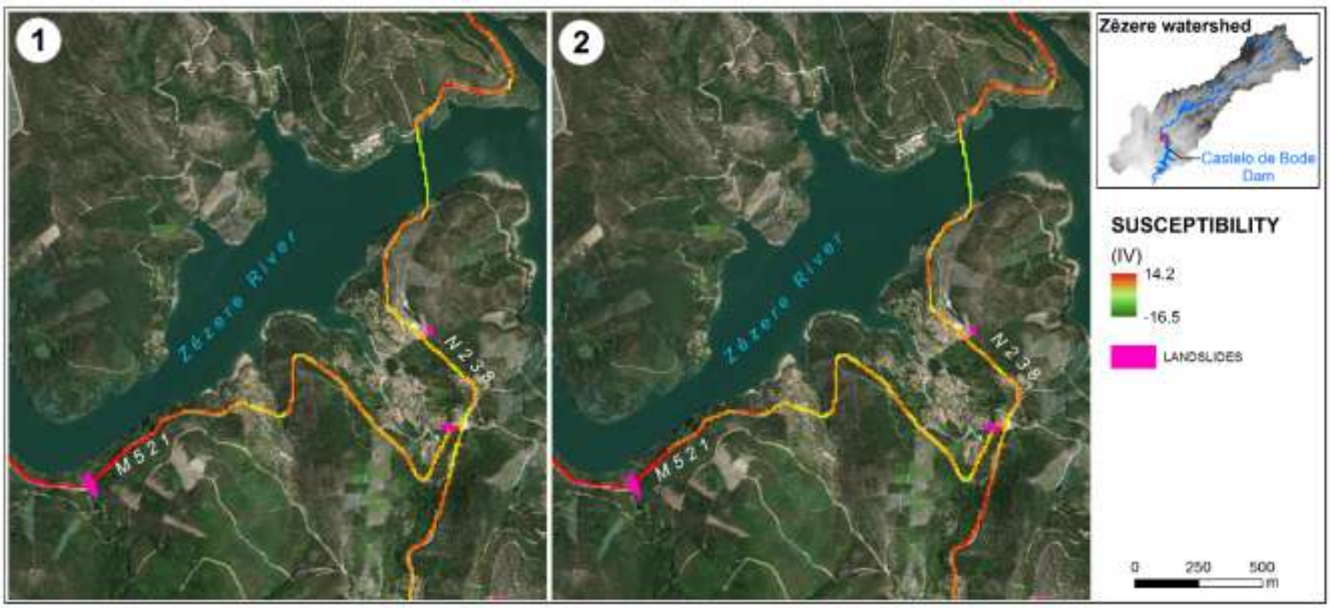


Figure 10. Examples of the landslide susceptibility of the road network in Ferreira do Zêzere municipality. 1 – LSRN1; 2 – LSRN2.

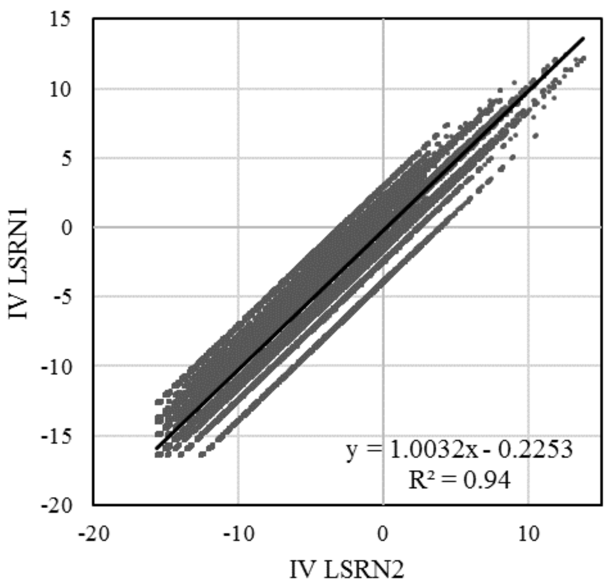
The ~~overall accuracy~~spatial agreement and Kappa coefficient between the LSRN1 and LSRN2 landslide susceptibility classes ~~of LSRN1 and LSRN2 are 94.8~~is 89.7 and ~~76.5~~83.1%, respectively (Table ~~4). The susceptibility class "very high" have 98% correspondence between LSRN1 and LSRN2, but the remaining~~5). In general, the individual susceptibility classes present ~~approximately 70% correspondence (except the class very low in LSRN2,~~ a high agreement (≥80%) but with ~~88.5 accuracy), i.e., 30~~differences between the two models. For example, the landslide susceptibility class "very high" comprises 0.06% and 0.05% of the total road network, but LSRN2 presents 20.42% of ~~each class not corresponding and are distributed by other~~the omission error compared to the 3.8% commission differences of LSRN1. The intermediary susceptibility classes of the two models highlight the omission and commission differences.

~~**Table 4.** Accuracy between LSRN1 and LSRN2 results (area %).~~

	~~LSRN2~~							
~~LSRN1~~	~~Very high (IV >7.55)~~	~~High (IV 5-7.5)~~	~~Moderate (IV 2.5-5)~~	~~Low (IV 0-2.5)~~	~~Very low (IV < 0)~~	~~Total (%)~~	~~Accuracy (%)~~	~~Commission error (%)~~

~~Very high (IV >7.5)~~	~~86.11~~	~~1.53~~	~~0.03~~	~~0.00~~	~~0.00~~	~~87.66~~	~~98.22~~	~~1.78~~
~~High (IV 5-7.5)~~	~~1.69~~	~~4.82~~	~~0.69~~	~~0.03~~	~~0.00~~	~~7.22~~	~~66.70~~	~~33.30~~
~~Moderate (IV 2.5-5)~~	~~0.07~~	~~0.44~~	~~2.44~~	~~0.36~~	~~0.00~~	~~3.31~~	~~73.62~~	~~26.38~~
~~Low (IV 0-2.5)~~	~~0.00~~	~~0.01~~	~~0.28~~	~~1.16~~	~~0.03~~	~~1.47~~	~~78.54~~	~~21.46~~
~~Very low (IV < 0)~~	~~0.00~~	~~0.00~~	~~0.00~~	~~0.09~~	~~0.23~~	~~0.32~~	~~70.89~~	~~29.11~~
~~Total area (%)~~	~~87.86~~	~~6.80~~	~~3.44~~	~~1.64~~	~~0.26~~	~~-~~	~~-~~	
~~Accuracy (%)~~	~~98.01~~	~~70.85~~	~~70.87~~	~~70.65~~	~~88.55~~	**~~Overall accuracy:~~**	**~~94.8%~~**	
~~Omission error (%)~~	~~1.99~~	~~29.15~~	~~29.13~~	~~29.35~~	~~11.45~~	**~~Kappa coefficient:~~**	**~~76.5%~~**	

Although ~~it has been~~ variations exist between LSRN1 and LSRN2 landslide susceptibility, the relationship between the two ~~model's~~models' outputs is high ~~(Fig. 10),~~, presenting a Pearson correlation coefficient of 0.~~96~~98 (significance level *p* ~~<~~ ≤0.05). The results of this correlation reflect the existence of an agreement on the spatial variation between LSRN1 and LSRN2, i.e., in general, when the IV of one ~~outputs~~output increases the other also increases, or vice versa, regardless of the discrepancy between the ~~IV~~IVs of the same ~~cell~~cells of each output.

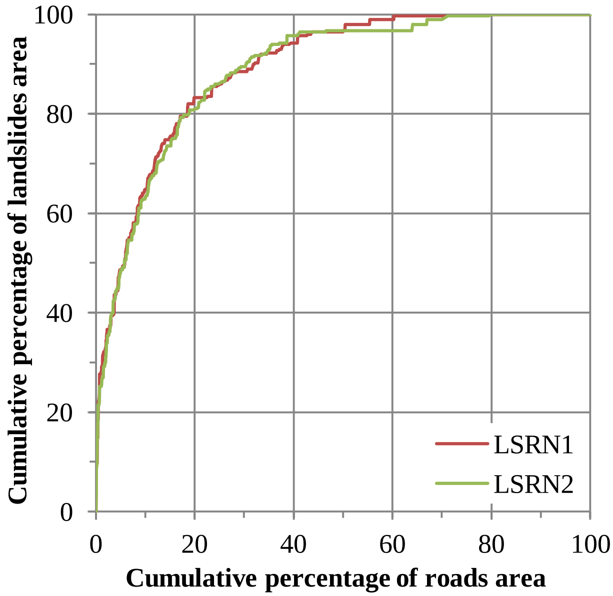


~~**Figure 10.** IV of the road network obtained by M1 versus IV of the road network obtained by M2. LSRN1 – IV extracted of the LSM1; LSRN2 – IV extracted of the LSM2.~~

Table 5. Spatial agreement between LSRN1 and LSRN2 (% of road network).

LSRN1	LSRN2 Very low (IV < -5)	Low (IV -5-0)	Moderate (IV 0-5)	High (IV 5-10)	Very high (IV >10)	Total area (%)	Agreement (%)	Commission differ. (%)
Very low (IV < -5)	46.35	2.18	0.00	0.00	0.00	48.53	95.51	4.49
Low (IV -5-0)	3.49	31.66	2.28	0.00	0.00	37.43	84.58	15.42
Moderate (IV 0-5)	0.00	1.66	10.10	0.51	0.00	12.27	82.35	17.65
High (IV 5-10)	0.00	0.00	0.19	1.52	0.01	1.73	88.10	11.90
Very high (IV >10)	0.00	0.00	0.00	0.002	0.05	0.05	96.20	3.80
Total area (%)	49.84	35.49	12.58	2.03	0.06			
Agreement (%)	93.00	89.19	80.32	74.98	79.58		Overall agreement:	89.7%
Omission differ. (%)	7.00	10.81	19.68	25.02	20.42		Kappa coefficient:	83.1%

The LSRN1 and LSRN2 results were crossed with all the landslides that caused perturbations or disruptions of the ~~roads~~road network~~ to validate~~, and the ~~landslide susceptibility~~performance of models~~.~~ was assessed. Overall, the results ~~are~~were very good, with 89.~~3~~48 and ~~88.9~~89.32% AUC for LSRN1 and LSRN2, respectively. However, LSRN1 offers slightly better results when compared to LSRN2, as it can be seen in the representation of the SRC (Fig. 11), i.e., ~~in~~up to 20% of the total area of the road network ~~are~~validates approximately 83% of the landslide susceptibility of LSRN1 and LSRN2. Nevertheless, the LSRN2 shows a slightly better performance (to approximately 45% of the total area of the road network), but the LSRN1 improves its validation performance at this point, being completely validated ~~83.3% LSRN1~~with 67% of the total area of the road network, while ~~for the same percentage of roads area~~LSRN2 is validated ~~only 81~~with 74% of ~~LSRN2~~its area.



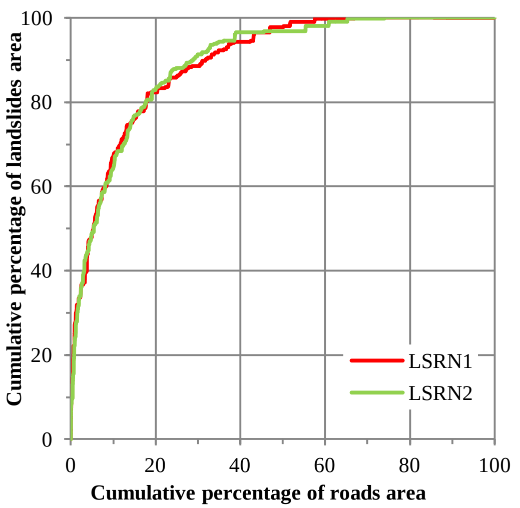


Figure 11. Success rate curves of ~~the~~ LSRN1 and LSRN2 models.

4 Discussion

~~According to this research, we showed that LUC GI detail concerning their properties in the input of the models is important in the landslide susceptibility evaluation and showed different results.~~

~~Some research works refer the quality of GI (scale and precision) in the final results changes (e.g. Etter et al., 2006). In this case, the degree of completeness, the positional, geometric, and thematic accuracy~~

of the selected LUC GI was evaluated by the different proprietary institutions, with more than 80%, i.e., where the semantic inconsistencies error was reduced, an important factor in the error propagation reduction and achieving product with best quality (Van Oort and Bregt, 2005; Regnauld, 2015).

According to this research, the results show that the LUC data details concerning its properties in the model input are important in the landslide susceptibility assessment. However, the differences observed in the landslide susceptibility models are a consequence of using different LUC data inputs (different properties) because the other predisposing factor maps are the same in both models. Although, if another method is used, the terrain mapping unit or other characteristic is changed, the results may vary, which has already been widely discussed (Chen et al., 2016; Den Eeckhaut et al., 2010; Guzzetti et al., 2006; Oliveira et al., 2015a; Zêzere et al., 2017).

Further, the data of soil and lithology was constrained and very generalized (1:1000000 and 1:50000 scales, respectively), and this factor can influence the IV results if more detailed data was considered in the modeling process. The performance of the landslide susceptibility mapping and assessment is controlled by the quality of the available data, not only on the method (Pourghasemi et al., 2014).

Some research works refer to the quality of geoinformation (scale and precision) on the final results changes (e.g., Etter et al., 2006). In this case, the degree of completeness, and the positional, geometric, and thematic agreement of the selected LUC data was evaluated by different proprietary institutions, with more than 80% accuracy, i.e., where the semantic inconsistencies error was reduced, an important factor in reducing the error propagation and achieving a product with best quality (Van Oort and Bregt, 2005; Regnauld, 2015).

The landslide inventory was obtained by photointerpretation, which is certainly not complete, especially in forest and agricultural areas, a fact that could have impact on the landslide susceptibility zonation of the study area. This inventorying method does not allow for shallow or small landslide identification in forest areas, where the type, height, and density of the vegetation is important to landslide activity (Guzzetti et al., 2012), or in cultivated areas where agricultural practices erase the morphological and LUC signature of slope failures (Fiorucci et al., 2011). The quality and completeness of the landslide inventories can interfere with the quality of future landslide spatial occurrences (Galli et al., 2008; Guzzetti et al., 2012; Reichenbach et al., 2018). However, the landslide inventory is the same for both landslide models presented in this research, and the variation results depend exclusively on the LUC datasets that integrated each model.

The correlation between the outputs of each model is high, but there are spatial differences between them. The COS ~~GI~~data is more detailed (1:25000) than the CLC ~~GI~~data (1:100000), ~~then~~thus, the LUC are more differentiated in the territory, allowing ~~to determine with~~ greater detail and ~~accuracy~~agreement in determining the areas with high landslide susceptibility, ~~fact~~which were verified in LMS1; while in M2, the CLC ~~GI~~data is less detailed, and the resulting ~~the~~ LSM2 ~~with~~and IV ~~tended more~~tend to be reduced (low and very low landslide susceptibility~~), comparatively~~) compared with LSM1.

~~There was also verified a greater IV generalization~~IV is more generalized along the road network at LSRN2 when compared with LSRN1, derived from the input of LUC ~~GI~~data, which is more generalized~~, with~~ on a smaller scale. The scale of the ~~GI~~data proves to be important in this ~~type of modelling.~~modeling process.

In the road network intersection with the LUC ~~GI~~data, a high absence of roads ~~GI~~data was observed in the class "industrial, commercial, and transport units~~",~~," which is explained by the cartographic generalization due to the minimum mapping unit ~~(MMU)~~ and minimum distance between lines of each LUC dataset. These factors exclude the roads ~~GI~~data due to the minimum requirements defined in the technical specifications of each LUC dataset~~.~~

creation. However, the distribution of the road network between the LUC classes is quite variable in ~~two~~both LUC datasets (the COS and CLC), ~~being~~ one of the factors that also justifies the variation of landslide susceptibility observed in different outputs.

~~The results of success rate curves and AUC for LSM1 and LSM2 show a high quality of two models in the landslides susceptibility areas determination (Guzzetti et al., 2006), but LSM1 present slightly better results. LSRN1 and LSRN2 results and respective validation demonstrates that the models effectively identify the places where the landslides occurred and the areas more likely to occur the future landslides. In this case, also noted through the SRC and AUC the high efficiency of the models (Guzzetti et al., 2006), with a slightly higher efficiency of the LSRN1.~~

The results of the PRC and AUC for LSM1 and LSM2 show a high quality and performance of both models in the landslides susceptibility areas determination (Guzzetti et al., 2006), but LSM1 presents a slightly better performance. Nevertheless, the prediction landslide results were validated with the landslide test group and present good results to be assigned in the road network.

The LSRN1 and LSRN2 models' validation results demonstrate that the models effectively identify the places where the landslides occurred and are more likely to occur in the future. In this case, the SRC and AUC note the high efficiency of the models (Guzzetti et al., 2006) with LSRN1 having a slightly higher efficiency, highlighting the properties of the LUC data.

Some roads in the study area were affected by landslides, a fact confirmed during the ~~field work~~fieldwork developed to validate the landslide inventory (examples of some roads blockage or damaged~~: CM1064, M521, N339, municipality roads of Fernandaires and Fernande local roads in~~ in the Estrela Mountain and sample areas). In certain cases, the affected roads are important accesses to the most isolated villages in the study area~~,~~ and ~~may~~, in some cases, a landslide ~~isolates~~can isolate the villages~~,~~ because part of the affected infrastructures are unique public ~~access~~accesses, a fact verified in the sample areas. ~~On the other hand, the central region of Portugal, presents the lowest percentage of landslide disaster cases, but one of the highest percentage of landslide fatalities (Pereira et al., 2017), underlining the importance of the accuracy of landslide susceptibility in this area.~~

~~In the analysis of the risk associated with road transportation, the higher probability of a given event or incident, greater are the consequences (Berdica, 2002). It is in this sense that the exact determination of the locals with the largest landslide susceptibility acquires importance, enabling act preventively and to minimize these consequences, or act better reactively when dealing with emergencies, because the road closed change time of course increasing the reaction time and relief (Meneses and Zêzere, 2012).~~

The results highlight the importance of LUC data properties in landside assessment. More detailed LUC data (COS data) allows better landslide susceptibility results, a fact that was also described by Dymond et al. (2006), identifying some places where landslides occurred in the study area. Detailed predisposing factors data is recommended in landslide susceptibility assessment, a fact also mentioned in other studies, e.g., Fressard et al. (2014) refer to the importance of detail in geomorphological variables to obtain high-quality results in landslides prediction.

In the analysis of the risk associated with road transportation, the higher probability of a given event or incident, the greater the consequences (Berdica, 2002). In this context, the determination of the locales with the highest landslide susceptibility is very important, enabling prevention and minimizing these consequences, or to enabling better reactions when dealing with emergencies, because road closures change the traveling and reaction time (Meneses and Zêzere, 2012).

5 Conclusion

Landslide susceptibility in the ~~study area~~Zêzere watershed is~~ very~~ spatially variable, highlighting some characteristics of the study area's geo-factors ~~of~~in the~~ study area in~~ high landslide density in a specific location, for example, the highest slope angles and certain types of LUC and lithology.

The properties of the ~~GI which~~data that integrates the models is also important in landslide susceptibility assessment, since the variation of the properties of the same geo-factor provided different results, in this case, LUC with different properties~~, provided different results~~.

More detailed LUC ~~GI~~data (COS) allows better landslide susceptibility results, while ~~LUC GI~~ more generalized~~, as is the case with~~ LUC data (CLC~~,~~) resulted in ~~the~~ IV reduction, ~~not allowing identify~~ disallowing the identification of some places where landslides occurred~~ effectively.~~

. However, the results of the two susceptibility models (M1 and M2) ~~are~~showed a good performance, a fact demonstrated by the validation of the ~~model's~~models' results (~~SRC~~PRC and AUC).

The ~~merging~~assignment of ~~these~~ the landslide susceptibility results to the road network allowed ~~identifying~~the identification of the locations with the highest spatial probability ~~to the landslides~~ for landslide occurrence~~, standing out the~~. The LSRN1 map stands out with better results~~,~~ because of the integrated ~~the~~ COS dataset, showing ~~this result~~ the importance of LUC ~~GI~~data detail in the ~~specific~~ identification of ~~locals in the roads~~locations where landslides have occurred. ~~In~~The LSRN2 map~~, after crossing of landslides validated in the field, it was verified that the model~~ does not ~~identify~~ have a good performance in the identification of high landslide susceptibility in all the road sections where landslides have occurred.

In general, both LSRN1 ~~as~~and LSRN2 show the same trend in the spatial variation of landslide susceptibility of the study area's road network~~ in the study area~~, highlighting the high susceptibility on the slopes of the Estrela Mountain and near the Castelo de Bode reservoir.

~~The results of this research~~In addition, LUC data properties are important ~~for the emergency services in Zêzere watershed, allowing the adoption of preventive measures and alternative evacuation paths determination in case~~in the variation of ~~the landslides occurrence.~~ landslide susceptibility results. Knowing the locations ~~most~~ where landslides are likely to ~~landslide~~ occur, ~~the~~ alternatives options can be created ~~avoiding~~to avoid partial or complete isolation of certain localities, ~~and allowing~~ reduce the social and economic constraints of this population~~.~~, and adopt preventive measures and alternative evacuation paths in case of landslide occurrence.

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References

Beguería, S.: Changes in land cover and shallow landslide activity: A case study in the Spanish Pyrenees, Geomorphology, 74(1–4), 196–206, doi:10.1016/j.geomorph.2005.07.018, 2006.

Berdica, K.: An introduction to road vulnerability: What has been done, is done and should be done, Transp. Policy, 9(2), 117–127, doi:10.1016/S0967-070X(02)00011-2, 2002.

Bíl, M., Kubeček, J. and Andrášik, R.: An epidemiological approach to determining the risk of road damage due to landslides, Nat. Hazards, 73(3), 1323–1335, doi:10.1007/s11069-014-1141-4, 2014.

Bíl, M., Vodák, R., Kubeček, J., Bílová, M. and Sedoník, J.: Evaluating road network damage caused by natural disasters in the Czech Republic between 1997 and 2010, Transp. Res. Part A Policy Pract~~,~~., 80, 90–103, doi:10.1016/j.tra.2015.07.006, 2015.

Blahut, J., Westen, C. and Sterlacchini, S.: Analysis of landslide inventories for accurate prediction of debris-flow source areas, Geomorphology, 119(1), 36–51, 2010.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V. and Reichenbach, P.: GIS techniques and statistical models in evaluating landslide hazard, Earth Surf. Process. Landforms, 16, 427–445, 1991.

Castella, J. C., Pheng Kam, S., Dinh Quang, D., Verburg, P. H. and Thai Hoanh, C.: Combining top-down and bottom-up modelling approaches of land use/cover change to support public policies: Application to sustainable management of natural resources in northern Vietnam, Land use policy, 24(3), 531–545, doi:10.1016/j.landusepol.2005.09.009, 2007.

Castellanos Abella, E. A.: Provincial landslide risk assessment, in Multi-scale landslide risk assessment in Cuba, edited by E. A. Castellanos Abella, pp. 101–152, Utrecht University, ITC Dissertation 154, Utrecht., 2008.

Che, V. B., Kervyn, M., Suh, C. E., Fontijn, K., Ernst, G. G. J., Del Marmol, M. A., Trefois, P. and Jacobs, P.: Landslide susceptibility assessment in Limbe (SW Cameroon): A field calibrated seed cell and information value method, Catena, 92, 83–98, doi:10.1016/j.catena.2011.11.014, 2012.

Chen, T., Niu, R. and Jia, X.: A comparison of information value and logistic regression models in landslide susceptibility mapping by using GIS, Environ. Earth Sci,., 75(10), 1–16, doi:10.1007/s12665-016-5317-y, 2016.

Chung, C.-J. F. and Fabbri, A. G.: Probabilistic prediction models for landslide hazard mapping, Photogramm. Eng. Remote Sensing, 65(12), 1389–1399 [online] Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-0032736758&partnerID=tZOtx3y1, 1999.

Chung, C.-J. F. and Fabbri, A. G.: Validation of Spatial Prediction Models for Landslide Hazard Mapping, Nat. Hazards, 30, 451–472, doi:10.1023/B, 2003.

Conforti, M., Robustelli, G., Muto, F. and Critelli, S.: Application and validation of bivariate GIS-based landslide susceptibility assessment for the Vitravo river catchment (Calabria, south Italy), Nat. Hazards, 61(1), 127–141, doi:10.1007/s11069-011-9781-0, 2012.

Conforti, M., Pascale, S., Robustelli, G. and Sdao, F.: Evaluation of prediction capability of the artificial neural networks for mapping landslide susceptibility in the Turbolo River catchment (northern Calabria, Italy), Catena, 113, 236–250, doi:10.1016/j.catena.2013.08.006, 2014.

Congalton, R. and Green, K.: Assessing the Accuracy of Remotely Sensed Data: Principles and Practices, 2nd Edition. CRC/Taylor & Francis, Boca Raton., 2009.

DGT: Avaliação da exatidão temática da Carta de Ocupação do Solo oficial de Portugal Continental (COS 2007 e 2010), Lisboa., 2013.

Drobnjak, S., Sekulović, D., Amović, M., Gigović, L. and Regodić, M.: Central geospatial database analysis of the quality of road infrastructure data, Geod. Vestn,., 60(202), 269–284, doi:10.15292/geodetski-vestnik.2016.02.269-284, 2016.

Dymond, J. R., Ausseil, A. G., Shepherd, J. D. and Buettner, L.: Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand, Geomorphology, 74(1–4), 70–79, doi:10.1016/j.geomorph.2005.08.005, 2006.

EEA: CLC2006 technical guidelines, European Environment Agency, Copenhagen., 2007.

Den Eeckhaut, M. Van, Marre, A. and Poesen, J.: Comparison of two landslide susceptibility assessments in the Champagne-Ardenne region (France), Geomorphology, 115(1–2), 141–155, doi:10.1016/j.geomorph.2009.09.042, 2010.

Etter, A., McAlpine, C., Wilson, K., Phinn, S. and Possingham, H.: Regional patterns of agricultural land use and deforestation in Colombia, Agric. Ecosyst. Environ., 114(2–4), 369–386, doi:10.1016/j.agee.2005.11.013, 2006.

Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E. and Savage, W. Z.: Guidelines for landslide susceptibility, hazard and risk zoning for land use planning, Eng. Geol., 102(3–4), 85–98, doi:10.1016/j.enggeo.2008.03.022, 2008.

Fiorucci, F., Cardinali, M., Carlà, R., Rossi, M., Mondini, A. C., Santurri, L., Ardizzone, F. and Guzzetti, F.: Seasonal landslide mapping and estimation of landslide mobilization rates using aerial and satellite images, Geomorphology, 129(1–2), 59–70, doi:10.1016/j.geomorph.2011.01.013, 2011.

Fressard, M., Thiery, Y. and Maquaire, O.: Which data for quantitative landslide susceptibility mapping at operational scale case study of the pays d'auge plateau hillslopes (Normandy, France), Nat. Hazards Earth Syst. Sci., 14(3), 569–588, doi:10.5194/nhess-14-569-2014, 2014.

Galli, M., Ardizzone, F., Cardinali, M., Guzzetti, F. and Reichenbach, P.: Comparing landslide inventory maps, Geomorphology, 94(3–4), 268–289, doi:10.1016/j.geomorph.2006.09.023, 2008.

Glade, T.: Landslide occurrence as a response to land use change: A review of evidence from New Zealand, Catena, 51(3–4), 297–314, doi:10.1016/S0341-8162(02)00170-4, 2003.

Guillard, C. and Zêzere, J.: Landslide susceptibility assessment and validation in the framework of municipal planning in Portugal: The case of loures municipality, Environ. Manage., 50(4), 721–735, doi:10.1007/s00267-012-9921-7, 2012.

Günther, A., Reichenbach, P., Malet, J. P., van Den Eeckhaut, M., Hervás, J., Dashwood, C. and Guzzetti, F.: Tier-based approaches for landslide susceptibility assessment in Europe, Landslides, 10(5), 529–546, doi:10.1007/s10346-012-0349-1, 2013.

Guzzetti, F., Carrara, A., Cardinali, M. and Reichenbach, P.: Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy, Geomorphology, 31(1–4), 181–216, doi:10.1016/S0169-555X(99)00078-1, 1999.

Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M. and Galli, M.: Estimating the quality of landslide susceptibility models, Geomorphology, 81(1–2), 166–184, doi:10.1016/j.geomorph.2006.04.007, 2006.

Guzzetti, F., Mondini, A. C., Cardinali, M., Fiorucci, F., Santangelo, M. and Chang, K. T.: Landslide inventory maps: New tools for an old problem, Earth-Science Rev., 112(1–2), 42–66, doi:10.1016/j.earscirev.2012.02.001, 2012.

Hilker, N., Badoux, A. and Hegg, C.: The swiss flood and landslide damage database 1972-2007, Nat. Hazards Earth Syst. Sci., 9(3), 913–925, doi:10.1002/asl.183, 2009.

IGP: Carta de Uso e Ocupação do Solo de Portugal Continental para 2007 (COS2007). Memória descritiva, 1st ed., Instituto Geográfico Português / Direção Geral do Território, Lisboa, Portugal., 2010.

Imprialou, M. and Quddus, M.: Crash data quality for road safety research: Current state and future directions, Accid. Anal. Prev., in press, doi:10.1016/j.aap.2017.02.022, 2017.

Jenelius, E. and Mattsson, L. G.: Road network vulnerability analysis of area-covering disruptions: A grid-based approach with case study, Transp. Res. Part A Policy Pract~~,~~., 46(5), 746–760, doi:10.1016/j.tra.2012.02.003, 2012.

Kazemi, S. and Lim, S.: Deriving Multi-Scale GEODATA from TOPO-250K Road Network Data, J. Spat. Sci~~,~~., 52(1)(June), 165–176, doi:OFEV_integrationSIG, 2005.

Leitner, H.: The Politics of Scale and Networks of Spatial Connectivity: Transnational Interurban networks and the Rescaling of Political Governance in Europe, in Scale and Geographic Inquiry: Nature Society and Method, edited by E. Sheppard and B. McMaster, pp. 236–255, Blackwell Publishing., 2004.

Meneses, B. M.: Susceptibility and Risk of Landslides in Tarouca County [in portuguese], Universidade de Lisboa. [online] Available from: http://riskam.ul.pt/images/pdf/msc_bruno_meneses.pdf, 2011.

Meneses, B. M. and Zêzere, J. L.: Modelação da Suscetibilidade e Risco de Movimentos de Vertente no Concelho de Tarouca – Determinação de Rotas de Emergência, in XIII Coloquio Ibérico de Geografía. Respuestas de la Geografía Ibérica a la crisis actual, edited by D. Royé, J. A. A. Vázquez, M. P. Otón, M. J. P. Mantiñán, and M. V. Díaz, pp. 341–351, Santiago de Compostela. [online] Available from: http://www.apgeo.pt/files/docs/Newsletter/XIIICIB_actas_v2.pdf, 2012.

Meneses, B. M., Reis, R., Vale, M. J. and Saraiva, R.: Land use and land cover changes in Zêzere watershed (Portugal) — Water quality implications, Sci. Total Environ~~,~~., 527–528, 439–447, doi:10.1016/j.scitotenv.2015.04.092, 2015a.

Meneses, B. M., Pereira, S. and Zêzere, J. L.: Landslides and debris flows in Algarve region: inventory and assessment of susceptibility at regional scale [in portuguese], in VII Congresso Nacional de Geomorfologia, edited by J. L. Zêzere, J. Trindade, R. Bergonse, R. A. C. Garcia, S. C. de Oliveira, and S. Pereira, pp. 179–185, Lisboa., 2015b.

Meneses, B. M., Reis, E., Vale, M. J. and Reis, R.: Modeling the Probability of Surface Artificialization in Zêzere Watershed (Portugal) Using Environmental Data, Water, 8(289), 1–19, doi:10.3390/w8070289, 2016.

Meneses, B. M., Reis, E., Pereira, S., Vale, M. and Reis, R.: Understanding Driving Forces and Implications Associated with the Land Use and Land Cover Changes in Portugal, Sustainability, 9(3), 351, doi:10.3390/su9030351, 2017.

Meneses, B. M., Reis, E. and Reis, R.: Assessment of the recurrence interval of wildfires in mainland Portugal and the identification of affected LUC patterns, J. Maps, 14(2), 282–292, doi:10.1080/17445647.2018.1454351, 2018a.

Meneses, B. M., Reis, E., Vale, M. J. and Reis, R.: Modeling land use and land cover changes in Portugal: a multi-scale and multi-temporal approach, Finisterra, ~~2018~~LIII(107), 3–26, doi:doi: 10.18055/Finis12258, 2018b.

Meneses, B. M., Reis, E., Reis, R. and Vale, M. J.: The effects of land use and land cover geoinformation raster generalization in the analysis of LUCC in Portugal, ISPRS Int. J. Geo-Information, 7(10), 1–21, doi:10.3390/ijgi7100390, 2018c.

Mugagga, F., Kakembo, V. and Buyinza, M.: Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides, Catena, 90, 39–46, doi:10.1016/j.catena.2011.11.004, 2012.

Oliveira, S. C., Zêzere, J. L. and Garcia, R. A. C.: Structure and ~~characteristics~~Characteristics of ~~landslide input data~~Landslide Input Data and ~~consequences~~Consequences on ~~landslide susceptibility assessment~~Landslide Susceptibility Assessment and ~~prediction capability~~Prediction Capability, in Engineering Geology for Society and Territory~~. Landslide~~

~~Processes~~, edited by G. Lollino, D. Giordan, G. B. Crosta, J. Corominas, R. Azzam, J. Wasowski, and N. Sciarra, pp. 189–192, Springer~~ International Publishing~~, Switzerland., 2015a.

Oliveira, S. C., Zêzere, J. L., Catalão, J. and Nico, G.: The contribution of PSInSAR interferometry to landslide hazard in weak rock-dominated areas, Landslides, 12(4), 703–719, doi:10.1007/s10346-014-0522-9, 2015b.

Van Oort, P. ~~A. J.~~ and Bregt, A.~~ K.~~: Do users ignore spatial data quality? A decision-theoretic perspective, Risk Anal~~,~~., 25(6), 1599–1610, doi:10.1111/j.1539-6924.2005.00678.x, 2005.

Orongo, N. D.: GIS Based. Cartographic Generalization in Multi-scale Environment: Lamu County, University of Nairobi., 2011.

Pereira, S., Zêzere, J. L., Quaresma, I. D. and Bateira, C.: Landslide incidence in the North of Portugal: Analysis of a historical landslide database based on press releases and technical reports, Geomorphology, 214, 514–525, doi:10.1016/j.geomorph.2014.02.032, 2014.

Pereira, S., Zêzere, J. L. and Quaresma, I.: Landslide Societal Risk in Portugal in the Period 1865–2015, in Advancing Culture of Living with Landslides, edited by M. Mikoš, V. Vilímek, Y. Yin, and K. Sassa, pp. 491–499, Springer International Publishing, Slovenia., 2017.

Persichillo, M. G., Bordoni, M. and Meisina, C.: The role of land use changes in the distribution of shallow landslides, Sci. Total Environ~~,~~., 574, 924–937, doi:10.1016/j.scitotenv.2016.09.125, 2017.

Piedade, A., Zezere, J. L., García, R. and Oliveira, S.: Modelos de suceptibilidade a deslizamentos superficiais translacionais na região a norte de Lisboa, Finisterra, 46(91), 9–26, 2011.

Pourghasemi, H. R., Moradi, H. R., Fatemi Aghda, S. M., Gokceoglu, C. and Pradhan, B.: GIS-based landslide susceptibility mapping with probabilistic likelihood ratio and spatial multi-criteria evaluation models (North of Tehran, Iran), Arab. J. Geosci., 7(5), 1857–1878, doi:10.1007/s12517-012-0825-x, 2014.

Promper, C., Puissant, A., Malet, J. P. and Glade, T.: Analysis of land cover changes in the past and the future as contribution to landslide risk scenarios, Appl. Geogr~~,~~., 53, 11–19, doi:10.1016/j.apgeog.2014.05.020, 2014.

Regnauld, N.: Generalisation and data quality, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch~~,~~., 40(3W3), 91–94, doi:10.5194/isprsarchives-XL-3-W3-91-2015, 2015.

Reichenbach, P., Busca, C., Mondini, A. C. and Rossi, M.: The Influence of Land Use Change on Landslide Susceptibility Zonation: The Briga Catchment Test Site (Messina, Italy), Environ. Manage~~,~~., 54(6), 1372–1384, doi:10.1007/s00267-014-0357-0, 2014.

Reichenbach, P., Rossi, M., Malamud, B. D., Mihir, M. and Guzzetti, F.: A review of statistically-based landslide susceptibility models, Earth-Science Rev., 180(March), 60–91, doi:10.1016/j.earscirev.2018.03.001, 2018.

Reis, E., Zêzere, J. L., Vieira, G. and Rodrigues, M. L.: Integração de dados espaciais em SIG para avaliação da susceptibilidade à ocorrência de deslizamentos, Finisterra, XXXVIII(76), 3–34 [online] Available from: www.ceg.ul.pt/finisterra/numeros/2003-76/76_01.pdf%5Cnhttp://revistas.rcaap.pt/finisterra/article/view/1569/1266, 2003.

Soeters, R. S. and van Westen, C. J.: Slope instability recognition, analysis, and zonation, Landslides Investig. Mitig~~,~~., Special Re, 129–177, 1996.

Stoter, J., Post, M., van Altena, V., Nijhuis, R. and Bruns, B.: Fully automated generalization of a 1:50k map from 1:10k data, Cartogr. Geogr. Inf. Sci., 41(1), 1–13, doi:10.1080/15230406.2013.824637, 2014.

van Westen, C. J., Castellanos, E. and Kuriakose, S. L.: Spatial data for landslide susceptibility, hazard, and vulnerability assessment: An overview, Eng. Geol., 102(3–4), 112–131, doi:10.1016/j.enggeo.2008.03.010, 2008.

Winter, M. G., Harrison, M., Macgregor, F. and Shackman, L.: Landslide hazard and risk assessment on the Scottish road network, Proc. Inst. Civ. Eng. - Geotech. Eng., 166(6), 522–539, doi:10.1680/geng.12.00063, 2013.

Winter, M. G., Shearer, B., Palmer, D., Peeling, D., Harmer, C. and Sharpe, J.: The Economic Impact of Landslides and Floods on the Road Network, Procedia Eng., 143(Ictg), 1425–1434, doi:10.1016/j.proeng.2016.06.168, 2016.

Yan, T.: Recent advances of quantitative prognoses of landslides in China, in Fifth International Symposium in Landslides, edited by C. Bonnard, pp. 1263–1268, Balkema, Rotterdam., 1988.

Yin, K. and Yan, T.: Statistical Preditiction Model for Slope Instability of Metamorphosed Rocks, in Fifth International Symposium in Landslides, edited by C. Bonnard, pp. 1269–1272, Balkema, Rotterdam., 1988.

Zêzere, J. L., Garcia, R. A. C., Oliveira, S. C. and Reis, E.: Probabilistic landslide risk analysis considering direct costs in the area north of Lisbon (Portugal), Geomorphology, 94(3–4), 467–495, doi:10.1016/j.geomorph.2006.10.040, 2008.

Zêzere, J. L., Pereira, S., Melo, R., Oliveira, S. C. and Garcia, R. A. C.: Mapping landslide susceptibility using data-driven methods, Sci. Total Environ., 589, 250–267, doi:10.1016/j.scitotenv.2017.02.188, 2017.