Nat. Hazards Earth Syst. Sci. Discuss., 1, C2746–C2766, 2014
www.nat-hazards-earth-syst-sci-discuss.net/1/C2746/2014/
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Natural Hazards and Earth System Sciences
Discussions
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Interactive comment on "Shallow landslide prediction and analysis with risk assessment using a spatial model in the coastal region in the state of São Paulo, Brazil" *by* P. I. M. Camarinha et al.

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Received and published: 27 February 2014

Review of the manuscript "Shallow landslide prediction and analysis with risk assessment using a spatial model in the coastal region in the state of São Paulo, Brazil" by P. I. M. Camarinha, V. Canavesi, and R. C. S. Alvalá submitted to Natural Hazards in Earth System Sciences.

"Spatial data of good quality needed to evaluate landslide risk is scarce. This work presents an innovative approach using available data to assess landslide risk in an economically important and highly populated area of Brazil that has been affected by mass movements in the past. The proposed method could be transferred to other study areas. While the manuscript addresses a relevant scientific question within the scope of NHESS, it lacks a clear structure and needs clarification of some of the main aspects. With the current text the line of argumentation is difficult to follow, and therefore the conclusion is arguable. I therefore recommend publication after major revisions."

General comments 1. Motivation: "Clearly state what is novel in this paper. Also highlight the differences of your newly created map to the risk sector classification of CPRM, otherwise it may seem that your work in this area is redundant. What are the limitations of the CPRM risk sector classification? "

-The methodology presented in this paper is different from the ones used by CPRM. The CPRM survey considered the following procedures: in-situ recognition, identification of soil subsidence and scars, estimation of the reach of the mass movement, the sketch of situation, and risk level for the residences threatened and, finally, design the risk areas sectors in GIS environment and input its metadata. We used CPRM's areas as units of validation of our methodology, since in Brazil there are no data of landslide-scars mapped or monitored. It would be possible to perform landslide-scars mapping, but we consider this mapping as a meticulous and detailed work that becomes unfeasible when the study scale is regional or municipal. It is highlighted that Brazil is a country with continental dimensions (area equal 8.500 Km2 and 5.565 municipalities). Furthermore, our methodology is focused on identifying high susceptibility within inhabited areas. Therefore, it is not in our interest to use landslide-scars sites because most of scars are in forested areas or in locations that offer no risk of population. Currently, CPRM presents risk sectors data only for few cities and they have a great demand to meet in coming years: risk mapping of urban areas in 821 municipalities and susceptibility mapping for the 286 municipalities considered critical. Thus, there is a need to seek alternative methods that are economically and methodologically viable, as well as allows to obtain robust results. So, the proposed methodology does not use

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field survey for the mapping, but information free and downloaded from the internet, as satellite images and maps with medium resolution for the final map generation, , which allowing larger areas to be included in the mapping. The obtained results were consistent with the detailed results presented by CPRM, which enables be applied for more municipalities characterized by have risk areas for landslides. The limitations of CPRM survey refers to the difficulty of standardizing the definition and categorization of risk sectors. Due to there are many Brazilian municipalities needing risk mapping, different work teams are created and the subjectivity involved in in-situ analysis eventually can lead to different results. Furthermore, CPRM usually directs his analysis only in places that have some reported for the Civil Defense. Also be possible to assess new critical places, which are identified by a susceptibility map, which takes into consideration only the slope, geology and soils maps.

2. Structure: "Especially the methodology, results and discussion section need restructuring as it is difficult for the reader to follow. Please thoroughly separate what belongs to the methodology, results and discussion sections. A good and consistent use of headings, subheadings and paragraphs will also help the reader, as a definition of the nomenclature would (e.g. susceptibility classes, themes, typologies, risk sectors, risk levels)."

-The methodology was divided in three parts: Susceptibility map construction: i) the Fuzzy Gamma technique, ii) Spatial database preparation and thematic classes weighting , iii) Survey and pre-processing of spatial database.

Some terms have also been introduced in the text: "Theme" is a nomenclature adopted for the data represented in each used map (i.e., topographic, soil, geological, land use maps, etc.). "Class" is associated with each division (categories) of evaluated themes (for example, for the thematic map of land use, “urban area” is a class, as “forest” or “pasture”, and so on. The "Susceptibility Classes" are the hierarchy categories of the susceptibility map, which was generated in the presented study through of Fuzzy Gamma technique. "Sectors risk" are geographical boundaries of a site (represented by a polygon) where there are natural threats which put population at risk. These sites were analyzed and designed by the Brazilian Geological Survey (CPRM), and are considered as basis for urban planning and risk management, especially for Civil Defense. "Risk Levels" are subdivisions of "Sectors Risk" types, designated by CPRM as a hierarchical categorization of risk sectors regarding to the probability of landslides occurrence and their potential impacts. Basically, it is related with an analysis that evaluates the geological and geotechnical conditions predisposing and the level of human intervention on each occupied slope, which are taken into account such factors as: type of terrain, signs of soil movement (steps abatement), cracks in houses, inclined poles or trees, erosion at the bases of slopes, length of slope, among others. The classes range from R1 (less critical, low probability of occurrence) to R4 (most critical, high probability of occurrence).

3. Length: "Some parts of the paper need to be shortened, especially through avoiding repetition. In some cases entire sentences are repeated (e.g. page12), in other cases facts are stated several times. Please also delete redundant information (highlighted in pdf)."

-The paper has been completely restructured and redundant parts were excluded.

4. Input data: "The data used is limited as it is based on “available” downloads. Especially for validation purposes, data at a higher resolution than those publicly accessible through the internet would be beneficial, e.g. to assess resolution effects and validation. Moreover, why were satellite images not used to map landslide scars? "

-The objective of the presented study was to establish a methodology to evaluate susceptibility using available data and free software. As mentioned above, Brazil is a very large country, which was not yet completely mapped to have all risks areas of landslides identified, although the needs to have a georeferenced database for urban planning and ecological economic zoning, monitoring of the territory (especially considering the local, state and federal law regarding the use and occupation of land) and

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supervision. The risk areas data, generated by CPRM, as well the ones proposed in the present study, should serve as a basis for urban territorial planning and might be inserted into a public georeferenced database. So, the principal objective is propose an alternative methodology to evaluate municipalities with a landslide-disaster historical without any mapping, which demands urgently information to subsides risk management. The satellite images were not used due to the focus of the study is on urbanized sites or areas near them. By using satellite images, it would hardly to find any landslide-scars in urban areas, since most of them have already received containment works and / or were re-urbanized. Also, the limitation of the spatial resolution of the images used (LISS III is close to 30 m) making it difficult to identify and design landslide-scars. As previously mentioned, there is no available database of landslides scars or even another record of these type of occurrences in Brazil, making it very difficult to be information about past episodes.

5. Weighting factors: "The assignment of weighting factors for land use and soil classes need justification. What is the degree of subjectivity in choosing these factors?"

-The first part of this question will be treated in part of the Methodology. The weights were assigned based on the work by Crepani et al. (2001), which was developed for a different region in Brazil . In addition, to have more confidence, consultations were held with specialists from a multidisciplinary team work of our Institute, allowing to have the weights more associated with the characteristics inherent to the studied region, as well as with the geomorphologies and climatic peculiarities of the region.

6. Discussion on resolution: "How does the resolution of your different data sets affect your results? What if the input data had 100% better resolution – how would this change your susceptibility maps?"

-The Fuzzy Gamma technique allows the use of data with different scales, especially if it included the relationships between themes and the analyzed phenomenon. Among the different maps used in the present study, it highlighted that the topography has an important relevance regarding the soil characteristics (it is one factor that determines the intensity of physical weathering), as well as being strongly related to land use. Regarding the triggering of shallow landslides, it is noteworthy that the topographical variables (slope, horizontal and vertical curvature) used are closely linked to water infiltration into the soil and sub-surface water movement process, characterized as great importance for the type of analysis concerned. Due to this fact, the topographic data have the highest resolution (30m), as well as the data associated with the land use map, which also have a great importance with regard to the triggering factors of landslides. Therefore, even the geological and soil data were obtained with lower resolution, they can be used to better delineate the regions more or less critical, since the scale of focus is on municipality level. While both land use and topography data refers to features that changes of a slope/aspect to another one, the soil and geological data define compartments with general characteristics more or less susceptible; thus, improving the quality of the final results. Considering data with higher spatial resolution, it is possible to obtain results that might change as regard to the design/sketch of the susceptibility classes. That is, the design (location) of the boundaries related with two susceptibility classes can change and facilitate, for example, the defining of polygons that represent urban areas exposed at landslide hazards. However, it is noted that the goal of the proposed methodology is not automatically defines risk areas or risk sectors, but rather identify critical locations ("very high" class), which must be further evaluated at field, in order to set, from in-situ evidences, those areas where the population is at risk.

Specific comments

1. INTRODUCTION "The introduction needs to be shortened and restructured. Some parts of the introduction are not directly relevant to the study and may be deleted, for example Page 3, lines 2-17 and 26-29, Page 4, lines 2-5, 9-15."

-The Introduction was restructured and reduced, as well as the irrelevant parts were excluded.

"Page 3, Line 23-25: You say here that a map of slope instability should provide information about spatial distribution, type, volume, speed and distance achieved by landslides.

-That's correct, but that's not what you deliver in this study! This part of the paper was deleted.

"Page 4, Line 1-2: you state that the input data include triggering factors and historic landslide occurrences. I do not see where."

- Line 1-2 will be replaced by the text presented below: Among the different methodological approaches related to the subject, it is common to include environmental factors, triggering factors, and historic landslide occurrences. However, these data are not always available for many places or cities, as is the case for most municipalities in Brazil. In such case, the lack of data is associated with the difficulty of obtaining information for a country of continental dimensions, which requires several teams of experts and, consequently, resources for feasibility. Moreover, in Brazil there is no tradition in obtain this type of survey, since only recently landslide-related disasters became more evident to society as a social, political and economical problem. In this way, few Brazilian cities have urban planning that take into account this kind of threat. Thus, due to the increasing number of landslide-related disasters in last decades along the Brazilian cities, especially in Southeast and South regions of the country, only recently the CPRM incorporated in this mission the demand to meet in coming years, the risk mapping of urban areas in 821 municipalities and susceptibility mapping for the 286 municipalities considered critical.

"Page 4 Line 2: Elements at risk – what do you mean by that? -The term was unsuitable; thus, the sentence was rewritten (see the answer above).

"Page 4 line 18-20: Sentence is difficult to follow, please reword.

-Such geophysical characteristics, associated with the great population growth, lack of urban planning and property speculation, are some determinant factors related with the occurrence of landslide and, sometimes, in disasters.

"Page 5, line 9: How far back reaches the historical landslide record in the study area? The earliest recorded case occurred in the municipality of Santos, in March 10, 1928."

-Landslides occurred in large part of the slopes of Mont Serrat, which buried many homes and several outbuildings of a great hospital and resulted in 80 deaths.

"Page 5, line 14: HDI-M value too high – do you mean very high? " - Yes. Changed to very high.

"Page 5, line 18: Delete first part of the sentence" - Done.

"Page 5, line 20: cannot follow sentence, please reword the last part of the sentence"

-Generally, in every rainy season (Nov-Apr) at the studied region, there are isolated occurrences of landslides, although the extreme meteorological events that trigger landslides usually occur between January and mid-March.

- Page 5, Lines 21-end: It may be interesting to pickup on these events in the discussion, i.e. did these landslides occur in areas that were classified to be of high risk according to your method? Yes. Yes. It is not possible to confirm if the events of the past occurred in the areas identified as risk areas in the present study, since there are no geo-referenced records or records in paper maps of such events, making it impossible to identify them today.

"Page 6, lines 11-12: Are these illegal occupations captured in your approach? If not this information seems redundant." -It was not evaluated. The sentence was removed.

2. METHODOLOGY "This section needs a consistent structure, which will make it easier for the reader. Please also make proper use of paragraphs. First, give a short outline of the section. When describing the environmental variables you may want to stick to the same order throughout, e.g. explain the particular variable, the type and

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source of the data you use to characterize it, and finally how the weighting factors are assigned. It would also be helpful if you could provide a short definition of the terms “class”, “typology”, “susceptibility class”, “theme”, “risk sector”, “risk level”."

-The methodology used considers basically four steps: i) survey and pre-processing of spatial database required for landslide susceptibility analysis; ii) preparation and formatting of spatial data to be properly used in Algebra Map through the technique Fuzzy Gamma (thematic classes weighting); iii) generation of landslide susceptibility map; iv) validation of results. The postulated recommendations to separating each variable addressed in the work are followed. The assignments of weights were made based on literature studies, as well as consultations with experts with field experience. Also, the peculiarities of the phenomenon under study and the environmental and climatic characteristics of the study area were considered. All of these aspects have been improved in the text, as well as inclusions of citations from articles published in international scientific journals. "Theme" is a nomenclature adopted for the data represented in each used map (i.e., topographic, soil , geological, land use and land cover maps). "Class" is associated with each division (categories) of the evaluated themes (for example, for the thematic map of land use, the “urban area” is a class, as “forest” or “pasture” and so on. The "Susceptibility Class" is the hierarchy category of the final map of susceptibility obtained from the Fuzzy Gamma technique. "Sectors risk" are geographical boundaries of a site (represented by a polygon) where there are natural threats which put population at risk. These sites were analyzed and designed by the Brazilian Geological Survey (CPRM), and are considered as basis for urban planning and risk management, especially for Civil Defense. "Risk Level" are subdivisions of "Sectors Risk", defined by CPRM as a hierarchical categorization of risk sectors regarding to the probability of landslides occurrence and their potential impacts. Basically, it is related with an analysis that evaluates the geological and geotechnical conditions predisposing and the level of human intervention on each occupied slope, which are taken into account such factors as type of terrain, signs of soil movement (steps abatement), cracks in houses, inclined poles or trees, erosion at the bases of slopes, length of slope, among

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others. The classes range from R1 (less critical, low probability of occurrence) to R4 (most critical, high probability of occurrence).

"Page 8, line7: add reference " Done.

"Weighting factors for the variables “Soil class” and “Land use” are neither sufficiently explained nor supported by references in the text. It’s not clear where the weighting factors come from."

-Each thematic class of all maps considered was assessed by landslides susceptibility standpoint, evaluating their particularities with regard to favor or mitigate the triggering of mass movements. A referenced study done to treat this type of weighting analysis for places in Brazil was developed by Crepani et al. (2001). The authors evaluated some thematic maps (soils, geology, topography, land use), previously obtained for some parts of the Brazilian territory, and weighting factors were associated from assumptions made by several experts from different scientific area, taking into account the specificities related to physical weathering Brazilian soils and destabilization of slopes. The same criteria was used in the present study, and, for the classes not evaluated by Crepani et al. (2001), the weighting factors were determined after consenting different analyzes made by a geotechnical engineer, a forestry engineer and an expert on natural disasters as well as other related studies (Fernandes and Amaral, 2003; Kannungo et al., 2006; Binda e Bertotti, 2007;; Vieira et al., 2010; Veloso, 2012). Before obtaining the susceptibility maps, the thematic maps related to landslide susceptibility must be weighted for the use by the Fuzzy Gamma technique. The weights vary from 0 to 1, where 0 indicates classes with no relationship to landslide occurrence and 1 indicates classes with a high relationship to landslides. This weighting transforms the thematic maps onto a numerical grid, in which each class of map receives a weight (from 0 to 1). For the land use and land cover map, the weights assigned to each vegetation class depend on the type of coverage. The volume of material removed and transported by rainwater is related to the density of vegetation cover and the slope declivity, and with vegetation removal. These processes become more intense, especially in areas with steep slopes (Vieira et. al, 2010). The land cover class ' forest' is the one that presents the lowest weight in that category (see Table 3), because the forest cover, along with the understory, add to the soil good interception of rainwaters, preventing runoff and, consequently, the landslide processes. In areas with Eucalyptus plantations, the soil is not fully protected if compared with areas of forests, since not always there is the presence of understory, which makes the soil more susceptible to landslide. Thus, all classes of this theme were evaluated. Note that our method considers the urban area as a strong contributing factor to the destabilization of slopes (weight equals 1.0), while forests and natural areas remains the most stable slopes. These relationships are inherent of the study area, because the urban areas that are on the slopes were occupied rapidly during the last decades and years without any planning, so that there are too many factors that increase the susceptibility of landslides, such as: urban system drainage is deficient, the houses have foundations supported on the shallow layers of soil (not on the rocks); and there are points with no sewage uptake and so the wastewater favor the erosion in the foothills of slopes.

For different types of soils, the weights were also based on the study of Crepani et al. (2001). The higher or lower susceptibility of a soil to landslides depends on many factors as soil structure, type and amount of clays, permeability, soil depth and the presence of impermeable layers (Lee and Min, 2001). For natural landscape units, associated with stable conditions, the value assigned to the soils varies in the range of susceptibility close to zero, and are represented by the class of soil type Latosols. Latosols are well developed, with great depth and porosity and are therefore considered the land whose soil materials are the most decomposed. They are considered old or mature soils. For the natural landscape units associated with intermediate conditions, the value assigned to the soils in relation to the susceptibility is close to 0.5, and are represented by the class of the soil type Podzolic. The Podzolic soils, if compared with Latosols, have smaller depth and are less stable and less weathered soils. Usually occur in reliefs with mountains. The Podzolic soils presents a B horizon, where there is accumulation of clay, ie during the process of its formation, a good part of the clay is translocated by eluviation from the horizon A to B horizon, where it accumulated. In these soils, the difference in texture classes between the A and B horizons (caused by accumulation of clay in the B horizon) hinders water infiltration in profile, which favors mass movements. For natural landscape units associated with susceptible conditions, occur soils whose values assigned are near to 1.0. These soils are young and undeveloped, with principal characteristics associated with the small evolution in soil profiles. In these soils, the horizon A establishes directly on the C horizon, or else occurs directly on bedrock (lack the B horizon). They are considered young soils in the initial phase of formation because they are still developing from source materials recently deposited, or because they are located in places of high slope, where the rate of soil loss is equal to or greater than the speed transformation of rock into soil (Coelho-Neto et al., 2009). In this group are also Gleisols, Spodosols, Cambisols, and Urban soils.

"Equation 1: Please explain all terms and variables in the text"

-Equation 1 (as in the manuscript)

where μi is the fuzzy membership function for the i-th map, and I = 1, 2, . . ., n maps are to be combined; and γ (gamma) is a parameter within the range (0 to 1). Discerning choice of λ produces output values that ensure a flexible compromise between the 'increase' tendencies of the fuzzy algebraic sum and the 'decrease' effects of the fuzzy algebraic product.

"Why didn't you analyse the satellite images for landslide scars for the validation?"

The satellite images were not used due to two reasons: 1) the susceptibility mapping proposed aimed to identifying areas of risk in urban areas and hardly there are not identifiable scars in this type of areas , 2) unavailability of satellite images with high resolution, which would result in high costs if images were acquired from institutions outside Brazil.

It is very important to notice that: Although the proposed methodology results in a susceptibility map, the inclusion of the land use map in the Fuzzy Gamma technique turns the susceptibility mapping into something broader, which approaches a hazard mapping. That is explained by the inclusion of the land use map in Fuzzy Gamma technique, especially by the highest weight assigned for the class of urbanized areas (weight = 1.0). This fact contributes for the methodology presents a bias in representing the most susceptible areas inside urbanized locations. So, the best validation unit to be used is the "risk sectors", instead of landslide-scars. It is highlighted that it is not relevant for the scope of the study to identify “very high” susceptibility in uninhabited areas. Also, for this reason, the use of risk sectors makes sense in our standpoint, because they could represent the intersection between high susceptibility and possible damages.

On the other hand, in traditional studies designed to evaluate natural susceptibility (without human intervention), such anthropogenic factors are disregarding. Thus, the slopes that were considered critical in these traditional studies necessarily need to be located in the same places where there are scars and, in these studies, the best unit validation is scar-landslides map.

"Page 9 Line 16: repetition from previous sentence" -Done.

"What data did CPRM use for the risk sector mapping?"

-The procedures adopted for the identification of risks in urban areas were carried out in detailed scale, ranging from 1:2,000 to 1:1,000, using also remote sensing and cartographic databases, as well as available literature for preliminary recognition. Technicians and specialists in Civil Defense from municipalities, together researchers from CPRM, (including pairs of geologists and / or geologists or hydrologists and geographers engineers), make the field survey of the cities, especially to delineate the urban and peri-urban areas, to identify the sectors of high and very high risk to mass movements. The delineation of risk areas is made through a polygon surrounding the portion of a hillside with potential to suffer some sort

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of natural or induced process, which can cause damage, and is bordered on images and / or photographs. Thus, the survey is a detailed work, based on a large scale and in situ. The CPRM's methodology is available, only in Portuguese, in: www.cprm.gov.br/gestao/Atuacao_CPRM_Programa_Gestao_Riscos.pdf

"Page 10 Line 5: risk sectors are limited to places. . ."

-It is highlighted that CPRM's risk sectors correspond to in situ locations, which show evidences of possible mass movements (cracks/signs of soil subsidence, scars, inclined trees and/or lampposts, etc.) and that threaten urban occupations.

"Page 10 line 20: delete 'with'" Done.

"Page 11 line 10: the study area / the literature" Done.

"Page 11 lines 15-22: It is not clear why it is necessary and beneficial to define "risk levels" in addition to the susceptibility map. It is also not clear how these risk levels were determined. Did you do it in this study? If yes, how did you do it? This classification seems rather subjective and you do not give clear classification criteria. Please provide more detail here."

-The classification considering "risks levels" is provided from CPRM that considers a hierarchical categorization of risk sectors, regarding to the probability of landslides occurrence and their potential impacts. This classification was done by experts from CPRM based on predefined criteria and findings on examination in-loco. Basically, it is an analysis that evaluates the geological and geotechnical conditions predisposing and the level of human intervention on each occupied slope, which are taken into account such factors astype of terrain, signs of soil movement (steps abatement), cracks in houses, inclined poles or trees, erosion at the bases of slopes, length of slope, among others. The classes range from R1 (less critical, low probability of occurrence) to R4 (most critical, high probability of occurrence). For these reasons, we chose to analyze separately the risk sectors of each "risk level" and calculate the distribution of suscep-

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tibility classes provided by our mapping. Even though the CPRM categorization has been made from in-loco evidences, the aim of this analysis is to evaluate the contributions and shortcomings of the proposed methodology. The hypothesis is that the less critical sectors (R1 and R2) present a minor proportion of high susceptibility classes compared to the most critical sectors (R3 and R4). The purpose of CPRM in using the risk levels classification is to support the Civil Defense, urban managers, as well as the National Centre for Monitoring and Early Warning of Natural Disaster (CEMADEN), which provides the alerts of landslides during the rainy season. Therefore, this CPRM classification is not a scientific product prepared for academic purposes but which can be embedded perfectly in the validation step of our proposed methodology.

We did not the delineation/sketch of risk areas as they had already been made by CPRM survey.

3. RESULTS "Actually there were some repeated phrases and they were withdrawn." "Page 12 lines 6-27: revised"

-The frequencies of occurrence of each susceptibility classes, for whole study area, were calculated, which are presented in Figure 8. The results indicate the predominance of "medium" susceptibility class (44.7%), followed by the class with "high" (30.8%) and “low” (23.9%). The "very low" susceptibility class represents only 0.1% of the study area, while the "very high" class occupies a slightly higher proportion (0.5%). This trend of most critical susceptibility classes (high and very high) occupy a larger proportion area than the more stable classes (low and very low) is consistent with the expected for the great slopes of the Serra do Mar and its rugged terrain, as well as the expansion of urban areas towards the hillsides.

A detailed analysis of the results indicates that the susceptibility modeling is consistent with the expected, that is, the risk sectors are located in areas more susceptible to landslides (represented by "high" and "very high" classes). The “Risk Concentration” index (RC) was calculated for all 233 risk sectors (which totalize an area of 282.44

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hectares) and correspond to the susceptibilities classes' distribution of frequency inside them. This step was done for three typologies of risk sectors, in order to have a differentiated analysis for each one, which is shown in Figure 9. When is considered only the risk sectors areas (three typologies included), the classes "high" and "very high" occupies about 56.1% and 8.6% of its areas, respectively (column "Total" at Fig. 9). These values are much higher than the average of the study area (30.8% and 0.5%, respectively), which indicates a positive correlation between risk sectors and high susceptibility class. This fact indicates the accuracy of the technique used, as well as it becomes more representative when only the Typology 1 is analyzed, that is, inhabited steep slopes, which is at risk of slipping. For Typology 1, the two classes "high" and "very high" account together a RC of 72.5% (60.5% and 12%, respectively).

"Page 14 lines 4-9: there were placed in discussion session." -Yes. There is already mentioned in the discussion session.

4. DISCUSSION

"I am missing a paragraph about the limitations of your method, and a critical discussion of the assumptions."

"Yes; it was missing the paragraph about the limitations of the methodology. It was inserted into the end of discussions."

"Comparative discussion": I do not trust such a comparison. Not only are these studies from very different terrains, but also are they based on landslide scar validation, which makes it difficult to compare to this study."

-Yes, the term "Comparative" is really inappropriate, which was We changed for "Rating from related studies"

Concerning to this topic, we considered relevant to keep it. Although there are differences between studies areas, the use of the indices (LP/RP and LC/RC) allows comparing the relations between one region and another. The using of the "risk sectors",

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as the validation unit rather than landslide-scars, do not interfere in the comparative analysis, because the assumptions are the same either for LP and LC or RP and RC: it counts up all validation units (scars or, in the present study, risk sectors) based on the pre-assumption that these sites are inserted into classes of high susceptibility. It is very important to notice that although the proposed methodology results in a "susceptibility map", the fact of include the land use map turns the susceptibility evaluation into something broader, which approaches a risk map. For this reason, the best validation units to be used are the "risk sectors". Note that the proposed method considers the urban areas as a strong contributing factor to the destabilization of slopes (weight equals 1.0), while forests and natural areas remains the most stable slopes. These relationships are inherent of the study area, since the urban areas installed on the slopes were occupied rapidly during the last decades without any planning; so, there are too many factors that increase the susceptibility of landslides, such as in appropriated urban system drainage, houses with foundations supported on the shallow layers of soil (not on the rocks); points with no sewage uptake and so the wastewater favor the erosion in the foothills of slopes. Therefore, the methodology proposed could be used to indicate critical places within urbanized areas; thus, considering this possibility, it was , used the risk sectors as the unit of validation. In the present study, it is expected to find high susceptibility in slopes where there are urban occupations. On the other hand, in traditional studies designed to evaluate natural susceptibility (without human intervention), such anthropogenic factors are disregarding. Thus, the slopes considered critical in these traditional studies need to be necessarily located in the same places where there are scars. This pattern does not necessarily occurs in the municipalities studied because if some area is urbanized, it is not possible to identify scars at the present time, since it is assumed that such phenomena may occur in the future.

"The origin of the “risk levels” is not clear. Therefore it is difficult to review and comment on your section 4.3. If you assign risk levels based on your six data sets of input data, it would not make sense to compare susceptibility classes to risk levels – as both susceptibility classes and risk levels are based on the same data and it is obvious that they agree well."

-The classification considering "risks levels" is provided from CPRM that considers a hierarchical categorization of risk sectors, regarding to the probability of landslides occurrence and their potential impacts. This classification was done by experts from CPRM based on predefined criteria and findings on examination in-loco. Basically, it is an analysis that evaluates the geological and geotechnical conditions predisposing and the level of human intervention on each occupied slope, which are taken into account such factors as type of terrain, signs of soil movement (steps abatement), cracks in houses, inclined poles or trees, erosion at the bases of slopes, length of slope, among others. The classes range from R1 (less critical, low probability of occurrence) to R4 (most critical, high probability of occurrence). For these reasons, we chose to analyze separately the risk sectors of each "risk level" and calculate the distribution of susceptibility classes provided by our mapping. Even though the CPRM categorization has been made from in-loco evidences, the aim of our analysis is to evaluate the contributions and shortcomings of the proposed methodology. The hypothesis is that the less critical sectors (R1 and R2) present a minor proportion of high susceptibility classes compared to the most critical sectors (R3 and R4).

"Page 14 line15: repetition from page 9 lines 10-18" -The session "Comparative discussion" has been modified, as recommended. A paragraph to explain the intent of this item was inserted and the repeated references were removed.

"Page 14 line 23 – page 15 line 10: you cite a PhD thesis and a research article that are both written in Portuguese, which makes it almost impossible for the general reader to follow up these references. Could you exchange these for references in English?"

-The study of Vieira (2010), several times cited in the discussion session, is not a work related with a PhD thesis, but a research article published by NHESS. The thesis of Vieira (2007) is referenced only once (page 14, line 15), just to highlight an example of the use of the technique.Concerning to the reference of Zaidan and Fernandes (2009),

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the article is not available in a English version. However, we consider important reference it because this is one of the few studies (maybe the unique) that linking the landslides in Brazilian densely urbanized areas with the use of related indexes. The methodology used by Zaidan and Fernandes (2009) is similar to the ones used in other studies published in English language (Dietrich et al., 1998; Keefer, 2000; Wang et al., 2004; Qi et al., 2010).

"Page 15 lines 16-24: This belongs to the results section"

-The text included on page l15, lines 16-24 is not clear and not make sense to be maintained in results section. On the other hand, the reason for keeping them in the discussion section is justified by the fact that the data refers to other studies and are referred only in terms to compare the results. Thus, it was improved in order to contextualize appropriately.

5. CONCLUSION "Please give a brief summary of the individual steps of your proposed methodology."

-According to what has been proposed, we decided to summarize the conclusion following the methodology structure and summarizing the main relevant aspects about the advantages and shortcomings regarding: i) use of spatial database proposed; ii) subjectivity and flexibility of classes thematic weighting; iii) the application of Fuzzy Gamma technique and its parameters; iv) the data used for validation and related indices and v) the overall results.

"Line 23 page 17: Please specify and discuss these considerations and assumptions, and how they may affect the proposed methodology in an additional paragraph in the discussion section (also see above). Delete “which are constantly used” as this is misleading."

-The first aspect is associated with the structure of the methodology adopted, which resulted in a map that not presents the pure and natural susceptibility. That is explained by the inclusion of the land use map in the Fuzzy Gamma step, specially by the highest weight assigned for the class of “urbanized areas” (weight = 1.0). This fact contributes for the methodology presents a bias in representing the most susceptible areas inside urbanized locations, approaching the concept hazard map for most critical susceptibility classes (and not a pure and natural susceptibility). It is highlighted that it is not relevant for the scope of the study to identify very high susceptibility in uninhabited areas. Also, for this reason, the use of risk sectors makes sense in our standpoint, because they could represent the intersection between high susceptibility and possible damages. The second relevant aspect is associated with the use of RC/RP indices, analogous to the LC/LP indices widely used in the literature, which permits comparison of the quality of the results. In this context, the presented methodology enabled to achieve equivalent ratio (LP> 5 %), similar to the ones presented in other studies considering high resolution data.

6. FIGURES AND TABLES "Fig 2: not directly relevant, delete" -Done.

"Fig 5: this is not your work, please reconsider if this figure is necessary" -In The figure is shown the risk areas mapped by CPRM, which are used to validate the results.

"Fig. 6: if possible, please also provide weighting factors" -It was not possible, because the image would be very loaded/poluted. In addition, the information about weighting factors can be found in Table 3.

"Fig. 9: add x axis tick labels on lowermost bar chart at the right." -Done. Changes can be seen in the figure presented in attached file.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 1, 5199, 2013.

Risk Sectors - Tipology 1			Risk Sectors - Tipology 2			Risk Sectors - Tipology 3			*Total*	
Quantity	150	64,38%	Quantity	37	15,9%	Quantity	46	19,7%	*233*	*100,00%*
Total Area:	181,93	64,42%	Total Area:	52,94	18,7%	Total Area:	47,57	16,8%	*282,44*	*100,00%*
Classes	**Area (ha)**	**RC**			**RC**			**RC**		**RC**
Very Low	0,00	0,0%	Very Low	0,00	0,0%	Very Low	0,00	0,0%	*0,00*	*0,00%*
Low	1,27	0,7%	Low	0,21	0,4%	Low	3,22	6,8%	*4,70*	*1,67%*
Medium	48,84	26,8%	Medium	16,94	32,0%	Medium	29,31	61,6%	*95,09*	*33,67%*
High	110,06	60,5%	High	33,48	63,3%	High	14,77	31,0%	*158,31*	*56,05%*
Very High	21,77	12,0%	Very High	2,30	4,3%	Very High	0,27	0,6%	*24,33*	*8,62%*

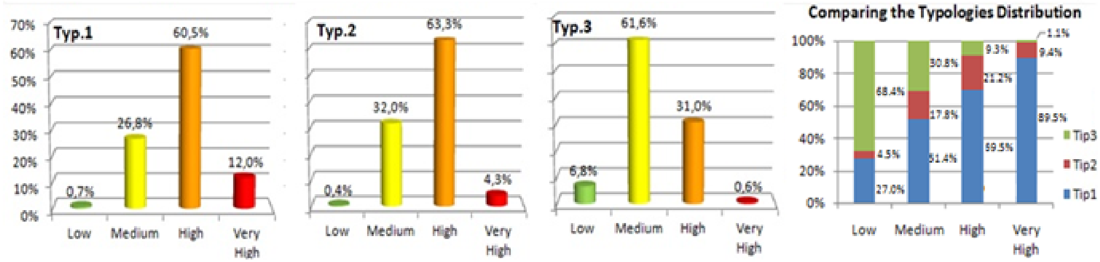

Fig. 1.

NHESSD
1, C2746–C2766, 2014

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