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Interactive comment on "Regional flood susceptibility analysis in mountainous areas through the use of morphometric and land cover indicators" *by* M. C. Rogelis and M. Werner

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We would like to thank Dr Marchi for the thorough and constructive review of the manuscript. We have carefully considered the comments, and through this document would like to provide a detailed response to each, as well as how we have adapted the manuscript where applicable.

GENERAL COMMENTS

This paper proposes a twofold approach to the characterisation of the susceptibility to debris flows in Colombia: an index that integrates morphometric catchment parameters and land use is developed and is combined with the results of a debris-flow propagation model.

Although affected by some problems (e.g. the selection of the morphometric parameters, discussed below), the approach is sound and potentially effective in classifying catchments based on the expected type and severity of hydrogeomorphic processes.

1. **The paper however, suffers from a major limitation, i.e. the lack of a convincing comparison of the susceptibility index with actual occurrence and type of hydrogeomorphic processes. Although the authors claim that "the distribution of flood records is well captured by the susceptibility index" (page 7567, lines 9-10), they admit that "The lack of information in the records of past floods in the area prevents a systematic characterization of the type of floods that occur in each watershed of the study area" (page 7573, lines 27-28). Data on the type of flood (streamflow or debris flow) were available only for three catchments: the agreement between predicted and observed catchment response for a so small number of cases does not permit any conclusion on the performance of the method proposed in this paper. As a matter of fact, the lack of documents describing occurrence and characteristics of floods does not prevent the assessment of the hydrogeomorphic response of a catchment: geomorphological and sedimentological field evidences, sometimes referred to as "silent witnesses" (Aulitzky, 1982) can provide information suitable to recognize the occurrence of debris flows, hyperconcentrated flows and water floods, even at distance of several years from event occurrence. Most of the papers aimed at the differentiation of debris-flow catchments from fluvial catchments cited in the introduction and in the section 2.2.1 of this paper did not rely**

on archive documents, whereas they were based on field recognition of past floods and debris flows. Field evidences suitable for differentiating debris flows from water floods have probably been obliterated in urbanized catchments near Bogota, but these evidences could be found in other regions, especially where low density of population is associated to the absence of documental flood records (e.g. upper Tunjuelo River basin, page 7567, lines 2-4). Of course, the recognition of hydrogeomorphic processes from geomorphological and sedimentological evidences at the spatial scale of this study requires systematic field work and cannot be performed by means of GIS analysis and remote sensing techniques. The authors briefly mention the issue of data availability and the time required for field observation at page 7551 (lines 25-29). The development of the predictive method has been possible even with limited data on flood and debris flows observed in the study area, but failure in validating the devised susceptibility index by means of evidences of catchment response undermines the scientific relevance of the paper.

RESPONSE:We agree with the reviewer that the absence of field evidence on past occurrence of debris flows that can support validation of the proposed method is an obstacle to the full validation of the proposed methodology. This is in fact the key comment raised by all three reviewers. However, as this reviewer also mentions in his comment, such field evidence is particularly difficult to obtain. This is indeed so in the peri-urban areas of Bogota as the urbanization processes have significantly altered the catchments. Furthermore, the susceptibility of the watersheds may not be independent of the land use in the watersheds, which could undermine possible validation using field evidence if that were to exist. In fact it is this dilemma that is the main motivation for the development of the research. The method proposed is primarily aimed at establishing an index that can help prioritise watersheds at the regional scale.

These can then be subjected to a more detailed field investigation and possible modelling, given that such a detailed analysis of all watersheds is not practicable. The reviewer suggests that data is available for only three watersheds. It would seem that this was not clearly described in the manuscript. Apart from the limited amount of flood records in the study area, three additional watersheds were used, two of which are located outside of the study area. This was clarified in the paper. Despite these three additional watersheds we do agree that the number of watersheds is still limited. The lack of flood records is a common condition in developing cities. In this revision we have extended the classification of the watersheds based on the database of floods in the area (maintained by the emergency response authority), and have made a more exhaustive analysis of field reports on past flood events. Based on these reports we have been able to increase the number of watersheds classified on the historical events to 11. Additionally, the results of the indicator proposed were compared with an independent method based on the propagation of debris flows using a digital elevation model.

In order to give more clarity about the method used for comparing the morphometric indicator with the results of the independent method and the available information, the methodology section was modified. Section 2.2 explains the approach that was followed, explaining the motivation and procedure used to develop the morphometric indicator, its comparison with the results of the debris flow propagation model, the flow type classification of the 11 watersheds and the comparison with the results from the three additional watersheds. In the subsections of the Methodology section a detailed and clearer explanation of the use of these data was included. Regarding the comparison methodology, this was improved using contingency tables providing a quantitative support to the discussion and conclusions.

Additionally, we think that one of the main issues underlying the concern raised by the referee is that the scope of the paper is perhaps not as clear as it could be.

Regarding the lack of documents describing the occurrence and characteristics of floods a clarification on the scope of the paper was added to the introduction:

"When historical data on the occurrence of flash floods and debris flows are not available, the recognition of hydro-geomorphological hazards can be carried out through field work analysis applying methods such as the proposed by (Aulitzky, 1982) based on hazard indicators, or through stratigraphic evidence in conjunction with age control (Jakob et al,2005; Giraud,2005). However, such fieldwork and detailed geological and geotechnical analysis at the regional scale requires significant resources and time, and may not be practicable in the extensive peri-urban areas of cities in mountainous areas such as those in the Andean cordillera. Furthermore, urbanisation processes in the peri-urban areas of these cities make geologic investigation difficult. Moreover the history of the watershed may not be a conclusive indicator of current hazard conditions, since anthropogenic intervention can play a significant role in the hazard dynamics. This calls for a more rapid yet reliable assessment of the watersheds, allowing a prioritization of watersheds where a more detailed analysis based on field data is to be carried out."

2. **Another issue that would have deserved more attention is the choice of the parameters for the development of the morphometric indicator. Some of the parameters listed in table 1 describe similar catchment characteristics, and one could argue that they are closely correlated. As an example, does it make sense to use in the same equation (eq. 3) watershed length and main stream length? The same observation could apply to the shape factors SF, C, E and LW in eq. 2. The paper does not clarify if a preliminary analysis aimed at a sound selection of morphometric parameters has been carried out.**

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RESPONSE: We agree that the parameters used can be highly correlated, and the reduction of the dimensionality of the dataset to avoid redundancy and duplication is a central step to the proposed methodology. The initial choice of parameters was carried out through an extensive literature review devoting attention to the morphometric parameters that have been used in the literature referenced to identify hydrogeomorphic processes. This overview is provided in Table 1. Once the parameters were chosen, a principal component analysis was applied. The central idea of principal component analysis is to reduce the dimensionality of a data set in which there are a large number of interrelated variables, while retaining the variation present in the data set as much as possible. This reduction is achieved by transforming to a new set of variables, the principal components, which are uncorrelated, and which are ordered so that the first few retain most of the variation present in all of the original variables (Jolliffe, 2002). To make this step clearer, a clarification was included in the section "Construction of the morphometric indicator":

"Morphometric parameters used in literature (see Table 1) were extracted for each watershed from the digital elevation model of the study area using GIS tools. Many of the variables as listed in Table 1 are, however, closely correlated. To reduce the dimensionality of the data set principal component analysis was applied. A reduction of the variables is achieved by transforming the original variables to a new set of variables, the principal components, which are uncorrelated and which are ordered according to the components that retain most of the variation present in the original set of variables (Jolliffe, 2002). These transformed variables were subsequently used to obtain the morphometric indicator."

3. **As the main objective of the study is to recognise the possible occurrence of debris flows, the title "Regional flood susceptibility: : :" is misleading and could be replaced by "Regional debris-flow susceptibility".**

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RESPONSE: Based on the combined suggestions of the three reviewers we propose to change the title to: “Regional flash flood susceptibility analysis in mountainous peri-urban areas through morphometric and land use indicators”.

SPECIFIC COMMENTS

4. **The term “energy” has been used to describe one of the classes of morphometric variables that explain occurrence and delivery of debris flows. As no explicit assessment of the energy involved in the transport processes has been performed, it should be clarified, also in the abstract, that some morphometric parameters have been used as indicators of the potential energy associated to elevation differences within the catchments.**

   RESPONSE: The term "potential" was added in the abstract to qualify the energy, as well as a phrase "The energy indicator, which provides a measure of the potential energy", was added in the Results section (Morphometric indicator subsection), describing the energy indicator.

5. **The text from page 7555, line 23 to page 7556 line 4 provides some very general comments on the conditions required for debris-flow occurrence: this part of the text could be omitted as these concepts are well-known to the readers of NHESS interested in floods and debris flows.**

   RESPONSE: The text was deleted as suggested.

6. **The reference to Sanchez-Marre et al. (2008) at page 7556, lines 2-4 requires a comment. The statement: “prerequisite conditions for debris flows include an abundant source of moisture (rainfall or snowmelt) and sparse vegetation” is from a well-known paper by Costa (1984, page 269):**

the original work should be cited. Moreover, the reference to Sanchez-Marre et al. (2008) is wrong: the authors of the paper referred to in the references list are Salvetti et al. (2008); M. Sànchez-Marrè, J. Béjar, J. Comas, A. Rizzoli and G. Guariso are the editors of the volume.

RESPONSE: The reference to Sanchez-Marre et al was deleted from page 7556, lines 2-4 according to the previous comment. The reference to Sanchez-Marre was corrected in the rest of the paper.

7. **In the introduction and in the section 2.2.1, the authors cite a number of papers dealing with the differentiation of debris flow, hyperconcentrated flow and flood catchments by means of morphometric parameters, but, surprisingly they do not mention the pioneering study by Jackson et al. (1987) in the Canadian Rocky Mountains. Another paper that deserves to be considered has recently been published by Bertrand et al. (2013): it combines datasets from several previous studies and performs linear discriminant analysis and logistic regression to differentiate debris-flow catchments from fluvial catchments.**

   RESPONSE: The suggested references were included

8. **The discussion on the slope-area diagram (page 7558) is not clear and the reader could find it difficult to recognise the sectors corresponding to hillslopes, unchanneled valleys, debris-flow dominated channels and alluvial channels.**

   RESPONSE:
   Regarding the difficulty to recognize the sectors corresponding to hillslopes, unchanneled valleys, debris-flow dominated channels and alluvial channels: The graph presented in the section "Classification of watersheds according to

the debris flows propagation capacity" was improved. The thresholds for the differentiation of sectors were drawn and the two sectors that were addressed in the paper (debris-flow dominated channels and alluvial channels) are identified in the plot. Additionally, segmented regression was used to identify the breaks in the curves.

Regarding the unclarity in the discussion, this was improved as follows:

"The analysis of the slope vs area curves shows that on average, the slope in La Chapa watershed is higher for a given drainage area than for the other watersheds considered. If the same drainage area, e.g. 1km^2, is considered for the three watersheds with segmented regression fit shown in Figure 5, namely Tunjuelo river basin, Eastern Hills and La Negra creek, the slope values from the slope vs area curves are 0.1, 0.15 and 0.16 respectively, which means that on average for this drainage area the average local slope in the Tunjuelo river basin is milder than in the Eastern Hills with the latter being slightly milder than the local slope in La Negra creek. In the case of La Chapa watershed the value of slope for a drainage area of 1km^2 is 0.4. This result is important given that La Chapa creek has a confirmed debris flow dominance, followed by La Negra creek where concentrations in the transition from hyperconcentrated flows and debris flows have been identified. High values of the morphometric indicator are concentrated in the watersheds located in the north east of the study area. This behaviour is in agreement with the characteristics of the slope-area diagram shown in Figure 5, where on average the watersheds in the Eastern Hills have higher local slope for a given area than in the Tunjuelo Basin watersheds. This condition reflects a difference in energy between the two areas that is captured by the morphometric indicator."

9. **At the pages 7561 (line 24) and 7562 (lines 7 and 8), the authors cite three times a paper published in a recent multi-author book. These cites do not focus on new findings: they remind, in a very general way, the protective**

role of vegetation and the increase of runoff and slope instability caused by deforestation. Such general observations, which could be find in many handbooks of hydrology and geomorphology, are probably unnecessary in this paper.

RESPONSE: We agree that these references reflect on knowledge that can be considered general. However, we feel that this does provide foundation for our introduction of the land-use indicator, and we decided to keep the text for that reason.

10. **The paper cited as "Santos (2006)" was actually authored by R. Santos and R. Menéndez Duarte.**

    RESPONSE: The reference was corrected as suggested.