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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "A coupled empirical approach for rainfall and land use correlation to landslide occurrence in the Esino river basin, central Italy" *by* E. Gioia et al.

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The authors would like to thank the three reviewers for their thorough work on the manuscript providing us with insightful and constructive comments, which helped improve this manuscript. We have tried our best to carefully consider and respond to all the comments raised.

Response to Anonymous Referee #1

The authors completely agree with Referee #1 on the consideration that this article is not about new methods of investigation, but rather the coupling of already known

methods to find both timing and location of landslide occurrence through an empirical (black box) analysis.

We acknowledge that the discussion and conclusions were a bit short and therefore we extended them reasoning about encountered problems and limitations.

P1566, line 16: "On the other hand, the MSPA analysis showed that the agricultural covers most affected by landslides are Crops and Mixed cultivations, while the vegetation structures more involved are the Core class, followed by the Edge, Branch, and Bridge classes. Overall, the Core areas are the most susceptible to landslides in Crops cover, whereas the transitional areas (Edge, Branch, and Bridges) become preponderant in Mixed Cultivations. Certainly, this study was subject to various limitations, including the fact that the available landslides data provided only location points. This was a constraining element for the MSPA; knowing the exact landslide areal extension would have sensibly improved the results. Nevertheless, this research reveals that anthropogenic vegetation covers and high vegetation fragmentation increase landslide susceptibility within the Esino river basin."

General comments:

a) "Considering the detailed description of the geological framework, a schematic geological map of the study area should be shown in a figure."

The map of the study area (Figure 1) was enriched with basic geological information.

b) "Authors sustain that the terrigenous sediments dominate in the hilly central Marchean ridge area but this information is missed when they divide the basin in two sections. Here the valley and low hills are dominated by post-orogenic sediments."

The text of P1560, line 17 to 20 has been revised as follows: "For this study, the Esino river basin was divided in 2 sections of approximately the same size: (i) mountains – western part, mainly composed of carbonate sediments, and (ii) valleys and low hills – eastern part, mostly characterized by post-orogenic and terrigenous sediments (Figure

1)."

c) "Data plotted in Figure 2 have been used to validate equation 2. The results are good but only the ID data in the valley and low hills of the 2014 event fall within the cloud in a position comparable to those of the historical data. How do you explain the differences between the historical data and the other groupings (2013 valley and low hills, 2013 mountains, 2014 mountains)?"

The following passages have been added: - P1563, line 23: "Furthermore, all the ID data of November 2013 plotted over the cloud of historical rainfall events that triggered landslides in the study area. Such detail is an indication of the great magnitude of the 2013 event, with intensities and durations higher than ever recorded, and possibly a further evidence of a changing climate." - P1564, line 21: "Indeed, the effect of precipitation on slope stability depends on local conditions, including soil characteristics. This result shows that, for a basin with such different lithologies, a generalization regarding the number of landslides expected from similar ranges of ID values is inapplicable. Hence, the considerations about the number of rainfall-triggered landslides in the valleys and low hills section of the Esino river basin cannot be exported to its mountains section; a specific rainfall threshold for this area should be developed."

Specific comments:

P1558, line 6: please replace "carried out" with "evaluated"; P1558, line 24 to P1559 line 1: please rephrase the sentence; P1558, line 27: please replace "exist" with "are available"; P1560, line 4: please replace "bands" with "areas"; P1561, line 21: please add "in hours" after "duration.

Authors agreed with the suggestions of the specific comments, and edited all of them as recommended.

Response to Anonymous Referee #2

Authors agree with Reviewers # 2 critics that a full integration of the two methods was

not achieved in the submitted version of the paper, and that the insertion of an explicit section on the coupled approach was necessary.

a) "The idea behind the contribution, in combining the two approaches is worth to be shown in the analysis of landslide hazards (as the Referee 1 mentioned) but the intention to combine the two approaches is not fully achieved at the end in the paper. In my opinion, the combination is still missing in the results chapter. In the conclusion chapter is mentioned that " an effective integration of the two approaches will facilitate. . .", but I do not see a good example here of integration (as also the title suggest . . ."coupled")."

We integrated the results and discussion chapter at P1565, line 13: "The positive results obtained with both the intensity-duration and the MSPA methods, allow for their coupled use in one single empirical approach for landslide forecasting in the Esino river basin. This proposed approach consists of two consequential parts: the first concerning the analysis of the rainfall intensity and duration patterns (from weather forecasts), the second concerning the activation of the landslide early warning procedures (modulated in the territory according to the MSPA forecast of where landslides will probably occur)."

b) "It seems that the results resumed in the abstract are not the same resumed at the end of the paper. In the abstract, it is mentioned that "the ID minimum threshold proposed in a previous study (Gioia et al., 2015) was verified", this is not further mentioned in the document. Therefore, I was wondering if this was the main purpose of the paper? To verify the ID thresholds? or to combine threshold with vegetation analyses?"

The purpose of the paper was twofold. The main purpose was to propose a novel integrated approach for landslide forecasting with the parallel use of two empirical methods. The second purpose was to test the feasibility of the ID threshold and the MSPA in the study area as parts of the integrated approach. The validity of the ID threshold was mentioned in the results at P1563, line 22 and P1564, line 8. Moreover, it was cited in the conclusions chapter at P1565, line 23.

c) “In agreement with the Referee 1, the methods used are not truly new, and the discussion of the results is too short. The second part explaining the WSPA is too short as well, if you have not read the other paper Carone et al., 2015 it is difficult to follow the explanation.”

We agreed with the comment that the methods are well known, especially the intensity-duration analysis. As we also responded to Referee #1, the paper is not aimed at inventing new techniques but at suggesting an integrated use for forecasting the timing and location of landslide occurrence. We extended the discussion part (see Response to Referee #1) and the MSPA description as reported below. P1562, line 10: “The Morphological Spatial Pattern Analysis - MSPA (Soille and Vogt, 2009) was performed over the study area’s anthropogenic agricultural land cover categories (e.g. Mixed cultivations, Crops, Shrubs, Mixed forests or Grasslands) by using the open source software GUIDOS 2.0. (Vogt, 2014). Land cover information was derived from a Corine Land Cover Map (available at: http://www.sinanet.isprambiente.it). Data were then integrated in a GIS environment. All the interested agricultural land cover categories were first transformed in binary images (1 = presence of the cover; 0 = absence of the cover), then, through the MSPA, were segmented in different patterns to highlight information on vegetation structures. Such patterns are mutually exclusive and, if merged, match the initial area. Soille and Vogt (2009) described these segmentation types as follow:

- Core - the innermost part of a vegetation patch, excluding the foreground perimeter, that has to be greater than an established minimum size;

- Islet - a portion of the vegetation cover that is too small to contain a Core area;

- Edge - the perimeter of a Core area;

- Perforation - a hole in the vegetation cover;

- Bridge - a connector (long-limbed vegetation patch) between different Core areas;

- Loop - a connector whose ends are located in the same Core area;

- Branch - a connector whose ends bonds a Core area and another connector, an Edge, or a Perforation.

Overlapping such a MSPA map to the landslide distribution map of the November 2013 and May 2014 rainfall events, the vegetation segmentation patterns more subjected to slope failures were highlighted. The results of this study were then compared with those of Carone et al. (2015) which already performed a multitemporal MSPA over the Marche region for the period 2000 - 2006. Carone et al. (2015) pointed out a higher number of landslides in Edge, Branch and Bridge patterns, which represent areas of transition between different covers, whereas Crops covers showed a great landslide occurrence in Core areas.”

d) It could be useful to mention why we need these thresholds? There is a governmental institution using them for early warning purposes, for example?

We added at P1566, line 19: “for local authorities and the civil protection”.

e) “It should be clarify from the very beginning the type of landslides that are under investigation (in agreement with Cruden and Varnes, 1996, or Hungr et al., 2013). Are they rock fall? Debris slides? Debris flows? Which type is more common in the mountains and which in the valley area? Thresholds can be different for different types of landslides also in the same area, some of them occur under short and intense rainfall, other depend more on cumulative rainfall, also taking into account the difference in geology. Landslides in clayed soils occurred not necessarily with high rainfall amount, but they are influenced by cumulative rainfall and wet soil conditions over a longer period, while landslides in more coarse and heterogeneous granular deposits occur with extremely short duration rainfall events and even with less saturated soil.”

A new paragraph regarding the landslides database was added in the text, as specified below in the general comments, in response to a similar question. Indeed, we

are aware that the triggering mechanisms depend on a wide number of factors such as for example soils or rainfall patterns. However, information on landslide types was not uniformly available either for the recent or for the historical landslides. In the attempt to overcome such limitation, we managed to split the study area in two parts with relatively similar lithologies. Thus, we could consider approximately comparable background conditions in each of the parts and we could compare the effectiveness of the ID threshold for both the mountain and the valley-low hills areas.

f) "Is important to take also into account the difference between the two rainfall episodes as you mentioned in the conclusions line 15 "the natural variability of atmospheric seasonality". Are these events chosen related to frontal activity or convective cells, etc? This would help to understand the different amount of rainfall in the different areas."

Information on such meteorological aspects of the rainfall events is not available. It might be assumed in both cases a frontal activity. However, this information is not critical for the application of the ID method, which is based on the effective amount of precipitation measured by the rain gauges, and is beyond the scope of this paper.

g) "It would be more interesting to compare historical events (fig. 2) from the same season looking at all events in autumn-winter and those in spring in order to analyze better the thresholds."

Authors were already conscious of the possibility to further improve the comparison of the recent and historical intensity-duration data. However, for reasons of limited space we decided to not extend the analysis. Nevertheless, this suggestion is undoubtedly worth to be taken into account for future work.

h) "What about snow smelting in the mountain? It worth to take into account in this region as a possible triggering factor?"

Snow melting is an important triggering factor for landslides, even in the hilly area. Yet, neither the rainfall event of November 2013 nor that of May 2014 have been character-

ized by snow. Therefore, we did not consider such parameter in the comparison of the ID data.

General comments:

- The vegetation segmentation should explained a bit longer in the introduction.

The sentence at P1559, line 4 was modified as: "To this extent, an interesting aspect, though little explored, is the characterization of the vegetation cover in rainfall-triggered landslide areas, using segmentation methods based on digital images."

- Could you explain why were chosen the November 2013 and May 2014 events?

The following phrase was added at P1559, line 27: "Similarly, the November 2013 and May 2014 rainfall events were chosen for this study because affected the entire Marche Region with well-documented effects, and because these two events were subsequent the 1953 – 2011 period, for which the intensity–duration threshold over the study area had been already developed by a previous investigation (Gioia et al., 2015). The data of the 2013 and 2014 rainfall events would help testing the applicability of such threshold."

- Could you mention if landslides occurred in natural slopes or in artificial slopes (like road cutting) or both? Could be interesting to discuss if the landslide types are of the same type in the mountain and in the valley and if there is some difference in types between May and November, more in natural slopes? More debris flows? Etc.

To add further information on the landslides collected, at P1563 line 13 we wrote in: "In terms of movement typology, they are mostly slides and flows, yet it is important to point out that this information was obtained from reports of the Centro Funzionale Multirischi della Regione Marche (CFRM), which mainly collect data about landslide events that impact human activities and infrastructures (e.g. agricultural covers, roads, residential buildings, etc.)."

- Introduction: line 16. . .mere or more?

The correct word is “mere”.

- What it does mean “landslide triggering effects” in line 26?

The line 26 at P1563 has been changed into: “and can trigger a very different number of landslides”

- In figure 2 “main events, secondary events, minor events, single events. . .” are these rainfall events? or landslide events, clarify it.

We agreed and modified the caption of Figure 2: “Intensity-Duration logarithmic graph modified after Gioia et al. (2015). Figure shows the comparison between the ID values of historical rainfall events (1953-2011), the ID threshold and the ID data of the November 2013 (blue) and May 2014 (pink) rainfalls. The historical rainfall events are represented according to the number of landslides triggered: main events are those that triggered more than 10 landslides (yellow), secondary events triggered 3-9 landslides (purple), minor events triggered 2 landslides (green), and single events triggered 1 landslide (light blue). The ID data of November 2013 and May 2014 are differentiated according to the rain gauges location: mountains or valleys-low hills.”

- How you explain why there were many landslides in November in the mountain and only one landslide event in May even if the rainfall amount was higher?

In fact, the rainfall amount in May 2014 in the mountains was not higher than the November 2013 event. Significant differences lay in the mean intensities and in the durations logged by the rain gauges. To explain the different effects caused by such dissimilarities we added a paragraph at P1564, line 21 as also suggested by Referee #1: “Indeed, the effect of precipitation on slope stability depends on local conditions, including soil characteristics. This result shows that, for a basin with such different lithologies, a generalization regarding the number of landslides expected from similar ranges of ID values is inapplicable. Hence, the considerations about the number of rainfall-triggered landslides in the valleys and low hills section of the Esino river basin

cannot be exported to its mountains section; a specific rainfall threshold for this area should be developed.”

- It could be possible to show in a figure (with the integrated approaches) the ID threshold and the results from WSPA?

Unfortunately, we could not show in a sole figure the results of both the approaches because the ID threshold is related to the rainfall conditions likely to trigger landslides, whereas the MSPA is related to the spatial distribution of such landslides. However, we added a new figure with the results of the MSPA analysis (Figure 3) and we commented it in the results section (P1565, line 13): “Figure 3 is a map showing the percentage of landslide occurrence in such covers for the November 2013 and May 2014 events. Given the consistency of the MSPA of this work with that of the previous study (Carone et al., 2015), we may consider such map as a first rudimentary landslide susceptibility map of the Esino river basin.”

Response to Anonymous Referee #3

The authors particularly appreciated the suggestion of Referee #3 to find a more suitable title for the manuscript. Accordingly, we revised it as follow: “Rainfall and land use empirically coupled to forecast landslides in the Esino river basin, central Italy”.

Specific corrections:

- Line 8, page 1561: “. . . than on the mountains (CFRM, 2014)”. We modified the text as suggested.

- Line 12, page 1561: “Rainfall data were downloaded. . .”. We modified the text as suggested.

- Line 13, page 1561: “. . .CFRM, which manages a network. . .” We modified the text as suggested.

- Line 22, page 1561: “where I is the rainfall intensity (in mm h-1), D is the rainfall

duration (in h)...” We modified the text as suggested.

- Lines 15-22, page 1562: In order to understand the vegetation patterns, it would be better to show examples of MSPA classes in a Figure. Unfortunately, we had limited space and we preferred to add an additional figure in the results section as recommended by Referee #2. However, we improved the description of the MSPA in order to allow a better understanding of the method (see Response to Referee #2).

- Line 8, page 1563: “Core areas...”. The meaning of this statement is not clear, explain better. We replaced the statement with: “Carone et al. (2015) pointed out a higher number of landslides in Edge, Branch and Bridge patterns, which represent areas of transition between different covers, whereas Crops covers showed a great landslide occurrence in Core areas.”

- Lines 14-15, page 1563: I would modify as follows: “..., while Fig.2 plots new and historic data (Gioia et al., 2015) in relation to the threshold defined by Eq. (2)”. We modified the text as suggested.

- Line 21, page 1564: I would change in “As a matter of fact, the ID...”. We could not find the text related to the comment.

- Line 23, page 1565: “Core areas...”. The meaning of this statement is not clear, explain better. We could not find the text related to the comment.

- Line 16, page 1566: I would modify in “Coupling the intensity-duration method with the land use classification, which allows identifying the vegetation structures more inclined to fail, it could be worth reasoning...” We modified the text as suggested.

- Table 1: values of mean intensity (mm h-1) cannot have two decimal points. It would imply that rain gauges are able to measure hundredth of millimeters. Please, use only one decimal. We modified the text as suggested.

- In Table 2 the percentage (%) symbol should appear under “Cr” and “Mix” in each column. We modified the text.

- Legend and caption of Figure 2 are unclear. Legend has to be more concise. The meaning of the different symbols (i.e. text in parentheses) should not be included in the legend, since it is already explained in the figure caption. In the caption only two colors (blue and pink) are reported. Please, describe also the other colors. We changed the figure legend and caption as also recommended by Referee #2 (see Response to Referee #2.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/3/C748/2015/nhessd-3-C748-2015-supplement.pdf

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Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 3, 1557, 2015.

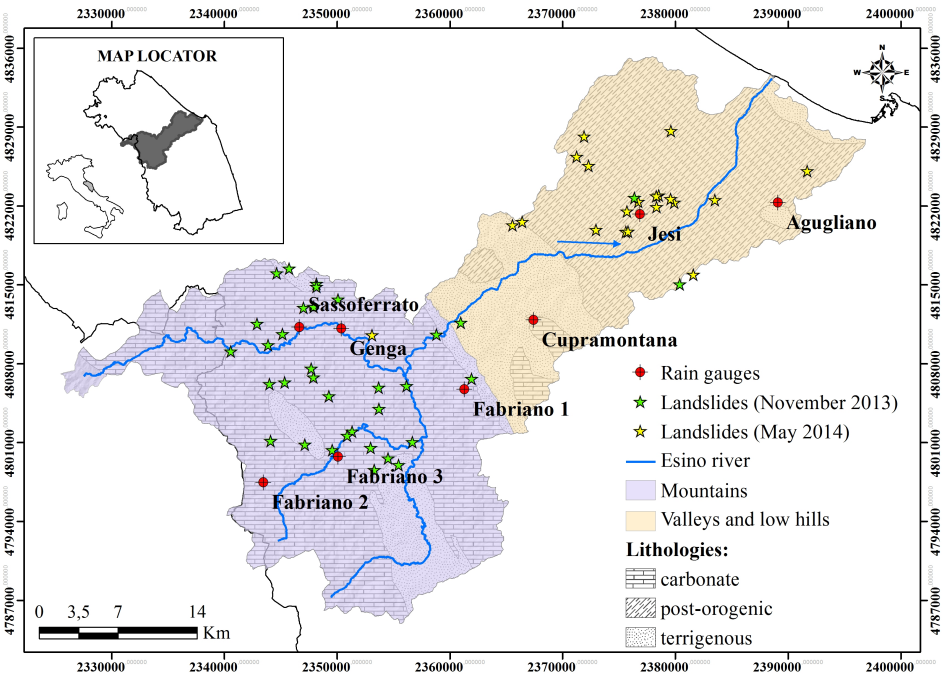

Fig. 1. Figure 1

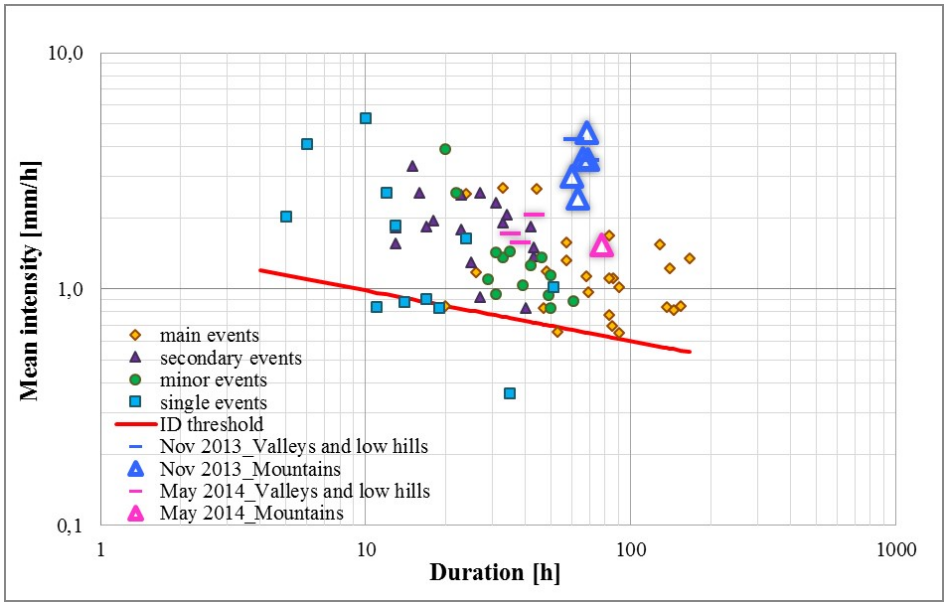

Fig. 2. Figure 2

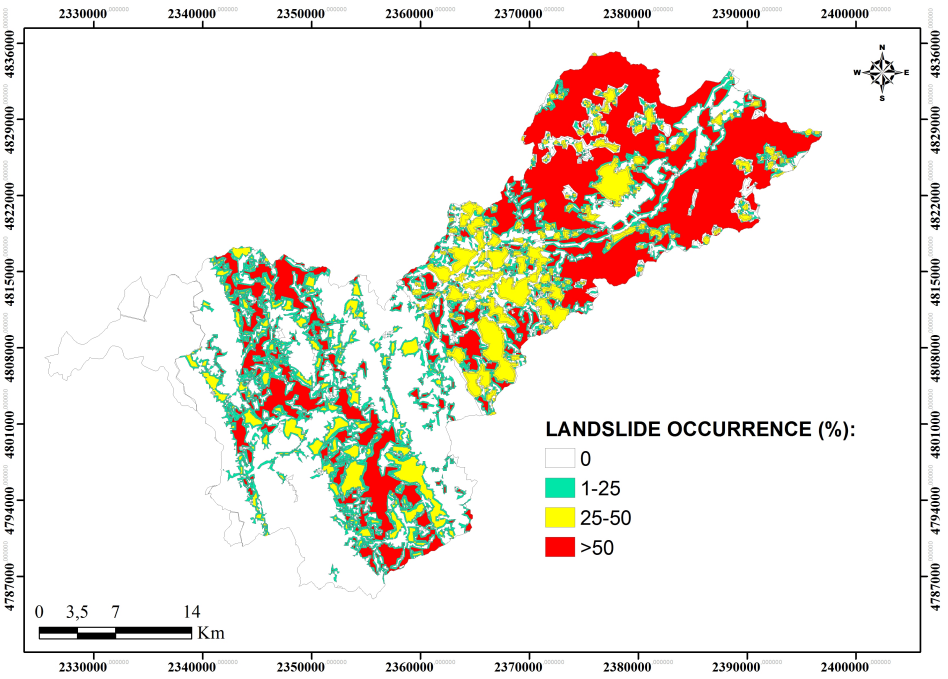

Fig. 3. Figure 3