

Inventory mapping of forest-covered landslides using Geographic Object-Based Image Analysis (GEOBIA), Jena region, Germany

Authors' response

Anonymous Referee #2

The manuscript presents a very interesting and potentially valuable contribution to the NHESS. The incorporation of GEOBIA into landslide mapping represents a notable advancement in this domain. However, several parts of the manuscript require further modifications and improvement before it can be considered for publication in the journal.

Comment: Authors should outline the specific landslide features that their method is able to identify. In the current case, it seems that we are discussing structured landslide failures such as translational slides.

Response:

Thank you for the comment. We agree that clarification is helpful, and we have added a brief explanation in the last paragraph (revised manuscript, at line 83) of the Introduction, as we primarily focused on deep-seated (rotational) landslides.

Comment: The authors mention that the area of interest has witnessed several landslide events, but without any clarification of the type of movement or the temporal resolution of the events. Are there event-based failures or is there a temporal scale of their occurrence?

Response:

Thank you for pointing this out, and agree that further clarification is needed. In the revised manuscript (lines 105-109), we clarify that the dominant type of movement in the study area consists of deep-seated rotational landslides, which are characteristic of cuesta landscapes with layered sedimentary rocks.

The age of these landslides is not precisely known and cannot be derived directly from the DTM data. However, as explained in the revised manuscript (lines 111-114), based on literature and geomorphological indicators, such as the widespread presence of dense forest cover over many large landslide bodies, we assume they are of Holocene origin with limited recent activity.

According to Achilles et al. (2016), and as now stated in the revised manuscript (lines 109–111), these landslides were probably triggered at the end of the Weichselian glaciation by increased precipitation, glacial meltwater infiltration, and related hydrological changes.

Comment: Regarding the manual mapping of landslides, authors should provide clear information on the procedure they followed to map the landslide features. This is crucial for the reader to understand the process of the accuracy assessment in the later stage.

Response:

Thanks for this comment. In the revised manuscript, at lines 132-141, we have clarified the criteria used for visual landslide mapping. The landslide inventory map (reference map) was produced through manual visual mapping in ArcMap 10.7, primarily based on traditional and multi-directional hillshade derived from 1m LiDAR-DTM data. This method follows the procedure described by Schulz (2004), which is already cited.

Although hillshade was the only data type directly used to create the inventory, additional land-surface variables (LSVs), such as slope, curvature (plan and profile), topographic openness, topographic position index (TPI) and terrain ruggedness index (TRI), were employed to assist with on-screen interpretation. These LSVs were particularly useful for improving the delineation of landslide boundaries where hillshade alone did not provide sufficient contrast. In most cases, the landslide scarp and body were mapped separately if they could be visually distinguished; however, in a few instances, identification of the scarp was not possible.

Comment: The highlighted advantage of this work is the application of the GEOBIA. The process of identifying objects instead of pixels is crucial and it gives the power for semantic labeling and contextual information incorporation. In this case authors should talk and discuss further the parameters for the segmentation phase, such as scale, shape/color, and compactness. More information is needed on the ruleset development and an explanation of the chosen parameters.

Response:

Thank you for this insightful comment. We fully agree that a detailed discussion of the segmentation parameters is essential to clarify the methodological robustness and enhance the transparency and transferability of our GEOBIA-based approach. While the original manuscript provided a general overview, we have now substantially expanded this section in the revised version. Specifically, we have included a comprehensive summary of the segmentation and classification parameter, such as **scale** (following trial-

and-error approach), **shape**, and **compactness** (default parameters), at lines 171-176, in the revised manuscript, as well as the corresponding ruleset logic now added in **Appendices A1–B2** (see revised manuscript). These additions provide explicit thresholds and decision rules used for the identification of both landslide scarps and bodies, thereby offering a clearer understanding of the classification strategy and its potential for adaptation to other study areas.

Comment: The section on Refinement and accuracy assessment (AA) needs more clarification. I propose to improve it by incorporating more information on how and why the procedure is critical for assessing the performance of the method.

Response:

Thank you for this important and constructive suggestion. We fully agree that the refinement and accuracy assessment steps are critical components of our methodology and required more clarification. Accordingly, we have substantially revised and expanded this section in the revised manuscript to better explain both the rationale and implementation of the refinement procedure. In particular, we now describe the purpose and structure of Stage III (GEOBIA-based refinement) in detail, including how expert knowledge was incorporated through a rule-based approach implemented in eCognition (see lines 178–206 in the revised manuscript). This includes explanation of key object-based features used in the refinement—such as morphometric, geometric, and contextual parameters—and the rationale for their selection.

We also clarified the iterative process of refinement, including how visual inspection, spatial inconsistencies, and accuracy metrics guided the semi-automated adjustments. Specific rules and thresholds used for reclassification (e.g., adjacency, shared boundaries, enclosure) are now explicitly included. Additionally, we noted that landslide scarps and bodies were refined using separate criteria to account for their different spatial characteristics. To ensure transparency and reproducibility, we referenced the full rule set provided in the Appendices (Tables A1–B2), as noted at the end of this section. The updates aim to clearly demonstrate how this refinement phase improved classification performance and why it was essential for reducing false positives and false negatives while maintaining high true positive rates.

We hope these revisions fully address your concerns and provide a clearer, more informative explanation of this critical methodological step.

Comment: The Results section would benefit from a more detailed and thorough presentation. Please provide a deeper interpretation of the findings to enhance clarity and understanding for the reader.

Response:

Thank you for this valuable comment. We fully agree, and in response, we have added two tables in Section 4.2 ("GEOBIA-based landslide modelling results") to provide greater detail and clarity regarding our findings. These tables (Tables 2 and 3 in the revised manuscript) present key morphological parameters for the GEOBIA-based mapping results, including both scarps and bodies, for Models I and II. Brief interpretations of these results have also been incorporated into the revised manuscript at lines 262 and 271. We further modified and improved Figure 6 (from the original manuscript) by splitting it into two figures (Figures 6 and 7) in the revised manuscript. Thus, this improvement provides a clearer presentation of our results as well. We hope that the inclusion of these tables and modification of the figures, along with the explanatory text, improves the clarity and interpretation of our results and addresses your concern as well.

Comment: There are several figures that look blurred on the manuscript. Please take a look at them and provide better quality as outputs to enhance the quality of the work.

Response:

Thank you for pointing this out. We agree that the figures should be clearly readable across all file types. Accordingly, we have modified the study area figure (Fig. 1), and we have also revised Figures 4, 5, and 7 (renumbered as Fig. 8 in the revised manuscript) to further improve clarity. In the updated figures, landslide scarps and bodies from the inventory and the GEOBIA results are depicted using distinct colors, which we believe improves visual interpretation and facilitates clearer comparison. Additionally, we have split the original Figure 6 into two separate figures (now Figures 6 and 7 in the revised manuscript) and revised them with higher resolution, larger dimensions, and improved layout. We have also updated the figure captions to be more detailed and descriptive. We hope these revisions effectively address your concerns (see the revised manuscript).