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

Authors' response

Community comments (CC):

CC1: Mihai Niculita

Comment: This is an approach for translational landslides, and this should be specified in the title.

Response:

> Please also refer to our response to Reviewer 1, Comment 1. We have added information about the landslides investigated in this study to the Introduction section (revised manuscript, line 83).

Comment: Beside that we will show bellow that the approach is actually not able to predict correctly: we would expect an object for every landslide, in order to be able to validate, but this is not the case so the area based metrics was introduced.

Response:

> This would be an ideal situation, however not a standard in object-oriented analysis. Area-and object-based metrics are more meaningful in evaluating the results of the object-oriented analysis, since they do not only assess the spatial coincidence, but the degree of spatial overlapping as well.

Comment: GEOBIA has potential in landslide research but the presented approach does not progress beyond what was already done in the literature (van den Eckhaut for example); this is shown by the results of stage II. The stage III is nothing more than an approach for (over)fit the landslide data, so its usage outside the study area is questionable. The failure of the segmentation approach is shown by the failure to identify the bodies especially, since their roughness is pretty different than of the surrounding hillslopes as it can be seen in Figure 7. So the big problem remains the segmentation approach which seems to get entire hillsopes rather than the landslides. Also the inventory is questionable: for example in Fig. 7 b the very wide landslide actually is composed on several clear events that should be mapped and considered separatelly. Scarp areas in this context of translational landslides is very hard to be morphometrically segmented.

Response:

1. A thorough examination the Van Den Eeckhaut et al. (2012) study reveals that, while they employed a GEOBIA approach in general, the specific criteria and steps we used differ significantly. For example, in Fig. 5E of their study, they manually created flanks for each landslide in a loop, which is entirely different from our approach. In our study, Stage II is substantially different from their methodology, and Stage III advances further by automating landslide detection in forested areas using high-resolution DEMs, without relying on other data sources.

   Our work takes a step forward by developing a model to map and semi-automatically clean up false positives. As demonstrated in our study, our method minimizes false positives more effectively compared to the previous studies in the same direction (refer to the Discussion section of our study).

2. Thank you for your comment regarding the inventory map, particularly Figure 7b (Fig 8b, revised manuscript). We agree that the large polygon in this figure may in fact represent multiple landslide events (or some secondary landslides). However, due to unclear geomorphological boundaries and possible anthropogenic modifications, it was not possible to confidently delineate the individual events. As a result, we mapped the area as a single landslide to ensure consistent validation, while acknowledging this limitation.

   To address your concern, we have added a paragraph in the Discussion section (at lines 328–333, revised version), where we explain that this issue can be handled through the area-based accuracy assessment approach (see Section 4.3.1). We also suggest potential strategies for dealing with such ambiguous cases in future studies.

Comment: The discussions should also point the fact that the proposed approach identify and not necessarily map the landslides. So the method does say there in this object there is a landslide but does not map its borders. Also the validity of the landslide inventory in terms of events should be questioned here. Many landslides are rather compound then single events and this does affect the application of the method.

Response:

Many studies on landslide detection using GEOBIA highlight the difficulty of accurately delineating landslide borders, especially compared to manually created inventory maps (Dias et al., 2023). This challenge is influenced by various factors, such as the modification of old landslide boundaries over time by both human and natural processes, and the quality of inventory mapping itself. For further details on the quality of landslide mapping, refer to (Guzzetti et al., 1999, 2012; Santangelo et al., 2010; and more resently

Ardizzone et al., 2023); This issue is also common in geomorphological mapping and other geomorphic features.

However, in our study, we were able to delineate landslide borders, including both scarps and bodies, using Model II. For example, in the central part of the study area (as seen in Fig. 7b), the right-hand landslide is mapped with approximately 90% accuracy compared to the inventory map (pink polygon/body, updated version). This demonstrates that our developed Model MII effectively maps landslides where geomorphological signatures are well-preserved under forest cover, even after hundreds of years.

That said, as shown in Fig. 7, some areas are not fully or accurately mapped. This is partly due to shared roughness between the landslide and the surrounding terrain, and where the GEOBIA merge small portions of true negatives with true positive were removed partly or vice versa and this type of misclassification recorded in other studies (see Knevels et al., 2019; Dias et al., 2023). Our approach prioritizes minimizing false positives while aiming for inventory mapping over a larger area (150 km^2) rather than perfect detection of individual landslides. Additionally, we have highlighted areas and examples where the model was unable to detect landslides accurately and these limitations can be addressed in future research steps.

Regarding the transferability of the model (MII), we assume it can be applied to other regions and larger areas. However, as noted in our results (Figures 4 and 5), this depends on the availability of high-resolution DTM data and the clear presentation of landslide features. MII can effectively detect and map landslides (scarps and bodies) when these features are well-represented in the DTM.

We acknowledge that the model (MII) and the ruleset in eCognition may require adaptation for different study areas or other landslide types. Nonetheless, this is the first model to use scaled LSVs for scarps and bodies detection and demonstrate the optimal moving window size for each feature. We also assume, supported by previous studies, that geomorphological features may require different moving window sizes for each LSV, which can vary between features. For instance, in landslides, the window sizes differ between scarps and bodies (see Figure 3 and Table 1, in the manuscript).

In the revised manuscript, we presented the morphological characteristics of the GEOBIA-based results from our models, highlighting clear dissimilarities between scarps and bodies in terms of mean LSV values. This demonstrates the feasibility of detecting them separately. For more details, please refer to Tables 2 and 3 in the revised version. Additionally, Figure 3 and Table 1 illustrate the differences between the default model (MI) and the optimized model (MII) regarding assigned LSVs.

The issue of scale has been discussed in numerous studies, and it remains a central focus of our research as the first study to incorporate both landslide components. While it would be fundamentally easier to map landslides as single polygons rather than distinguishing and classifying their components, as some studies have done, our approach aims to refine this process.

Our next research steps will aim to generalize the model to a wider area in Germany to evaluate its transferability at a regional scale. We will also explore further adaptations of the model and assess how effectively we can minimize LSVs and streamline the refinement steps. This research marks an initial step in this direction and in advancing landslide mapping the surrounding region and in Germany, however, we assume that different mass movements may require different criteria and parameter.

Comment. Lines 42-59 present a sparse review of GEOBIA applications in landslides, without clearly stating the state-of-the-art in this regard; since the approach is considered to be an advance, it should be framed better.

Response:

While many studies have utilized GEOBIA to detect landslides, we provided only a brief review, beginning broadly before narrowing the focus. As our study specifically addresses the application of GEOBIA for landslides in forested areas, and more specifically, for identifying old landslides, we have included the most relevant studies within this context. This is why we transitioned from general landslide detection using GEOBIA to the challenges of detecting old landslides based solely on DTM data.

Additionally, we aimed to address the issue of scale, which is a central aspect of our study (see Model II). For this reason, we provided an overview of scale-related challenges, from landform classification to landslide-specific applications. Initially, we even considered beginning directly with the topic of old landslides in vegetated areas using GEOBIA (relying exclusively on DEM data) and focusing solely on the issue of scale. Therefore, while we acknowledge the possibility of including additional studies, we respectfully consider the current review to be appropriately scoped for the objectives of this manuscript.

References

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