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Review of the doctoral thesis submitted by mgr Kamila Pawłuszek

Application of Airborne Laser Scanning Data for the Identification of Landslide Areas

Introduction

Landslides are among those natural surface processes which are not only capable of doing large-scale remodeling of slopes in relatively short time, but they may also cause considerable damage to infrastructure if they occur in managed terrains. Therefore, they have long attracted attention of scientists and hazard assessment and reduction practitioners, resulting in the multitude of approaches and pathways of landslide research. Whereas geomorphologists are primarily interested in explaining the origin of landslides, recognizing the mechanisms of displacement and evaluating their contribution to long-term slope evolution, engineering geologists focus on the properties of failed rock masses and conditions of slope stability, and geodesists explore different remote sensing data sources to help identifying landslide terrains and to monitor their movement over time. The doctoral thesis submitted by mgr (M.Sc.) Kamila Pawłuszek most readily subscribes to the latter line of research and explores the potential of products derived from Airborne Laser Scanning (ALS), also known as LiDAR, in landslide recognition, but her approach clearly fits into the field of geomorphometry, since digital elevation models are the fundamental data sources. While LiDAR datasets, wherever available, are now routinely used for this purpose, recognition and delimitation of landslides are usually done by expert method. The author of the thesis intends to make a step forward and develop algorithms which would allow for automatic recognition of landslide terrains and specific topographic features within such terrains, thus enhancing the potential of ALS data. Her approach has been largely successful, although several problematic issues have also emerged, as will be elaborated in this review.

Structure of the thesis and authorship

The doctoral thesis by mgr Kamila Pawłuszek was presented as a collection of seven publications, published in 2016–2019. One paper was presented as "submitted" but was approved for publication in the meantime. All papers are in English. Three publications (no. 1–3) are parts of conference proceedings and are more of the type of extended abstracts rather than full-size proper research papers, although they were peer-reviewed. Moreover, they show research progress during execution of the PhD project and as such, remain important constituents of the thesis. The remaining four papers have been published in established international journals, all indexed in Web of Science, with Impact Factor above 1.5. These are *Landslides*, *ISPRS International Journal of Geo-Information* and *Natural Hazards* (two papers). The very fact of acceptance to such journals highlights considerable scientific value of individual studies. Except one, all other papers are multi-authored publications, but the contribution of the PhD candidate is substantial and varies from 45% to 90%, usually evaluated as 80% (4 cases). In all publication, Kamila Pawłuszek is the leading author. Thus, there is no doubt that the thesis is mainly an original contribution of the candidate and can be easily evaluated as a single-person work.

The collection of papers reproduced as the doctoral thesis is preceded by a very extensive commentary, 68 pages in total, including bibliography. Its scope goes beyond the usual guidance to the collection of published papers and includes a long section on landslide definition and typology, as well as an even longer review of landslide studies, with the focus on remote sensing applications. While these are generally useful for the reader to find the context, they also have their weaknesses, such as unbalanced presentations of the state-of-the-art in particular sections. However, given that the relevant law act specifies that the PhD thesis is the collection of papers (or a monograph, which does not apply here), it is these papers which should be evaluated, not the commentary, perhaps except part 6 which explains the logic and run of the thesis, the content of individual papers, and summarizes conclusions. In this respect, I have slight reservations concerning section 6.3 (Conclusions from articles). It consists of 18 bullet points of equal weight which is not helpful and actually dilutes the key findings into too many partial achievements. It would be much more useful to apply some sort of hierarchy to the findings, for instance related to the three main application trends of ALS data specified in Abstract (p. 7): identification of landslides, specific landslide features, and susceptible areas. 'Three main findings' presented on page 69 seem in turn too general, but this may just be a subjective feeling of the reviewer.

Evaluation

Significance of the topic. There is little doubt that the subject chosen for the doctoral dissertation is significant, both in the broad sense – landslides are too important factors of landform evolution and too costly events from human perspective to be ignored, as well as in the specific context of remote sensing applications to landslide studies. While there is no need to elaborate on the former, a commentary on the latter is required. The author is correct while saying that field-based methods (called 'conventional' in the thesis) of landslide recognition are time-consuming and have serious limitations, especially in forested or otherwise poorly accessible terrains. They 'require experience of people performing landslide identification' (p. 7). However, the same applies to landslide identification from DEMs and good expert knowledge of landslide geomorphology is required to correctly recognize areas affected by slope failures and their characteristic signatures. Moreover, in the opinion of the reviewer, automatic identification will always require verification in the field for practical applications. It is unclear to me after reading the thesis if the author believes that automatic approach will eventually overcome these requirements and allow for unequivocal and fast recognition of landslide terrains, even if we restrict the field of application to relatively recent landslides, not modified by subsequent processes or human activities. Having said that, it is certainly an interesting avenue of research and the methods proposed may assist in landslide delimitation and, especially, in the recognition of specific topographic patterns within landslides (as explored in paper no. 6).

Order and scope of publications and their mutual relationships. Publications constituting the doctoral thesis do not follow chronological order, but – as explained by the author – represent three main research directions. The bulk of the thesis, papers no. 1–5, explore the key problem of landslide recognition. Paper no. 6 is focused on more detailed characterization of relief within landslides, whereas paper no. 7 is within the theme of landslide susceptibility mapping.

Papers no. 1–5 collectively illustrate an attempt to find the best algorithm to recognize landslides automatically, using various DEM derivatives as input data. The trial and error approach is focused on replacing these DEM derivatives by Principal Components (paper no. 1), finding those DEM derivatives which provide the most valuable information (paper no. 2), finding the most effective resolution (pixel size) for landslide identification (paper no. 3), towards combined analysis of both resolution and moving window size (paper

no. 4), ending with comparative test of pixel-based versus object-based approach (paper no. 5). Altogether, they nicely illustrate the scientific way forward and adequately document the ability of the PhD candidate to work towards the most satisfactory solution of the problem. However, some methodological and presentation problems also emerged and these will be addressed below. Papers no. 6 and 7 are somehow independent from papers no. 1–5 but fit well the overall goal of the research and their inclusion into the collection is fully justified.

Assessment of results and major critical remarks. The principal results, at the generalized level, have been formulated by the author as follows:

- automatic landslide identification can be successfully performed using DEM derivatives and their various transformations, as well as various classification approaches, although effectiveness of the approach is limited to 'fresh' (i.e. relatively recent) landslides.
- Principal Component Analysis of DEM derivatives adds new value to the characterization of landslide morphology and is capable of detecting features otherwise escaping attention.
- high-resolution DEM is sufficient to perform landslide susceptibility mapping.

Regarding the first result, accuracies of identification between 70 and 80% were achieved. Is it good or unsatisfactory result? The authors appears to think that this is good, judging from the phrase used "effective landslide mapping". However, nearly one third unrecognized landslides is still a significant error, especially for practical applications such as landslide delimitation for improving land use policy, safety and insurance issues. In areas such as the Polish Carpathians landslides typically leave readable geomorphic signatures and manual mapping (such as that carried out within the SOPO project) performs fairly well and is not necessarily that time-consuming and is quite cost-effective. Furthermore, expert knowledge can solve the problem of inadequate performance of algorithms on older landslides, subsequently modified by denudation and erosion, as well as on those modified by human activities. This comment does not invalidate the results, but highlights that automatic detection is unlikely to become an alternative to thorough check by a trained geomorphologist. There is, however, an associated problem here which is the accuracy of non-automatic landslide recognition against which the procedure was tested. There seems to be an assumption that expert recognition was entirely correct which is not necessarily the case. This issue was not sufficiently discussed (if at all) by the author of the thesis.

Concerning the second main finding, this is the most valuable one in the opinion of the reviewer, although in the current state it opens a new avenue of research, focused on explanation of features revealed by PCA, rather than solves a problem. Characteristically, while the author herself states that 'this allows for more effective identification of characteristic landslide signatures and a generation of more complete landslide geomorphological maps', she did not attempt such an exercise in the paper no. 6. Historical maps of landslide no. 1 (Fig. 10 in original paper) should have been contrasted with a map based on this new approach. It is unfortunate that geomorphic interpretation (in terms of process – form relationship) is missing.

The third finding does not require special comments and the procedure and conclusions emerging from paper no. 7 are sufficiently documented.

Secondary critical remarks. Some of these may arise from space limitations imposed by publishers of original papers, but formal review of the PhD thesis is considered as an opportunity to raise a few issues:

- the choice of 19 DEM derivatives for further processing in papers no. 1 and 2 were not justified (although paper no. 7 partly filled the gap). Why these and not others? What they tell us about slope morphology in the context of landsliding? Some are not really important for landslide processes (e.g., stream power index) whereas others duplicate information (e.g., slope and TPI) or may be correlated with one another. Why the number of derivatives was reduced to 12 in paper no. 3? Because of experience from papers no. 1 and 2? This is not explained.
- results of automatic classifications versus the actual extent of landslides (e.g., Fig. 6 and 7 in paper no. 1, Fig. 3 in paper no. 2) lack explanation. It would be very interesting to discuss mismatches – why certain areas were classified as landslides whereas they are not, and vice versa. This would be very helpful for the overall assessment of the automatic detection method.
- it is also regrettable that all tests were performed in the same area, where landslides are similar and developed in broadly the same type of bedrock. It would be interesting to know how the algorithms perform in different types of landslides, such as multiple rotational slides involving rigid blocks (widely present in other parts of the Carpathians or parts of the Sudetes).

Technical issues. In addition to those critical remarks above, which have their roots in the "published papers" formula, several associated technical issues have to be emphasized.

If a traditional research monograph model is followed, the author retains full control on the way of presentation of the results. This is not the case if published papers are parts of a thesis, as layout, size and legibility are largely beyond the control of the author. In this particular case, data presentation and hence, reception of the papers suffer from inadequate reproduction. Several figures are poorly or not legible, e.g. 1-1 (number of paper first, followed by number of figure), 3-1, 4-5, 4-6, 4-7, 6-3, 6-8, 7-3. The same is true for tables in Appendix to paper no. 4. In a few cases captions are too vague and do not provide good guidance for the reader (Fig. 1-4, Fig. 6-9). Figures 5 and 6 in paper no. 3 have colours which are not explained in the key.

Conclusions

As the main conclusion of this review it is stressed that the presented doctoral thesis fulfils the criteria set for doctoral dissertations by the relevant "Act on academic degrees and academic title and degrees and title in art" and my final assessment of the work, despite questions and issues raised earlier (partly independent from the author), is unequivocally positive.

The dissertation by mgr Kamila Pawłuszek constitutes an original, creative solution of a scientific problem which is how to use DEMs to assist in automatic landslide detection and mapping. The candidate proved her ability to state the problem, select appropriate methods towards the solution, execute necessary analyses and computations, and critically evaluate the results. The commentary shows that she is sufficiently familiar with both literature on landslides and the state-of-the-art of remote sensing applications.

Therefore, I recommend to accept the thesis as it is and to allow mgr Kamila Pawłuszek to take further steps in the procedure as stated by relevant rules. In addition, in recognition of the high scientific value of the thesis I recommend the thesis to be subject to the relevant award.

Piotr Migoń

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