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Evaluation of shallow landslides in the Northern Walgau (Austria) using morphometric analysis techniques

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Abstract

Landslides play a key role in landscape evolution in the Eastern Alps. These geomorphic phenomena are influenced by multiple interdependent and interacting natural and anthropogenic factors. An in-depth evaluation of the spatial distribution of existing landslides enables to gain first insights into potentially hazardous areas. Morphometric analysis techniques of mapped landslides as well as their date of occurrence allow to infer their activity and also potential impacts on affected areas. The prevalent slow moving landslides and inactive slipping areas were mapped and analysed via digital terrain models (DTM), shaded relief images of highly resolved airborne laserscanning (ALS) data and in-field observations. Orthophotos from aerial surveys and ALS data allowed a deferred-time analyses of past landslide occurrences including a record of recent slope movements. All mapped landslides were classified and analysed with geomorphometric indices. Pedological processes, the lithological setting and anthropogenic landscape transformationwere taken into account when interpreting the results. The geomorphometrical evaluation of the sliding areas determine the creation of a multitemporal landslide inventory in the Northern Walgau.

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Keywords: Shallow translational landslides, geomorphometry, morphometric indices, landslide inventory, Walgau.

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1. Introduction

Shallow translational landslides vary in their extent and dynamics. To interpret static or slow moving landslides accurately, it is important to determine the dispersion and the dimension of landslide features. Morphological analyses can help to understand the connection between appearances of landslips in reference to their immediate environment and the related triggering events. Especially for regions with less or no information about date of landslide occurrences, the quantification of landslide features can help to draw conclusions about mobility, impact on the landscape and material involved. Several techniques have been developed to analyse and quantify morphometric issues of landslides and to describe process-related properties of landslide dynamics[1-7]. An accurate interpretation of morphologic-process relationships appears to be elaborate in situ. The quantification of the relative landslide mobility is designated by the angle of reach[8], expressed by the connecting line between head of landslide source to the distal margin of the displaced mass[6]. Accordingly, the tangent of the reach angle depicts the equivalent coefficient of friction[1]. Several studies[1, 3, 9]explained the relation between the tangent of reach angle and volume of mass material that large landslides tend to develop longer angles of reach than small landslides and are thus more mobile. Whereas it was persisted[5] that the mobility of a landslide increases due to the height of fall. It was shown that a relation between landslide volume, reach angle and topographic constrains on the path that influence the mobility of a slide[6]. Hence, these studies have shown that accurate interpretation of morphologic-process relationships are strongly dependent on intrinsic properties of each landscape. However, morphometrical analysis techniques can help to understand the distribution and the diversity of landslide dynamics in an area.

Mapping of landslides and the development of landslide inventories was decisively simplified with the emerging use of light detection and ranging (LIDAR) to generate very detailed Digital Elevation Models (DTMs). Advantages of using these highly resolved DTMs to locate, delimit and characterise landslides were highlighted in earlier studies[7, 10-12]. Landslide inventories which were created by support of LIDAR are more accurate compared to landslide inventories purely based on observations from satellite images or field survey-based[13, 14]. However, most of these inventories do not consider morphology-process relationships, especially when they do not include temporal information. Hence, the quantification of different landslide features are able to upgrade the information content of a landslide inventory concerning morphometrical dimensions and process dynamics.The quantitative morphological analysis presented in this study is based on morphometrical indices, developed by Crozier[15]. These indices allow statements about the morphology-process-relationship due to their objectivity and significance[15] by using simple mathematical coherences. The primary intention of this study is the development of a multitemporal landslide inventory for the investigation area of the BioSLIDE-project in Vorarlberg, Austria. The combination of detailed airborne laserscanning data and aerial images from different dates of record can improve the temporal and spatial accuracy of the landslide inventory. Hence, the objective of this study is to upgrade the degree of information of this inventory by applying morphometric indices on the precisely delimited landslides from DTMs generated by laserscanning data. Moreover, a multitemporal landslide inventory shall be created for the whole Walgau area with additional information about the relationship of landslide morphology and landslide dynamic from the morphometric indices defined by Crozier[15].

Nomenclature

L	Total length of the landslide
L_x	Length of convex part
L_c	Length of concave part
L_f	Length of the bare surface on the displaced material
L_m	Length of displaced material
L_r	Length of surface of rupture
D_x	Thickness of convex part
D & D_c	Total depth of landslide or depth of concave part respectively
W_x	Width of the convex part
W_c	Width of the concave part

2. Study area

The study site is located in Vorarlberg, Western Austria, within the Walgau valley. The Walgau is drained by the lower course of the Ill River, which itself is recharged by the rivers Lutz, Meng and Samina and finally drains into the Rhine at the Illspitz near Feldkirch. The borders of the three municipalities Düns, Dünserberg and Schnifis (‘Dreiklang’) delimit the area of investigation (Fig. 1). Large parts of the Northern Walgau are located in the Rhenodanubian Flysch zone[16]. The glacial transformation left highly consolidated morainic material with silty-sandy substratum on the southern-exposed site of the Walserkamm ridge, which delimits the Walgau valley from the Laternsertal in the North. On these glacial sediments developed primarily calcareous cambisols and partly wetlands with calcaric gleysols. The changing Pleistocene climate conditions affected the intensity of the geomorphological processes over time. In the recent centuries however, fluvial and slope processes dominate the non-glaciated landscape of the Walgau[17]. Moreover, slow deep-seated movements and partly rockfalls affect the, depending on the intensity of rainfall events, the amount of snowmelt in spring and saturation of the morainic and marly lithic zone respectively.

The Dreiklang area extends over an area of ~12 km² on the south site of the Walserkamm ridge and is drained by three main creeks: Gandabach, Montanastbach and SchnifnerTobl. The latter two converge in the flatter downslope area and form the Vermühlsbach. The altitude ranges between 657 m up to 1985 m at the Hochgerach peak and covers several zones from the alpine zone down to the sub-montane zone. The monthly maximum amount of precipitation does not exceed 150mm in August. The cumulative annual amount of rainfall is around 1136mm, the southern exposed hillslope and an average annual temperature of 7.8°C lead to a relatively high biological diversity. Coniferous and mixed forests in the sub-alpine and montane zone cover approximately 37% of the area. Primarily spruces (*Piceaabies*), firs (*Abiesalba*), scots pines (*Pinussilvestrys*), oaks (*Quercusrobur*) and European beeches (*Fagus sylvatica*) depict the most common tree species in the forested areas. The region was commonly used for both timber harvesting and as alpine pastures for dairy cattle. Hence, the areas on the southern Walserkamm were under a frequent land use change for the last decades[18].

3. Material and Methods

3.1. Landslide mapping and classification

Landslide mapping was conducted in several field surveys to determine both landslides and potential moving areas. Highly resolved DTMs respectively from freely available ALS data of 2004 and 2011 with resolutions of 1 x 1 m² and 0.5 x 0.5 m² were used to support the morphological mapping in the field. Orthophotos from 195x, 198x, 2006, 2009 and 2011 helped to recognize changes in the morphological appearance of the landslides, e.g. differences in the dispersion of the mass material (see Fig. 2). Additionally, archive reports of the Torrent and Avalanche Control (Wildbach- und Lawinenverbauung; WLV) allowed to identify already rebuilt and thus not visible shallow landslides. In total, 34 landslide areas were mapped and classified according to the classification scheme of Cruden& Varnes19. The dimension of certain landslides was considered when the total displacement area was clearly recognizable on the DTM or the orthophotos. The process-morphologic setting was summarized in morphologic overview maps (fig. 2).

Although, temporal data were available from the orthophotos and DTMs, not all mapped landslides show the true distribution at the date of their occurrence. This is mainly due to recultivation and ploughing of the landslide mass material and thus straightening of the topography. Some of the landslides were just recognizable through archive data because of rebuilding or reconstruction of the ground.

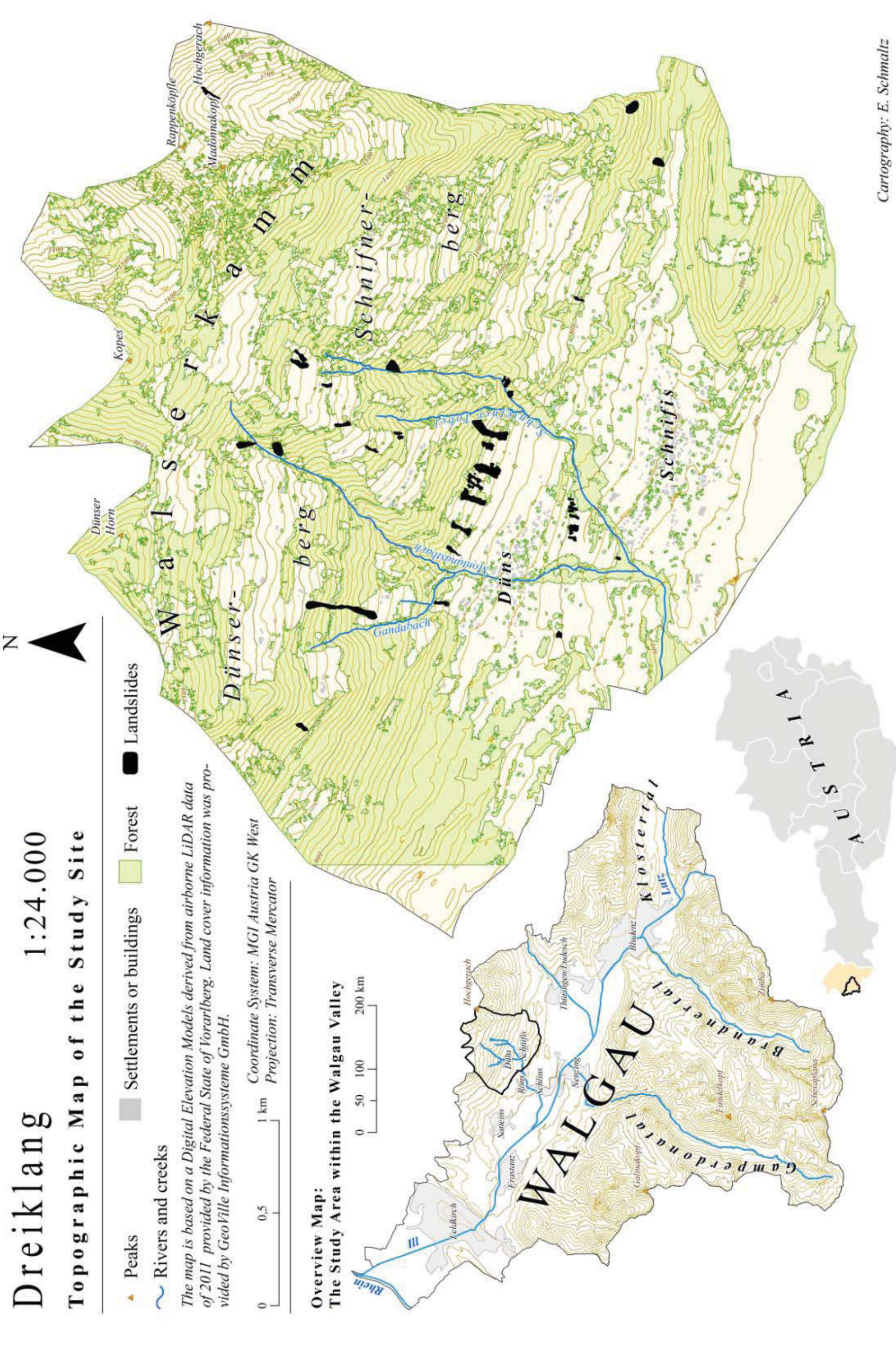

Fig. 1. Study site within the Walgau valley in Vorarlberg, Austria.

3.2. Morphometrical indices

After delimiting and classifying the landslide areas, the distinct features shown in figure 3 were determined in-situ and with digital data.

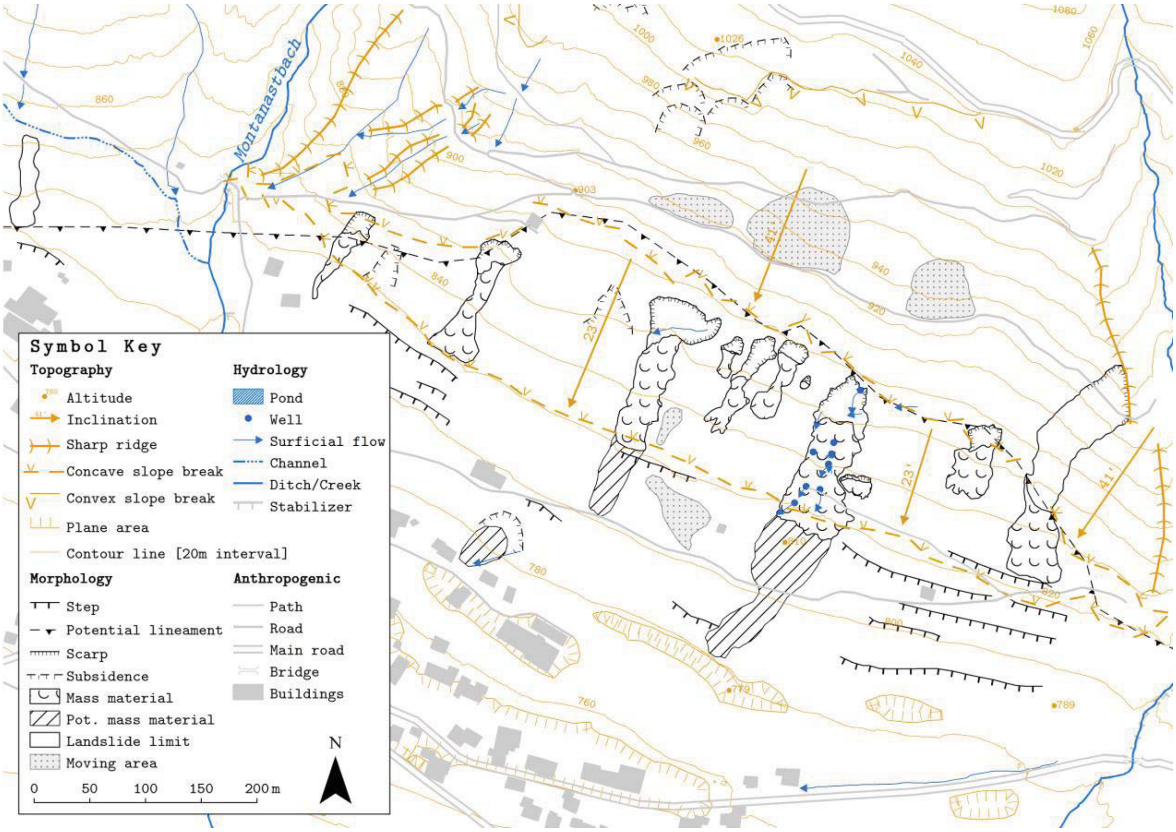

Fig. 2. Process-morphologic overview of the investigated lower slope section.

Table 1. Mathematical description and meaning of morphometrical indices after Crozier[15].

Morphometrical Index	Equation	Description
Classification Index	D/L	The ratio of the maximum depth of the displaced mass material to the maximum length from the scarp to the toe of the landslide.
Dilation Index	W_X/W_C	A precise measure of landslide shape and a classification parameter, particularly for earthflows.
Flowage Index	$\left(\frac{W_X}{W_C}-1\right)*\frac{L_m}{L_C}*100$	Reflects the water-controlled fluidity, the effect of slope angle and indicates the speed of action at the time of the landslide occurrence.
Displacement Index	L_r/L_C	Describes the amount of displacement of the displaced mass material from its original position on the parent slope.
Viscous Flow Index	L_f/D_C	Due to the distinct patterns of landslides at the surface of rupture, this index is only a useful measure for earthflows and describes the displacement of material away from the scar or the surface of rupture respectively.
Tenuity Index	L_m/L_C	Reflects the tenuity of the displaced material in relation to its original size and indicates the effect of slope inclination and the micro-relief features.

With the information of the field observations and comparison with the orthophotos, the landslides were integrated in class of movement scheme considering the classifications after Cruden and Varnes[19]. Hence, 9 viscous flows, 27 slides/flows and 7 planar slides after the structure of Crozier[15] could be distinguished. The morphometrical indices were calculated after the equations given in table 1.

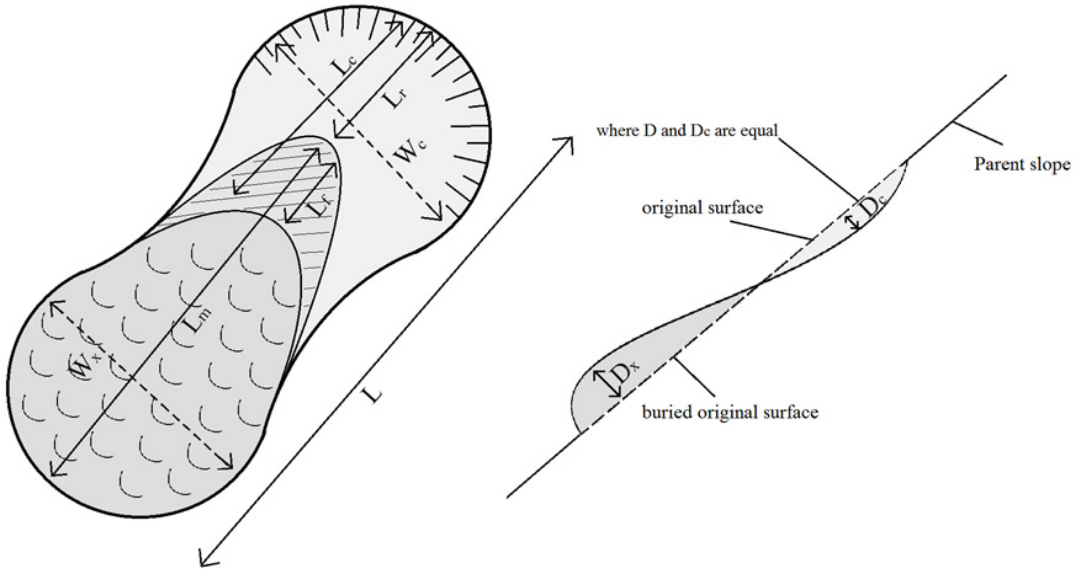

Fig. 3. Measurements of landslide features used in the morphometric indices (after Crozier[15]).

4. Results and Discussion

As it was proposed in the study of Crozier[15], the results of our research showed as well that the landslide morphology is strongly connected to the genetic processes. The majority of the applied indices reflect the related processes adequately, whereas the application of the Viscous Flow Index did not appear to be suitable for the landslides of our study site, because no real earthflows with long travel distances were existent. For this reason, the visualization in Fig. 4 is missing. The ‘process’ – as it is described in the plots of Fig. 4 – depicts the values of the Classification Index, which was stated as an index that can describe the physical dynamics of a landslide process according to its relation between maximum depth (D) and total length (L)[15]. Compared to the appearance of the landslides observed in the field, the correctness of the classification based on the depth-length ratio in respective process groups appear to be quite imprecise and vague. The nine landslides were classified as earthslides or debris slides according to conventional classification schemes[19] and thus come under the process group of planar flows[15]. This is due to the reason that some landslides appear in steep areas with less soil cover. Therefore, a higher amount of debris and coarse grained material is involved when the surficial regolith gets in movement. Nevertheless, the D/L ratio remains to be a very simple and accurate tool to estimate dynamics and distinguish several generic landslide processes[20, 21]. Considering the fact that in our investigation area no real fluid flows according to Cruden and Varnes[19] are existent, dilation and process are showing a significant exponential relation for the process classes 4 to 11 (Fig. 4a). However, taking into account results from different studies, the dilation-process-relation would probably change from an exponential to 3rd order polynomial relation when slides of class 1 to 4 or fluid flows respectively were existent in the study area. The displacement-process-relation shows a significant positive relation (Fig. 4b). Within the flowage index, the degree of fluidity of the sliding process is described. Whereas fluidity defines the water content or the amount of fluid material respectively, that is involved when soil material is displaced by the slide. Hence, the negative relation between fluidity and process indicates decreasing water content with increasing depth-length ratio (Fig. 4c). Considering fluidity isolated from the effect of slope angle, indicates that fluidity increases when flows appear to be more superficial. Due to difficulties in delimiting a clear surface of rupture at some sliding areas, the zonation is based on estimations. This led to imprecise quantification that makes the results not reliable. The lack of relation between tenuity and angle of the parent slope (Fig. 4d) can be explained by the high resolution of the DTM from which slope values were derived. The high resolution leads to inhomogeneous slope angle values in the parent slope area and to some sort of overestimation of topographic effects by the DTM. Filtering or resampling of the DTM or the slope grid could solve that problem or increase the accuracy of the tenuity-angle-relation respectively. In contrast, the relation between tenuity and depth-length ration appears to be high (Fig. 4e). The reason for that is the increasing thinning of the mass material with increase of the distance while traveling down the slope. This is particularly reliable for very shallow planar slides.

Although the results yield more information about morphology-process relationships of the landslides, it remains doubtful whether morphometrical indices can reproduce reliable process conditions. Generally, the methods used in this study to quantify depth of apparent mass material are mostly based on in-field measurements and estimations. To discover the actual thickness of the landslide mass – if it has not already been artificially removed – is to conduct coring or to use geophysical methods such as geoelectrical resistivity tomography. However, both possibilities appear to be challenging to use in a steep environment with primarily consolidated morainic material. Especially anthropogenic landscape transformation in some locations within the study area caused problems in quantifying distinct parts of the landslides. In this regard, orthophotos from different dates of recording were very useful for reconstruction of the original landslide distributions. The linkage of multitemporal orthophotos, highly resolved DTMs, field surveys and available archive reports were fundamental to get reliable results from quantitative techniques such as morphometric indices.

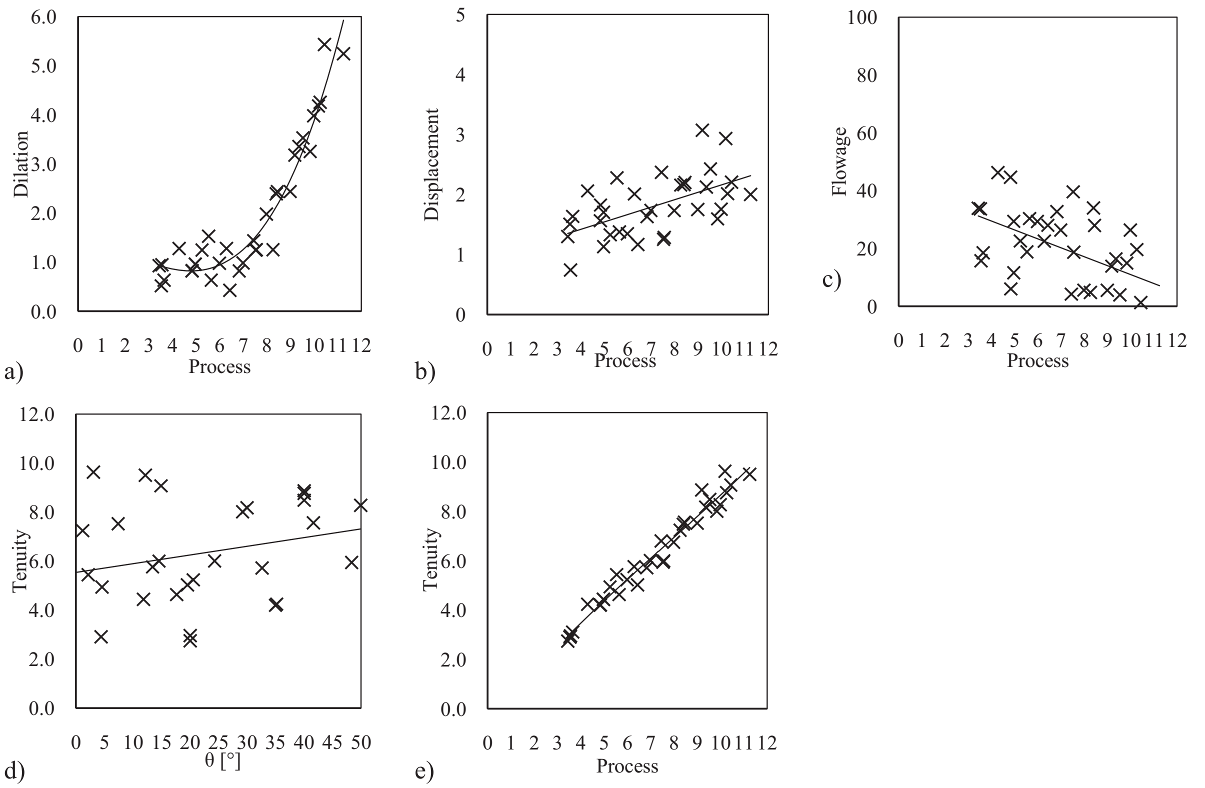

Fig. 4. Regression relations of geomorpho-metric indices with the classification index (process): a) dilation/process; b) displacement/process; c) fluidity/process; d) tenuity/slope; e) tenuity/process

5. Conclusion

The application of morphometric indices is an easy way to quantify landslides, to demonstrate morphologic-process relationships and hold the potential to upgrade the level of information of a landslide inventory. However, the quantification of the several landslide features should be conducted in a combination of in-situ measurements and digital data. In this regard, multitemporal information about the landslides or the date when the landslide occurred respectively are necessary to reproduce the morphometric conditions and material displacement at the moment of occurrence. Morphometric indices hold the potential to give valuable and reliable information about process and condition.

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References

1. Shreve RL. The Blackhawk landslide. *GeolSoc Am Bull* 1968, Special Paper 108.
2. Scheidegger A. On the prediction of the reach and velocity of catastrophic landslides. *Rock Mech* 1973;**5**:231-236.
3. HsüK.J. Catastrophic debris streams (Sturzstroms) generated by rockfalls. *GeolSoc Am Bull* 1975;**86**:129-140.
4. Voight B. Lower GrosVentre slide, Wyoming, U.S.A. In: *Rockslides and avalanches*. Edited by B. Voight. Elsevier, Amsterdam. 1978;**1**:113-166.
5. Skermer NA. Discussion of paper "Nature and mechanics of the Mount St Helens rockslide-avalanche of 18 May1980". *Géotechnique* 1985;**35**:357-362.
6. Corominas J. The angle of reach as a mobility index for small and large landslides. *Can. Geotech*1996;**33**:260-271.
7. Dewitte O, Demoulin A. Morphometry and kinematics of landslides inferred from precise DTMs in West Belgium. *Nat. Hazards Earth Syst. Sci* 2005;**5**:259-265.
8. Heim A. Bergsturz und Menschenleben. FretzandWasmuth, Zurich. 1932.
9. Voight B, Janda RJ, Glicken H, Douglas PM. Nature and mechanics of the Mount St. Helens rockslide-avalanche of May 18, 1980. *Géotechnique* 1983;**33**:243-273.
10. Van Den Eeckhaut M, Poesen J, Verstraeten G, Vanacker, V, Moeyersons J, Nyssen J, van Beek LPH. The effectiveness of hill shade maps and expert knowledge in mapping gold deep-seated landslides. *Geomorphology*2005;**67**:351-363.
11. Gold RD. A Comparative Study of Aerial Photographs and LIDAR Imagery for Landslide Detection in the Puget Lowland, Washington. *Washington Division of Geology and Earth Resources* 2004:66.
12. Haugerud RA, Hardling DJ, Johnson SY, Harless JL, Weaver CS, Sherrod BL. High resolution Lidar topography of the Puget Lowland, Washington – a bonanza for earth science. *GSA Today* 2003;**13**:9.
13. Petley DN, Bulmer MH, Murphy W. Patterns of movement in rotational and translational landslides. *Geology*2002;**30**:719-722.
14. Liu JK, Woing TC. A practical approach to creating a landslide database using Taiwan SPOT Mosaic. *Proceedings of the 20th Asian Conference on Remote Sensing (ACRS 1999)* Hong Kong, 1999.
15. Crozier MJ. Techniques for the morphometric analysis of landslips. *Z. Geomorphology*1973;**17**:78-101.
16. Friebe G. Steine und Landschaft – Zur Geologie der Jagdberggemeinden. In: NaturmonographieJagdberggemeinden. Dornbirn: *inaturaErlebnisNaturschau.* 2013:41-52.
17. Seijmonsbergen AC. Geomorphological evolution of an alpine area and its application to geotechnical and natural hazard appraisal in the NW. Rätikonmountains and S. Walgau (Vorarlberg, Austria) including map series at 1:10,000 scale. PhD. Thesis, University of Amsterdam. 1992.
18. Beiser A. Eine kurze Charakterisierung des Naturraums der Jagdberggemeinden. In: NaturmonographieJagdberggemeinden. Dornbirn: *inaturaErlebnisNaturschau*. 2013:15-34.
19. Cruden DM, Varnes DJ. Landslide Types and Processes. Special Report, *Transp Res Board* 1996;**247**:36-75.
20. Skempton AW. Soil Mechanics in Relation to Geology. *Proc Yorks Geol Soc* 1953; **29**: 33-62.
21. Selby MJ. Aspects of the Geomorphology of the Greywacke Ranges Bordering the Lower and Middle Waikato Basins. *Earth Sci J* 1967;**1**:37-58.