Geomorphometric Pump Track Analysis Using Object-based Image Analysis (OBIA)

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Abstract

Mountain biking has become an increasingly popular sport in the last decades. One of the new trends in mountain biking includes the construction of pump tracks, compact and hilly tracks that can be traversed continuously without pedalling. While the number of pump tracks continues to grow, there is still little research on the topic. The study aims to analyse the pump track in Koppl, Salzburg regarding its geomorphometric features using object-based image analysis (OBIA) methods. This is done by integrating multiresolution segmentation and expert-based classification into a classification scheme, that is specifically adapted to pump track morphology. Six classes were developed that cover plateaus, peaks, slopes, smaller hills, and valleys. The general workflow and rulesets based on the methodology developed allow for a semi-automated and reproducible classification of pump tracks that are in general transferable to other study areas. Transferability and robustness of the classification scheme was tested on another pump track in Wals, which produced overall correct classifications but highlighted that some manual adjustments to ruleset thresholds remain necessary.

1 Introduction

Mountain biking has become an increasingly popular sport in the last decades with a new surge in popularity since the Covid-19 pandemic (NADERER 2021). One of the new trends in the mountain biking domain include the construction and use of pump tracks. Pump tracks are compact, hilly, and often closed tracks that can be traversed continuously without pedalling. The biker's speed in the track depends on his ability to gain momentum by 'pumping' the terrain in the terrain transitions (LIGHTCAP 2009). Riding pump tracks improves general fitness, endurance, as well as curve and jumping techniques and is an easy way to practice mountain biking skills (SALZBURGERLAND 2022). While early pump track designs have mostly been created without a blueprint and solely relied on experienced mountain bikers (LIGHTCAP 2009), increasing professionalism and competitiveness have led to more permanent and complex track designs, made out of asphalt. These tracks are not only suited for mountain bikers, but also for other athletes such as skateboarders or inline skaters (SALZBURGERLAND 2022).

While the popularity of mountain biking as a recreational sport continuous to rise, it remains relatively little researched in academia. The Web of Science database shows 864 entries for the keywords 'mountain' and 'biking', compared to 72.739 for 'swimming', 3.845 for 'jogging', or 9.333 for 'biking'. The search also reveals that current and past mountain biking research is mainly conducted in four key domains: sport sciences (268 entries), tourism (114 entries), environmental sciences (58 entries), and health (mainly focused on orthopaedics with 46 entries and physiology with 42 entries), but only few studies are linked to geography (19 entries), physical geography (12 entries), geosciences (4 entries), or remote sensing (4 entries). When extending the research with the keywords "pumptrack" or "pump" and "track" no results are shown. A quick search in the Scopus database came to similar results, showing that pump tracks represent a research gap that needs to be addressed. Extending the research to pump tracks could not only benefit related research, but also the many track users and designers, giving it additional significance.

The attempt to analyse the earth's surface according to scientific criteria is not new. It is a critical part of multiple domains in earth science, including the discipline of geomorphology. A more quantitative approach to terrain analysis is geomorphometry. Geomorphometry describes methods and approaches to quantitative land-surface analysis (PIKE 1995) and evolved from the related fields of geo-sciences, mathematics, and computer sciences. The operational focus of geomorphometry is the extraction of land surface parameters and objects from digital elevation models (DEMs) by the use of algorithms (PIKE et al. 2009). Geomorphometry has two overarching modes, the analysis of specific and discrete surface features (i.e., landforms) and the general analysis of continuous land surfaces (EVANS 1972). Information about landforms and surface characteristics are obtained by a series of mathematical operations (PIKE et al. 2009).

Different image analysis methods have been developed to discretize and classify land surfaces, which can be categorized into pixel-based and object-based approaches (BLASCHKE & STROBL 2001). Object-based image analysis (OBIA) has the advantage over per-pixel analysis that it includes important additional factors into the analysis results, such as topological relationships of neighbourhood, embeddedness, or shape information of the object (BLASCHKE & STROBL 2001; DRĂGUŢ & BLASCHKE 2006). While OBIA originated in field of remote sensing, it has since also been applied in geomorphometry. DRĂGUŢ AND BLASCHKE (2006) developed a first workflow to apply object-based methods to DEMs to improve classification results of morphological landforms. In comparison to existing digital classification methodologies they identified three main advantages of OBIA to geomorphometric analysis: (a) the reduction of human errors by eliminating manual classification steps, (b) the facilitation of comparisons of results derived from different datasets and (c) the reduction in processing time (DRĂGUŢ & BLASCHKE 2006).

Since then, the number of OBIA applications has continuously increased. In the field of landform mapping OBIA is used to automatically detect and delineate geomorphological features such as volcanic and glacial landforms (PEDERSEN 2016; FEIZIZADEH et al. 2021), drumlins (EISANK et al. 2014), archaeological sites (VERHAGEN & DRĂGUŢ 2012; NOACK 2019), and more. This study aims to analyse pump tracks regarding their geomorphometric features based on OBIA methods, by segmenting and classifying a very high-resolution DEM of the study area. The goal is to verify whether:

I. Geomorphometric methods are suitable for the analysis of pump tracks
II. OBIA can be applied in this scale and resolution
III. Methodology and rulesets are transferable
IV. Pump track analysis can help improve track design

2 Methods and Data

2.1 Study Area

The study area of the main geomorphometric pump track analysis is the pump track near Koppl, Salzburg at 47.820290 N, 13.143099 E (Figure 1). The pump track itself is part of the mountain bike tracks of the Union Mountainbike Club Koppl and was constructed in summer 2021. The total area is about 1013 m², of which about 420 m² is asphalted (KLUG 2021).

Morphologically, the pump track is characterized by various hills and valleys of different sizes. The pump track itself can be divided into three parallel tracks running from east to west. The outer tracks are mirrored and contain the same geomorphological features, allowing for competitions between two track users. All tracks are connected, enabling endless circulations within the tracks. Height differences between the lowest and highest areas are relatively low, ranging between 90 cm at the highest elevations to only 30 cm at the smallest elevations. Horizontal distances between individual peaks also vary, ranging from 2,08 m to 3,75 m, depending on the pump track feature.

The second study area is located near Wals, Salzburg (47.820290 N, 13.143099 E) and is used to verify the methodology and classification scheme developed from the pump track in Koppl. The pump track in Wals is characterized by an overall larger total area and bigger elevation differences.

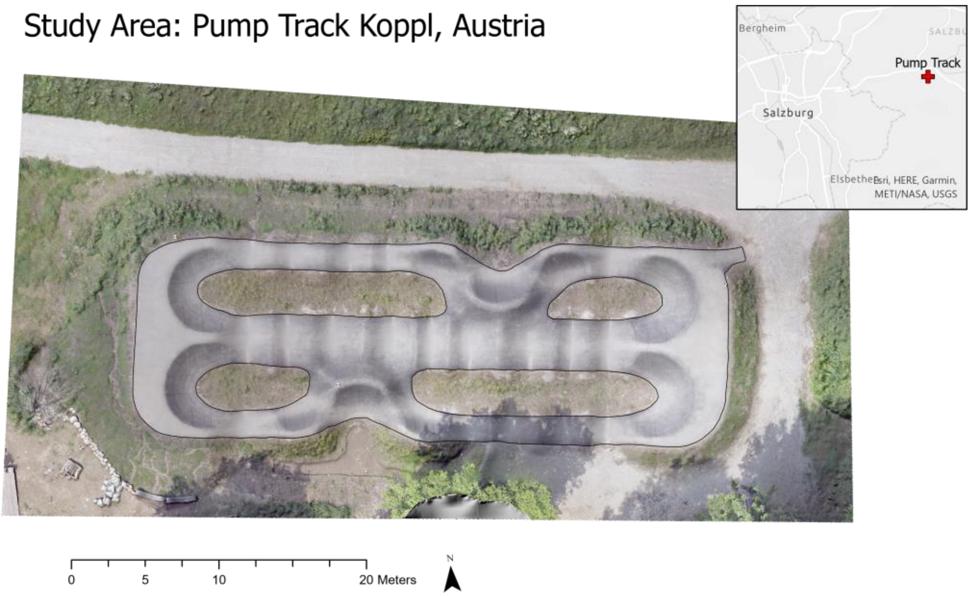

Figure 1: Pump track near Koppl, Salzburg. The superimposed outlines represent the area of interest.

2.2 Analysis Workflow

The geomorphometric analysis is divided into two software environments, ESRI ArcGIS Pro 2.9 and Trimble eCognition Developer 10.2 (see Figure 2). Within ArcGIS Pro most of the pre-processing has been conducted. This contained deriving the surface parameters slope and curvature, as well as the delineation of the paved area as polygon shape. The second part has been conducted in eCognition. This contained the creation of a normalized DEM, the image analysis, and the post-processing. The analysis result was exported as shapefile.

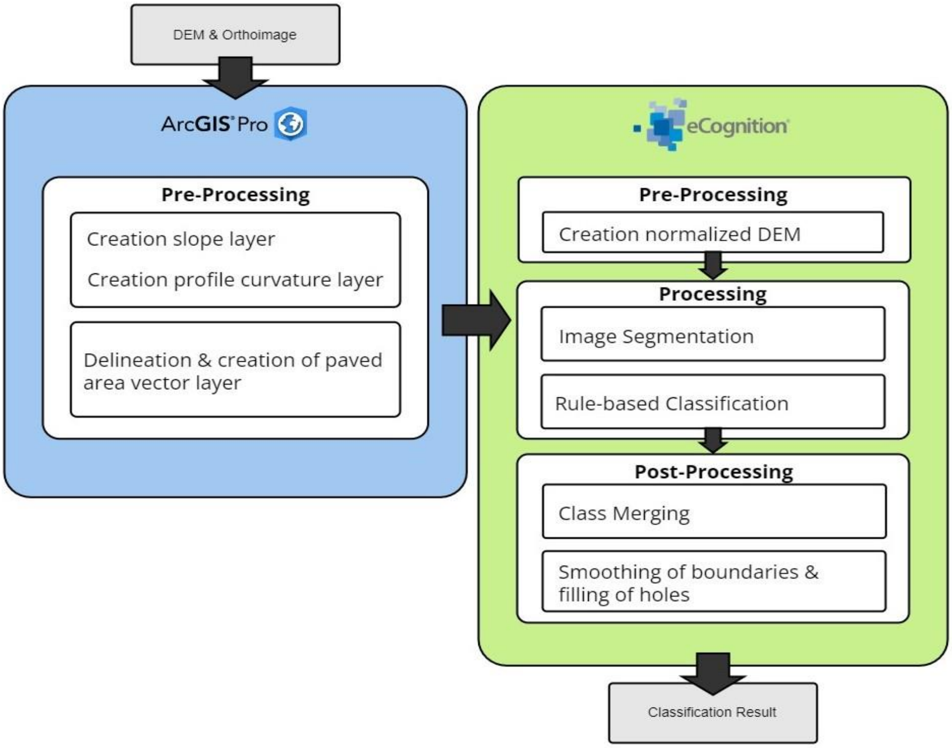

Figure 2: General workflow of the pump track analysis, containing the layer delineation in ArcGIS Pro and the image analysis is eCognition Developer.

2.2.1 Input Data

The datasets used in the geomorphometric analysis are based on imagery acquired by drone. The flight was conducted at the 08.06.2021 shortly after the pump track construction was completed. The resolution of the imagery is about 2.4 cm. After the flight, the imagery was processed via photogrammetry and an orthophoto, as well as a DEM were derived.

2.2.2 Pre-processing and layer delineation in ArcGIS Pro

In ArcGIS Pro, the pre-processing was comprised of two steps. First, the 'surface parameters' geoprocessing tool was used to delineate additional layers of slope and profile curvature from the DEM. The output parameters were calculated cell-by-cell based on fitting a local surface around the target cell (ESRI 2022a). For the calculation of slope and profile curvature, multiple parameters need to be defined. The settings are specified in Table 1.

Table 1: Parameters used for the layer calculation in ArcGIS Pro.

Parameter Type	Slope	Profile Curvature (MINÁR et al. 2020)
Local surface type	Biquadratic	Biquadratic
Neighbourhood distance	Default	Default
Use adaptive neighbourhood	---	---
Z Unit	Meter	---
Output slope measurement	Degree	---

Besides setting the surface parameter type, it is necessary to define the neighbourhood distance for the calculation. The neighbourhood distance value can be defined as the distance from the current processing cell to the centre of an orthogonal neighbour (ESRI 2022b). By defining the neighbourhood distance value, the user regulates how much local variability in the surface is considered. For this calculation the settings are left at default, as this setting already represented a good balance between detail and noise. Adaptive neighbourhood has not been considered in this calculation. The local surface type was set to biquadratic, as the input dataset is highly accurate. This setting has been set according to the recommendations given by ESRI (ESRI 2022a).

In a second part, the paved area was manually derived and saved as a polygon shapefile. This is necessary, as the area of interest is very difficult to automatically derive from the acquired aerial imagery due to shading in parts of the orthoimage and similar spectral values between paved area and gravel/dirt areas around the pavement. This did result in bad automatic delineations within eCognition in test runs which made it necessary to move to manual delineation. All layers were set to use the WGS 1984 UTM Zone 33N reference system.

2.2.3 Pre-processing in eCognition

After switching the software environment to eCognition, the final pre-processing step was conducted to normalize the DEM height values by subtracting every cell with the lowest height value of the elevation model. This was done to make the following analysis less susceptible for absolute height values and to possibly increase the transferability of the rulesets to other pump tracks.

2.2.4 Segmentation

The DEM segmentation was conducted by creating two hierarchy levels. In the first hierarchy level, the area of interest was segmented, using a chessboard segmentation with a very large object size (100.000), and incorporating the thematic vector layer created in the pre-processing. The result was several larger segments, one covering the area of interest (paved area) and one covering the remaining area. Then, the area of interest was classified. In the second segmentation step, the area of interest was segmented again, creating a more detailed segmentation level below the previous segmentation. As segmentation algorithm 'multiresolution segmentation' developed by BAATZ AND SCHÄPE (2000) was used. The advantage of the algorithm is that it incorporates local and global optimization techniques grouping individual pixels into spatially and spectrally homogeneous segments. Segments are created by merging pixels with similar values to image objects and adjacent image objects are merged if they fulfil a predefined homogeneity criterion. The homogeneity criterion assigns a "merging cost" to each possible merge. If the merging cost is too high, further merging between image objects stops. The "merging cost" can be influenced by changing the values of the scale parameter (BAATZ & SCHÄPE 2000). For the pump track analysis, a scale parameter of 5 seemed to be the best fit. Scales smaller than 5 have been proven to produce unwanted over-segmentation, while scales greater than 5 did not recognize smaller and less pronounced surface characteristics. In case of the pump track in Koppl, smaller hills and elevation differences of a height of less than 30 centimetres could be registered in the segmentation process. Finding the best-fitting scale parameter is crucial for a successful classification, as it directly influences the boundaries and numbers of image objects in the area of interest. The determination of a certain scale parameter thus always represents a compromise between producing too small objects and too large objects, covering multiple surface features (DRĂGUŢ & BLASCHKE 2006). Besides finding the best fitting scale parameter, the composition of the homogeneity criterion poses another challenge for successful segmentation. In the composition of the homogeneity criterion, the user must apply a weighting between the factors of shape and compactness. While shape has an influence on the spatial homogeneity, compactness influences the compactness of the image objects (TRIMBLE 2022). Based on the experiences of EISANK et al. (2014) who found out that land surface modelling is improved when the shape factor in the multiresolution segmentation is omitted, shape was not used as a parameter in this segmentation. Instead, only compactness was valued with 0.9. By omitting the shape criterion in the terrain segmentation, elongated image objects with similar height were created which on the first sight resemble contour lines.

2.2.5 Classification

A core component of geomorphometric analysis is the creation of a classification scheme. In difference to existing methodologies and classification schemes, the geomorphological analysis of pump tracks requires new approaches. Unlike existing methods, pump tracks are generally very limited in extent and only have marginal elevation differences. This means that current approaches do not work for this environment and classification results remain insufficient. Therefore, this work proposes a classification scheme specifically designed for pump track analysis with a system that is built on expert knowledge. The overall classification approach is based on the semantic modelling approach developed by DRĂGUŢ AND EISANK (2012). As there are no geomorphologic classifications for this scale, new classes had to be derived. The pump track can be divided into a handful of characteristic surface features. That includes table areas at both ends of the track, as well as hills and curves in various sizes. To better differentiate between the individual features, six classes were defined: plateau, peak, high slope, hill, valley, and noData/unclassified.

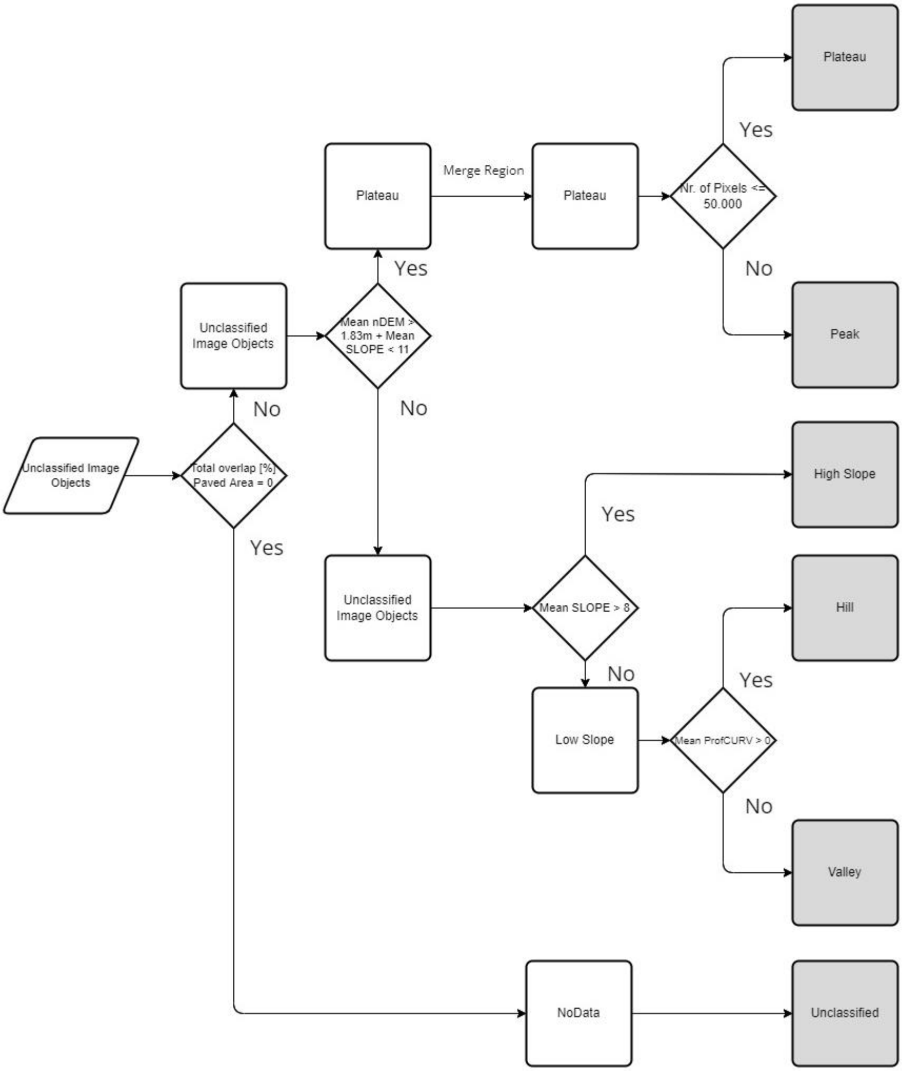

Figure 3: Classification scheme used to delineate surface elements

Every class was then formalized by creating class dividing thresholds based on the image object statistics (see Figure 3). After the segmentation, the first rule checked if the image object lies outside the area of interest (total overlap with paved area = 0). If yes, the object was to be classified as unclassified and would be ignored in the rest of the classification process. The other image objects were then checked for their relative height and their mean slope. If the condition were true (mean nDEM > 1.83 m and slope < 11°), then the image object would be classified as plateau. The plateau image objects were merged in the subsequent step and then checked for their size (number of pixels <= 50.000). If this condition would be true, then the plateau image object would be reclassified as peak, otherwise the class would stay the same. All remaining image objects that were not yet classified as either unclassified, peak or plateau were then checked for their slope. If the mean slope would be greater than 8°, then the image object would be classified as high slope. If the mean slope would be lower than 8°, then the image object would be classified as low slope. In a final classification process, the low sloped image objects were further subdivided by checking their profile curvature properties. If the low slope image object was convex (>0), then the low slope would be reclassified as hill. If the low slope image object was concave (<0), then the low slope would be reclassified as valley.

2.2.6 Post-processing

After classifying the image objects, further cleaning and class merging was conducted. Individual image objects were joined together when objects of the same class were adjacent. This was done for all classes, to achieve a clear result. While the creation of small image objects in the previous segmentation was necessary to detect small-scale surface features, over-segmentation tends to produce scattering in the classification and makes further generalization necessary. This problem increases with high resolution datasets (DRĂGUŢ & BLASCHKE 2006). Additionally, the omission of shape in the multiresolution segmentation process leads to elongated and filamentous image objects. Thus, a post-processing filtering technique was applied to erase finer extensions of image objects and to smooth the image object borders. The filter used, is a proprietary algorithm included in eCognition called 'morphology'. For the closing of the image objects, a circular mask with the size of 25 was applied. The opening of the image objects was filtered with a mask size of 15. While the filtering can erase small details in the classification and might be not applicable in all scenarios, it seems to improve the results in the Koppl pump track analysis. In a final step, the classification results were then merged and exported.

3 Results

The results of the pump track analysis are shown in Figure 4. While an exact delineation of geomorphometric features is difficult due to continuous nature of the pump track's surface, the most distinct areas have been successfully identified. The plateau areas on both sides of the track are clearly segmented, as well as the smaller peaks of the centre curves. By applying the developed classification scheme, elevation differences below 30 cm could be detected and successfully be classified. Smaller pump track features such as the roller and steps have been identified, but no further distinction between the different types of small elevations has been made. They are collectively identified as hills and valleys. Besides the successful classification of the individual pump track features, a standardized workflow and classification scheme was developed, that is designed to be applicable to other pump tracks.

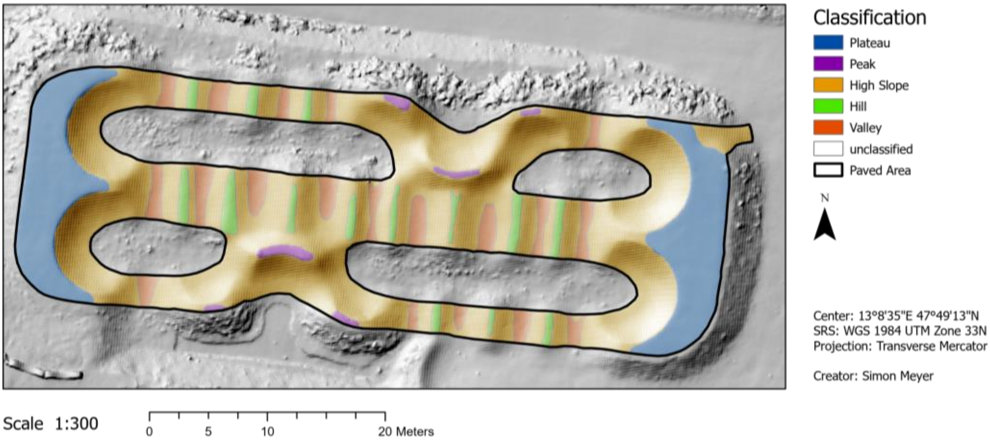

Figure 4: Pump track classification result

4 Validation & Discussion

To validate the robustness and transferability of the workflow and the classification scheme, the rulesets were applied to a second pump track in Wals, Salzburg. While most conditions and thresholds could be directly taken over, some manual adjustments had to be made to the DEM normalization, where the minimum value had to be changed, as well as the threshold of the plateau classification. This was necessary because the DEM had larger elevation differences than the one used for Koppl, an issue whose effects were not initially considered in the original pump track classification scheme. For example, plateaus in the Koppl elevation model were set to >1.83 m while in Wals they had to be changed to >11.8 to get meaningful results. This reliance on absolute values for the classification remains an issue that has been discussed by Drăguţ and Blaschke (2006) who recommended to use (more) relative values to increase the transferability. While a more general classification approach would potentially increase the robustness of the classification approach, it would mean the abandonment of the height criterion, an important factor in the classification of peaks and plateaus and contributor to the creation of meaningful classification results.

A second issue of the methodology developed can be located the influence of resolution and scale in the image segmentation, as OBIA is highly dependent on the quality of the image segmentation (Hossain & Chen 2019). The decision to use certain scale parameters for the surface segmentation was based on observations and trials based on the Koppl pump track. While the trial-and-error method is commonly used in research (Eisank et al. 2014; Hossain & Chen 2019), the influence on other pump track morphologies and datasets needs further research.

Besides the issues in segmentation and classification a third problem of the methodology has been identified the post-processing of the results. The filtering settings applied for the smoothing of the class boundaries were specifically developed for the use in the Koppl pump track. But the application to the pump track in Wals showed that a simple transfer of rulesets created less robust results, indicating that scale can influence the classification results and limit the overall transferability of the approach.

Apart from the shortcomings and design limitations discussed previous, the overall segmentation and classification of the pump track in Koppl has been successful. Small features and elevation differences were detected and classified successfully. With limitations, the workflow and the classification scheme are transferable.

Issues in the classification and definition of thresholds could be solved by applying fuzzy classification rules (DRĂGUŢ & BLASCHKE 2006). For example, the classification threshold for high and low slope areas is set to 8°. This proved to be a good threshold for the pump track in Koppl to narrow down certain areas, but this does not mean that it can necessarily be applied to other areas in the same way. Decreasing the influence of hard thresholds therefore could improve the classification results.

5 Conclusion and Outlook

In the past, OBIA methods have been successfully used for landform extractions and surface classifications. However, previous applications have predominantly been applied to larger scales. The application of OBIA for the geomorphometric analysis of pump tracks has shown that small-scale study areas can also be successfully captured and analysed. For the future, this promises a simpler and more reproducible method for the analysis of pump tracks, which can be easily applied through existing rulesets.

Based on the results, further research can be conducted regarding the effects of terrain types on the mountain biking experience. Additionally, geomorphometric analyses enable pump track designers to easily compare the construction results with the original sketch pla ns, which could lead to improved designs. The biggest current limitation is the limited transferability of the rulesets, as absolute values were used for the class thresholds (such as DEM height for classification of peaks). This limits the application to other study areas and makes a future revision of the classification scheme recommendable.

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References

BAATZ, M. & A. SCHÄPE (2000), Multiresolution Segmentation: an optimization approach for high quality multi-scale image segmentation. Proceedings of Angewandte Geographische Informationsverarbeitung Nr. XII, p. 12-23.

BLASCHKE, T. & J. STROBL (2001), What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. Geo-Informations-Systeme Nr. 14(6), p. 12-17.

DRĂGUŢ, L. & T. BLASCHKE (2006), Automated classification of landform elements using object-based image analysis. Geomorphology (Amsterdam, Netherlands) Nr. 81(ISSN: 0169-555X), p. 344, 10.1016/j.geomorph.2006.04.013.

DRĂGUŢ, L. & C. EISANK (2012), Automated object-based classification of topography from SRTM data. Geomorphology (Amsterdam, Netherlands) Nr. 141-142(ISSN: 0169-555X), p. 33, 10.1016/j.geomorph.2011.12.001.

EISANK, C., M. SMITH & J. HILLIER (2014), Assessment of multiresolution segmentation for delimiting drumlins in digital elevation models. Geomorphology (Amst) Nr. 214(ISSN: 0169-555X), p. 464, 10.1016/j.geomorph.2014.02.028.

ESRI (2022a), Surface Parameters (Spatial Analyst). Retrieved: 11.06.2022 Last, from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/surface-parameters.htm.

ESRI (2022b), How Surface Parameters works. Retrieved: 11.06.2022 Last, from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-surface-parameters-works.htm.

EVANS, I. S. (1972), General Geomorphometry, Derivatives of Altitude, and Descriptive Statistics. Methuen & Co. Ltd., London.

FEIZIZADEH, B., M. KAZEMI GARAJEH, T. BLASCHKE & T. LAKES (2021), An object based image analysis applied for volcanic and glacial landforms mapping in Sahand Mountain, Iran. Catena (Giessen) Nr. 198(ISSN: 0341-8162), 10.1016/j.catena.2020.105073.

HOSSAIN, M. D. & D. CHEN (2019), Segmentation for Object-Based Image Analysis (OBIA): A review of algorithms and challenges from remote sensing perspective. ISPRS Journal of Photogrammetry and Remote Sensing Nr. 150, p. 115-134, https://doi.org/10.1016/j.isprsjprs.2019.02.009.

KLUG, H. (2021), Union MTB Club Koppl. Der Koppler Pumptrack. Koppl, Union Mountainbike Club Koppl.

LIGHTCAP, S. (2009), Pumpin': An Introduction to the world of pump tracks. Retrieved: 28.03.2022 Last, from https://adventuresportsjournal.com/pumpin-an-introduction-to-the-world-of-pump-tracks/.

MINÁR, J., I. S. EVANS & M. JENČO (2020), A comprehensive system of definitions of land surface (topographic) curvatures, with implications for their application in geoscience modelling and prediction. Earth-science reviews Nr. 211(ISSN: 0012-8252), 10.1016/j.earscirev.2020.103414.

NADERER, M. (2021), Was Mountainbiken in Salzburg so beliebt macht. Radurlaube stehen hoch im Kurs. Salzburg24. Salzburg, Salzburg24.

NOACK, D. (2019), Gis-based analysis for the detection of medieval ridge-and furrow soil cultivation patterns within the prignitz region (North-eastern germany). AGIT-Journal fur Angewandte Geoinformatik Nr. 5, p. 60-72, 10.14627/537669006.

PEDERSEN, G. B. M. (2016), Semi-automatic classification of glaciovolcanic landforms: An object-based mapping approach based on geomorphometry. Journal of volcanology and geothermal research Nr. 311(ISSN: 0377-0273), p. 40, 10.1016/j.jvolgeores.2015.12.015.

PIKE, R. J. (1995), Geomorphometry - progress, practice, and prospect. Zeitschrift fur Geomorphologie, Supplementband Nr. 101, p. 221-238.

PIKE, R. J., I. S. EVANS & T. HENGL (2009), Geomorphometry: A Brief Guide. In: HENGL, T. & REUTER, H. I. (Hrsg.). GEOMORPHOMETRY: CONCEPTS, SOFTWARE, APPLICATIONS. 33, p. 3-30.

SALZBURGERLAND (2022), PUMP IT UP! Die Pumptracks im Salzburger Land liegen voll im Trend. Retrieved: 25.06.2022 Last, from https://www.salzburgerland.com/de/pumptracks-im-salzburgerland/.

TRIMBLE (2022), Trimble eCognition Developer for Windows operating system - Reference Book. Trimble Germany GmbH, Munich.

VERHAGEN, P. & L. DRĂGUȚ (2012), Object-based landform delineation and classification from DEMs for archaeological predictive mapping. Journal of archaeological science Nr. 39(ISSN: 0305-4403), p. 703, 10.1016/j.jas.2011.11.001.