Towards delineation of the morphostructural division of the Western Carpathians using object-based image analysis

Peter Bandura, Jozef Minár, Tatiana Harciníková
Faculty of Natural Sciences
Comenius University in Bratislava
Bratislava, Slovakia
peter.bandura@uniba.sk; jozef.minar@uniba.sk

Lucian Drăguţ
Department of Geography
West University of Timişoara
Timişoara, Romania
lucian.dragut@fulbrightmail.org

Abstract— **Preliminary results of an object-based methodology for delineation of the morphostructural division of the Western Carpathians region are presented. Normalized slope gradient and vertical dissection were used as input layers. Automated object extraction was carried out using a multi-resolution segmentation algorithm implemented in the eCognition® Developer software. Visual evaluation and preliminary quantitative quality assessment of the resulting segments boundaries showed a potential of using this method for delineation of objects fairly similar to the expert-made (manually drawn) traditional geomorphologic regions. Future work on both segmentation and classification, as well as quantitative accuracy assessment of the objects is needed.**

INTRODUCTION

Description of the Western Carpathians mountain arc as an active dome-like megamorphostructure was mentioned for the first time by [1]. This mountain range can be considered as the first-order morphostructural division, which includes a mosaic of mountains and valleys (divisions of the 3rd order) [2] aggregated, at a higher level, into concentric morphostructural regions of the 2nd order. Lacika and Urbánek [3] relied on the above mentioned hierarchy to create a 2nd order morphostructural division, but only for the territory of Slovakia and without further interpretation. Minár et al. [4] proposed the most recent morphostructural subdivision of the whole Western Carpathians by integrating the traditional geomorphological regions based on both morphometric analysis and geodynamics. Use of hand-drawn traditional geomorphological regions could be considered as shortage or lack of objectivity here.

The first significant application of object-based image analysis (OBIA) in geomorphometry was introduced in the same time by [5] and [6]. Many other studies that followed showed the potential of segmentation for landform mapping.

In contemporary geomorphology and geomorphometry the demands for objective and reproducible methodological approaches are very high. Thus, we try to realize a fully automated method for delineation of morphostructural division of the Western Carpathians in a relatively objective manner. Since the active morphostructures are well-reflected in terrain morphology and therefore they should be also reflected in the traditional geomorphological regions, the regionalization using only DEM and its derivatives should be feasible. The location of the study area (boundary used here has gradational character and contains also transitional and marginal areas) and the traditional geomorphological regions can be seen in Fig. 1.

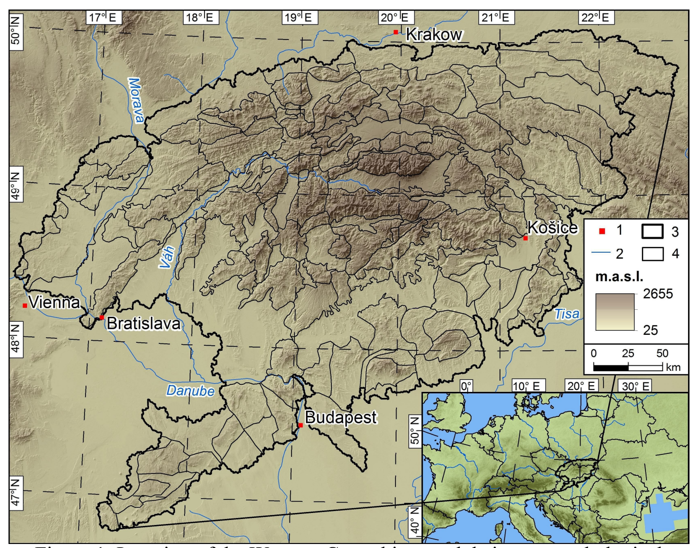

Figure 1. Location of the Western Carpathians and their geomorphological regions as compiled by [4]. Legend: 1) main cities; 2) main rivers; 3) boundary of the Western Carpathians; 4) traditional geomorphological regions

In: Geomorphometry for Geosciences, Jasiewicz J., Zwoliński Zb., Mitasova H., Hengl T. (eds), 2015. Adam Mickiewicz University in Poznań - Institute of Geoecology and Geoinformation, International Society for Geomorphometry, Poznań

METHODS

Input data and their pre-processing

SRTM V4 dataset [7] resampled to 80-meter resolution (approximated cell-size for latitude of our study area) was employed. Part of the noise was removed using r.denoise algorithm with a threshold value of 0.99 and 5 iterations [8]. The DEM was then used for the derivation of two land-surface variables - slope gradient and vertical dissection, which is often referred to by other terms, e.g. available relief or range. The latter represents the amplitude of the land surface undulation.

The slope gradient was computed with a size-changing moving window using the Characteristic scale script in LandSerf GIS [9]. This method allows to measure a surface parameter at a range of scales and find the most extreme one. The largest moving window size was set to 25 cells. The vertical dissection of terrain was computed as the standard deviation of elevation in the circle moving window with a diameter of 2 km [10].

Before performing multi-resolution segmentation, the values of the slope gradient and vertical dissection were transformed in order to bring their frequency distribution close to a normal (Gaussian) distribution. According to the results of the Normalization script developed by [11], we used logarithmic function for slope gradient and square root function for vertical dissection. The tool [11] was developed for slope gradient and curvatures, and because the vertical dissection raster had quite similar data distribution, it was successfully applied on it as well. These transformed input layers were used in the subsequent object-oriented image analysis.

Multi-resolution segmentation

The delineation of morphometric individuals was performed using multi-resolution segmentation in the eCognition® Developer software. The most fundamental parameter in multi-resolution segmentation is the scale parameter (SP), that was determined with the automated tool called Estimation of scale parameter 2 (ESP2) [12]. The tool automatically creates objects at three scale levels. The SP increments for levels were set to 1, 2 and 5 (with a starting SP of 1); values for shape and compactness parameters were set to default (0.1 and 0.5); number of loops to 200, and both hierarchical and non-hierarchical approach were applied. The segmentations were carried out for single input layers, as well as for combination of the layers. Since the SP values picked by the ESP2 are just approximations, the final values were selected by additional visual examination of the local variance graph computed in the non-hierarchical approach (as the most prominent peaks). For technical details on multi-resolution segmentation, the reader is referred to [12].

Compatibility assessment

Preliminary compatibility and significance assessment of boundaries of the delineated objects were at first done by visual comparison and then by calculation of some of the quality measures suggested by [13] against boundaries of the reference polygons – traditional geomorphological regions of the whole Western Carpathians (Fig. 1). Calculation of these quality measures is based on matching reference and delineated polygon boundaries. This was carried out by creating a series of buffers (so-called domains) with a range of widths around object boundaries (reference and delineated) and their intersection with the original boundaries (delineated and reference, respectively). As a result, two quality measures and their ratio were computed by a python script in QGIS (PyQGIS):

1. Completeness – percentage of the reference boundaries length within the delineated data domain, saying how complete the delineated network is (optimal value is 1).
2. Correctness – percentage of the delineated boundaries length within the reference data domain, saying how correct the delineated network is (optimal value is 1).

Based on their ratio (Correctness/Completeness) the most optimal segmentation was determined.

RESULTS AND DISCUSSION

To perform successful segmentation of the terrain data resulting in meaningful objects with relatively compact shape, the transformation of the data distribution is crucial. As a result of MRS, relatively homogeneous objects in terms of terrain roughness were delineated. The segmentation of individual layer allowed us to see which terrain boundaries are represented by each layer. Segmentation of both layers combined proved to be the most suitable. Based on the values from the Local Variance graph, five levels of segmentation with SP 71, 83, 115, 135 and 154, with equal weights for both layers, were carried out. Generally, the course of the object boundaries from all segmentations (not shown here) in most cases clearly divided the terrain into basic and simple block structures – mountains ranges and intermountain basins and in some cases also into their smaller parts. Since higher values of SP generally led to larger and thus less homogeneous segments, MRS with higher SP (e.g. 154) resulted in larger regions, which in some cases consist of relatively smaller mountains or plains. On the contrary, MRS with lower SP (e.g. 71 or 83) even subdivided larger structures into their smaller parts. Objects from all five segmentations were used as an input into the quantitative compatibility assessment, whose results are in the Table 1.

We included some basic statistics of both the delineated objects and the geomorphological regions.

TABLE I. COMPATIBILITY ASSESSMENT OF THE DELINEATED OBJECTS AGAINST GEOMORPHOLOGICAL REGIONS WITH THEIR BASIC STATISTICS

Level	Com	Corr	Corr/ Com	N	Mean area (km^2)	Mean elevation (m a.s.l.)	SD elevation (m a.s.l.)
SP 71	0.80	0.53	0.66	536	165.66	403.97	233.93
SP 83	0.76	0.55	0.73	402	220.88	399.98	239.98
SP 115	0.67	0.61	0.91	223	398.18	408.71	238.34
SP 135	0.62	0.63	1.01	173	513.26	416.76	245.61
SP 154	0.60	0.65	1.09	142	625.31	426.91	244.71
Geomor. regions	-	-	-	144	616.6	476.2	239.89

Com – completeness; Corr – correctness; Corr/Com – ratio between them; N – number of polygons

The value of *Correctness* increases with higher SP values. On the other hand, the values of *Completeness* show the opposite trend, which is obvious because with lower SPs the delineated network and its domain are more extensive. Therefore, we combined these two measures and based on the value of their ratio the segmentation with SP 135 was selected as the most plausible (the value of the ratio is closest to 1). Resulting objects of the chosen segmentation are displayed in Fig. 2.

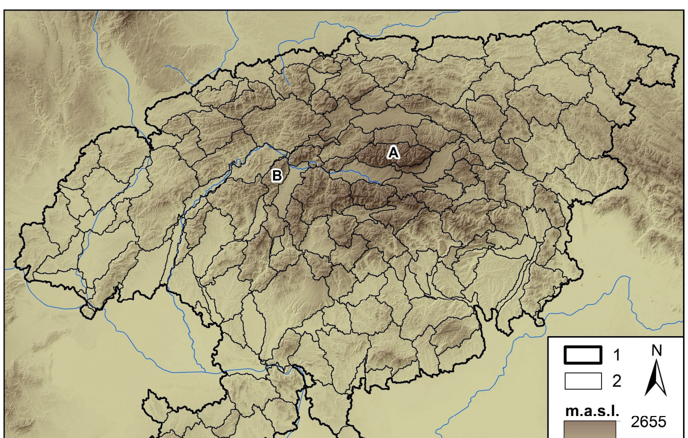

Figure 2. Preliminary results of the multi-resolution segmentation with SP 135. The High Tatras (A) and the Malá Fatra (B) mountains.
1) boundary of the Western Carpathians; 2) delineated objects.

There are several cases where the mismatch between the delineated and reference boundaries is clearly visible. There is also a small difference between the number of delineated and reference polygons as well as between their average area, which can be attributed to several reasons. Firstly, it might be caused by local differences in the level of detail in manual mapping, while the scale of segmentation holds globally. Especially in areas with large extent, highly rugged terrain and contrast topography, being the case of the Western Carpathians, the globally set SP value tends to over-segment rough areas, while under-segmenting smooth ones. This could be possibly eliminated by using refining segmentations of objects by separating mountains and basins delineated on higher (relatively rough) level, and creating lower levels with specific SPs for each domain. Secondly, traditional geomorphological regions could have been delineated also by other criteria than geomorphometric (e.g. geology, geomorphological development), and subjective decisions of the authors played some role, too. Moreover, inconsistent methodological approaches in different countries might have also contributed to different levels of detail in the reference regions. This should be eliminated by using only the Slovak part of the area for compatibility evaluation. The traditional regions here are more (and relatively consistently) detailed due to existence of subregions and parts.

Most distinctive and relatively unquestionable boundaries appear between contrasting areas - relatively flat basins bounded by high mountains with steep slopes e.g. High Tatras and Low Tatras mountains, Malá Fatra mountains and their surroundings. Thus, in these cases the boundaries are quite similar to those manually-drawn. Major differences occur in the areas where the reference polygons were apparently drawn according to other criteria than terrain morphology.

The classification shown in Fig. 3 clearly points to a gradational structure of the Western Carpathians terrain. Furthermore, the concentric clustering of objects towards the central and highest part of the area (High Tatras mountains) is clearly visible. However, this is just an example out of many possible classifications, and a feasible illustration of relatively meaningful object delineation even in this stage of research.

Future work will focus on the improvement of both object delineation (segmentation), as well as quantitative compatibility assessment of the delineated objects using both the already employed polyline-based method [13, 14], and some of the available methods designed for polygons described in e.g. [15], [16] and [17]. Even though the compatibility evaluation of segmentation is based on a comparison with the traditional geomorphological regions as the reference objects, our main goal of this part of the research is not to fully recreate these regions, but rather to provide their alternative in more detailed way, mainly in the fuzzy and questionable areas. Furthermore, some refinement of the final objects resulting from the most plausible segmentation will be needed due to over/under-segmentation in some parts of the area.

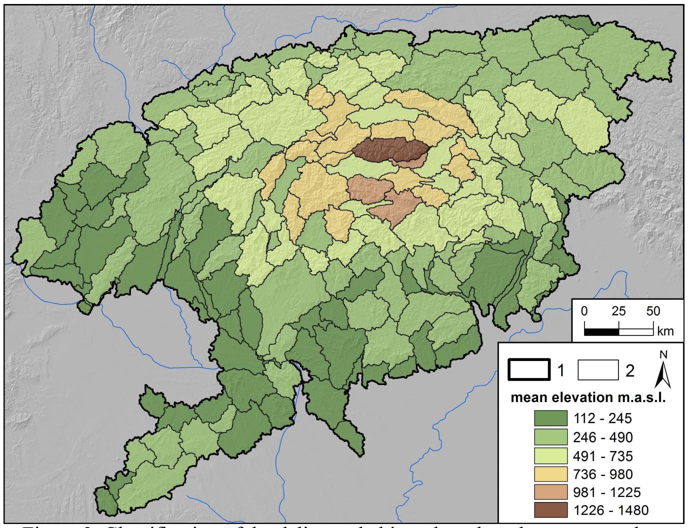

Figure 3. Classification of the delineated objects based on the average values of elevation per polygon. Classes represent multiplied values of its standard deviation. 1) boundary of the Western Carpathians; 2) delineated objects.

CONCLUSIONS

According to the results so far, object-based image analysis seems to be a suitable tool for the automated delineation of the gemorphometric divisions that represent the whole or parts of active morphostructures within the Western Carpathians. The segmentation based on layers representing meaningful morphometric characteristics such as slope gradient and vertical dissection of terrain can be used for the definition of basic morphotectonic regions. Nevertheless, further work composed of several steps mentioned in the discussion is necessary. However, using this approach, we should be able to objectivize the input objects basis for subsequent analysis resulting in morphostructural regionalization as proposed by [4].

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0625-11 and by the Comenius University in Bratislava under the contract No. UK/137/2015. Peter Bandura is grateful to Ovidiu Csillik for all the help and support provided during internship in Timişoara.

REFERENCES

[1] Mazúr, E., 1965. "Major features of the Western Carpathians in Slovakia as a result of young tectonic movements". In Geomorphological Problems of Carpathians, Edited by: Mazúr, E. and O. Stehlík, SAV, Bratislava.

[2] Mazúr, E., 1979. "Morphostructures of the Western Carpathians and their development". AFRNUC. Geographica, 17: 21-34 (in Slovak)

[3] Lacika, J. and J. Urbánek, 1998. "New morphostructural division of Slovakia". Slovak Geol. Mag., 4: 17-28.

[4] Minár, J., M. Bielik, M. Kováč. D. Plašienka, M. Stankoviansky, and H. Zeyen, 2011. "New morphostructural subdivision of the Western Carpathians: An approach integrating geodynamics into targeted morphometric analysis". Tectonophysics, 502: 158-174.

[5] Drăguţ, L. and T. Blaschke, 2006. "Automated classification of landform elements using object-based image analysis". Geomorphology, 81: 330-344.

[6] Asselen, S. and A. C. Seijmonsbergen, 2006. "Expert-driven semi-automated geomorphological mapping for a mountainous area using a laser DTM". Geomorphology, 78/3-4: 309-320.

[7] Jarvis, A., H. I. Reuter, A. Nelson, and E. Guevara, 2008. "Hole-filled SRTM for the globe Version 4". Available from the CGIAR-CSI SRTM 90m Database.

[8] Stevenson, J. A., X. Sun, and N. C. Mitchell, 2010. "Despeckling SRTM and other topographic data with a denoising algorithm". Geomorphology, 114: 238-252.

[9] Wood, J., 2009. "Chapter 14 Geomorphometry in Landserf", In Geomoprhometry-Concepts, Software, Applications. Development in Soil Science, vol. 33, Edited by: Hengl, T. and H. I. Reuter.

[10] Mazúr, E. and V. Mazúrová, 1965. "The map of relative relief of the territory of Slovakia". Geografický časopis, 17: 3-18 (in Slovak).

[11] Csillik, O., I. S. Evans and L. Drăguţ. "Transformation (normalization) of slope gradient and surface curvatures, automated for statistical analyses from DEMs". Geomorphology (submitted).

[12] Drăguţ, L., O. Csillik, C. Eisank, and D. Tiede, 2014. "Automated parameterisation for multi-scale image segmentation on multiple layers. ISPRS Journal of Photogrammetry and Remote Sensing, 88: 119-127.

[13] Heipke, C., H. Mayer and C. Wiedemann, 1997. "Evaluation of automatic road extraction". Int. Arch. Photogramm. Remote Sens, 23: 47-56.

[14] Thommeret, N., J. S. Bailly, and C. Puech, 2010. "Extraction of thalwegs networks from DTMs: application to badlands. Hydrology and Earth System Sciences, 14: 1527-1536.

[15] Clinton, N., A. Holt, J. Scarborough, L. Yan, and P. Gong, 2010. "Accuracy assesment measures for object-based image segmentation goodness". Photogrammetric Engineering & Remote Sens., 76/3: 289-299

[16] Zhan, Q., M. Molenaar, K. Tempfli, and W. Shi, 2005. "Quality assessment for geo-spatial objects derived from remotely sensed data". International Journal of Remote Sensing, 26: 2953-2974.

[17] Eisank, C., M. Smith, and J. Hillier, 2014. "Assessment of multiresolution segmentation for delimiting drumlins in digital elevation models". Geomorphology, 214:452-464.