Multi-scale Landform-based Recognition of Selected Mountain Peaks from DEMs in Slovakia

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Abstract: *Results of evaluation of using two automated methods for landform recognition – modules r.param.scale and r.geomorphon in GRASS GIS – for the purpose of fuzzy delimitation of mountain peaks in multi-scale manner are presented. For the analyses, some of the most famous and frequent hiking destinations in Slovakia and two different DEM resolutions were selected. For both tested methods and DEM resolutions, we applied various settings to evaluate the most suitable ones. Consequently, we assessed accuracy of the landform extraction against a dataset of spot heights from topographic maps and evaluated to which degree such maps reflect the terrain itself. In conclusion, results of this study could present contribution not only for geomorphologists but also for the general public by providing different perception of the surrounding landscape from general paper maps when hiking or walking in mountains.*

Keywords: *landforms, geomorphometry, objective mapping, fuzziness, GRASS GIS*

Introduction

Fisher et al. (2004) asked in their paper one simple question: “Where is a mountain?” This, however, does not seem to have one simple or consistent answer. The most common answer in the country with terrain as in Slovakia would be that it is the area with the altitude higher than the altitude in the adjacent area, i.e., higher forms elevated above their surroundings (e.g., High Tatras Mts. above Podtatranská kotlina basin). Another simple answer could be that the mountain is where the highest point or summit is situated. However, such answers contain many ambiguities. On the contrary, we could at least agree that mountain is not represented by a mere point or summit; it has a spatial extent consisting of various parts. Therefore, mountain is not a so-called bona fide object, with real and crisp boundaries, but it can be interpreted as a so-called fiat object, strongly dependent on human definition and having variable boundaries (Fisher et al. 2004). Based on this, we can conclude that some landforms are clearly part of a mountain (e.g., the highest points or ridges), some have slightly smaller membership (e.g., slopes downwards from the ridges) and some have transitional or unclear membership (e.g., foothills or their adjacent slopes), suggesting that mountains do not have sharp boundaries that would separate them from their surroundings (Mark and Smith 2004). This statement suggests that the concept of mountain as well as its parts (partial landforms) is vague, mainly in definition of their spatial extent (Fisher et al., 2004). Therefore, approaches to landform classification can be subdivided into two groups – rigid (e.g., sharp) and continuous (e.g., fuzzy) (Burrough et al. 1997 in MacMillan et al. 2000). In sharp classification (i.e., classic set theory), an object (i.e., grid cell) is assigned by either value 1 (if it belongs to the class) or value 0 (if it does not belong to the class). In fuzzy set theory, this binary perception is replaced by a membership function, with an object assigned in the interval <0, 1> (1 represents full and 0 no membership) based on its similarity to the class description (Fisher et al. 2004, Minár 2006). The same fuzzy logic can be applied not only to the landform definitions but also to geomorphological regions (e.g., mountains or basins) or elementary terrain forms (Minár et al. 2016). Background to the notion of vagueness in geography can be found in works of Varzi (2001) or Smith and Mark (2003), wherein authors ask a philosophical question if mountains exist and analyse an ontology of landforms.

This study is focused on fuzzy identification or delimitation of the most prominent and undeniable parts of the mountains – their highest parts (peaks) – and is inspired by the previously cited work of Fisher et al. (2004), wherein multi-resolution approach to the definition of fuzzy set membership of morphometric classes of landscape is applied in the Lake District (England). However, the presented study analyses only one of the six morphometric classes included originally – peaks. Therefore, results of fuzzy recognition of some of the most popular and frequently hiked mountain peaks in Slovakia are presented.

Work of Fisher et al. (2004) was expanded and modified in Fisher et al. (2005), wherein they applied multi-resolution classification as the basis of the morphometric classes as fuzzy sets to the Ben Nevis area (Scotland) and the Ainsdale coastal sand dunes (England). Similar issues were dealt with also in other studies; Deng and Wilson (2008) mapped mountain peaks as multi-scale fuzzy entities with modifiable boundaries and variable contents in the Santa Monica Mountains (California), Podobnikar (2012) focused on detection of mountain peaks and delineation of their shapes using DEM and autometrical methodological procedures in the Kamnik Alps (Slovenia), Schmidt and Hewitt (2004) presented fuzzy land element classification from DTMs based on geometry and terrain position applied on different landscapes of the New Zealand South Island, and Šašak and Gallay (2014) presented multi-scale analysis of Spišská Magura Mts. (Slovakia) using r.param.scale tool.

The main aims of the presented study are to evaluate suitability of two GRASS GIS terrain classification methods (r.param.scale and r.geomorphon) for mountain peaks recognition, applied on several peaks with various shapes and properties located in different mountains in Slovakia using two input DEMs different in resolution and, subsequently, to evaluate accuracy of peak representation as spot heights in the reference map – (topographic map of scale 1:10 000. Comparison of the two computationally different approaches and their application on several mountain peaks differing in their shape and situation can be considered as original contribution to the fuzzy topic in geomorphology.

Material and methods

Location of the 12 analysed mountains peaks within the territory of Slovakia is shown in fig. 1. Tab. 1 lists the peaks with their elevation values extracted from spot heights in the reference map and input DEMs and slope gradient values extracted from the input DEMs. The peaks were chosen based on several criteria – local knowledge of the author as well as their popularity among tourists and hikers.

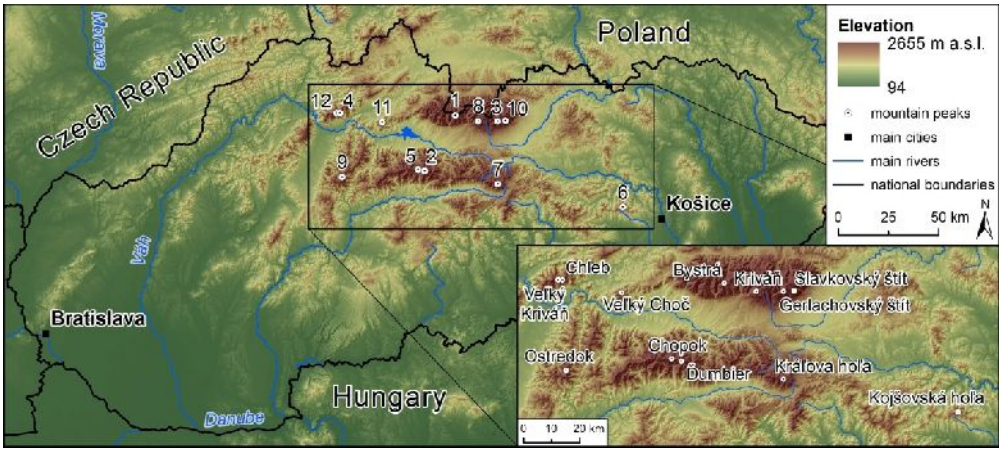

***Fig. 1**. Position of the analysed mountain peaks within Slovakia; numbers of peaks correspond to the ID numbers in tables*

As an elevation input, two DEMs with different spatial resolution were used: coarser one was a section of freely available global SRTM model with 30-meter resolution (USGS 2016) and finer one was DEM with 10-meter resolution derived from contours of a topographic map in scale 10:000 (GKÚ SR). Two methods of automated landform classification performing multi-scale calculations in GRASS GIS software were tested: the r.param.scale tool (Wood 2009) classifying terrain according to different geometries of individual landforms (classification is based on different values of the first and second derivatives of elevation) and the r.geomorphon tool (Jasiewicz and Stepinski 2013) representing new and progressive approach to terrain classification based on its overall topographic pattern (it uses computer vision as a substitute to human visual terrain classification). Analyses of landform classification (feature extraction in r.param.scale and terrain form calculation in r.geomorphon) for 30-meter DEM were carried out using 10 rowing window sizes of 5×5, 11×11, 17×17, 23×23, 29×29, 35×35, 41×41, 47×47, 57×57, 67×67 cells, representing areas with planimetrical sizes from 150 to 2010 m. For 10-meter DEM, 15 rowing window sizes from 5×5 to 89×89 cells (with an equal increment of 6 cells) were used, representing areas with planimetrical sizes from 50 to 890 m. Different rowing window sizes, used due to different resolution of input DEMs, allowed us to evaluate the its effect on the method performance.

Tab. 1. *List of analysed mountain peaks with values of elevation and slope gradient*

Mountain peaks		Elevation (m a.s.l.)			Slope gradient (degrees)	
ID	**Name**	**Topo. map**	**DEM 10 m**	**SRTM 30 m**	**DEM 10 m**	**SRTM 30 m**
1	Bystrá	2248.40	2241.63	2221	14.03	7.51
2	Ďumbier	2046.90	2049.23	2009	7.96	36.09
3	Gerlachovský štít	2654.40	2651.17	2588	26.34	8.98
4	Chleb	1647.00	1639.53	1624	17.24	2.90
5	Chopok	2023.60	2022.34	1998	10.44	8.10
6	Kojšovská hoľa	1245.70	1243.13	1238	10.61	6.47
7	Kráľova hoľa	1946.10	1945.02	1936	5.08	5.48
8	Kriváň	2494.70	2488.03	2415	25.97	29.47
9	Ostredok	1596.00	1592.67	1587	6.04	4.22
10	Slavkovský štít	2452.40	2449.26	2405	12.45	7.66
11	Veľký Choč	1607.10	1602.58	1593	15.03	11.73
12	Veľký Kriváň	1708.70	1704.32	1681	18.09	15.91

With the direct relationship between its value and the likelihood of an analysed cell being identified as peak, the slope tolerance parameter in the r.param.scale module is crucial (Wood 1996 in Fischer et al. 2004). This statement was tested and confirmed here as well. As we wanted to set the most representative value, we sampled 33 various mountain peaks all over Slovakia with different shapes and properties. The value was calculated as their mean slope gradient value, i.e., 8.73° for 30-meter DEM and 11.62° for 10-meter DEM. Other parameters were left as default.

In r.geomorphon the flatness threshold parameter (relatively similar to the slope tolerance parameter in r.param.scale) was left as default (1°), since it showed no influence on peak (or summit, as called in the module) delineation in the testing phase. Other parameters were left as default, too.

The calculation of membership of a raster cell to peak landform (i.e., fuzzy membership calculation) was carried out according to the formula used in (Fisher et al. 2004):

$$\mu = \frac{\sum_{i=1}^{n} w_i m_i}{n \sum w_i}$$

where μ is fuzzy membership of a raster cell to peak landform, w is a weight applied to each scale (i.e., rowing window size), m is a binary variable expressing presence of peak, n is number of applied scales (10 and 15 for 30-m and 10-m DEM, respectively). Same weights $w = 1/n$ were applied to all scales.

Extents of resulting fuzzy area of all peaks were calculated for both memberships: lower than 0.5 and higher than 0.5.

Results and discussion

Overall, three aspects of automated peak recognition can be evaluated in this study:

1. Resolution of the input DEM and its effect on differences in peak recognition.
2. Suitability of the algorithm to correctly recognise peaks and its effect on differences in peak recognition.
3. Influence of topographical accuracy of the spot height designation in the reference topographical map (scale 1:10 000) regarding the terrain shape (e.g., localisation of triangulation spots not in the exact highest part of peaks on purpose).

In general, the r.param.scale tool tends to extract much larger fuzzy peak area than the r.geomorphon tool (this applies to both used DEM resolutions). It is due to the slope tolerance parameter, which allows recognition of adjacent slopes as peaks when slope gradient values fall within the set threshold. Also, the extracted fuzzy area is in both methods larger for plainer than for sharper peaks (e.g., Kojšovská hoľa vs. Gerlachovský štít). In r.param.scale this is due to the mentioned slope tolerance threshold, while in r.geomorphon the extracted fuzzy area tends to get widened along ridges. Thus, success of the algorithm in peak recognition increases with the size of the fuzzy area extracted (i.e., spot height localisation falling into the extracted peak fuzzy area). This area is naturally larger when using coarser input DEM for both used algorithms. Since r.geomorphon tool extracts much smaller fuzzy area, the contained cells have generally greater membership to peak (e.g., no cells with membership smaller than 0.5). Next, the r.param.scale fails to correctly locate peak with slope gradient higher than the used slope tolerance threshold (e.g., Ostredok or Veľký Kriváň), which is not the case with r.geomorphon.

Principally, the results from the DEM with 10-meter resolution would be expected to be more precise than those from the DEM with 30-meter resolution. However, this was not always the case here, probably because of low quality of some contours or even their absence in high and sharp mountains such as High Tatras Mts. and Nízke Tatry Mts.

The graphical results of fuzzy recognition of the analysed peaks are depicted in fig. 2 to 5 and their fuzzy values (at spot height) and extent of fuzzy areas with membership lower than 0.5 and higher than 0.5 are in tab. 2. The results are complemented with photographs of the analysed peaks (fig. 6).

According to the results of fuzzy peak area computations (tab. 2) two regularities can be seen. In the fuzzy area extracted using r.param.scale tool and both input DEMs, prevailing is the area with membership to the peak landform < 0.5. This applies to all the peaks and difference between area with membership < 0.5 and > 0.5 tends to be larger for plain shaped peaks (e.g., Kojšovská hoľa or Kráľová hoľa). On the contrary, in the fuzzy area extracted using r.geomorphon tool and both input DEMs, prevailing is the area with membership to the peak landform > 0.5 (in some cases it is equal to the area with lower membership). This applies to all the peaks except two with plain shape – Kojšovská hoľa and Kráľová hoľa. Thus, since the extracted fuzzy area using r.geomorphon tool is smaller and contains higher proportion of membership to the peak landform > 0.5 for majority of the analysed peaks, it should also incorporate less ambiguity in their recognition. Though, r.geomorphon tool tends to extract more fragmented fuzzy area which in some cases contains more separated objects with membership > 0.5 separated by areas with smaller membership to the peak landform (e.g., Gerlachovský štít or Chopok. More detailed description of the 12 analysed peaks follows.

Tab. 2. *Values of the fuzzy membership and extent of fuzzy areas for analysed mountain peaks*

Method		**r.param.scale**						**r.geomorphon**					
Mountain peaks		**SRTM 30 m**			**DEM 10 m**			**SRTM 30 m**			**DEM 10 m**		
		Height spot memb.	**Fuzzy area**		**Height spot memb.**	**Fuzzy area**		**Height spot memb.**	**Fuzzy area**		**Height spot memb.**	**Fuzzy area**	
ID	**Name**		**< 0.5**	**> 0.5**		**< 0.5**	**> 0.5**		**< 0.5**	**> 0.5**		**< 0.5**	**> 0.5**
1	**Bystrá**	1.00	0.38	0.06	1.00	0.09	0.02	0.93	0.01	0.05	1.00	0.01	0.01
2	**Ďumbier**	0.20	0.11	0.02	0.13	0.06	0.03	1.00	0.11	0.13	0.00	0.01	0.02
3	**Gerlachovský štít**	0.90	0.49	0.04	0.47	0.07	0.01	0.87	0.04	0.07	0.80	0.01	0.01
4	**Chleb**	0.80	0.16	0.03	0.53	0.09	0.04	0.87	0.01	0.05	1.00	0.00	0.01
5	**Chopok**	0.60	0.47	0.08	1.00	0.08	0.05	1.00	0.05	0.08	1.00	0.03	0.03
6	**Kojšovská hoľa**	0.90	0.67	0.21	1.00	0.21	0.18	0.60	0.11	0.07	0.80	0.06	0.02
7	**Kráľova hoľa**	1.00	0.72	0.67	1.00	0.18	0.13	0.93	0.10	0.07	0.90	0.04	0.03
8	**Kriváň**	0.20	0.23	0.02	0.13	0.03	0.01	0.93	0.03	0.08	0.70	0.01	0.01
9	**Ostredok**	0.60	0.30	0.07	1.00	0.03	0.03	1.00	0.02	0.06	0.93	0.01	0.03
10	**Slavkovský štít**	1.00	0.17	0.05	1.00	0.06	0.02	0.87	0.01	0.07	0.90	0.01	0.02
11	**Veľký Choč**	0.10	0.47	0.04	0.00	0.06	0.03	0.87	0.03	0.07	1.00	0.03	0.03
12	**Veľký Kriváň**	0.70	0.41	0.12	0.87	0.19	0.05	0.67	0.01	0.03	0.90	0.00	0.01

Fuzzy area of peaks with membership < 0.5 and > 0.5 is in km^2

Bystrá peak (fig. 2), located in its eastern part on the south spur of the main ridge, is the highest peak of Západné Tatry Mts. (2248.4 m.a.s.l.). View on its rather sharp shape from west can be seen from Klin peak in fig. 6, A. The peak is well recognised with both methods and input DEMs, except for one case (r.geomorphon and 30-meter DEM) with the spot height located in the fuzzy membership of 0.93. Extracted fuzzy peak area is smaller with r.geomorphon and for 10-meter DEM for both tools, as expected.

Ďumbier peak (fig. 2) is the highest peak in Nízke Tatry Mts. (2046.9 m a.s.l.), located in its central part on the main ridge. View on the peak with steep and high northern slopes from Krúpovo sedlo saddle is in fig. 6, B. Although it was recognised as a peak landform, it did not reach good membership value at the spot height; in one case, it is not even located in the fuzzy peak area. Major reasons are the peak's location on the edge of a glacial cirque (i.e., absence of contours on the northern slope influenced the results from the 10-meter DEM) as well as higher slope gradient value at spot height in 30-meter DEM, which influenced results of the r.param.scale tool with maximum fuzzy membership reaching only 0.8. Also, while r.param.scale extracted fuzzy area as one object, r.geomorphon tool subdivided it into two parts. The separated north-western part apparently contains another peak not marked in the map.

Gerlachovský štít peak (fig. 2), located in its western part on the northern edge of well-known Gerlachovský glacial cirque, is the highest peak in High Tatras Mts. (2654.4 m a.s.l.). View on its sharp and rocky shape as seen from north-east from Ľadový štít peak is in fig. 6,C. Using r.geomorphon and both input DEMs, the peak was recognised with membership value at spot height of more than 0.8. Results of r.param.scale for both input DEMs were again influenced either by missing contours or by higher slope gradient value at spot height. Also, in northern part of the fuzzy area with membership > 0.5 r.param.scale with 10-meter DEM separated another peak that is not marked in the map. Next, r.geomorphon tool with 10-meter DEM separated southern part of the fuzzy area with membership > 0.5, which is marked in the map as Gerlachovská veža peak (2614 m a.s.l).

Chleb peak (fig. 3) is the third highest peak in Malá Fatra Mts. (1647 m a.s.l.), located on the main ridge of its northern part called Krivánska Fatra Mts. View on its conical shape from west from Veľký Kriváň peak can be seen in fig. 6, D. The peak was recognised relatively well, except for one case (r.param.scale and 10-meter DEM – influenced by gradient value at spot height slope higher than threshold, with resulting maximum fuzzy membership only 0.8) with membership at spot height more than 0.8, and the smallest fuzzy peak area extent was generated with r.geomorphon and 10-meter DEM. Furthermore, r.param.scale tool with 10-meter DEM partially recognised (membership < 0.5) another peak in north-eastern direction from Chleb which is not marked in the map. The same peak was recognised also by r.geomorphon tool in fuzzy area with membership > 0.5 (for 30-meter DEM it is located in Chleb´s own fuzzy area, for 10-meter DEM it is separated).

Chopok peak (fig. 3) is the second highest peak in Nízke Tatry Mts. (2023.6 m a.s.l.), located in its central part on the main ridge with similar properties as Ďumbier peak. View on the peak from east as seen from Demänovské sedlo saddle is in fig. 6, E. Peak was recognised well, except for one case (r.param.scale with 30-meter DEM) with fuzzy membership value of 1, influenced probably by overall terrain pattern. Here, too, was recognised another peak, with similar properties in terms of its recognition by both tools as in the Chleb peak case. It is located in south-west and not marked in the map.

Kojšovská hoľa peak (1245.7 m a.s.l.) (fig. 3) is located in eastern part of Volovské vrchy Mts. slightly north of the main ridge. View on its plain conical shape with meteorological radar from its north-western slopes is seen in fig. 6, F. Even though its spot height is not located exactly in the highest part due to a building with the meteorological radar included in both input DEMs, it was recognised with relatively high membership values at spot height (more than 0.8). Results of r.geomorphon with 10-meter DEM (membership at spot only 0.6) were affected by the previously mentioned location of the height spot. In addition, three partial peaks are visible in results of r.param.scale tool. For 30-meter DEM all are located in the fuzzy area with membership > 0.5 (unseparated by lower membership), unlike for 10-meter DEM, where all have also membership > 0.5 but are separated by lower membership. Based on the field experience, two of them (excluding the main peak in the centre) can be labelled as small elevations, which are not marked in the map. However, r.geomorphon tool recognised them only partially, mainly the eastern one (for 30-meter DEM with membership > 0.5, for 10-meter DEM with membership < 0.5).

Kráľova hoľa peak (fig. 4), with its plain shape elongated in east-west direction, is located in eastern part of Nízke Tatry Mts. and is the highest peak of so-called Kráľovohoľské Tatry Mts. (1946.1 m a.s.l.). View on the peak with a transmitter building as seen from west from Orlová peak is in fig. 6, G.

The peak has similar properties as Kojšovská hoľa peak (fig. 3), i.e., location of a transmitter and plain shape, which affected mainly the results of 30-meter DEM and r.param.scale tool (i.e., large extent of fuzzy peak area), but overall it has surprisingly high membership values at spot height (more than 0.9). Moreover, both tools and input DEMs recognised not only its own peak, but also another two elevations, one to the west and other to the east. Eastern one is unmarked in the map, unlike western one, which is marked in the map as spot height (1944 m a.s.l.) and visible in the photograph in fig 6, G.

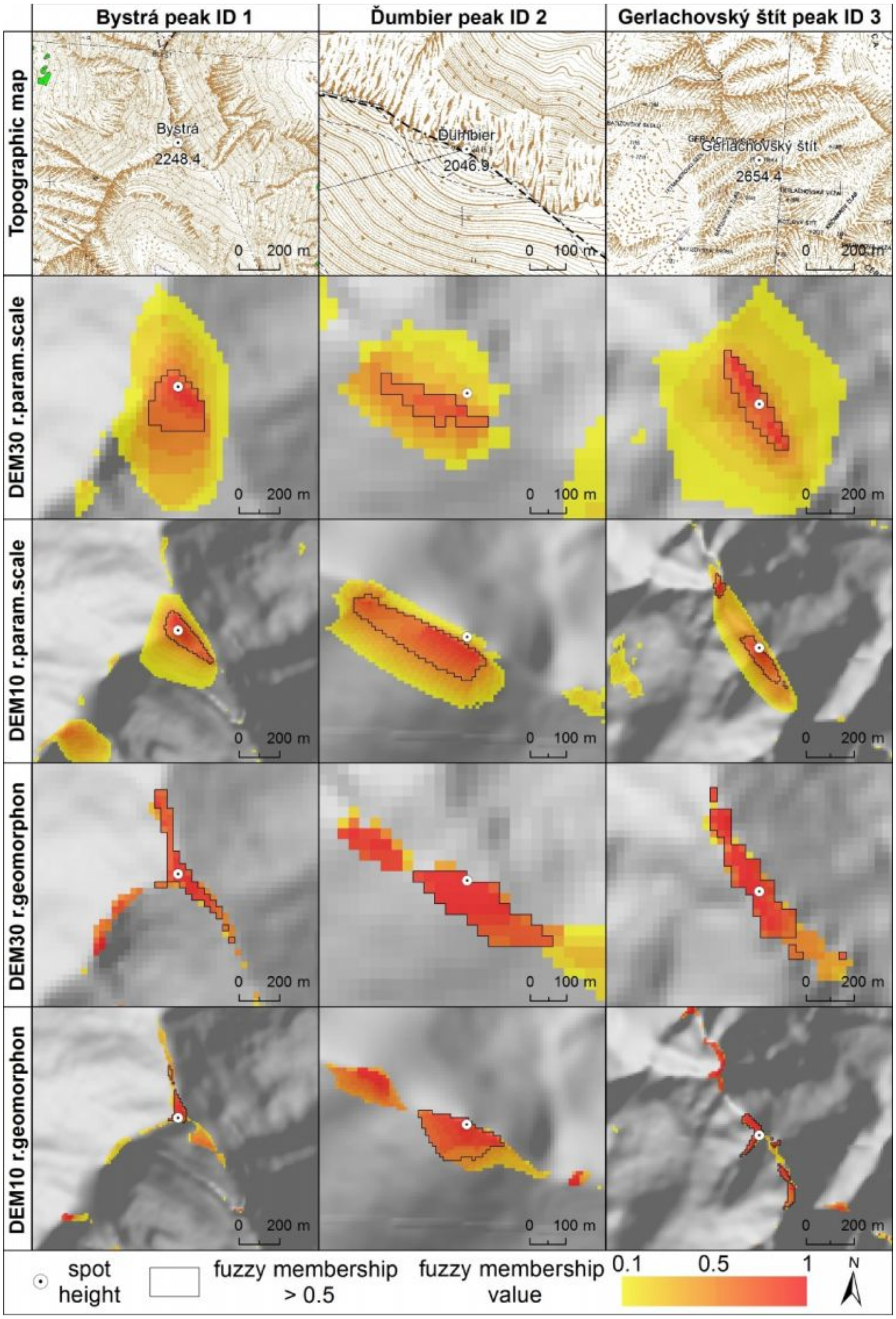

Fig. 2. *Fuzzy membership of peak landform of peaks Bystrá, Ďumbier and Gerlachovský štít extracted using the r.param.scale and r.geomorphon tool with input DEMs with 10 and 30-meter resolution, numbers of peaks correspond to the ID number in Tables*

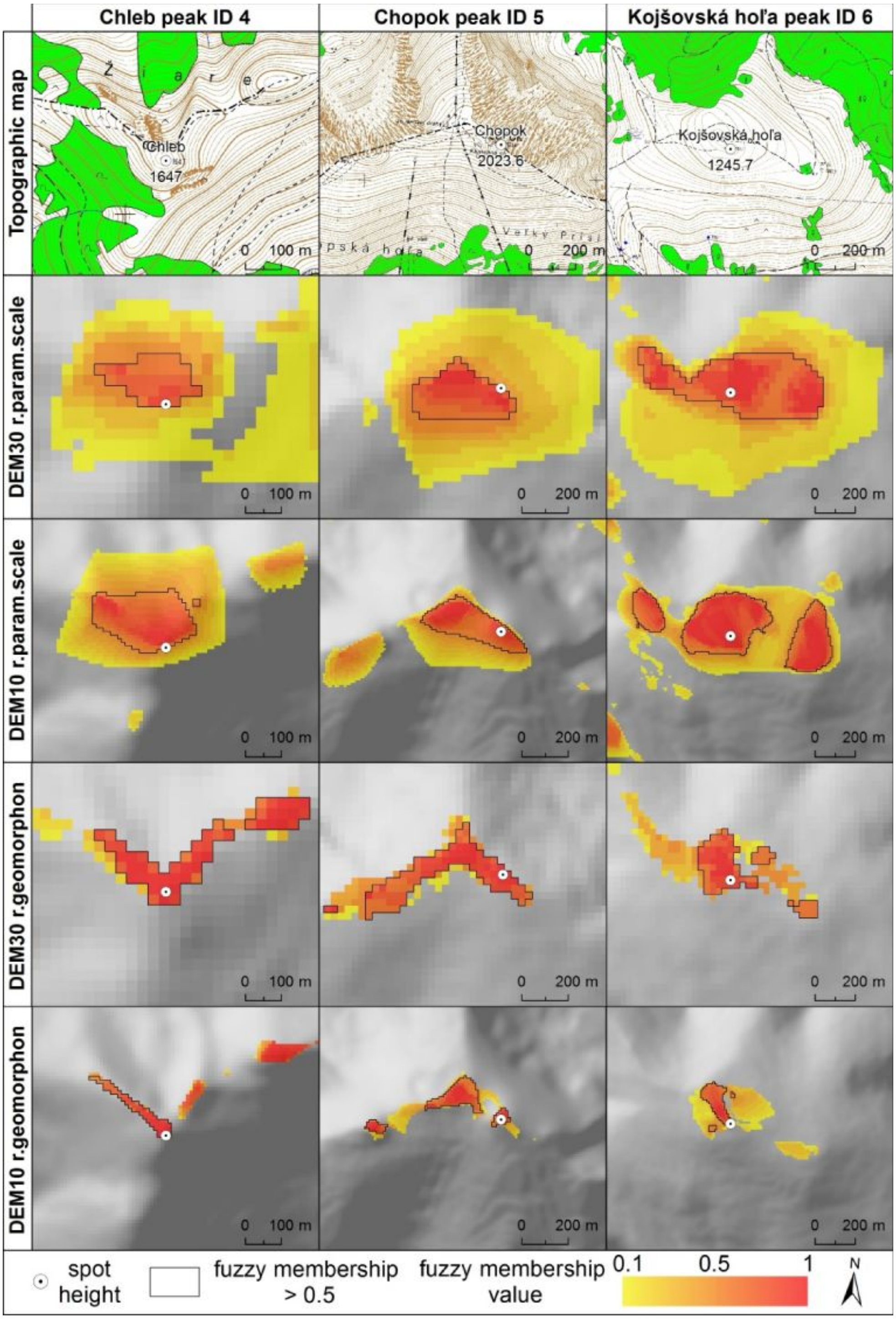

Fig. 3. *Fuzzy membership of peak landform of Chleb, Chopok and Kojšovská hoľa extracted using the r.param.scale and r.geomorphon tool with input DEMs with 10 and 30-meter resolution, numbers of peaks correspond to the ID number in Tables*

Kriváň peak (2494.7 m a.s.l.) (fig. 4) is located at the end of a long ridge of spur jutting out of the main ridge of High Tatras Mts. in its western part. North-eastern view on the peak with relatively sharp shape from Kôprovský štít peak is seen in fig. 6, H. The peak has high slope gradient at spot height, which affected the results of the r.param.scale tool using both input DEMs. Moreover, the spot height is not located precisely in the highest part of the peak, therefore the membership values at spot height are expect one case (r.geomorhon with 10-meter DEM) lower than 0.9. With r.param.scale it has membership at spot height only 0.2 and 0.13 using 30- and 10-meter DEM, respectively. Both methods using 30-meter DEM as well as r.param.scale using 10-meter DEM resulted in maximum fuzzy membership of only 0.7, which is probably affected by overall accuracy of the used DEMs. Also, r.geomorphon tool with 30-meter DEM extracted fragmented fuzzy area with membership > 0.5.

Ostredok peak (fig. 4), located in its southern part on the main ridge, is the highest peak in Veľká Fatra Mts. (1596 m a.s.l.). In fact, it has two peaks ca. 300 metres apart - lower northern one (1593 m a.s.l.), which was for a long time considered and marked as the highest point, and slightly higher southern one, which is analysed. View on their indistinctive and plain shape as seen from east from Frčkov peak is in fig. 6, I. Overall, both methods and input DEMs performed well in its recognition with at spot height membership more than 0.9, except for one case (r.param.scale with 30-meter DEM with at spot height membership 0.6). Its composition of two peaks mostly affected the results of r.geomorphon extracting the fuzzy area as an elongated ridge line connecting the peaks together. In addition, r.param.scale tool with 30-meter resolution DEM surprisingly connected fuzzy area not with the northern partial peak but with another unnamed peak marked in the map as spot height (1545 m a.s.l.).

Slavkovský štít peak (fig. 5), located in the central part of High Tatras Mts. (2452.4 m a.s.l.), has broad, burly and relatively plain shape, with sharp edges though. Northern view on the peak as seen from Priečne sedlo saddle is in fig. 6, J. Surprisingly, regarding its plain shape, both methods and both input DEMs performed quite well in its recognition (membership value at spot height higher than 0.8 with small extent of fuzzy peak area). In 1813 a massive rock blocks collapsed from peak down to Veľká Studená dolina valley, where it is still visible to this day. According to assumptions, Slavkovský štít peak could have been the highest peak of High Tatras Mts. until this event.

Veľký Choč peak (fig. 5) is the highest peak in Chočské vrchy Mts. (1607.1 m a.s.l.), located in its south-western part. View on the peak as seen from south-east from Poludnica peak (Nízke Tatry Mts.) is in fig. 6, K. It has pyramid-like rugged shape with steep slopes, relatively small extent of the highest part and no centralised spot height. Thus, the r.param.scale tool did not perform well in its delineation with either input DEMs (membership values at spot height 0.1 and 0, respectively). On the other hand, the r.geomorphon tool handled this shape better, with both input DEMs reaching membership values at spot height higher than 0.8 and relatively small fuzzy area extent.

Veľký Kriváň peak (fig. 5) is the highest peak in Malá Fatra Mts. (1708.7 m a.s.l.), located on the main ridge of its northern part called Krivánska Fatra Mts. Western view on its sharp and conically shaped peak as seen from Pekelník peak is in fig. 6, L. Even though maximum fuzzy membership values are 1 for both methods and input DEMs, fuzzy membership at spot height has lower values. Results of r.param.scale using 30- and 10-meter DEM reach membership values of 0.7 and 0.87, respectively. The tool was influenced mainly by slope gradient value at spot height higher than the set threshold. Results of r.geomorphon have not full membership at spot height (0.9 and 0.67), either, which was probably affected by the peak's shape.

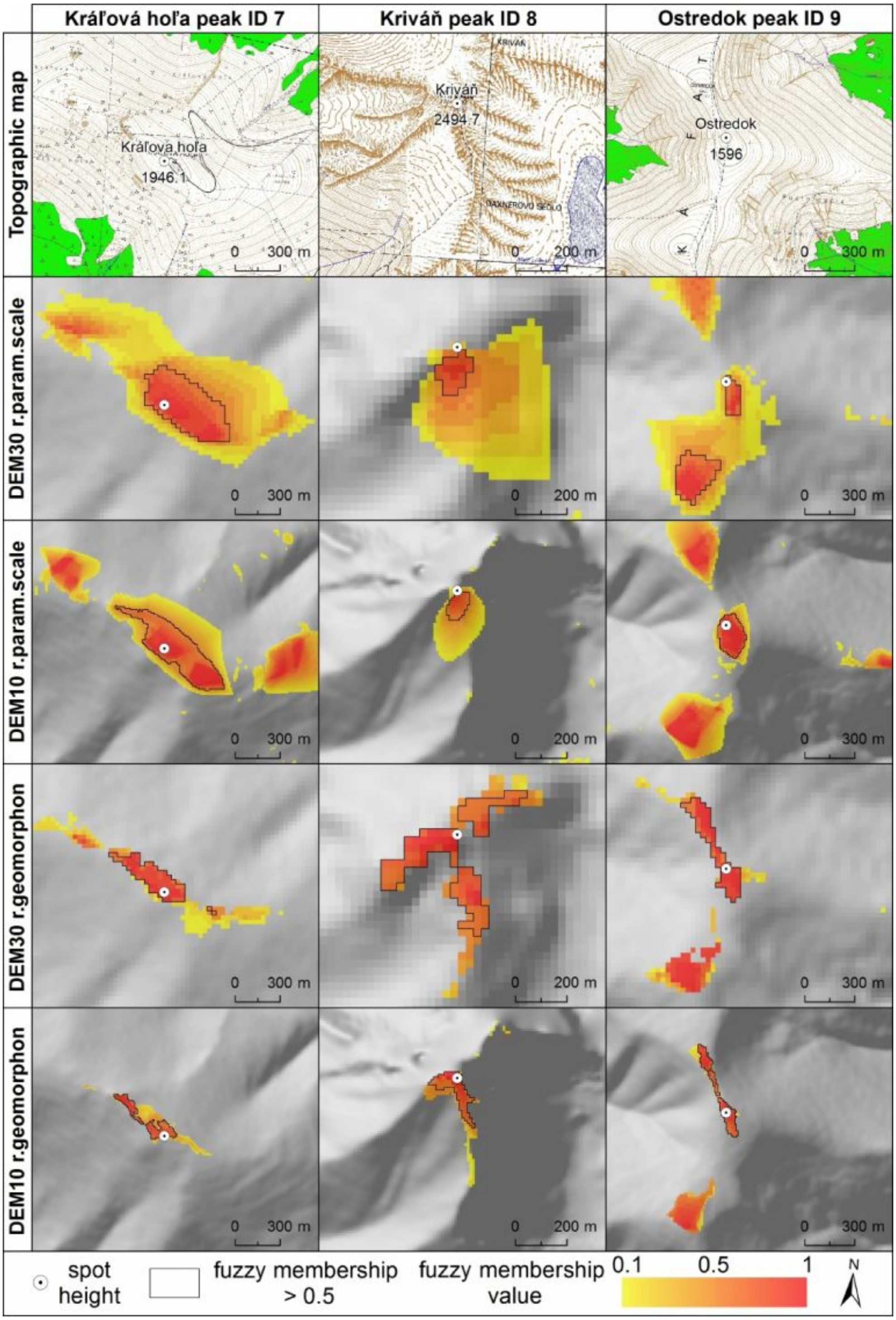

***Fig. 4**. Fuzzy membership of peak landform of peaks Kráľová hoľa, Kriváň and Ostredok extracted using the r.param.scale and r.geomorphon tool with input DEMs with 10 and 30-meter resolution, numbers of peaks correspond to the ID number in Tables*

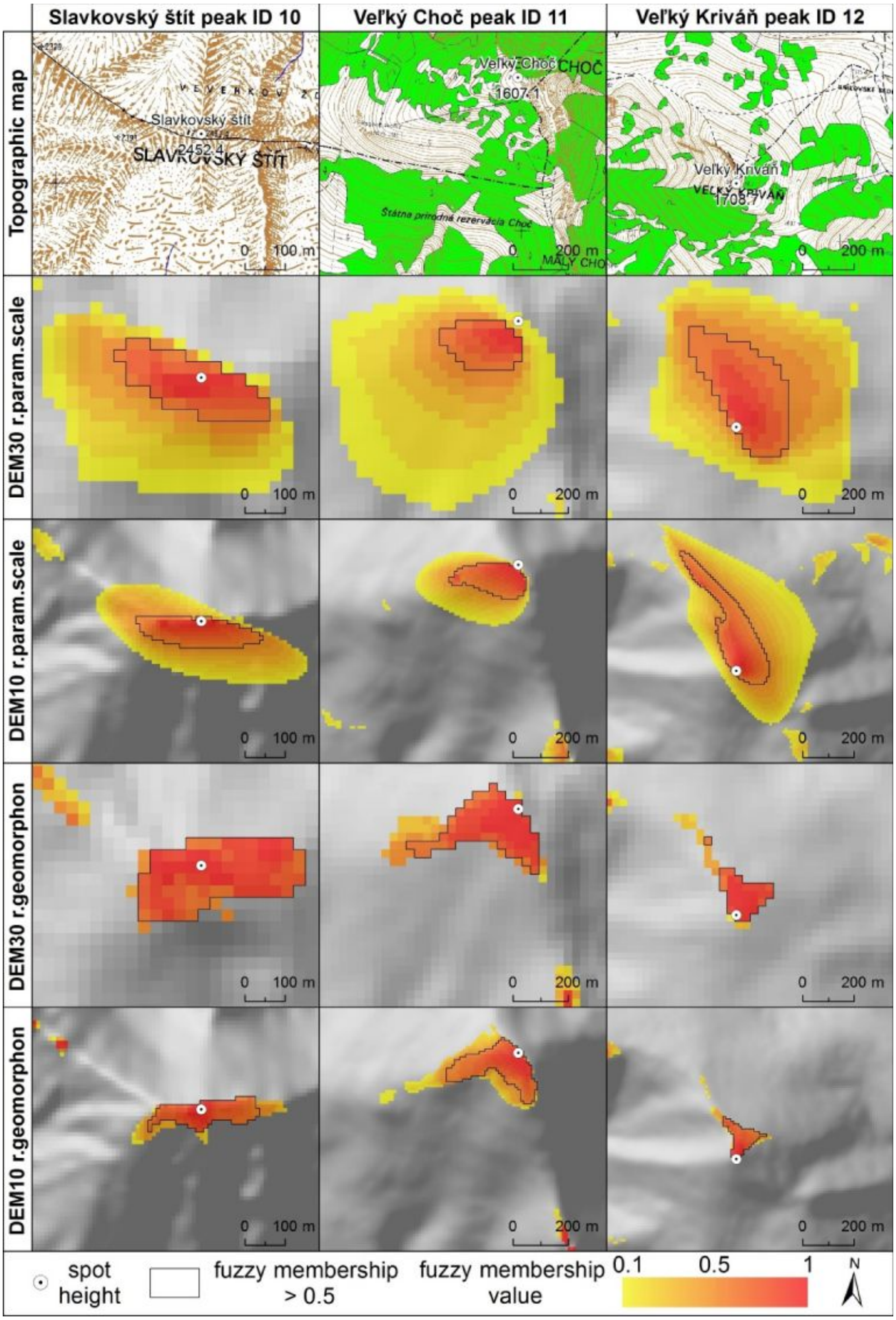

***Fig. 5**. Fuzzy membership of peak landform of peaks Slavkovský štít, Veľký Choč and Veľký Kriváň extracted using the r.param.scale and r.geomorphon tool with input DEMs with 10 and 30-meter resolution, numbers of peaks correspond to the ID number in Tables*

Fig. 6. *Photos of view on the analysed peaks: Bystrá (A), Ďumbier (B), Gerlachovský štít (C), Chleb (D), Chopok (E), Kojšovská hoľa (F), Kráľova hoľa (G), Kriváň (H), Ostredok (I), Slavkovský štít (J), Veľký Choč (K) and Veľký Kriváň (L), photos by Vladimír Mačák*

Conclusions

We successfully applied fuzzy membership logic on recognition of some of the most known mountain peaks in Slovakia using two automated landform classification methods in GRASS GIS as well as two different DEM resolutions. Overall, the r.gemorphon tool performed better than the r.param.scale tool for this purpose (due to the great impact of input slope tolerance parameter in the case of r.param.scale tool), and the DEM resolution (30 vs. 10 meters) did not have great effect on the results. However, using finer resolution is more appropriate, and it would be even more proper to apply these methods on high-resolution DEM representing actual terrain (e.g., LiDAR-based). To remind, these 12 selected mountain peaks were used only as examples for evaluation of suitability of this approach, thus the study calls for extension. Nevertheless, the results of this study could be a contribution for geomorphologists in terms of providing comparison of two computationally different approaches for application in fuzzy recognition of several mountain peaks different in shape and situation. Moreover, contribution can also be for the general public by providing different perception of the surrounding landscape from general paper maps when hiking or walking in mountains.

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Viacmierkové rozpoznávanie vybraných horských vrcholov z DMR na Slovensku založené na tvare georeliéfu

Peter BANDURA

Zhrnutie: *Téma exaktnej a fuzzy logiky aplikovaná na určenie rôznych hraníc patrí k najdiskutovanejším problematikám v geomorfológii (napr. definícia hraníc regiónov, foriem alebo elementárnych foriem georeliéfu). Vďaka neustálemu vývoju pokročilých automatizovaných metód a prístupu ku globálnym DMR s čoraz vyššou presnosťou sa možnosti riešenia takýchto problémov zlepšujú. Táto štúdia sa inšpirovala v prácach, ktoré túto tému spracovávajú, a je zameraná na fuzzy rozpoznávanie vrcholovej formy georeliéfu viac-mierkovým prístupom. Zhodnotili sme dve automatizované metódy klasifikácie foriem georeliéfu implementované v softvéri GRASS GIS – nástroj r.param.scale, ktorý klasifikuje georeliéf podľa rozdielnej geometrie jednotlivých foriem, a nástroj r.geomorphon, ktorý reprezentuje nový a progresívny prístup ku klasifikácii georeliéfu podľa jeho celkového topografického vzoru. Na analýzy sme použili niektoré z najznámejších a turisticky často navštevovaných horských vrcholov na Slovensku s rozličnými tvarmi a vlastnosťami (napr. vo Vysokých a Nízkych Tatrách, Veľkej a Malej Fatre) a dva DMR s rôznym rozlíšením – globálny model SRTM s 30-metrovým rozlíšením a DMR interpolovaný z vrstevníc topografickej mapy v mierke 1:10 000 s výsledným 10-metrovým rozlíšením. Veľkosti plávajúceho okna sa nastavili rozlične pre oba vstupné DMR, aby sme zistili, či to ovplyvní výsledky metód. Výsledné rozpoznané fuzzy plochy vrcholov sme porovnali s príslušnými kótami v referenčnej mape - často využívanej topografickej mape v mierke 1:10 000. Analýza presnosti bola vykonaná vizuálnym hodnotením, hodnotou fuzzy príslušnosti na mieste kóty, maximálnou hodnotou fuzzy príslušnosti a rozlohou fuzzy plochy. Celkovo lepšie výsledky dosiahol nástroj r.geomorphon, ktorý na rozdiel od nástroja r.param.scale, v ktorom je pre rozpoznávanie vrcholov rozhodujúci parameter tolerancie sklonu (nastavený bol na priemernú hodnotu sklonu všetkých vzorových vrcholov), neovplyvnili vstupné parametre ani geometria georeliéfu. Úspech rozpoznania vrcholu závisí aj na jeho celkovom tvare a vlastnostiach. Grafické výsledky sú doplnené turistickými fotografiami analyzovaných vrcholov. Keďže analyzované vrcholy slúžili len ako príklady na zhodnotenie prezentovaného prístupu, existuje stále priestor na ďalšie analýzy (napr. použitie DMR s vysokým rozlíšením). Napriek tomu môžu byť výsledky tejto práce prínosom nielen pre geomorfológov, ale aj pre laickú verejnosť, ktorej môžu počas túr alebo prechádzok v horách poskytnúť iný pohľad na vnímanie krajiny naokolo ako obyčajné papierové mapy.*

Tab. 1. *Zoznam analyzovaných horských vrcholov s hodnotami nadmorských výšok a sklonu georeliéfu*

Tab. 2. *Hodnoty fuzzy príslušnosti a rozlohy fuzzy plochy pre analyzované horské vrcholy*

Obr. 1. *Lokalizácia analyzovaných horských vrcholov v rámci Slovenska*

Obr. 2. *Fuzzy príslušnosť k vrcholovej forme pre vrcholy Bystrá, Ďumbier a Gerlachovský štít odvodená nástrojmi r.param.scale a r.geomoprhon so vstupnými DMR s rozlíšením 10 a 30 metrov*

Obr. 3. *Fuzzy príslušnosť k vrcholovej forme pre vrcholy Chleb, Chopok a Kojšovská hoľa odvodená nástrojmi r.param.scale a r.geomoprhon so vstupnými DMR s rozlíšením 10 a 30 metrov*

Obr. 4*. Fuzzy príslušnosť k vrcholovej forme pre vrcholy Kráľová hoľa, Kriváň a Ostredok odvodená nástrojmi r.param.scale a r.geomoprhon so vstupnými DMR s rozlíšením 10 a 30 metrov*

Obr. 5*. Fuzzy príslušnosť k vrcholovej forme pre vrcholy Slavkovský štít, Veľký Choč a Veľký Kriváň nástrojmi r.param.scale a r.geomoprhon so vstupnými DMR s rozlíšením 10 a 30 metrov*

Obr. 6. *Fotografie pohľadov na analyzované vrcholy: Bystrá (A), Ďumbier (B), Gerlachovský štít (C), Chleb (D), Chopok (E) and Kojšovská hoľa (F), Kráľova hoľa (G), Kriváň (H), Ostredok (I), Slavkovský štít (J), Veľký Choč (K) a Veľký Kriváň (L); autor fotografií: Vladimír Mačák*

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